Accomplishments and Future Challenges in Dryland Soil Fertility Research in the Mediterranean Area

John Ryan
editor

International Center for Agricultural Research in the Dry Areas

ICARDA

Institut Mondial du Phosphate

About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is governed by an independent Board of Trustees. Based at Aleppo, Syria, it is one of the 16 centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is an international group of representatives of donor agencies, eminent agricultural scientists, and institutional administrators from developed and developing countries who guide and support its work.

The mission of the CGIAR is to promote sustainable agriculture to alleviate poverty and hunger and achieve food security in developing countries. The CGIAR conducts strategic and applied research, with its products being international public goods, and focuses its research agenda on problem-solving through interdisciplinary programs implemented by one or more of its international centers, in collaboration with a full range of partners. Such programs concentrate on increasing productivity, protecting the environment, saving biodiversity, improving policies, and contributing to strengthening agricultural research in developing countries.

In the context of the challenges posed by the physical, social and economic environments of the dry areas, ICARDA's mission is to improve the welfare of people in the dry areas of the developing world by increasing the production and nutritional quality of food while preserving and enhancing the resource base. ICARDA meets this challenge through research, training, and dissemination of information in partnership with the national agricultural research and development systems.

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of on-farm water-use efficiency, rangeland and small-ruminant production in the West Asia and North Africa region for the improvement of bread and durum wheats, chickpea, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural resource management practices.

Much of ICARDA's research is carried out on a 948-hectare farm at its headquarters at Tel Hadya, about 35 km southwest of Aleppo. ICARDA also manages other sites where it tests material under a variety of agroecological conditions in Syria and Lebanon. However, the full scope of ICARDA's activities can be appreciated only when account is taken of the cooperative research carried out with many countries in West Asia and North Africa and elsewhere in the world.

The results of research are transferred through ICARDA's cooperation with national and regional research institutions, with universities and ministries of agriculture, and through the technical assistance and training that the Center provides. A range of training programs is offered extending from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and specialized information services.

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Editor

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Foreword

From its inception in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) has focused on the constraints to increasing output of the major dryland crops, i.e., cereals (bread wheat, durum wheat, barley) and legumes (chickpeas and lentils). Notwithstanding the overall dominance of drought, it is clear that low soil fertility is a major obstacle to increasing yields. The problem of low fertility can, however, be solved by judicious fertilizer use.

Research at ICARDA's principal research station at Tel Hadya and at the various sub-stations throughout the rainfall zones in northern Syria has demonstrated substantial yield gains with the use of nitrogen and phosphorus. Such findings have stimulated increased use of fertilizer and indeed have had an impact on national fertilizer allocation policy. ICARDA has had a major role in transferring fertilizer-use technology to other countries in the West Asia and North Africa (WANA) region. Fertilizer trials are gradually shifting from experimental stations to farmers' fields. Today, fertilizer is widely used in most countries of the region. The concept of networks for information dissemination and technology transfer has been a major plank in ICARDA's platform. Its *Soil Test Calibration Network* grew out of the conviction that a rational basis for using fertilizer was needed. In collaboration with the national programs, the *Network* demonstrated that soil nutrient deficiencies can be diagnosed and appropriate fertilizer recommendations made. But soil fertility is not static, it must evolve in response to changing soil management. The issue of fertility within the broader context of long-term farming practices is of major concern. In addition, new constraints, such as micronutrient deficiencies and toxicities, have been identified. Soil fertility research must respond to the change from dryland farming to supplemental irrigation, and to issues of pollution. Apart from applied aspects of fertility, some fundamental gaps in our knowledge still remain.

The contributions of future soil fertility research to crop yield enhancement can only be guaranteed if it is broadly-based and interactive with other disciplines and the other partners in the agricultural sector—educators, commercial sector and international agencies. There is little room for research duplication; the problems for research must be defined by those who have the problems as well as those who can solve them. Partnership and communications have to characterize our future research in soil science, as in any other discipline.

The presence at the Workshop on "Accomplishment and Future Challenges in Dryland Soil Fertility Research in the Mediterranean Area", held in November 1996, of people from so many diverse institutions bodes well for the future. The diversity of topics on the agenda suggests that the "challenges" in the workshop title are being pursued with vigor. ICARDA is honored to be part of this collaborative effort to improve the lives of the farming community in the WANA region.

Prof. Dr Adel El-Beltagy
Director General

Introduction

The papers presented in this volume represent the proceedings of the Soil Fertility Meeting at Tel Hadya during 19-23 November 1995. That meeting was, in essence, a continuation of the previous Soil Test Calibration workshops held in Aleppo (1988), Ankara (1987), Amman (1988), and Agadir (1991). The meeting was a turning point in the WANA dryland soil fertility research. The terms of reference for the participants were to review and take stock of what had been accomplished in soil fertility research, and to look to the future and assess what needs to be done. The meeting agenda represented a large degree of success in both endeavours.

New issues to be addressed included a holistic concept of soil fertility as reflected in rotation trials; the use of N-15 to elucidate the dynamics of supplemental irrigation; the use of P in rangelands; assessment of micronutrient stress in terms of deficiency and toxicity; breeding to adapt crops to nutrient stresses, assessment of soil tests and laboratory management, practical considerations for soil fertility trials; aspects of soil fertility education; and economic assessment of fertilizer use policy.

The meeting differed from previous ones in that a considerable part of the program was devoted to group discussion. The meeting was also characterized by the diversity of participants. In addition to a cross-section of ICARDA scientists from several programs and representatives of Syrian institutions and 13 other WANA countries including Ministries of Agriculture and universities, the meeting attracted several international institutes: Food and Agriculture Organization, International Potash Institute, and International Atomic Energy Agency, and the co-sponsor, Institut Mondial du Phosphate.

The papers in this volume have been edited for style and content; most have been shortened from the original versions. For considerations of expediency and costs, the abridged manuscript were not returned to the authors. However, in a few instances where serious concerns were evident, the respective authors were contacted for revision. Any misrepresentation of the authors' intentions is my responsibility. In addition, as there was considerable variation in the manuscripts with respect to length and content, I have relegated some papers to short communications. For considerations of space, I have condensed the questions and answers section and the rapporteurs' reports from the discussion groups into a short overview of what was needed for the future.

While the papers were not refereed in the conventional sense, it is hoped that the volume with meet acceptable international standards for such proceedings and will make a valuable benchmark reference to soil fertility research in the WANA region. In that context, I have included a guest review article on a topic of direct relevance to the region -- the author in question was unable to attend the meeting. The volume should be instrumental in assisting us obtain funding for future collaborative research between ICARDA and the various national soil fertility and agronomy research programs.

John Ryan
Editor

Acknowledgements

First of all, I would like to thank Prof. Dr Adel El-Beltagy, Director General of ICARDA, for opening the workshop and giving the inaugural address; Drs Mohan Saxena, Research Coordinator, and Michael Jones, Leader, Farm Resource Management Program (FRMP), for their words of welcome to the participants; and my colleagues in FRMP and in other Programs who so willingly contributed to the meeting.

The contributions of those people behind the scenes who assisted in making the workshop a success were vital. I thank the members of the Organizing Committee, Dr Mustafa Pala, Dr Sonia Garabet, and particularly Mr Afif Dakermanji for arranging hotel details and the protocol for Syrian invitations, and Mr Mohamed Hamwieh and Mr Louay Naasani who took care of transport arrangements.

Particular thanks is due to Mrs Zuka Istanbouli who so ably served as the Workshop Secretary and who handled all the paperwork prior to the meeting. During the workshop she was a most gracious and efficient hostess. Zuka shared the burden of registration and handling all the needs of the participants (re-confirmation of travel, documents for financial re-imbursement, photocopy, question and answer sheets, etc.) with Mr George Estephan from the Soils Laboratory. George did an outstanding job as our ambassador at the meeting. To him and Zuka, I am deeply indebted for making the participants' stay a trouble-free one; both spared no effort to give the best impression to our visitors. Zuka was again on hand to put the final touches on the document before it went to publication.

But the greatest credit is due to Miss Ramzia Wafaii for bringing the proceedings to publication in a timely fashion. Ramzia approached the job of typing the over 40 manuscripts with a sense of professionalism and good humor. She spent countless hours over the past 6 months—and many weekends—applying herself to this onerous task. Many of the originally submitted papers were drastically changed to fit the standards of a conference proceedings; she never lost her patience with the many editorial corrections—and my sometimes undecipherable handwriting. Words are not adequate to thank her for her contribution to this document; it is as much hers as mine.

Finally, my personal thanks to the Institut Mondial du Phosphate in Morocco for the valuable financial support that made this meeting possible.

A. FULL PAPERS

1. Plenary Session

Phosphate Use Potential in Mediterranean Countries

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Abstract

This paper gives an overview of the use of phosphate fertilizers in the Mediterranean region. It takes a broad look at agricultural development in the region and stresses the importance of fertilizers in the process. The impact of government policy on fertilizer use is highlighted.

Introduction

The main concern of all the nations in the world, even more so in Mediterranean countries, is to develop ways and means to feed the ever-growing population. The annual growth rate of the population of the Mediterranean countries (MCs) has outstripped all other sectors. The MCs, defined as North Africa, excluding Egypt; Near East, excluding Turkey; Egypt; and Turkey, represent 3.6% of the world population, i.e., 199 million. Their share of the world is 4.2% of arable land, 6.8% of the cereal production, and only 2.9% of fertilizer consumption. Egypt and Turkey account for more than 70% of the cereal production and fertilizer consumption figures (Table 1). Data for crop production are abstracted from FAO Production Yearbook (FAO 1985a; 1992; 1994a) and information on fertilizers from FAO also (FAO 1985b; 1994b).

During a span of 12 years (from 1980 to 1992), the population of the MCs has gone up from 151 million to 199 million, an increase of 32%. The corresponding increases were 37% for North Africa (47.9 to 65.5 million) and 47% for the Near East (15.4 to 22.6 million). The prospect of a 60% increase of this population in the next 30 years or so has serious implications for the region's food requirements (World Bank, 1994). A net exporter of food less than 40 years ago, most countries of the region have become food importers due to their fast-growing population and a sluggish growth in their agriculture production. Food imports account for over 13% of the region's total import bill. The agricultural trade balance of the MCs for the period 1970-72 to 1989-91 indicates that there has been an increase in the food deficit (Rodríguez, 1995), i.e., Morocco (72 to 134%), Algeria (155 to 573%), Tunisia (106 to 187%), Egypt (52 to 672%), Jordan (494 to 467%), Syria (85 to 110%), and Turkey (17 to 56%).

The objective of this paper is: (i) to emphasize the agricultural input policies adopted by the governments of the MCs during the last three decades to increase agriculture production to feed the growing population, particularly those regarding fertilizer production, import, supply, distribution and pricing, (ii) to demonstrate the implications of the fertilizer subsidy removal and liberalization on the fertilizer consumption and, in turn, in food production, and (iii) to stress the need to sustain these efforts in order to intensify agricultural production to satisfy the increasing need for food and to maintain soil fertility, and hence its productivity.

Table 1. Some relevant facts for Mediterranean countries.

Region	Population	Arable Land	Cereal Production	NPK Consumption
		--ha--	--------- M tons	-------------
1. Mediterranean Countries				
Millions	199.0	61.0	59.0	3.9
World Share (%)	3.6	4.2	6.8	2.9
2. North Africa (Egypt)	4.2	6.8	2.9	
Millions	66	24.0	11.0	0.6
Region's Share (%)	33.1	39.3	18.6	15.3
3. Near East (Turkey)				
Millions	23.0	7.0	4.0	0.5
Region's Share (%)	11.6	0.3	6.8	12.8
4. Egypt				
Millions	53.0	2.5	14.7	1.0
Region's Share (%)	26.6	4.1	24.9	25.6
5. Turkey				
Million	57.0	27.5	29.3	1.8
Region's Share (%)	28.7	45.1	49.7	46.3

Source: FAO (1992, 1994a).

Agricultural and Economic Development

Agricultural is a vital sector of the economy of the MCs. It accounts for 17% of the GDP (Rodriguez, 1995), provides employment to 40% of the work force, and generates foreign exchange. The importance of agriculture in GDP ranges from 7% in Jordan to 30% in Syria. The percentage of the population in agriculture ranges from 10% in Jordan to about 47% in Egypt and Morocco. But more important than anything else, it provides the basis for food security. For the MCs, food security means achieving self-sufficiency in food grain production for supplying them in adequate quantities and at affordable prices to the population.

Success of Agricultural and Fertilizer Policies

During the last three decades or so, feeding the growing population has been a major challenge to MC planners and policy makers. The agricultural policies of the governments of the MCs, and especially policies relating to fertilizer and pricing, have produced excellent results in terms of substantial increase in fertilizer production and consumption. For example, in 1961-66 total nutrient use (1000 tons) was 587 for the whole region (Egypt and Turkey, 381; North Africa 114; Near East 92). In 1992 the figure for the region had increased to 4380, with the major contribution from Egypt and Turkey (3207), which, in turn, has contributed to significant gains in productivity of cereals and food grains. Cereal production increased from 43.8 M tons in 1979-81 to 58.9 M tons in 1991-92 (34%); the respective increases were 18% in the Near East, 55% in North Africa, and 32% in Egypt and Turkey.

Between 1961-66 and 1986-87, fertilizer consumption of MCs increased substantially, growing from 0.59 to 3.47 M tons. However, from 1987 to 1992, there was a sluggish growth in fertilizer consumption. This can be explained by the pressure made by the World Bank and the FMI on developing countries to phase out subsidies of fertilizers in the framework of Structural Adjustment Programs. These decisions has distributed the fertilizer consumption, which played, and will play, an important role in improving the food production in future for the growing population of the region. It was observed that fertilizer use in countries with subsidies increased at a much faster rate than in those without it. From 1971 to 1981, the annual percentage increase in fertilizer consumption was 16.2, 19.6, and 11.0% in Africa, Asia, and Near East with a subsidy, but only 8.9, 10.2, and 6.9%, respectively, without subsidy.

The Dilemma of Fertilizer Subsidy

While the above-mentioned international financing agencies are obliging most MCs to remove the subsidies of the fertilizers, it is worthwhile to recall that, with few exceptions, agriculture is heavily subsidized in one way or another in almost all countries of the world. Japan and Western European countries initially had high fertilizer subsidies, which were phased out only when an advanced stage of agricultural development was reached. There is no longer a direct subsidy on fertilizers in any developed country, but substantial subsidies of various kinds are accorded to agriculture. The average effective level of subsidy in the OECD countries, expressed as a percentage of the value of domestic production, increased from 30 to 50% during the 1980s (Isherwood, 1995).

The MCs as all developing countries went through three stages of development of fertilizer use: 1) *awareness of the benefits of fertilizer use*; at this stage of development, heavily subsidized fertilizers were normally distributed by government agencies and advice was given by the government extension services; 2) *use of extension and promotion* techniques to increase per-hectare consumption and efficiency of fertilizers; 3) *mature stage* of fertilizer development: at this stage the private sector may be encouraged to cater for the market. After these three stages of fertilizer-use development, as it was recognized long ago in the developed countries, an effective distribution and marketing service in the MCs is essential for efficient use of fertilizers--and must be paid for. In most developed countries, the proportion of the farm delivered cost accounted for by the distribution function is surprisingly high, when everything is taken into account (Isherwood, 1995).

In the MCs, the move towards *privatization* and *deregulation* could be seen as a logical way of letting free market forces streamline the whole fertilizer sector, from production to retail trade. Unfortunately, many sectors of the fertilizer industry and trade in MCs are not robust and could still be prone to failure if left without protection. Likewise, the small-scale farmers practising agriculture at close to subsistence levels may be left without access to vital farm inputs if all support and protection programs are abandoned. Dealers in a privatized fertilizer marketing system normally want to concentrate on business in high-consumption / easy-access areas, while abandoning remote, low-consumption areas altogether unless special rules, subsidies or incentives are provided. Since small-scale farmers represent a high proportion in the MCs, a complete privatization of fertilizer trade would probably do more harm than good to this class of farmers. This can be seen by considering data from selected countries of the region. With subsidy removal fertilizer use in Egypt increased from about 100 kg ha^{-1} in 1961/66 to over 300 kg ha^{-1} in 1986/87, which gives the evaluation of the rate of fertilizers use per hectare during the period of subsidy, i.e., and after the removal of subsidy de-control.

Fertilizer: Key to Self-sufficiency

The prospect of a 60% increase of the population of the MCs in a mere 30 years has serious implications for the food requirements of the region and the ability of its agriculture to satisfy them. During the last three decades, growth in cereal production has been remarkable in the MCs. However, most MCs still show a deficit in cereal production. For example, in the years 1979, 1985, and 1990, wheat production was 1.5, 2.4, and 3.61 M tons for Morocco, whereas the requirement was 3.49, 3.94, and 4.51 M tons for these years, respectively. The situation is similar in Algeria. Both production and requirements are higher in Egypt, but the disparity still exists. There is an urgent need to raise cereal production to fill this gap. According to the FAO data (Fadda, 1991), the sources of increases in food production in the region are estimated as follows: 7% from the increase of arable land; 21% from more intensive cropping, particularly through the replacement of follows by feed legumes and multiple-cropping; and 72% from the increase of the productivity of the land under cultivation in the region.

The most important way to increase food production is therefore through yield increase of the land under cultivation in the region, because of the following reasons. The opportunities for opening new agricultural land to cultivation have already been exploited. Between 1981 and 1992 the area of arable land and permanent crops increased slightly in North Africa (22.5 to 24.2 M ha), but decreased in Egypt and Turkey (31.0 to 30.3 M ha) and the Near East 7.0 to 6.9 M ha. This expansion has brought rather marginal and fragile land under cultivation, which led to land degradation and environmental imbalances. Some sobering facts have to be considered:

- Available land per capita, as a result of growth in population in the region, is decreasing and is expected to drop even further in the future, from 1980 to 1992, the available land per capita decreased in North Africa (0.47 to 0.31), the Near East (0.45 to 0.30), and Egypt and Turkey 0.35 to 0.27.
- There is very little land left to bring under irrigation; from 1981 to 1991, the area of irrigated land increased from 1.88 to 7.14 M ha in North Africa, 0.92 to 1.06 in the Near East and 4.59 to 5.04 in Egypt and Turkey.
- Economically active population in agriculture is decreasing (FAO, 1992). For instance, from 1975 to 1992, the declines were from 43.7 to 27.5% for North Africa, excluding Egypt; from 25.2 to 9.5% for the Near East, excluding Turkey; from 48.8

to 39.5% for Egypt, and from 64.5 to 46.5% for Turkey.

- The increase of the productivity per hectare can be achieved by: improved and efficient crop husbandry; better land preparation, timely planting of best varieties; proper fertilizer use and improved control of weeds, diseases and insects; and proper nutrient balances and soil conservation under rainfed conditions and better water management under irrigation. Regarding fertilizers, there is a close relationship between fertilizer consumption and cereal yields.

Since increases in food production have to come almost entirely from intensification of production on currently cultivated arable land, it is worthwhile to recall here that an intensive land use in the region without a net increase in fertilizer rate use will no doubt result in a dangerous depletion of soil nutrient reserves, as more plant nutrients are removed through harvested crop parts and losses than cannot be replenished. It is demonstrated that average P application to wheat in three MCs is lower than crop removal i.e., decreases of 2, 26, and 4 kg P_2O_5 $ha^{-1}year^{-1}$ in Morocco, Egypt and Turkey, respectively. The respective figures for P application (kg $ha^{-1}year^{-1}$) were 14, 36, and 22; while those for P removal were 16, 62, and 26. This will result in a steady "mining" of soil P. Every cropping season, the soil pool supplies more P to balance the nutrient deficiency. This strategy of P fertilization in not sustainable, because when soil can no longer offset the negative budget, crop yield will fall sharply.

The increase of the consumption of P and other nutrients has to be maintained at the same growth rate recorded during the last decades in order to maintain soil potential productivity and in turn to sustain the increase in food production to meet the requirement of the growing population. The MCs have a tremendous NPK production capacity. They are producing more fertilizer than they are consuming, with the exception of Egypt. Regarding P fertilizer production, they are producing 2.9 million tons of P_2O_5 and consuming only half of it, i.e., 1.4 M tons. The MCs produce 30% of phosphate rock of the world and represent 65% of the world phosphate rock exports.

Conclusions and Recommendations

The MCs are the largest food importing region in the developing world, due to the rapidly growing population and to a sluggish growth in the agricultural production. To satisfy the increasing need for food, the agricultural production has to be intensified. Since water resources and land reserves are limited in the region, the only way therefore to increase food production is to increase yields. For this, more fertilizer must be used in the MCs, as it is well known that nowhere in the world are high yields obtained without using fertilizer. Given the scientific "know-how" and the available supply of fertilizers in the MCs, it is possible for most countries of the region to achieve their food self-sufficiency. Mineral fertilizers must be expanded two to three-fold in order to improve and maintain soil fertility and to sustain food production increase.

The example of the industrialized countries demonstrates that there is no success in agriculture without a strong political support of the government to the farmers. Initially, these countries had high fertilizer subsidies, which were phased out only when an advanced stage of agricultural development was reached. But agriculture as a whole is still highly subsidised in these countries. In MCs, where agriculture still needs more development and where many sectors of the fertilizer industry and trade are not robust and are prone to failure if left without protection, governments should not move to *liberalization* and *deregulation* of such a vital farm input. In the MCs food grain prices must be kept at a reasonably low level to protect the weaker sections of the society. In that case, a value ratio of 3 kg grain per kg nutrient is necessary to stimulate fertilizer consumption. In those MCs where use is relatively low and not well established, there appears to be little realistic alternative to subsidies and distribution through public sector agencies.

The need for subsidies of fertilizers must be reduced by increasing efficiency and cost effectiveness of the fertilizer distribution and crop marketing systems. The liberalization of fertilizer market might contribute to improve the availability of wide range of fertilizers to farmers, provided it is implemented carefully and step by step, and provided it is accompanied by a series of measures which should be assumed by the governments such as the following:

- Quality control: quantity of nutrients the fertilizer contains, the form in which they are present, particle size, hygroscopicity, impurities, the quantity in the bag, labelling.
- The enforcement of the regulations.
- Easy access to foreign exchange for private companies importing fertilizers.
- Easy access to credit for farmers in order to purchase vital farm inputs such as fertilizers.
- Storage of staple food in order to guarantee fair prices to farmers and to avoid speculation.

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Potassium, the Forgotten Nutrient in West Asia and North Africa

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Abstract

Increasing demand for food and fiber from a restricted area of cultivable land in the West Asia-North Africa (WANA) region is contrasted by a considerable imbalance in fertilizer use, both in quantity and quality. The imbalance centers around potassium; its present use lags increasingly behind the removal with the harvested crop. In addition, the imbalance between the major nutrients, nitrogen and potassium in particular, is an obstacle for further yield and quality development as required by a steadily growing population. The consequences of continuing fertilizer imbalance can be seen in declining soil fertility due to *soil mining*, increasing susceptibility of crops to stress situations and in environmental problems.

The Problem

The fertilizer consumption in the West Asia North Africa region, the so-called WANA region, is characterized by two major facts: an imbalance in nutrient *quantity* when related to the nutrient budget, and an imbalance in *quality*, i.e., the ratio between the nutrients. These facts are in stark contrast with the need to feed a steadily growing population from shrinking land reserves. The need for an increase in productivity of the land is underlined by the following statistics:

- the population of the WANA region increased during the last 20 years by 56%,
- arable land and the area under cereals increased by only 2% and 8%, respectively,
- the gap in food supply was balanced by 61% higher yields, which even improved the per-capita cereal supply from 210 kg to 242 kg (Table 1).

However, the population is still growing; this requires further increases in the productivity of the available land, i.e., higher yields and cropping intensities. Higher yields means higher nutrient demand during the vegetation period and ultimately, higher nutrient removal. This questions the present fertilizer use practice and nutrient management when compared with the future demand for food and fiber.

Potassium Use and Crop Removal Disparity

Crop production, in the WANA region almost doubled during the last two decades (Table 1). Cereal output, increased from 59.2 Mt in 1969-71 to 106.2 Mt in 1989-91 and 109.4 M t in 1992-94 (3-year means). Nutrient removal increased accordingly (Table 2). Removal of nitrogen with all major crops increased from about 2 Mt in

1969-71 to a present level of about 3.9 M t per annum. Removal of potassium is in a similar order as N. Nitrogen consumption quintupled from 1 Mt in 1969/71 to more than 5 Mt in 1992-94. The resulting N balance became increasingly more positive. In contrast to N, the use of K remained low. Although there was an increase in consumption in the last two decades, the total quantity is far too small to compensate for the export of K with the harvest, resulting in an increasing deficit in the K balance.

Table 1. Development of the cereal supply in the WANA region.

	1970	1980	1990	Δ% 1970 vs 1990
Arable land, ha x 10^6	102.8	103.5	105.1	+2.2
Cereal, ha x 10^6	54.2	52.9	58.3	+7.6
Cereal, t x 10^6	59.2	77.0	106.2	+79.4
Cereal, kg ha^{-1}	1093.0	1295.0	1764.0	+61.4
Population,	282.3	325.2	439.2	+55.6
ha arable/head	0.36	0.32	0.24	-34.0
ha cereal/head	0.19	0.16	0.13	-32.0
kg cereals/head	210.0	237.0	242.0	+15.1

Source: FAO (1970-1990).

Table 2. Nitrogen and potassium balance of the WANA region.

Period	Crop N Removal	Fertilizer N Input	Balance	Crop K Removal	Fertilizer K Input	Balance
	----------	----------	----------	1000 t nutrient	----------	----------
1969-71	2052	1059	-933	1962	100	-1862
1979-81	2635	2951	+316	2647	167	-2480
1989-91	3824	4982	+1158	3532	299	-3233
1992-94	3909	5260	+1351	3836	294	-3543

Other sources of K are limited, especially in rainfed agriculture. Farmyard manure is widely misused as fuel and building materials. This also applies to crop residues--green manure cannot, unlike N, generate K. In irrigated agriculture, river and canal water may contain K, which adds to the balance. However, irrigation water is also a cause of K leaching losses, especially when salinized water is used. For example, K losses from a sandy loam soil (illitic) were more than doubled with water of a salinity of EC = 2 dS m^{-1} compared with non-saline water, and K leaching in sandy soils was accordingly accelerated and pronounced (Bajwa et al., 1993). A similar observation was made by Syvertsen et al. (1993) with salinized citrus. Also, Schleiff (1978) found a very close relationship between Cl^- and K^+ in drainage water, indicating that the higher the Cl^- content of the irrigation water, the more K is leached from the soil.

Fertilizer Use: Nitrogen-Potassium Imbalance

The fertilizer use in the WANA region shows a persisting imbalance, especially in N and K consumption. Regardless of the considerable global depression in fertilizer use during the late 1980s, the Nitrogen and P consumption in the WANA region showed a continuous increase over the last 10 years. N use increased by more than 40% and use of P by almost 20%. By comparison, K use is very small. However, the resulting N/K ratio remains almost unchanged at about 100 to 6. This extremely wide N/K ratio is rather unique in the global comparison, and contrasts sharply with the ratio at which plants absorb these nutrients (Table 3).

The closest N/K ratio is presently observed in South America (100:91), followed by Europe (100:42), North/Central America (100:38) and Africa (100:22). Asia, as a whole, also has a rather wide N/K ratio of 100:14, ranging from 100:169 in Malaysia to 100:13 in India and 100:10 in China as the major K-consuming countries. The global mean is 100:28 (1991/92-93/94). Continuous imbalance in fertilizer use prevents full exploitation of the yield potential, restricts quality formation and increases the susceptibility to abiotic and biotic stress such as heat, frost, drought, salinity, pests and diseases.

Table 3. Nitrogen and potassium uptake of selected crops.

Crop	Yield	Nutrient Uptake		N/K Ratio (N=100)
		N	K_2O	
	- t ha^{-1} -	------kg ha^{-1}----		
Wheat	5	150	160	107
Potato	40	175	320	183
Sugar beet	45	200	300	150
Soya	3	220	170	78
Rapeseed	3	165	220	133
Cabbage	70	370	480	130

Negative K Balance

Maintaining soil K mining at negative K balances impoverishes nutrient reserves, depletes soil fertility and destroys the basis for future crop production. To assess the effect of soil K mining on soil fertility, the principle of K dynamics in soils has to be taken into consideration. Soil K availability is governed by dynamic processes. In soils, K is partitioned into three major fractions, the *solution K*, the *exchangeable K* and the *structural K*. These fractions are in a dynamic process interrelated to each other.

- *Solution K* is the smallest fraction. Plants absorb K directly from the soil solution. The K in the soil solution moves along a concentration gradient created by K uptake by plant roots. The steeper the gradient the better is the K supply to the roots. A high K concentration and a good water supply improve the diffusive flux of K in soils. Shortage of water can -- at least partially -- be compensated for by increasing the K concentration with potash applications.

- Potassium taken up (or leached) from the soil solution is replenished from the pool of *exchangeable K*. The quantity and the rate of release into the soil solution is related to the clay content and the nature of soil minerals. Sandy soils release K quickly, but the effect is not lasting. On the other hand, clay soils, although having relatively high K contents, can have a rather restricted K release. Unlike nitrate, plant roots have to compete for K with the exchange processes.
- *Structural K* is a constituent of the lattice of soil minerals. This fraction usually becomes available only at rather slow rates with the destruction of the soil minerals, i.e., at weathering and forced demineralization as soil mining.

Quantity/intensity curves illustrate different K release rates by typical soils of the irrigated and rainfed sectors of Punjab, Pakistan (Krauss and Malik, 1995). Sandy soils of the Rasulpur Series release K very rapidly from the exchange sites into the soil solution but this rate does not persist. Minor changes in the content of exchangeable K result in large changes in water-soluble K. The soil is soon depleted of available K if not replenished with top dressing; the soil has a poor buffering capacity. Irrigated clay (39%) soils of the Tarkhoba Series show a much better buffering capacity. Large changes in the content of exchangeable K results in rather small changes in the K concentration of the soil solution, which keeps solution K fairly constant. However, the relatively low K-release intensity restricts K availability to the crop. The irrigated silty soils of the Faisalabad Series (20% clay) react intermediately, i.e., they have a reasonable release rate at a sufficiently good buffering capacity.

The silty soils from the Missa series (20% clay) of the rainfed sector behave quite different from silty irrigated soils. Although they have a similar clay content (20%), the buffering capacity of the Missa soil is much better (steeper linear part of the exchange curve) than the buffering of the irrigated soils from the Faisalabad Series (flat curve). But, in contrast to the soils from the irrigated soils, the equilibrium K concentration of the rainfed soil is substantially lower, indicating less readily available K in the soil. Finally, K fixation of the rainfed soils is much more pronounced than in irrigated soils; this is caused by vermiculite, which is found in rainfed soils but not in irrigated soils.

The crop response (wheat) to K on irrigated soils corresponds with the K release characteristics (Table 4). One can deduce from the data that 1) yields increase by more than 12% with irrigation on sandy soils, reflecting their poor buffering capacity; 2) a fairly good response was also obtained on clay soils (9.4% yield increase), although having relatively high K contents, because the indigenous K release rate was obviously not enough to satisfy the K requirement of the crop; 3) on silty soils there was hardly any response, because K release intensity and quantity seems to meet the demand of the test crop, and 4) contents of exchangeable K, as determined with routine soil tests, fail to predict crop responses to K unless related to soil texture and thus, the K release characteristics.

Table 4. Wheat response to K as affected by clay content in irrigated soils from Punjab, Pakistan.

Soil Texture	Clay	Exchangeable K	Grain Yield		
			K_0	K_{150}	Δ K_{150}-K_0 (change)
	-%-		-------- ha^{-1} ------		------- % --------
Sand	11	129	2.96	3.33	(+ 12.5)
Silt	20	204	3.37	3.43	(+ 1.8)
Clay	40	333	3.10	3.39	(+ 9.4)

Source: Krauss and Malik (1995).

Potassium Requirement and Plant Growth

Unlike N and P, uptake of K by plants is not uniform during the vegetative growth period (Karlen and Sadler, 1992). Most plant K is absorbed within a relatively short time span, e.g., in cereals, from stem elongation to spike emergence. During that period of time, K uptake rates increase to about 6-8 kg K_2O ha^{-1} day^{-1} in cotton, potato, sugarbeet and wheat, 12 in soybean, 16 in tobacco, and up to 19 kg in maize. Thereafter, the K content of the plants declines caused by re-translocation of K into the roots, and leaching from leaves. Re-translocation of K in plants towards maturity results in about 20% lower K contents at harvest compared with the peak of the season, thus incompletely reflecting the actual K requirement during plant development.

The seasonal K uptake pattern of plants forces the soil to release K with the corresponding intensity and quantity. To meet this demand, K should occupy about 3-5% of the cation exchange capacity (CEC) to warrant a sufficiently high K-release intensity. In light-textured soils, split application of K is necessary to compensate for a restricted K-release capacity and to prevent major K leaching losses. Split application of K is suitable for heavier-textured soils, taking the restricted mobility of K in such soils into account.

"Soil Mining", Negative K Balance, Diminishing K Reserves

The declining content of exchangeable K at *"soil mining"* restricts K release into the soil solution. The soil loses its potential to maintain an appropriate K content in solution and, thus, an appropriate K flux to the roots. Crop production under these conditions starts to become less reliable and vulnerable to stress situations such as drought, frost, heat, pests and diseases. In the rainfed area of Pakistan, which hardly receive any K fertilizers, a rate of depletion of 4.7 ppm K per annum during the last 15 years (Malik and Hassan, 1992). At the same time, the control yield of wheat declined by 15 kg ha^{-1} annually. In the irrigated sector of Punjab, Pakistan, long-term trials revealed a decline of the content of exchangeable K of 12-20 ppm K per season, depending on soil texture and control yield (Krauss and Malik, 1995). In Iran, Siadat et al. (1993) also showed an appreciable reduction of the K status of soils over time.

The share of soil tests with high K contents declined in favor of those indicating a low K status. For example, at one station (Baraan), the number of samples with 300-400 ppm decreased from 98% in 1979-80 to 18% in 1991-92, while in Shavoor, the number of deficient samples (100-200 ppm K), increased from 4 to 30% from 1983 to 1992. Consequently, soil fertility depreciates, resulting in declining yields as indicated in the close correlation between exchangeable K content and wheat yields in Iran (Doroudi, quoted by Siadat et al., 1993).

Assessing the soil K status by determining the content of exchangeable K reflects only incomplete changes occurring in the K fractions at soil mining (Kemmler, 1986). The content of exchangeable K decreased in the long-term experiment by about 20%, whereas the content of the reserve K declined by more than 40% apart from the fact of substantial differences in the quantity involved in the changes of the different fractions. Where NPK was used instead of NP alone, the trend was reversed, i.e., exchangeable K was increased by 27% after 6-9 years and the reduction in reserve K greatly reduced.

Depleted Soils, Potassium Fixation

Potassium fixation involves fertilizer K being incorporated into the structure of soil minerals and becoming virtually inaccessible for plants. With exhaustive cropping, the content of exchangeable K declines simultaneously with increasing K fixation. The presence of the K-fixing clay mineral "vermiculite" in soils of the rainfed area in Pakistan may result from the permanent cropping without any replenishment of the exported K (Krauss and Malik, 1995). Extended K fixation is also reported from the rice soils in the Caspian region of Iran, where K use has been introduced only recently. In an exhaustive cropping study (Tributh et al., 1986), the soil in question had initial exchangeable K of 112 ppm and K fixation of 328 ppm. However, with 3 years grass/clover cropping, exchangeable K decreased to about 80 ppm and K fixation increased from 546 to 679 ppm.

Crops on K-fixing soils fail to respond to K fertilizer at common rates, a fact which is often the source of misguided potash recommendations. A classical example in this regard is given by Kemmler and Hobt (1985). With 300 kg K_2O ha^{-1}, which is considered as an ample supply, there was hardly any response of maize to potash, i.e., from 5.34 to 5.63 t ha^{-1}. However, with addition of 600 and 900 kg ha^{-1}, yields increased to 8.66 and 9.37 t ha^{-1}, respectively. The corresponding ratios of grain K were 1, 5.5 and 4.5, respectively. Ignoring K fixation would result in classifying the soil as *very fertile in K.* Only quantities which exceeded standard rates revealed the true character of the K-fixing soil, and maize responded accordingly.

Misinterpretation of Soil Test, Incorrect K Recommendations

Apart from the case of K fixation, routine soil tests are also prone to misinterpretation. This pertains in particular to the fact that crop yields are very often related to a static value, the K content, and not to the underlying dynamic process. For example, yields of sugarcane in Upper Egypt varied independently from the content of exchangeable

K, i.e., exchangeable K (meq/100 g soil) values were 0.86, 1.00, and 0.92, while the corresponding sugarcane yields (kg/stalk) were 1.68, 1.54 and 1.08, respectively (Etourneaud, 1993). Misinterpreting this finding would mean that the variability of yield derives from factors others than soil K, and soil K does not seem to be a limiting factor. However, relating the cane yield to K saturation of the CEC and therefore taking the dynamics of K release into consideration, it results in a close relationship between the two parameters; exchangeable K as a percentage of CEC was then 2.54, 2.26, and 1.97. Potassium release improves with K saturation and, thus, the K availability and supply of plants.

Fertilizer Imbalance: Yield, Stress, Quality Implications

Potassium—Versatile Nutrient

Potassium is involved in various physical process which impact on yield and quality.

Enzyme Activation. More than 50 enzymes are directly or indirectly affected by K, in those enzymes which are involved in energy transfer, assimilation and the synthesis of sugar, starch, protein.

Phloem Transport. A high rate of assimilation can only be maintained if assimilates which are produced are removed from the source--the leaves--and translocated into the "sinks", such as roots, tubers, seeds, or fruits. Potassium is involved in "phloem loading". A high rate of phloem loading at the source and unloading in the "sink" brings about a speedy flow of assimilates and subsequently, a high rate of yield formation.

Assimilate Storage. An active storage tissue is a prerequisite for intensive flow of assimilates. In cereals, for instance, K has a marked effect on the number of grains per spike and the weight per grain. By supplying enough assimilates, more florets remain alive acting as a "sink" for further assimilates. More grains per spike means higher yield. It has been observed repeatedly that the leaves of plants well supplied with K remain greener for a longer time, thus providing the growing grains with assimilates over an extended period.

Cation/Anion Balance. Potassium neutralizes soluble organic acids, as well as insoluble negatively-charged macromolecules, to maintain the cytoplasmatic pH at 7 to 8, which is optimal for the activity of a wide range of enzyme systems.

Osmo-regulation. Accumulation of K in cells leads to an increase of their osmotic pressure, so that water moves into the cells. A good K supply to root cells is therefore essential to extract water from soils even at declining moisture contents or at salinity.

Stomata Regulation. Accumulation of K in the "guard" cells of the stomata is the driving force of stomata-movement. By opening and closing of the stomata, the plants regulate water relations and gas exchange. Under water stress, plants well supplied with K quickly close the stomata, thus preventing excessive water loss by the plant. In contrast, plants under-supplied with K show a sluggish stomata-movement; it takes more time to close the stomata at water stress or at high temperature and plants start wilting and assimilation ceases. Early wilting at beginning of water stress is a very important indicator for K deficiency.

Nitrogen Metabolism. Major K involvement in N metabolism can be seen in: stimulation of the nitrate uptake through increased secretion into the xylem vessels, K activates the enzyme nitrate reductase, a prerequisite in N assimilation, K activates the enzyme glutamine synthetase, which regulates the transfer of NH_3, coming either from ammonium uptake, nitrate reduction or biological N_2 fixation via glutamate into organic low molecular weight N compounds such as amide and amino acids. These compounds are precursors of protein synthesis.

Under-supply with K, either due to insufficient fertilization, inefficient release from exchange sites or competitively inhibited by excessive NH_4 from N fertilizers, results in disturbed N assimilation in the plant. Under these conditions, nitrate uptake is reduced, leaving more residual N in the soil, and low molecular weight N compounds accumulate in the plant due to suppressed enzyme activities. With the accumulation of nitrate, amides and amino acids, crop quality deteriorates and resistance to pests and diseases declines.

Results from on-farm trials with rainfed wheat in Algeria confirm the importance of balancing N and K nutrition (Daoud, 1993) for yield development. This shows that both grains and straw respond to K with higher yields; lower N, but in balance with K (67+200) yielded, higher than imbalance in N use without K (134+0); the grain/nutrient ratio for N increased from 10-12 kg grain (kg N)$^{-1}$ at K_0 to 16-18 kg grain (kg N)$^{-1}$ at K_{200}. Each unit of K_2O was returned by an additional 5-7 kg grains. The higher yield at the same N level indicates less residual N, which could pollute the environment. There are numerous other results providing evidence that K application is indispensable for high yields and good quality also under rainfed conditions.

Long-term field trials in the rainfed area of Punjab, Pakistan, reveal a fairly good response to K, even under sub-optimal water conditions. Malakouti and Mirsolaymani (1993) reported from Iran that application of 100 to 200 kg K_2O ha^{-1} substantially increased potato yields. For the Damarouad region, it was advised to apply 150-100-200 kg N-P_2O_5-K_2O ha^{-1} on soils with less than 200 ppm exchangeable K in order to maintain quality as well as the target yields. Cotton in Turkey responded to K with yield increases between 2 and 16%. Fiber length, fiber fineness (micronaire) and fiber strength were also improved by use of potash (Anaç and Colakoglu, 1993).

Farmers in Madhya Pradesh, India, applying K to wheat and soybean, report higher procurement prices of the seeds due to better appearance, boldness and shininess after using potash, although a premium system is not officially introduced. Groundnut in Orissa, India, showed higher shelling and oil contents with K (Table 5). Groundnut usually receives 1 or 2 initial irrigations, otherwise feeding from residual soil moisture.

Table 5. Effect of potassium on yield and quality of groundnuts (Orissa/India).

Parameters	Potassium			
	kg ha^{-1}			
	0	40	60	80
Pod yield, kg ha^{-1}	1661	1905	2099	2125
Shelling, %	63.6	66.1	69.2	69.6
Oil content, %	41.6	43.1	45.1	47.5
Oil yield, kg ha^{-1}	439	543	655	702
Gross income, \$ ha^{-1}	533.8	614.5	677.1	685.5
Extra net income, \$ ha^{-1} due to K	68.4	125.8	129.0	

Assuming a per-capita edible oil requirement of 6.57 kg/annum (FAI, 1994), the number of people receiving their allocation from 1 ha groundnut could increase from 67 persons at the NP control to 107 persons at a balance in nutrition with 80 kg/ha K_2O. The added value with higher oil yield (\$ 334) is a multiple of the cost of 80 kg K_2O (\$ 21).

Potassium: Important Factor in Crop Stress Alleviation

The following responses of the plant to K application are important prophylactic steps to increase the resistance to abiotic and biotic stress such as heat, frost, drought, pests and diseases by accumulating monovalent cations, K in particular, in root cells lowers the osmotic potential which improves water uptake at declining soil moisture or at saline conditions. In this context, care has to be taken not to contribute with fertilizers to the osmotic pressure of the soil solution or to salinity, especially during the seedling stage of the crop. The "salt index" provides an idea of to which extent a fertilizer contributes to the osmotic pressure. The salt index by definition is *"the ratio of the increase in osmotic pressure produced by the fertilizer material to that produced by sodium nitrate"* (Rader et al., 1943). The lower the salt index, the better is the fertilizer suited for saline conditions. Potash fertilizers differ in this respect, i.e., KCl 116.3; KNO_3 73.6; K_2SO_4 46.1; $NaNO_3$ 100.

Other physiological effects of K are as follows: 1) Rapid stomata movement due to the osmotic properties of K prevents early wilting at drought stress and thus, preventing yield loss. By lowering the freezing point in cell liquids, K assists in frost tolerance. Potassium as an activator in numerous enzymatic reactions improves N metabolism and thus prevents accumulation of low molecular weight organic N compounds such as amides and amino acids, which are the preferred foodstuff for pests and diseases. 2) Potassium also prevents early breakdown of chlorophyll and thus maintains the green color of plants. Yellowish color attracts aphids in particular. 3) Potassium, in contrast to N, improves the mechanical structure of plants and therefore strengthens the plant tissue and increases the penetration and chewing resistance for fungi hyphae and insects (Perrenoud, 1977). Potassium fertilization reduced fungal diseases (- 49%), bacteria (- 48%), and insects and mites (- 27%), while at the same time increasing yield by 44, 70, and 14%, respectively, in each of these cases.

Balance Nutrition: Natural Resource and Environment

Yield increase is an important contribution to safeguard the natural resource, "land". Assuming a per-capita cereal requirement of 200 kg/annum, the yield increase from 4668 kg ha^{-1} to 6020 kg ha^{-1} in wheat with balanced nutrition will feed 7 persons more from the same area of land. In this context, Ange (1992) estimated that in order to ensure the minimum food crop production requirement, cereal yields in Asia have to be increased from at present 2.8 t ha^{-1} to 3.2 t ha^{-1} by the year 2010 and 4.75 t ha^{-1} by 2030 to cope with increasing population. Increasing yields in irrigated agriculture is also a contribution to safeguard the natural resource "water" (Malik and Hassan, 1992). In this respect, K contributes to both higher yields and improved water-use efficiency due to its osmotic function in plants--the highest grain yield per unit water used was with K fertilization in association with N and P.

Higher yields also leave less N in the soil, which otherwise, if leached, would pollute the groundwater, and if volatilized, would contribute to global warming and destruction of the ozone layer. The dimension of losses in N is considerable. According to Ange (1992), India loses around 101 kg N ha^{-1} or 67% of the total N supply (fertilizers and other sources), China loses 149 kg N ha^{-1} or 64% of the N supply, while France loses 81 kg N ha^{-1} or 27% of the total supply. Balanced nutrition affects the content of residual N in the soil (K + S, Germany, long-term trial 1980-92). With K fertilization at 300 kg ha^{-1}, sugarbeet yield increased from 59 to 88 t ha^{-1}. Mineralizable N without fertilization was 16, 16, and 29 kg ha^{-1} at depths of 0-30, 30-60, and 60-90 cm, respectively. With K fertilization, these values were reduced to 5, 14, and 4 kg ha^{-1}, respectively. The relationship between fertilization and N balance involves, of course, more steps than only to increase the yields, as explained by Bley (1990).

Discussion and Conclusions

The steadily growing population of WANA, and indeed most developing areas of the world, increasingly requires more food and fiber from agriculture. Advancing urbanization and improving purchasing power call for diversification in food and for higher quality. To provide 1 kg meat requires 9 kg cereals. Faced with the restriction in land and water availability, the countries in the WANA region can only meet the growing demand either by crop diversification, by increasing yields and productivity of the given natural resources--land and water--or by spending foreign exchange for imports. In this context, the world cereal stocks are dwindling, cereal yields in Asia are stagnating or even declining--indeed the former Soviet Union has emerged as an important cereal importer. From this it can be concluded that the future world cereal market is becoming increasingly tougher.

Disregarding the alternative of balancing the food gap with imports, it seems that as traditional rural land use approaches expansion limits, further increases in production are only be achievable with improved technology. Unless productivity of the cultivated land can be further increased, the growing demand for food and fiber might also be met by utilizing unsuitable marginal land with devastating consequences for the environment. Continuation of the imbalance in fertilizer use, as observed in the WANA region, can only jeopardize the goal of increasing productivity of land and water.

Potassium is a "silently" working nutrient, it often takes time to realize the loss in yield and quality when it is withheld and to benefit from higher yields after it is applied, especially after previous "soil mining". The soil as a buffer may supply K--for a certain period--to low-yielding, and, thus low-demanding, crops. The fertilizer strategy adopted decades ago for low-yielding, i.e., low-demanding traditional crops, which focused on N and relied on the K supply of soils relatively rich in K-bearing minerals, was correct under the conditions of that time. The situation has substantially changed with introduction of high-yielding varieties and crop types which are less efficient than cereals in K absorption. This also makes fertilizer recommendations based on traditional low input agriculture obsolete. The nutrient management has to be adjusted accordingly, but also taking into consideration the uncertainty in water supply. Its potential to establish and stabilize yields also under adverse soil, water and climatic conditions renders K an integral part of crop management.

The demand for environmentally friendly crop production has become a major issue with the public. Attention focuses on N fertilizers as the potential source of leachable and volatilizable substances which can pollute groundwater and adversely affect the atmosphere. However, it is often argued that in low input agricultural systems, as prevailing in the dryland zone, the quantity of N used is too low to contribute substantially to environmental pollution. But taking into account N losses of 64 and 67%, as in India and China, respectively, the N loss of the WANA region would be the equivalent of around 3.3 M t N lost to the environment. Potassium is the natural partner of N, assisting in improving the N fertilizer efficiency, and thus leaving less N in the rhizosphere. This should also be acknowledged by the respective fertilizer policy and the advisory service receiving the backing up from it. It is deemed necessary to reconsider the present fertilizer strategy towards balanced nutrition.

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Use of Isotopes in Agriculture with Special Reference to Soil Fertility and Plant Nutrition

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Abstract

The use of commercial fertilizer and organic nutrient sources represent the most important factor worldwide for increasing and sustaining soil fertility and crop productivity. Nuclear techniques provide the only direct means of following the fate of nutrients in soils and their uptake by the plants. Only a fraction of fertilizer nutrients applied to soil is taken up by the crop; the rest either remains in the soil or is lost through leaching, physical wash-off, fixation by the soil, or release to the atmosphere through chemical and microbiological process. Therefore, it is necessary to obtain information on the relative merits of different fertilization practices in different soil and climatic conditions in order achieve maximum fertilizer-use efficiency in the most economical way, and to reduce farmers' production costs and to sustain or increase soil fertility and crop productivity.

Since the plant does not discriminate between synthetic fertilizers or native soil nutrients, the exact amount of nutrients taken up by the plant from different sources can be measured only by using the isotope techniques. Isotopic-aided studies involve the application of labelled fertilizer as tracers (with ^{32}P or ^{15}N) for quantitative and precise determination of the fate of specific nutrient elements in soil-plant systems. Optimum fertilizer application, in an integrated manner, as appropriate as possible to each farming system, will manage and ensure efficient nutrient use for sustainable agriculture. "Nutrient mining", without adequate replenishment, can result in soil fertility deterioration, which is no less dangerous than other forms of environmental degradation. Some of the results of the research undertaken with fertilizers labelled with stable and radioactive isotopes and other related nuclear techniques in different countries, through various Coordinated Research Programs facilitated by the Soil Fertility, Irrigation, and Crop Production Section of the Joint FAO/IAEA Division, are discussed in the paper.

Introduction

In October 1994, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture celebrated its 30th Anniversary. For the Soil Fertility, Irrigation and Crop Production Section, one of the six Sections which form the Joint Division, these 30 years were quite successfully. From the very beginning, the use of isotopes and related techniques has proven to be extremely valuable in a wide range of applications such as increasing the efficiency of fertilizers and optimizing plant nutrition. Isotope labelling of a nutrient in a fertilizer or in the soil had already proven to be an invaluable and direct method to distinguish between the amount of the nutrient taken up in the plants that originated from either of the two sources.

The history of research in isotope studies dates back to 1923 when G.V. Hevesy made his classical experiment with living organisms, signifying the start of isotope applications in agricultural research. The first research grants approved by the IAEA in 1959, on an individual contract basis, were awarded to Japan and the Federal Republic of Germany to support work on fertilizer-use efficiency. Starting in 1962, research contractors from developing countries, and agreement holders from developed countries, were integrated in Coordinated Research Programs (CRP). The first two CRPs initiated by the IAEA (1962-1968) were also in the area of soil fertility: 1) application of isotopes to rice fertilization, and 2) plant nutrient supply and movement in soil systems. One year later, in 1963, the CRP on "Maize fertility using fertilizers containing labelled nutrient elements" (1963-1968) was initiated. From the beginning of the Joint FAO/IAEA Division, until today, the Soil Fertility, Irrigation, and Crop Production Section has had the technical responsibility for 29 CRPs as listed:

- Application of isotopes to rice fertilization, 1962-68.
- Plant nutrient supply and movement in soil systems, 1962-68.
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- Nuclear techniques to improve crop production in salt affected soils, 1985-92.
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- Use of isotope studies on increasing and stabilizing plant productivity in low phosphate and semi-arid and sub-humid soils of the tropics and sub-tropics. 1989-94.
- The use of nuclear and related techniques in assessment of irrigation schedules of field crops to increase effective use of water in irrigation projects, 1990-95.
- The use of nuclear and related techniques in management of nitrogen fixation by trees for enhancing soil fertility and soil conservation in fragile tropical soils, 1990-95.
- Enhancing soil-fertility and crop-production by better management of *Rhizobium*. 1990-93.
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- The use of nuclear techniques for optimizing fertilizer application under irrigated wheat to increase the efficient use of fertilizers and consequently reduce environmental pollution, 1994-99.
- The use of irradiated sewage sludge to enhance soil fertility and crop production and to protect the environment, 1995-99.

I should mention the great contribution to the development of the use of nuclear techniques in soil fertility and plant nutrition studies of M. Fried, the first Director of the Joint FAO/IAEA Division. As a well-known soil scientist and author of the "A value" concept and of the isotope dilution method, he worked in close cooperation with H. Broeshart, then Head of the Agricultural Laboratory at Seibersdorf. From a slow beginning towards the end of the 1950s, research activities in various fields of soil science gained momentum under the inspired leadership of M. Fried, who worked with the IAEA from 1960 to 1983, while H. Broeshard provided critical back-up in the laboratory during this development period. The pioneering efforts of these scientists and their promotional activities would leave its mark on soil scientists all over the world (Fried, 1978).

FAO/IAEA International Programs on Fertilizer-Use Efficiency

The Joint FAO/IAEA Division, through the Soil Fertility, Irrigation and Crop Production Section, has, for three decades, coordinated several international research programs and technical cooperation projects (TCP) on the use of isotope techniques in fertilizer-use efficiency studies of major food grain crops such as wheat, maize and rice (IAEA, 1970, 1974, 1978). The main objective of these programs was to achieve higher and more stable grain yields by maximizing the uptake of nutrients from applied fertilizers and other sources while reducing potential harmful effects on the environment through the use of isotope techniques. For instance ^{15}N-labelled fertilizers were applied to a crop in different ways (sources, timing, placement) to determine and measure the amount of N derived from the fertilizer which is present in soil-plant systems and to elaborate on the most efficient methods of fertilizer application for different soils and climatic conditions.

In the first *rice fertilization* program (1962-1968), one of the relevant questions to be answered was the relative efficiency of NH^+_4 and NO^-_3 as sources of N when surface applied or incorporated in the top 5 cm. Field experiments using ammonium nitrate labelled in either the NH^+_4 and NO^-_3 ion with ^{15}N were carried out in five countries. The results, shown in Table 1, clearly demonstrated that the NH^+_4 was by far the most effective source of N to paddy rice and the highest uptake of N was obtained from the NH^+_4 when incorporated in the top 5 cm. Placement had no significant effect on the utilization of nitrate.

Table 1. Nitrate and ammonium as sources of N to flooded rice.

Location	Fertilizer N Source	% N Derived from Fertilizer	
		Surface	5 cm depth
Korea	[1] NH_4NO_3	10.0	14.0
	NH_4NO_3	2.2	2.0
Egypt	[1] NH_4NO_3	7.0	10.0
	NH_4NO_3	4.7	0.8
Hungary	[1] NH_4NO_3	7.0	14.0
	NH_4NO_3	2.4	3.0
Sri Lanka	[1] NH_4NO_3	10.0	20.0
	NH_4NO_3	5.9	2.4
Burma	[1] NH_4NO_3	12.0	20.0
	NH_4NO_3	2.7	2.4

[1]-labelled with ^{15}N

The 1972-73 field study of the CRP on *rice fertilization* compared the utilization of 100kg N/ha treatment when applied at four different times in four countries using ^{15}N-labelled ammonium sulfate (Table 2). Only one application was labelled with ^{15}N in each treatment. The basal application involving placement at 5 cm depth at transplanting was superior to the treatment when N was applied three weeks after transplanting. But the greatest efficiency of fertilizer N utilization in the grain was obtained when fertilizer N was applied at primordial initiation. It is supposed that rice plants growing with sufficient N supply through vegetative stages will take up and translocate to grain this late supplement of N in a very significant manner. Noteworthy also was the fact that if N supply was limited at early growth stages, it is possible to correct such deficiency at least 3 weeks before primordial initiation to avoid yield reduction. Similar results were obtained in follow-up field experiments conducted in seven countries.

Table 2. Fertilizer N utilization by rice when applied in increments as ^{15}N-labelled ammonium sulfate at four growth stages, 1972-73.

Time of Fertilizer N Application[1]				Grain N Derived from ^{15}N-Labelled Fertilizer				
T_1	T_2	T_3	T_4	Bangladesh	India	Sri Lanka	Thailand	Average
------------kg N ha^{-1}------------				------------ % ------------				
25	25	25	25	7.8	6.6	6.1	10.2	7.7
25	25	25	25	3.0	4.7	3.1	10.3	5.3
25	25	25	25	6.0	6.4	3.0	10.9	6.6
25	25	25	25	8.3	11.8	6.4	17.8	11.1
			LSD (05)	1.7	2.1	1.7	2.1	
			Total	25.1	29.5	18.6	49.2	

T_1 basal at transplanting; T_2 3 weeks after transplanting; T_3 midway between T_2 and T_4; T_4 primordial initiation.

The first *wheat fertilization* program involved six countries. The ^{15}N single treatment fertility design was utilized for investigating the optimum time of application of different fertilizer N sources such as $NaNO_3$ and $(NH_4)_2SO_4$ when applied at 120 kg N ha^{-1} in three equal split applications at various growth stages (planting, tillering, and boot stage). From the grain yield alone, it could be inferred that both fertilizer N sources tested were equally effective and that there were no yield differences due to the split application. The isotope data indicated that: 1) both N sources were equally effective when applied at planting time; 2) the largest uptake of fertilizer N was obtained from the N broadcast at tillering as $NaNO_3$, and 3) the applied N at boot stage was generally too late for most effective N utilization in the grain.

The results from the Romanian wheat program show a preferential absorption capacity of ions from fertilizers having different chemical composition. From the total of 120 kg N ha^{-1} of ammonium nitrate applied, half in autumn and half in spring, NH_4^+ accounts for 29% at kernel formation, and 21.8% at straw formation, the general utilization coefficient being 50.8% (Hera, 1979a). Under in the same conditions, the nitrate form was more efficient, the utilization coefficient (amount of nutrient taken up by the crop from applied fertilizer) being 34.8% for kernel, 30.8% for straw, and the total 65.6% (Table 3). The higher contribution of NO_3^- at the time of grain formation is indicated by the percentage of N derived from fertilizer (Ndff); the utilization coefficient for NO_3 was higher in all cases due to the higher mobility of this ion.

It is known that in contrast to the NH_4^+ ion, NO_3^- ion is retained to a much lesser extent by the soil adsorptive complex, moving in the soil solution by mass flow. The fact that NO_3^- moves with the water allows the root system to exploit this N form better. This explains the superior values of the NO_3^- utilization coefficient. The adoption of these improved fertilizer practices in many countries around the world has resulted in the saving of fertilizers worth many millions of dollars each year.

One of the most successful CRPs was on *maize fertilization*. In the eight countries which participated in the program, results were obtained using fertilizers labelled with

Table 3. Nitrogen uptake from NO_3^- and NH_4^+ from ^{15}N-labelled ammonium nitrate.

Time/Rate N Fertilizer		Kernel			Straw			Total		
Autumn	Spring	% Ndff	N	Efficiency	% Ndff	N	Efficiency	% Ndff	N	Efficiency
		kg ha^{-1}	kg ha^{-1}	--- % ---	kg ha^{-1}	kg ha^{-1}	--- % ---	kg ha^{-1}	kg ha^{-1}	--- % ---
$^{15}NH_4NO_3$										
60†	60	8.0	7.6	25.3	7.9	6.1	20.3	15.9	13.7	45.6
60	60†	10.4	9.82	32.7	9.0	7.0	23.3	19.4	16.8	56.0
Total		18.4	17.4	29.0	16.9	13.1	21.8	35.3	30.5	50.8
$NH_4{}^{15}NO_3$										
60†	60†	10.2	9.6	32.0	10.6	8.3	27.7	20.8	17.9	59.7
60	60	12.0	11.3	37.7	13.0	10.2	34.0	25.0	21.5	71.7
Total		22.2	20.9	34.8	23.6	18.5	30.8	45.8	39.4	65.6

† Labelled entity.

^{15}N and ^{32}P led to the conclusion was that by applying half of the N rate and the full P rate in bands at seeding and the other half of the N rate side-dressed during the vegetative period of maize (at the time of mechanical weeding control), an increase in the utilization coefficient of nutrients (N and P from fertilizer) and a yield increase per unit area, compared to the classical application--broadcast on the soil surface and plowed down--could be obtained.

A relevant example of results which were gradually applied to agricultural practices comes from Romania. On the basis of positive responses obtained in experimental fields, seeders equipped with special devices for applying fertilizer at seeding time, and cultivators for weed control equipped with devices for applying fertilizer at the vegetative period were mass produced. The new technology was extended to production on an area of 2 M ha planted with maize. The results highlight the 6-year average yield increase of 0.62 t ha^{-1} obtained in research and production compared to those obtained through the classical method of broadcast application. In 2 M ha of maize growing area, the increase due to banding translated into 62,000 tons (Hera, 1979b). The investment costs for adapting seeders and cultivators to the new fertilizer application method represents only 5% of the total value of the yield increase that can be realized in any year. The advantages of the new method are obvious if we also take into consideration the elimination of the supplementary work in applying the fertilizer in the classical method, and as a result the diminution of the fuel consumption and the diminution of the possibilities of degrading the physical soil characteristics by a supplementary soil compaction.

FAO/IAEA Programs on Soil N Fertilizers as Pollutants

Against a background of rising world population needs, which effectively diminishes agricultural and forestry land resources per capita, soil N has emerged as the critical element in meeting the global needs for food, feed, fuel and fiber in the immediate decades ahead. Thus, the increasing and essential role of fertilizer N amendments for increasing agricultural productivity, especially in developing countries, is well recognized. At the same time, many industrialized countries have a problem of a different kind, namely, the entry of N into groundwater and pollution of drinking water and lakes. In this case, there is a simultaneous need to protect existing and potential agricultural soil N resources and to recognize the rising standards of environmental protection worldwide.

The stable isotope ^{15}N provides a particularly powerful tool for studying the behavior of fertilizer N in the environment. Because of the relevant expertise and available facilities, the Joint FAO/IAEA Division with generous support from the Federal Republic of Germany (1976-1982) carried out an international program of studies on the fate of fertilizer N residues in agriculture. A wealth of information and data has been accumulated as a result of the program. Useful development and application of laboratory and field techniques has also been achieved. The following general conclusions have been drawn:

- Taking into account the prospects and time needed for developing alternative agricultural practices, conventional N fertilizer application must continue to intensify and extend for the immediate decades ahead.

- As a result of this intensification, increasing amounts of both native soil and added fertilizer N will be lost from the soil-plant system and will find their way into the environment. Soil-N levels and contingent productivity can nevertheless be maintained by improving soil N management practices.
- In some situations, the nitrate levels in groundwater and drinking water are likely to continue to rise. A proper diagnosis of the various sources responsible for this problem should be made.
- In developing countries the losses of fertilizer N represents a relatively high cost input while in the more advanced industrialized countries, because of high amounts utilized, they represent an addition to the problems and costs of environmental quality and health protection. The data generated and the information reviewed here suggest that these problems can be contained by improved soil and water management in agricultural systems. In particular, there is scope for better exploitation of alternative N sources, such as biological N fixation in legumes and non-legumes and bio-fertilizers.
- A call is made where feasible and appropriate for the development of sustainable agricultural systems and protection of the environment.
- The United Nations Agencies, such as FAO, IAEA, UNEP and WHO, with an improved collaboration with appropriate regional and national programs have a vital and urgent role in implementing the required improvements and short-term research needs, and accelerating the simultaneously needed education and training.

FAO/IAEA Biological Nitrogen Fixation Program

In spite of its abundance in the atmosphere (78% of all gases), N is one of the most crop growth-limiting factors--N fertilizer also represents one of the major costs of crop production. Biological nitrogen fixation (BNF) is a feasible alternative for farmers in both developing and developed countries. Only certain plants, such as *legumes* and other species in symbiosis with appropriate microorganisms, are able to directly utilize atmospheric N_2 through the BNF process. Utilization of this N source offers several advantages, such as relatively less expensive N, reduced pollution hazards, increases in protein content of legumes, and enhanced soil fertility due to greater N residual effect in a crop rotation. The contribution of N fixation to the N economy of both soil and plant through properly managed N_2-fixing systems appears to be the most promising alternative to supplement chemical N fertilization in different agro-ecosystems (Danso, 1994).

Great emphasis has been placed on BNF in the FAO/IAEA Program due to these advantages of this N source in developing countries and the unique usefulness of ^{15}N isotopic techniques for providing quantitative and integrated values of N fixed in both natural and agricultural systems. During the last two decades, several FAO/IAEA international research programs have focused on measuring and enhancing BNF in various cropping systems. Furthermore, current programs emphasize the improvement of both yield and N_2 fixation in grain legumes through an integrated multidisciplinary approach (Hera et al., 1984). Large N-fixation differences occurred between grain legume species, with some, such as faba bean, being very effective and others, e.g., common bean, rather poor; these differences were persistent under a wide range of environmental conditions. Also, considerable genotypic variation in N fixation between cultivars of common bean was found in different CRP countries participating (Bliss and Hardarson, 1993).

Of particular interest in BNF are *nitrogen-fixing trees* (NFT) as an important component of several agricultural systems. They play a significant role in restoring or increasing soil fertility and in decreasing soil erosion and are able to grow well on N-deficient soils. Methods to accurately measure the contribution of soil N and fixed N_2 to the growth of NFTs under different management conditions are of great importance in elaborating the strategies for optimizing N fixation. Techniques based on ^{15}N for measuring N_2 fixed in NTFs are still in the developmental stages, but most of the results to date indicate their potential for measuring N_2 fixed and in research aimed at increasing N fixation.

An important role on N inputs to lowland rice fields is played by blue-green algae and their association, particularly *Azolla*. High-yielding rice varieties require large amounts of expensive chemical N fertilizers. Scientists have long recognized that the aquatic N-fixing *Azolla-Anabaena* symbiosis could replace, at least in part, the N requirement for rice. Although the *Azolla-Anabaena* symbiosis has been used for centuries as a green manure for rice in parts of China and Viet Nam, intensive scientific research only began after the 1973 oil crisis dramatically increased the cost of N fertilizers. *Azolla* can grow very rapidly, doubling its weight in 3 to 4 days under optimal conditions. From 1984 to 1989, a program with financial support from the Swedish International Development Authority (SIDA) was coordinated by the Joint FAO/IAEA Division to investigate the benefits of using *Azolla* as a bio-fertilizer for rice. This program involved scientists from nine rice-producing countries (Bangladesh, Brazil, China, Hungary, Indonesia, Pakistan, Philippines, Sri Lanka and Thailand).

Before this program began, there was little evidence from field experiments to indicate whether the N accumulated by *Azolla* in the field was primarily from fixation of atmospheric N_2 or from competition with rice for available N. Although there was substantial evidence to show that incorporating *Azolla* into the soil increases rice yields, only a few experiments demonstrated that the N was available to rice (Kumarasinghe and Eskew, 1993). Using ^{15}N, it was shown that 70-80% of the N in *Azolla* is derived from N_2 fixation and that no significant competition with rice for limited soil N occurs. In fact, the most recent experiments have shown that the presence of a cover of *Azolla* floating on the surface of the floodwater can even improve the efficiency of chemical N fertilizers.

Urea is the most common N fertilizer used for rice; however, its efficiency is usually low and 50% or more of the N can be lost to the atmosphere. Hydrolysis of urea in the water produces an alkaline reaction and, combined with the effects of algal photosynthesis, pH values over 9 are commonly observed. At this pH, ammonium (NH^+_4) is converted to the volatile gas, ammonia (NH_3). Fortunately, *Azolla* limits algal growth through shading of the floodwater. Following fertilizer applications, pH values 1-2 units lower were observed when *Azolla* was present. The second effect is that *Azolla* takes up part of the fertilizer N from the water. If the *Azolla* is then incorporated into the soil, this fertilizer N becomes available to the rice along with N which has been fixed.

In an experiment in Fuzhou, China, losses of N from a urea top-dressing applied 2 weeks after transplanting were reduced from 50% without *Azolla* to 25% when the field was inoculated with *Azolla* at transplanting. Uptake of ^{15}N-labelled fertilizer by rice was increased from 26 to 35%. In Thailand, application of urea at transplanting with and without inoculation with *Azolla* resulted in 10-15% yield increase in plots with *Azolla* (Kumarasinghe and Eskew, 1993). When *Azolla* was incorporated into the soil, it proved to be as good as urea as an N source for rice. Averaged over many experiments in all nine countries, different years, and different seasons, the yield response of rice to 60 kg N ha^{-1} added as *Azolla* was equal to that for 60 kg N ha^{-1} added as urea following the locally recommended agronomic practices. Not only the uptake of N from *Azolla* was squalled to that from urea but there was also the additional benefit that more of the N added as *Azolla* remained in the soil after harvest. In some of the tests there was sufficient N available to the next crop to produce a field increase of 2-3 times compared to urea, particularly when wheat followed rice.

Estimated savings from one crop of rice by the use of *Azolla* as a N fertilizer are substantial. This program has been very successful and demonstrated that a group of scientists from different parts of the world, working together and using the same critical methodology, could make rapid progress toward common goals through collaboration. Since these results have been achieved over a wide range of environments, the results can be widely applied.

Isotopes in Photosynthesis and Water-Use Efficiency Studies

Isotope techniques are indispensable in studies of *photosynthesis*, plant metabolism, translocation and nutrient uptake. By exposing plants to carbon dioxide labelled with ^{14}C, photosynthesis and movement of metabolites throughout the plant can be monitored using techniques such as autoradiography. Recently, the stable isotope of carbon, ^{13}C has been increasingly used in carbon-tracer studies because of its greater availability and the ease with which it can be measured. Moreover, ^{13}C being a stable isotope is environmentally friendly and is therefore invaluable in soil organic matter and greenhouse-gas studies. Of the naturally occurring ^{12}C and ^{13}C isotopes in the earth and the atmosphere, about 1.1% is present as ^{13}C. However, plants discriminate against ^{13}C during photosynthesis and this discrimination which varies depending on the plant species, is closely associated with a plants' ability to utilize water.

Use of ^{13}C isotope-discrimination can be a useful tool in selecting cultivars of crop and tree species efficient in *water use*. In a CRP on increasing and stabilizing plant productivity in low P and semi-arid and sub-humid soils of the tropics and subtropics, several genotypes of food crops and trees have been identified that are highly efficient in the use of limited resources of water. In Morocco and Tunisia, genotypes of wheat have been discovered which are efficient both in water use and producing high yields. In Sudan, original landraces of the gum arabic tree, *Acacia senegal*, have been identified as highly efficient for growing in drought-prone regions. In Sri Lanka, the ^{13}C isotope discrimination technique has assisted scientists in identifying cultivars of coconut that are highly tolerant to drought, and therefore eminently suitable for cultivation in the dry zone region of that country.

Increasing the effective use of scarce water resources to maximize plant productivity is the main objective of a CRP initiated in 1990. The use of neutron moisture meters and other related techniques contributed to the assessment of irrigation scheduling of field crops to increase effective use of water in irrigation projects and to ameliorate the concept of water-deficit irrigation to improve traditional irrigation practices. The neutron moisture meters were used successfully, not only to measure soil water contents, but also to understand water dynamics under field conditions. The Soil Fertility, Irrigation, and Crop Production Section of the Joint FAO/IAEA Division carried out a CRP which was concerned with the efficiency of water and fertilizer use in semi-arid farming systems.

Its objective was to extend our knowledge to improve crop production in semi-arid regions which, by definition, are limited in rainfall. Any increase in the efficiency of water use is thus reflected in increased production, the most important output for the developing countries in this area, where soil water deficiency is the main factor limiting plant growth and crop yield. The amounts, frequency and duration of rainfall are inadequate. In addition to the inherently unfavorable climatic conditions, the commonly encounted low yields are often related to inappropriate management for water conservation and utilization of the limited rainfall. Proper management to ensure the availability of the necessary plant nutrients in adequate amounts has significantly contributed to increase water-use efficiency and total food and fiber production under dryland farming in semi-arid regions.

Technology Transfer

Several activities are simultaneously carried out to ensure the transfer of nuclear technology and the appropriate implementation of these FAO/IAEA international networks in soil/plant/water research for sustainable agricultural development. The Soil Science Unit at the FAO/IAEA Agriculture and Biotechnology Laboratory, Seibersdorf, is actively involved in conducting back-up research and training in support of these programs. Training is continuously provided in the form of courses and fellowships on the use of nuclear and related techniques in soil science and plant productivity.

Training Courses

The FAO/IAEA Program and the IAEA Department of Technical Co-operation has organized annual inter-regional training courses on the use of isotopes and radiation techniques in studies of soil-plant relationships at the Seibersdorf Laboratories since 1978. A total of 385 participants from 80 countries took part in 18 training courses from 1978 to 1994, while there were 142 fellows involving 872 man-months from 1962 to 1994. Trainees were from Africa (30%), Asia (28%), the Middle East and Europe (26%), and Latin America (16%). The corresponding figures for fellows for these respective regions were 26, 36, 22, and 16%. The main objective is to give scientists from developing countries a sound working knowledge in the use of stable and radioactive isotopes and radiation techniques in various aspects of soil/plant/water research. Each training course usually lasts 5 to 6 weeks and can be attended by up to 20 participants from all geographical regions. Invited lecturers and FAO/IAEA and Soil Science Unit staff give lectures and practical exercises during these courses. The staff members, with their available expertise and resources, are supporting regional and national training courses as well as other training events. These courses train personnel of other host countries, and assist in defining the syllabus of such training courses and in providing lecturers and supplying training materials such as manuals, brochures and video films.

Fellowship Training

The FAO/IAEA Programme conducts fellowship training for scientists from developing countries. The Soil Science Unit at the IAEA Laboratories, Seibersdorf, hosts about 10 fellows involving approximately 50 person-months every year. Together with back-up research the Soil Science Unit has a long tradition of training. There are two categories of fellows: *Analytical fellows* are accepted for a period of 2 to 3 months to learn isotope analytical techniques used in soil-plant research studies, e.g., ^{15}N assay techniques by optical emission spectrometry. This training includes technical tutoring and hands-on practical sessions. *Research fellows* are accepted for periods between 6 and 12 months to work on a topic within the FAO/IAEA Programme of Work. The fellows receive guidance on experimental strategies and use of isotope and related techniques relevant to a particular area which he/she will pursue upon returning home. They are expected to complete and write-up a piece of research work (Zapata and Hera, 1994). In addition, IAEA sponsors scientific visitors of approximately one-week duration, awarded to senior scientists to get acquainted with recent developments on particular topics of soil science research. There is also other modalities for scientists of both developed and developing countries to be accepted at the IAEA Laboratories, such as cost-free interns, cost-free experts, FAO associated professional officers, and scientists on sabbatical or study leave.

Supportive Services

In support of the international and regional networks created by the coordinated research program and technical cooperation projects of the Joint FAO/IAEA Division, the Soil Science Unit at the IAEA Laboratories performs other supportive services, which are required for successful implementation of the various programs. Approximately 15,000-20,000 samples mainly for N isotopic ratio and related analyses are performed every year for projects in developing Member States. Also, ^{15}N-labelled fertilizers required for carrying out the experimental plans are dispatched to participants in these networks. The Unit also provides necessary analytical support to laboratories in developing Member States which receive IAEA technical assistance but lack analytical facilities. The Unit promotes the development and transfer of ^{15}N assay technology for routine purposes; these are currently used in IAEA technical assistance projects.

As one step further in the transfer of ^{15}N technology to developing Member States, the Soil Science Unit at the FAO/IAEA Agriculture Laboratory, Seibersdorf, will establish an international *quality assurance service* for ^{15}N analysis by optical emission spectrometry (Zapata and Hera, 1994). The Soil Science Unit's ^{15}N analytical facilities will act as the FAO/IAEA control "reference" laboratory. The following benefits are expected from such a service:

- The ^{15}N data generated by local laboratories are internationally acceptable.
- Giving confidence and encouragement to counterparts in their analytical procedures.
- Promoting cooperation at the regional level and ensuring an effective transfer of ^{15}N technology to developing Member States through the FAO/IAEA programs.
- Dissemination of scientific/technical information. The scientific staff of the Soil Fertility, Irrigation, and Crop Production Section and the Soil Science Unit are very active in publishing the major scientific achievements from coordinated research programs and results of practical importance from technical assistance projects. The main findings of the CRPs or TCPs are published as IAEA-TECDOC, technical report series, proceedings of scientific meetings, or in scientific journals.

Future Concerns

There are many problems to be solved in the field of soil fertility, plant nutrition, irrigation and crop production. As it is known, land represents a mere 29% of the world's total area; of this, about 61% of the soil has low fertility, 28% moderate fertility, and only 11% has high fertility. Approximately 98% of the world's food comes from the agricultural area, and only 2% from the water area, which covers 71% of the world's surface. In most developing countries, land, nutrient, crop and water management practices are quite poor. Nutrient "mining" results in soil deterioration, which is no less dangerous than any other form of environmental degradation. This is the reason why security of nutrients and water is, and should be, the major concern in many areas of the world, especially in developing countries.

Minimizing losses and replenishment of nutrients are major issues. Maintenance of soil fertility through an appropriate application of plant nutrients in order to replenish the nutrients removed by the produce harvest, and to build up the nutrient status of soils that are inherently infertile or have been depleted, is essential (Davidescu, 1968). Optimum utilization of fertilizer, water and other resources in an integrated manner, as appropriate as possible to each farming system, would be necessary. Many national and international organizations are paying increasing attention to the development of integrated plant nutrition systems. The basic idea underlying this concept is the maintenance and possible increase of soil fertility for sustaining enhanced crop productivity through optimal use of all possible sources of plant nutrients. This approach is ecologically, socially and economically viable, and will protect the environment (Hera, 1994).

We all (5.5 billion people) depend on plants for our food, and plants depend on mineral nutrients and water for their growth and development. There is no question that food production has first priority. To meet the demand of food security for present and future populations and to conserve natural resources and protect the environment, it is imperative that agricultural production in developing countries be intensified in an overall framework of sustainable development. The problem addressed is the increase and sustenance of crop production with minimum or no adverse effects on the environment.

The isotope method is the only way to solve a particular question or obtain specific information. Nuclear techniques, which are normally complementary to conventional or classical techniques in agricultural experimentation, provide direct and quick means to obtain the needed information resulting in a high economic return. These are the reasons that the Soil Fertility, Irrigation, and Crop Production Section of the Joint FAO/IAEA Division *focus their activities* on optimizing plant nutrients and water management practices to increase crop yields, sustain soil productivity and to protect the environment under different farming systems through research using nuclear and related techniques.

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Fertilizer Use in the Near East: Changing Patterns in Egypt and Saudi Arabia

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Abstract

Soil fertility research in the West Asia and North Africa (WANA) region is often seen in the limited context of soil analyses and related fertilizer trials in experimental stations and, less frequently, in on-farm trials. It is vital to understand the broad socio-economic factors--governmental and industrial--and policy issues which impinge on fertilizer use. This paper gives an overview of the fertilizer industry in two contrasting countries of the region, highlighting the evolution of the industry as well as technological developments and policy changes that have dictated its development.

Introduction

The Near East, which includes 26 countries in the Middle East, West Asia and North Africa (Member States of RNE/FAO), is a vast region. Arable lands, however, are about 125 million M ha, constituting only 7.2% of the total land area. In 1994, the region's population reached 532 M, allowing only 0.23 ha of arable land per capita, lower than the world per capita of 0.28 ha. To add to the problem of limited arable land, water resources are also limited, and the majority of Near East countries are considered water-deficient. Irrigated areas in the region constitute about one third of the total arable area, yet they produce over 70% of the agricultural output. Because horizontal expansion in land utilization is often faced with various problems, the vertical expansion through increased inputs, mainly chemical fertilizers, is inevitable to raise agricultural production. Fertilizer use in the region, therefore, witnessed a big increase from 0.5 M tons in 1961 to over 8.28 M tons in 1994.

The fertilizer industry started in Egypt in 1936 by producing single superphosphate. Then calcium nitrate production followed in 1951. Nitrogenous fertilizers such as ammonium sulfate and calcium nitrate were the main types; the use of urea increased later. The predominance of N-fertilizer use over P fertilizers continued, with N consumption being several times that of P region-wide. During the 1960s, several fertilizer factories were established in the area, mostly for producing N fertilizers, particularly in the Arab Gulf States. The Self Sufficiency Index rose quickly in the region from about 10% in 1961, 90% in 1990, and exceeded 110% in 1992 for the overall N fertilizers produced versus quantities consumed. For P fertilizers, the area was almost self-sufficient as early as 1961, with a 95% index then, rising to 127% in 1992 and 165% in 1994.

Egypt is a major user and producer of chemical fertilizers in the region, with about 3.25 M ha under irrigation. The country's overall consumption in 1993/94 was about 1.2 M tons of fertilizer nutrients (NPK). Local fertilizer industry produced about 950,000 tons of NPK in 1994. The lifting of Government subsidies in 1991, coupled with higher fuel and other inputs prices, depressed fertilizer use during the last three years. Farmers tend to substitute the less costly N for P and potash (K).

In Saudi Arabia, the terms of trade for fertilizer industry are different, and the private sector plays a more prominent role. The Governmental subsidy on Free-On-Board (FOB) prices of fertilizers was 50% until 1983, when it was eliminated. Other subsidies on the products such as wheat, barley and dates certainly had a positive impact on fertilizer use and on the industry as well. The total cropped area was about 1.25 M ha in 1989/90, with wheat as a major crop. Granting interest-free loans with soft terms, which started in the late 1970s and continued through the 1980s, encouraged farmers to grow wheat on desert sandy soils using liberal amounts of fertilizers (sometimes over 500 kg ha^{-1} of nutrients) injected through central-pivot irrigation systems. In 1969/70, the country consumed just 4000 tons of all fertilizers, but reached 455,000 tons of elemental NPK in 1993/1994. Saudi Arabia became a significant producer of fertilizers, whereby over 2.16 M tons of urea and 320,000 tons of P and mixed fertilizers were produced in 1993/1994.

The above two case studies revealed a real need for a regional effort aiming at updating and exchange of statistical data related to fertilizers. Cooperation among regional and international organizations, governments of the Near East countries, as well as the private sector, is called for in order to lay down sustainable fertilizer use policy leading to promoting the integrated plant nutrition system approach for fertilizer management by the users.

Land and Water Resources in the Region

Land and water are the two basic elements of natural resource systems. The proper utilization of these resources, including agricultural inputs, such as fertilizers, is essential for sustainable agricultural production. Limitations of both resources warrant *the* adoption by the region's countries of strategies leading towards actions for combating land degradation, stopping desertification, preserving forests and ranges, and protecting the environment.

Land

The land resources inventory for the Near East Region is divided into five geographic groups, i.e., Gulf States, North Africa, West Asia (Syria, Iraq, etc.), Sudan and Saudi Arabia, etc., and highland countries (Turkey, Iran, Afghanistan, Pakistan). The following observations are worth noting: 1) Total arable land constitutes 7.2% of total land area, including 4.6% as rainfed arable and 2.6% irrigated arable. Areas of permanent pastures represent 26.0% and forest and woodland are 7.2%, while about 60% are waste and other lands; 2) only 5% of the lands are considered humid with a growing period of over 180 days; 3) the region's average arable land is only 0.23 ha per capita, which is lower than the world average of 0.28 ha; 4) this per capita share of arable land is the lowest in high-income countries (Gulf States), which adds to their intricate problems of adverse ecological conditions, scare water resources, and poor soil fertility; 5) most of the arable lands (60%) are in only four countries, namely, Afghanistan, Iran, Pakistan, and Sudan, all of which, except Iran, are lacking adequate capital investments needed for agricultural development.

Water

Water resources availability poses another major problem facing agriculture. It is estimated that 80% or more of the water consumed goes to agriculture in 16 countries of the region. In addition to the fact that most of these countries are water-deficient, reports on over-exploitation and deterioration of water quality for irrigation are quite common. These issues are already of major concern for countries like Jordan, Bahrain, Qatar, Saudi Arabia, and Syria. Fast growth rates in other sectors involving industry, urbanization and tourism are already competing with the agricultural sector for water.

Where irrigation is used, traditional practices (surface methods) are dominant. However, modern water-saving techniques of localized irrigation, such as sprinklers and drip systems, were widespread in countries like Saudi Arabia (center pivots), Jordan (drip/trickle), Libya (sprinklers), Cyprus (drip), and the United Arab Emirates (drip and sprinklers). Undoubtedly, the use of these modern systems has introduced new application methods for injecting fertilizers and other chemicals.

With sprinkler or drip irrigation systems, a fertilizer injection unit is usually supplied, which generally has a positive impact on fertilizer-use efficiency. Fertigation and chemigation terminology came into common use among agriculturists and farmers in most countries of the Near East. The FAO Regional Office for the Near East (RNE) sponsored an Expert Consultation on "Fertigation/Chemigation" on 8-11 September 1991 in Cairo. This consultation recommended promoting these new application methods for the safe efficient use of chemicals and plant nutrients.

Overall Fertilizer Production and Consumption

Production of chemical fertilizers in the region dates back over 60 years. Several factories were established in Egypt, Morocco, Tunisia, Jordan, Saudi Arabia and other Gulf States. Single N-fertilizers such as ammonium sulfate (AS), ammonium nitrate (AN), as well as P fertilizers such as triple superphosphate (TSP) and single superphosphate (SSP) were initially produced; urea, diammonium phosphate (DAP) and other complex fertilizers followed later. The Near East and North Africa countries exported 1.7 M tons of N in 1990/91, while their production was about 4 M tons. For P, the share of Morocco and Tunisia in total international TSP exports was about 62% in 1992. Morocco was the largest exporter of rock phosphate, reaching about 14 M tons in 1990 (Nabhan, 1994).

Due to the expansion in irrigated areas, N fertilizer production rapidly went from 35,000 tons in 1961 to about 6.6 M tons in 1994. This dramatic increase in N production was necessary to meet the growing demand of national consumption in the region which rose from about 372,000 M tons (N) in 1961 to over 5.5 M tons in 1994. Self-Sufficiency Index (Table 1) reflects a rising trend during the same period from 10% to over 120%, allowing some surplus for export; the Near East Region is not a net exporter of fertilizers as reflected by the sufficiency index. In 1991, the region imported about 2.96 M tons of various NPK fertilizers. Phosphate (P) fertilizers followed the same growing trend from about 136,000 M tons of P_2O_5 in 1961 to reach over 4 M tons in 1994. Consumption of P-fertilizers was parallel to production up to 1985, then in 1990 it started to be exceeded by production to a significant degree (165% Index).

Table 1. Fertilizer production, consumption and self-sufficiency in the Near East Region.

Fertilizer	1961	1970	1980	1985	1990	1992	1994
	Nitrogen, M tons x 10^3						
Production	35.4	382.5	2,360.8	3,328.8	4,552.6	6,063.2	6,668.2
Consumption	372.5	1,114.2	3,046.8	4,082.5	5,032.5	5,470.1	5,548.1
Index (%)[1]	9	34	77	81	90	110	120
	Phosphorus (P_2O_5), M tons x 10^3						
Production	135.2	483.1	1,490.4	2,472.9	3,359.0	3,145.9	4,045.2
Consumption	142.6	440.7	1,644.4	2,120.7	2,468.5	2,474.4	2,444.9
Index (%)[1]	95	109	90	116	136	127	165
	Potassium (K_2O), M tons x 10^3						
Production	0	0	0	544.9	841.6	807.6	822.1
Consumption	34.4	64.5	149.1	260.3	282.0	266.7	292.5
Index (%)[1]	0.0	0.0	0.0	209	298	302	281

[1] Self-Sufficiency Index (%)= (Production/Consumption) x 100.

Potassium is produced only in Jordan, which it has mineral deposits. Production of potassium chloride (Muriate) started with 544,000 M tons of K_2O in 1985 and in 1994 reached over 820,000 M tons, which is almost entirely exported. Low figures for the region's consumption rates of K reflect the dominance of N and P in the fertilization formula used by most countries. Behind this situation is the soil types prevailing, whereby most of agricultural soils in the region are low in organic matter content (less than 1%) and adequate levels of K are common (available K could exceed 200 ppm). Of particular interest is the high rate of fertilizer consumption in some countries (Table 2). The two case studies selected, Egypt (347 kg ha^{-1}) and Saudi Arabia (366 kg ha^{-1}) are among the countries using the most fertilizers worldwide. In Egypt, the old alluvial soils along the Nile and in the Delta are intensively cultivated, with a crop intensity of 2.5. For Saudi Arabia, the high rate of fertilizer use is due mainly to the subsidies on both agricultural inputs (fertilizer) and outputs (wheat, barley and dates).

Table 2. Comparative fertilizer use per unit arable land in selected countries.

Country	NPK	Country	NPK	Country	NPK
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}
S. Korea[1]	466	Iran	75	Africa	3
India	72	Algeria[2]	37.2	Developing Countries	22
Pakistan	73.7	Morocco	35.6	Developed Countries	38
China	300	Tunisia[3]	20	World (Average)	28
		Libya[3]	39		
		Sudan	4.9		
Egypt	347.3	Germany	239		
Saudi Arabia[4]	366	Japan	395		
		USA	42		
		Ireland	702		

Sources:[1] FAO, 1994a; [2] FAO, 1994b; [3] Nabhan, 1994; [4] Based on 1992/1993 consumption figures.

Fertilizers in Egypt

Egypt is a major producer and consumer of fertilizers, with an irrigated area exceeding 3.25 M ha, out of which enough food and fiber needs to be produced for some 62.9 M people (UN Population Fund, 1995). Although Egypt started using chemical fertilizers in 1902 by importing some Chilean nitrate, manufacturing started only in 1936 with production of single superphosphate (SSP) by the Financial and Industrial Co. (EFIC) in Kafa El-zayyat. In 1951, the first N fertilizer (calcium nitrate, 15.5% N) was produced by Al-Nasr Company for Fertilizers and Chemical Industries (SEMADCO) in Suez. Potassium fertilizers, as well as compound and liquid fertilizers, are all imported from other countries. Table 3 summarizes the fertilizer factories in Egypt with their annual production and fertilizers produced. Overall national production capacity is 980,000 tons of urea, 1.5 M tons of AN and 75,000 tons of AS, adding to an equivalent of about 6.4 M tons of 15% N. Similarly, the total present P production capacity is 1,075,000 tons of single superphosphate and 145,000 tons of concentrated superphosphate (CSP), equivalent to 1.5 M tons of 15% P_2O_5.

These estimates take into consideration the high crop-intensity factor, the special rates of fertilizers needed for the newly reclaimed non-fertile desert soils in Sinai, as well as the new cropping patterns with some prevailing cash crops, i.e., vegetables. Of particular interest is the figure estimated for K, whose needs became more obvious due to the loss of annual deposits of rich-K silt from the Nile flooding, in addition to the conditions of use land, especially in the Delta.

Table 3. National production capacity of the fertilizer industry in Egypt.

Factory	Year	Fertilizer	Annual Production Capacity
			------- Tons x 10^3 --------
Abu Qir[1]	1980	Urea (46% N)	500
		Ammonium nitrate	
Al-Nasr[2] (SEMADCO)	1951	(33.5% N)	
		Urea	480
		Ammonium nitrate	560
		Ammonium sulfate (20%)	60
Chemical Industries (KIMA)[3]	1960	Ammonium nitrate	260
Coke Industries Co[4]	1964	Ammonium nitrate	45
Financial/Industrial (EFIC)[3]	1936	Superphosphate (15% P_2O_5)	750
		S. Superphosphate	325
Abu Zaabal[6]	1948	Conc. Superphosphate (37% P_2O_5)	145

Sources: [1] Abu-Qir Company For Fertilizers and Chemical Industries (Alexandria); [2] Al-Nasr Company for Fertilizers and Chemical Industries/SEMADCO (Talkha, Suez); [3] The Chemical Industries Company/KIMA (Aswan); [4] Coke Company and Chemical Industries (Helwan); [5] The Financial and Industrial Company/EFIC (Kafr El-Zayyat, Assiut); [6] Abu Zabbal Company for Fertilizers and Chemical Industries.

Future Industry Trends

Based on Governmental statistics, about 7.18 M feddans (3.02 M ha) are cultivated, including traditional Nile Valley areas, as well as the newly reclaimed areas. The cropped area, however, reaches about 14.48 M feddans (6.08 M ha) due to high cropping intensity. Thus, the estimated national requirements for NPK are: 6.4 M tons of 15.5% N, 2.1 M tons of 15% P_2O_5, and 1.1 M tons of 48% K_2O. Considering the above estimates and assuming 2% annual growth in fertilizer consumption, the future national fertilizer requirements (M tons) can be summarized as follows: Nitrogen (15% N): 7.1 for the year 2000, 7.8 in 2005, and 8.6 in 2010; Phosphate (15% P_2O_5): 2.3 for the year 2000, 2.6 in 2005, and 2.8 in 2010; Potassium (48% K_2O): 1.1 for the year 2000, 1.2 in 2005, and 1.5 in 2010. Plans are underway to implement the following new facilities:

1. Establishing Abu-Qir No. 3 Plant, scheduled to start production in 1999 with a target out-put of 60,000 tons of urea (46% N). Upon completion, the Abu-Qir factory will be one of the largest fertilizer complexes in the whole Mediterranean region.
2. Starting upgrading the Abu Zabal Plant to produce triple superphosphate (TSP, 46% P_2O_5) and later to produce diammonium phosphate (DAP 18/46/0) and mono-ammonium phosphate (MAP 11/52/0).

3. Completion within a year of Phase-I of the New Valley Mines for producing 2 M tons of treated rock phosphate for local use and for export.
4. Finalizing feasibility studies for establishing a new plant N fertilizers in Helwan, near Cairo, with a designed capacity of 750,000 M tons of ammonium nitrate (33.5% N).
5. The two complexes in Suez and Aswan are under review for upgrading or possible establishing new plants.

Recent Fertilizer Consumption Patterns in Egypt

The widespread use of fertilizers is relatively recent in Egypt. Traditionally, farmers depended on the annual Nile flood to renew the land with valuable silt deposits. Following the completion of the Aswan Dam in 1968, demand for fertilizers grew rapidly. Since then, the growth and development of the Egyptian domestic fertilizer industry have been impressive. Prior to the Government's policy reforms, first introducted in 1986, the Principal Bank for Development and Agricultural Credit (PBDAC) was assigned a monopoly role for the procurement and distribution of fertilizers. Prices were both controlled and subsidized. In mid-1991, all fertilizer subsidies were eliminated (except for a subsidy on a limited amount of imported potash). The PBDAC distribution monopoly was terminated, and the cooperatives and private sector dealers were allowed direct access to fertilizer supplies at the factory. During the first 6 months of 1991 alone, the private sector's share of the market increased to 77%, while the cooperative decreased to about 23%.

The elimination of fertilizer subsidies had a negative impact on P and K fertilizer use in 1990, and particularly in 1992. Consumption estimates for 1993 indicate that fertilizers use, on the whole, may be back on track or with a little increase. Farmers tended to substitute less costly N for P_2O_5 and K_2O. During the reform period, the increasing availability of ammonium nitrate (AN) resulted in an increase in the share of this product in the N product mix. Following the full elimination of subsidies on N, the more favorable price of AN and its increased supply availability strongly influenced its broader use, with a concurrent decline in the use of calcium nitrate (CN) and ammonium sulfate (AS). The use of concentrated superphosphate (CSP) also declined in relation to the use of single superphosphate (SSP). The impact of the subsidy removals on the use of potassium sulfate (KS) has been serious; consumption is now about half of what it used to be.

During 1994 and in early 1995, all imports of AS fertilizer were from Eastern European countries. The vast majority of K imports were from the USA. Exports of significant quantities of CN (about 1.1 M tons, the equivalent of 367,000 tons of urea or 550,000 tons of AN), created severe shortages in the availability of N fertilizers during the summer of 1995. In order to rectify this shortage, the Government temporarily suspended all tariffs on N fertilizers through the end of October 1995. The Government subsequently allowed the PBDAC to restore its principal role in fertilizer handling and distribution in Egypt.

Fertilizer Production and Consumption in Saudi Arabia

Prior to 1972, the use of fertilizers in the Kingdom of Saudi Arabia was rare and randomly practised, if at all. Traditional agriculture was mainly around *wadis* (valleys) and oases where water was available from springs and shallow wells. Manuring was the main fertilizing practice being applied in palm tree orchards and on vegetables. A new wave of agricultural development started by 1973/74 and resulted in vast areas of desert soil being put under cultivation, with a significant portion of those areas recovered from sand dunes. These virgin soils are characterized by the following features: calcareous, sandy texture, low water retention, less than 1% organic matter, very low available P, medium to adequate supply of extractable K, low cation exchange capacity, and alkaline soil pH. Such soils evidently require heavy fertilizer applications to produce crops of economic value.

The increase in fertilizer use, as a major agricultural input, in the 1970s coincided with other similar agricultural developments which together resulted in high growth rates in agricultural production (Table 4). Fertilizer N consumption was always a small portion of N produced, leaving an ample quantity for export. Phosphate fertilizer production has not met the local demand so far; the sufficiency index is about 70%, while liquid K fertilizers and minor elements are mainly imported.

Table 4. Fertilizer production and consumption in Saudi Arabia.

Fertilizer	1961	1970	1980	1985	1990	1992	1994
	----------	----------	----------	Tons x 10^3	----------	----------	----------
Nitrogen (N)							
Production	0	23.0	152.0	421.3	584.0	713.9	831.7
Consumption	2.0	1.2	25.2	169.0	273.0	291.9	250.0
Index (%)	--	1916	603	249	213	245	332
Phosphorus (P_2O_5)							
Production	--	--	--	--	53.4	146.0	132.0
Consumption	2.0	3.5	14.4	142.3	193.0	218.2	190.0
Index (%)	--	--	--	--	27.6	66.9	69.5
Potash (K_2O)							
Production	--	--	--	--	--	--	--
Consumption	0	0	1.4	32.5	23.0	28.6	15.0
Index (%)							
Total NPK	4	4.7	40.9	343.8	489.0	538.7	455.0

Source: FAO (1994b).

The Saudi Arabian Fertilizer Company (SAFCO) complex in Damman, established in 1964, was the first gas-based petrochemical venture. The urea plant was started in 1969 with a capacity of 330,000 tonnes per annum (tpa). An integral part of the SAFCO complex is a 200,000 tpa ammonium facility, with most of its output serving as feedstock for the urea plant. In addition, the company started up, at the same location, a 100,000 tpa sulfuric acid plant in 1980 and a 20,000 tpa melamine facility in 1985. The second gas-based petrochemical N complex was established on the Gulf Coast at Jubail, Eastern Province with a capacity to produce 300,000 tpa ammonia and 500,000 tpa urea; production started in late 1983. The production of urea from both complexes strengthened the position of Saudi Arabia as a major exporter of this product to international markets. A third major fertilizer complex was established in Jubail. Also, the National Chemical Fertilizer Company known as Ibn Al-Baytar Co. Production started in 1987 for producing 300,000 tons/year of urea, 1 M tons of P fertilizers and 10,600 tons of liquid fertilizers. SABIC (Saudi Arabian Basic Industries Corporation) is the holding company for all three fertilizer companies stated above. Fertilizers produced are all marketed under the trade name of SANAPIK and handled by SABIC for local and foreign markets.

The manufacturing of P and compound fertilizers by Ibn Al-Baytar began in 1990. Start-up production concentrated on P fertilizers, familiar to Saudi farmers, such as DAP (18-46-0) and MAP (11-52-0). Other compound formulations produced included: 12-35-8; 23-23-0; 18-18-5, TSP, and later 28-28-0 fertilizer. Recently, additional formulations were produced including: 12-27-18, 14-38-10, 11-29-19 and the liquid fertilizer, 10-34-0. These formulations exceed in their analysis (total NPK elements) the traditionally used ones like 20-20-0, 18-18-5-1.5 that prevailed in the country markets in the 1970s. By incorporating the state-of-the-art production technology, Saudi Arabia became a main player in fertilizer markets worldwide. Urea, for example, is produced with a guaranteed 46% N and less than 1% biuret.

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2. Nitrogen and Crop Rotations

Nitrogen Challenges in Dryland Agriculture

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Abstract

Nitrogen is the most spectacular of all essential nutrients in its effects on plant growth. Because of the transitory nature of N in soil, and its potential for becoming a pollutant of air and water, it should receive more care in its overall management than any other major or minor plant nutrient. In this paper, a few aspects of N management in dryland agriculture are reviewed. While the observations are largely based on the author's experience in Morocco, they are pertinent to the broad West Asia-North Africa region as a whole. The effect of N on crop production is well documented and has been discussed briefly in this paper. Methods of estimating crop N fertilizer needs are still not well developed and require more attention. Also, in relation to the estimation of the amount of N fertilizer to apply to a crop, more work is needed in order to determine the quantity of mineral N coming from soil organic matter during a growing season, and to improve N use efficiency. Spatial variability is another area of research which is not well documented in dryland regions. Nitrogen recommendations based on soil tests require a representative soil sample and appropriate soil testing methods. Furthermore, dryland regions are characterized by small farms with different management and this enhances physical and chemical spatial variability. Therefore, an appropriate soil sampling method which includes the number of soil samples to be taken per homogenous unit area, depth of the sample, and time of sampling is necessary. While much has been achieved in N research, some gaps in our knowledge remain to be refined and elucidated.

Introduction

Early scientists have attributed the plants gain in weight to water; they missed two key contributors to plant growth, carbon that plants obtain from carbon dioxide in the atmosphere by photosynthesis, and mineral nutrients, nitrogen, phosphorus, potassium, calcium, magnesium, sulfate, and others. Nitrogen is vital to the growth of plants. It is part of all essential constituents of cells: the chlorophyll that is essential to photosynthesis, nucleic acids, DNA and RNA in which the patterns for plant growth and development, as well as proteins, and cell walls are encoded. Nitrogen-containing compounds are involved in practically all the biochemistry of life.

Nitrogen is not the only vital nutrient. Phosphorus has a major role in the building of nucleic acids and in the storage and use of energy in cells. Potassium plays a key role in the transport of carbohydrates from where they are produced to where they are used. It also helps plants to use water efficiently and to maintain their osmotic and electrical balance. Magnesium is central to the function of chlorophyll, while sulfur is a constituent of some key proteins. Calcium is important in structural tissue and in other ways. A number of other elements although needed very small amounts have a key role; they are known collectively as "trace elements".

All the nutrients increase the growth and yield of crops, but N has, by far, the largest effect, except for crops which have large storage organs such as potato tubers, which are strongly influenced by the supply of P and K as well. Nitrogen is the main key to yield. Unfortunately, costs of producing N fertilizer have risen in tandem with energy costs. Therefore, improved management of N is more crucial than ever before. Effective management of N presents a greater challenge to researchers, extension agents and farm operators than does that of any other fertilizer nutrient. No other nutrient requires as much attention, nor brings greater rewards for wise management, and no other nutrient enters and leaves the soil-plant system by more routes or more easily than N.

Nitrogen and Crop Yield

Cereal crops are prominent in semi-arid regions where N has been shown to be a key input affecting production (Ben Halima, 1989; Soltanpour et al., 1986, 1987; Simonis, 1988; Abdel Monem et al., 1990b; Ryan et al., 1992a; Lamsalek, 1992) and may be as critical as water to growth and N uptake (El Mejahed, 1993). Nitrogen application has been reported to double grain yield in dryland farming. However, this increase in yield depends on soil type, previous crop and annual precipitation. Soil types differ in their fertility and moisture-holding capacity, and therefore their productivity.

The effect of previous crops on N availability in soil for the following crop is influenced by the crop management, the amount of water stored in soil, and the amount and quality of residues returned into soil, and perhaps by other factors that are not identified yet. In fact, El Mejahed (1993) has found that N uptake of wheat is higher after fallow, medium after chickpea, and low after wheat. The effect of N on crop production is greatly influenced by moisture and temperature. It is common to see significant effects of N application in wet years and no response in dry years. Pala et al. (1992) reported increases in grain yield ranging from 61 to 100%, depending on previous crop, when comparing wheat yields under 250 and 450 mm of annual rainfall.

Applying N Fertilizer: How Much?

The quantity of N required is based on the yield goals that are established. Yield goals must be realistic to be of value. Because, for a given crop, N concentrations in well nourished plants vary within relatively narrow limits, total N required is much more dependent upon yield goal than on differences in N concentrations. Though N application invariably increases yields, it is not uncommon to see negative effects or no effect at all on crop yield due to N fertilizer application. This raises the question of how optimum application can be estimated.

One way of determining the optimal quantity of N to apply is to conduct field experiments in which the crop of interest is grown on field plots that receive different rates of N fertilizer (Matar and Ryan, 1990). The yield of interest is then plotted against the rates of fertilizer applied. Using this procedure, we usually encounter three types of response curves. The common one is called the diminishing returns curve, i.e., as more N is supplied the increase in yield per kilogram of N becomes smaller. There is also a straight declining line curve, which is obtained when the soil already contains a lot of N that is available to the crop. A negative response curve occurs when extra N causes a steady increase in yield up to a point at which there is a very sharp decrease in yield.

These response curves can be interpreted in different ways, and the optimum application can be calculated. But the most common criteria for making decisions nowadays tends to be that of financial return; and the optimum that is usually calculated is therefore the economic optimum. However, this calculation is unsatisfactory because it depends on the price of fertilizer and the price of the grain, both of which vary considerably.

Field experiments in different countries have shown that the N needs of a crop are modified by the crop rotation or previous crop (Soltanpour et al., 1988). Legumes, depending on how they are managed, may reduce the need for addition of N for the subsequent wheat crop. The effect of legume crop on soil N is dependent on its N fixation, which is species-specific, the crop yield, and the extent to which residues are removed. Nowadays, N recommendations for cereals in Mediterranean countries are based on the potential crop yield and average crop N removal (Gaid, 1991), or on mean crop response to N application, which gives an overall recommendation that does not consider cropping system, nor soil type or initial nutrient content of soil, or a predictive balanced sheet for mineral N in soil between planting date and harvest (Mary et al., 1988).

The use of soil NO_3-N at planting has been shown to be a reliable guide for N fertilization (Soltanpour et al., 1989; Pala and Matar, 1990; Matar et al., 1988; Aziz et al., 1988; Mosseddaq et al., 1992). Soil NO_3-N at planting as a guide for fertilizer N recommendation was improved significantly when combined with an N availability index using biological or chemical method (Ben Halima, 1989; Mosseddaq, 1991; Lamsalek, 1992) or with soil water content at emergence (El Mejahed, 1993). Although other authors suggest that soil NO_3-N as a guide for N fertilization will never be as reliable as $NaHCO_3$ test for P, because NO_3 in soil is mobile and dependent on soil moisture regime, and fluctuates with biological processes of mobilization-immobilization and turnover (Orphanos and Metochis, 1990; Abdel Monem et al., 1990b). Meisinger (1984) concluded, after an extensive literature review, that soil NO_3 is an important component of available N in modern agriculture. Actually, measurement of mineral N is the only way of accounting for N remaining from previous fertilizer N inputs. However, to be of value, a proper sampling technique needs to be established. Depth of soil to sample and the number of samples to take represent primary decisions for the manager. Time of the season is also a factor to consider since NO_3 is highly mobile in soil, but sampling times are usually limited to pre-plant or post-harvest periods.

Residual Nitrogen

Continued fertilization and increased application rates have widened concern about the carry-over effects of fertilizer to the next and subsequent growing seasons. Both N and P fertilization have a residual effect but, unlike P, N in soil is subject to rapid transformations and can be easily lost from soil. Under conditions of high rainfall, N has normally little carry-over effect. However, in arid and semi-arid regions, considerable amounts of N in the form of NO_3 accumulate in the soil profile and remains available for the subsequent crop (Orphanos, 1992). The residual N may be a result of mineralization of organic soil N or previous N fertilizer application and the results may vary widely. Values between 77 and 100 kg N ha^{-1} in the top 60 cm of soil profile have been reported to be available for crop at planting date depending mainly on previous crop (Mosseddaq et al., 1992; El Mejahed, 1993). Grain yield increases were reported when residual N was less than 50 kg ha^{-1} (Soltanpour et al., 1989; Abdel Monem et al., 1990c). Orphanos (1992) reported a threshold of 12 mg NO_3-N kg^{-1} of soil, NO_3-N, below which an increase in grain yield is expected due to N fertilization. Direct effects of residual N on crop yield are difficult to assess due to the large number of factors that govern soil N availability. The response of wheat to residual N in terms of dry matter and grain yield varied from none in the first and second year to a significant effect in the third year (Abdel Monem et al., 1990c; Soltanpour and El Gharous, 1986).

Mineralization

Fertilizer N requirement is the difference between the crop's need and the soil's supplying capacity. The soil N-supplying capacity for the plant is dependent on two pools: (i) mineral N, primarily NO_3, available in soil at planting time, and (ii) N which can be mineralized from organic matter during the growing season and N losses from soil. In many productive soils, mineralization of soil organic N may provide substantial quantities of mineral N during a growing season (El Gharous et al., 1990; Soudi et al., 1990). Values between 50 and 90 kg N ha^{-1} were reported by Lamsalek (1992) for soil of the Tadla region in Morocco. Avçin and Acvi (1992) reported values of mineral N of 100 to 150 kg ha^{-1} in brown and reddish brown soils of Turkey, coming from soil organic matter, depending on previous crop.

Soils of the Mediterranean region have a high mineralization potential. However, this potential is subject to fluctuation due to a number of factors such as soil organic matter content and its quality, cropping systems, and climatic conditions (El Gharous et al., 1990; Soudi et al., 1990). The mineralization potential of Moroccan soils varies from 62 to 273 mg kg^{-1} (El Gharous, 1990, 1993; Soudi et al. 1992). This variation is attributed to the nature and quality of soil organic matter. In fact, Soudi et al. (1992) have found that most of N mineralized comes from the hydrolyzed N fraction of the soil organic matter.

The actual amount of N mineral coming from soil organic N is difficult to estimate and cannot be considered as a fixed amount annually. Soudi et al. (1990) reported amounts of 30 to 70 kg mineral N ha^{-1} depending on soil moisture and soil temperature. This amount is also affected by the quality of soil organic matter (Soudi et al., 1992) and cropping system (El Mejahed, 1993). However, the quantity of N taken up from unfertilized control plots is often used as an approximation of the amount of indigenous soil N mineralized.

Efficiency Fertilizer Use

Fertilizer N uptake by crop is generally low. Farmers and agricultural researchers alike are interested in management techniques that can improve the efficiency of N fertilizers. The efficiency of N fertilizer is expressed in several ways (Parish et al., 1980; Novoa and Loomis, 1981; Bock, 1984), but the term *"nitrogen use efficiency"* has usually referred to the relationship between yield and N rate (yield or agronomic efficiency), between N recovered and N rate (N recovery efficiency), or between yield and N recovered (physiological efficiency). The efficiency of N use is considered as the yield increase per unit of N applied (Bock, 1984). When ^{15}N isotope is used we talk about real N recovery. As criteria for efficient use of fertilizer N, the extent of its uptake, its percent recovery, and the efficiency of utilization are often used. Uptake refers to the whole plant or crop including the roots, whereas recovery relates to the above-ground or harvested parts of the crops.

Fertilizer N-use efficiency has been studied by a number of authors and the results reported vary widely. Values ranging from 44 to 63% of N recovery by wheat and barley were reported by Bloom et al. (1988), Dilz (1988), and Nielsen et al. (1988). For Algeria, Gaid (1991) reported a wider range of values from 30 to 70% for the same crops. In dryland regions of Morocco, El Mejahed (1993), using isotopic methods (^{15}N), found that real N recovery values for wheat were even lower, i.e., from 25 and 35% depending on climatic conditions and cropping systems. The average N efficiency values for cereals in Greece were also low, i.e., ranged from 17 to 32% for durum wheat, 25 to 40% for barley and 17 to 37% for bread wheat (Simonis, 1988).

Nitrogen use efficiency in rainfed one agriculture is not explicitly described and has been shown to vary from year to year and from one field to another. The factors that mostly affect the crop N-use efficiency are, in general, related to climatic conditions, to soil chemical and physical characteristics, to plant characteristics, and/or to cropping systems. It is generally accepted that N-use efficiency by crops in wet years is higher than in dry years. Soil characteristics such as depth, N mineralization potential and initial mineral N content also affect the efficiency of N use by plants. Crops are less efficient in terms of N use at high levels of N application. Varieties with high yield capacity use N more efficiently than those with low yield potential.

Application Methods for N Fertilizer-Use Efficiency

Potential environmental contamination from fertilizer has increased interest in efficient use of fertilizer and water. In arid and semi-arid regions, production is limited by low and variable precipitation in terms of frequency, distribution, and amounts. Nitrogen fertilizers may be applied in many different ways and at various times of the year. In some cases, the N source itself dictates the methods that are suitable for application; in other cases, time of application with respect to crop growth stages may determine the most efficient application method to use. The method and timing of application affect the efficiency of N fertilizers and often may be adjusted to improve efficiency. Nitrogen is mobile in soil as NO_3-N, and therefore little advantage over broadcasting is expected except in reducing gaseous losses of NH_3 in calcareous soils under warm conditions. For instance, broadcast application of urea onto the surface of a dense vegetative cover may result in large amount of NH_3 volatilization. When urea is applied on bare soil, NH_3 is less likely to volatilize than when it is applied to crop. Nevertheless, though urea is the principle source of N being used as top-dressing in dryland agriculture of Morocco, its potential volatile losses of N have not been clearly established.

Fertilizer N placement increases N content of plants at early growth stages (Tanaka et al., 1990) and helps in reducing the potential for environment contamination due to N. Abdel Monem et al. (1990a) found that banding of N increased not only N uptake but also dry matter and grain yields in all soils studied except shallow ones, and thus improved N use efficiency (Raun et al., 1987).

Spatial Variability

Soils are known to have both lateral and vertical variability. This variability can be expressed in terms of the spatial differences in particular properties of the soil or can be revealed and expressed in terms of plant growth response. The variability of soil properties is not widely appreciated or understood by the increasing numbers of soil data users. This development is inadequate and suggests a lack of utilization of available information and may result in erroneous prediction of system responses to management. The variability of soil properties has been a concern primarily for pedologists, who are responsible of classifying and mapping soils, and most of the progress in evaluating spatial variability has therefore been in this area.

Nitrogen is present in soils in both organic and inorganic forms. These forms differ in degree of persistence and mobility and hence residence time in soils. Consequently, it is expected that NO_3 concentrations in soils fluctuate more rapidly than organic matter, which, in turn, implies greater spatial variability of NO_3. On the other hand, the greater mobility of NO_3 in soil may suggest that large spatial differences imposed by inputs may be eliminated quickly and therefore reduce spatial variability. Ryan et al. (1990, 1992) reported considerable spatial variation of soil properties and fertility in different soil types of the semi-arid region of Morocco. Some results obtained in this investigation are summarized in Tables 1 and 2.

Spatial variability is an important property of soil that should be considered in managing nutrients such as N for crop growth or evaluating the environmental impact of N fluxes from one region to another. Attempts are being made to recognize the problem of spatial variability in making fertilizer recommendations, but such attempts appear to be limited (Biggar, 1978).

Table 1. Spatial variability of nitrate and organic matter at five agricultural experiment stations in semi-arid regions of Morocco.

Location	Nutrient	Range	Mean	CV (%)
Sidi El Aydi	NO_3-N (mg kg^{-1})	7.0 - 49.5	18.4	56.1
	OM (%)	1.9 - 3.4	2.5	12.5
Ain Nzagh	NO_3-N (mg kg^{-1})	3.0 - 15.0	7.3	51.3
	OM (%)	2.3 - 5.6	5.0	26.4
Jemaa Shaim	NO_3-N (mg kg^{-1})	3.4 - 25.2	9.4	65.3
	OM (%)	1.1 - 2.8	1.5	29.4
Khemis Zemamra	NO_3-N (mg kg^{-1})	3.2 - 52.0	10.0	12.4
	OM (%)	1.2 - 2.6	1.8	21.9
Jemaa Riah	NO_3-N (mg kg^{-1})	4.6 - 17.2	8.0	12.4
	OM (%)	1.1 - 2.2	1.7	21.9

Source: Ryan et al. 1990.

Table 2. Spatial variability of organic matter, nitrate, phosphorus, potassium and pH in 25 soil types of the semi-arid region of Morocco.

	Organic Matter	Nitrate	Phosphorus	Potassium	pH
	------- % -------	---------- ppm	----------	----------	
Mean	3.2	6.7	14.1	220	8.1
Minimum	1.1	3.0	3.6	15	6.4
Maximum	6.2	19.3	37.4	1450	8.6
CV (%)	38.5	38.0	69.7	75.5	4.9

Source: Ryan et al. 1992.

Conclusions

Nitrogen fertilizer supply is the primary nutrient limitation for both food supply and protein content. Proper N fertilizer use involves accurate assessment of crop requirement before application. This in turn requires accurate judgement of yield goals. Choice of fertilizer source depends on economics and the crop situation. Timing of N application to match the point of maximum uptake by the plant is vital for maximizing uptake by plants and increasing N-use efficiency. Fertilizer N-use efficiency could be increased further by considering previous land use, previous fertilizer input, soil type, and available N in soil. Also, it is important to consider residual effects. This will enhance our understanding of the N behavior in soil and its interactions with other nutrients and crops, which, in turn, will help in making fertilizer recommendations.

Future Research Needs

The contribution of N fertilizer application to yield increases has been shown by past soil fertility research. However, a number of challenges to fully understand N behavior in soil still exist. The following are areas of research that need to be further developed:

- Continue development of fertilizer recommendation based on soil testing.
- Assessment of the contribution of soil organic matter to the mineral N pool during the growing season.
- Modeling N fertilizer recommendations using available soil, climate, and crop data.
- Spatial variability is a fruitful area of research while at the same time providing practical guidance for improved management of soil fertility and environmental problems.
- Soil sampling methods (number of samples per unit area, sample depth, time of sampling, and the handling of samples) need further refinement.
- More research needs to be oriented towards techniques and crop cultivars that improve the N-use efficiency.
- Impact of N applications on the environment and how the *negative effect of N applications* on the environment can be reduced.
- Determine N-use efficiency as related to previous crops, soil and climate.
- Biological N fixation of legumes and its contribution to soil N and subsequent crops.
- More effort is needed for the transfer of research results to farmers.

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Nitrogen Fertilizer Use Efficiency in WANA as Determined by ^{15}N Technique

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Abstract

After drought, nitrogen deficiency is the most serious constraint to crop production in the Middle East region. Concern abounds as to it efficient utilization because of costs and the potential for pollution. Using the isotope of N helps elucidate the behavior of this element. Studies in several countries of the region, i.e., Tunisia, Syria, Morocco, Pakistan and Egypt, have involved ^{15}N to pinpoint crop uptake and N loss mechanisms. While losses vary with the circumstances, leaching can be a problem in irrigated cropping, while volatilization can occur in both irrigated and dryland cropping. Understanding the behavior of N in farming systems is the basis for more effective and efficient N-use management.

Introduction

The climate of the region of West Asia and North Africa (WANA) is principally a Mediterranean climate. Rainfall is highly erratic in both time and space. It ranges from 50 to over 1200 mm annually. The variation between years in climate increases the risk to crop production. The area of land suitable for agriculture in the region is small, i.e., only about 128 million (M) hectares, or 8% of the area's 1.7 billion hectares (van Schoonhoven, 1989). The soils of the region are generally calcareous and low in phosphorus, nitrogen and organic matter. Four broadly defined agriculture systems (Cooper et al., 1988) have evolved in response to the prevailing climatic and soil conditions, 1) steppeland and native pasture, 2) systems dominated by livestock and barley production, 3) systems dominated by wheat, food legumes, and summer crop production, and 4) irrigated farming systems.

The region's population is expected to be 620 million by the year 2000 (World Bank, 1987). To meet the projected food gap, improving the agriculture through better use of the limited resources is vital. Using fertilizers is a key element in improving crop productivity in the region. Although limited water resources have discouraged the widespread use of N fertilizers, the increasing demand for food requires the use of N at its peak efficiency. Response to N fertilizers is governed by the availability of water and the crop rotation. Response of cereals to N fertilizer is particularly influenced by the type and performance of the preceding crop.

Nitrogen Consumption

Countries in WANA vary with respect to their consumption of the N fertilizers. Data presented in Table 1 show that there is an increase in N consumption for all the countries listed. Increase in consumption is usually due to an increase in the cultivated area, release of new crop varieties, or an increase in the recommended rate for the applied fertilizer. In the irrigation farming systems, the consumption of N fertilizers is higher than in the rainfed agriculture. In Egypt, an intensive agriculture system is practiced. The highly fertile soils allow cropping intensities of up to 2.5. The rate of fertilizer use in Egypt is one of the highest in world (Badian et al., 1994), with use of 372 kg ha^{-1} compared with 3 for Africa and 28 for the world as a whole; the figure for developed countries (38 kg ha^{-1}) is almost double that of developing countries (22 kg ha^{-1}). The recommended rate for wheat is 170 kg N ha^{-1} in Egypt (Hamissa and El Mowelhi, 1989), while it is 80 kg in Yemen (Said, 1993).

Table 1. Nitrogen consumption in some countries of the WANA region

Country	1978	84	86	88	90	92	94	Change
	1000 Mt							%
Algeria	66	59	98	80	46	41	74	12
Egypt	460	722	640	684	754	775	858	87
Libya	17	34	21	25	30	35	30	76
Morocco	75	103	137	147	148	148	130	73
Sudan	32	37	92	49	47	77	59	84
Tunisia	17	32	45	51	50	52	55	224
Iran	189	570	465	524	668	659	600	217
Iraq	45	61	120	149	138	95	150	233
Jordan	2	9	11	9	15	15	3	50
Pakistan	551	914	1128	1282	1468	1463	1659	201
Syria	57	109	137	117	154	180	230	303
Turkey	666	1021	916	1142	1140	1099	1335	100
Yemen	2	15	17	8	17	16	8	300

Source: FAO (1979, 1994)

Nitrogen-use Efficiency

Fertilizer-use efficiency is a quantative measure of the actual uptake of a particular fertilizer nutrient by the plant in relation to the amount of the same nutrient added to the soil (Zapata, 1990). A common form of expression of fertilizer-use efficiency is plant recovery or percentage utilization of the added fertilizer. However, the concept of fertilizer use also implies the availability of the applied nutrient under variable climatic conditions. Environmental aspects, such as pollution resulting from fertilizer application, are also considered (Zapata, 1990). Soil and environmental conditions dictate fertilizer behavior and indicate where loss in efficiency can occur (Cooper et al., 1988). Under rainfed conditions of the dryland areas, loss through leaching is not likely to be a problem, whereas in the irrigated systems it represents one main potential reason for losses. Other mechanisms of N loss include denitrification and ammonia volatilization. Fertilizer-use efficiency could be assessed by 1) the classical method to measure the biological response or the effect of increasing fertilizer rates on crop yield, 2) the *difference method,* whereby nutrient uptake of the crop from the control plot is subtracted from that of the fertilized treatments, and 3) *isotopic method,* which is the only *direct* means of measuring nutrient uptake from applied fertilizers.

Nitrogen-15 Isotope to Determine N-Use Efficiency

Use of the N isotope in fertilizer-use efficiency enables researchers to exactly quantify the amount of N taken up from applied fertilizers. In an isotopic-added fertilizer experiment, a labelled fertilizer is added to the soil and the amount of fertilizer nutrient taken up by the plant is determined. The fraction of the N in the plant derived from the labelled fertilizer is expressed as a percentage, i.e., % Ndff (N derived from fertilizer). From a simple isotope dilution principle, the following relationship is used for calculating % Ndff: % 15-N atomic excess in labelled plant sample / % 15-N atomic excess in labelled fertilizers. Since the crop has only two sources for providing N, the % N derived from soil is obtained by difference as follows: % Ndfs = 100 - % Ndff. The amount of fertilizer N taken up by the crop is calculated by multiplying the total N yield by % Ndff. Percentage of fertilizer N utilization is obtained as: N uptake/fertilizer N applied multiplied by 100 (with units of measurements as kg N ha^{-1}). By analyzing plant and soil samples collected from the marked microplots where labelled N was added for 15-N atom excess, the N balance for the system under study can be calculated, and N losses can be estimated.

Examples of ^{15}N Studies in WANA Region

As a useful tool, 15-N technique was used in some countries of the WANA region to evaluate different N sources, to compare rates of fertilizer application, to study methods of N losses, and to compare several crops or varieties with respect to fertilizer-use efficiency under different soil types or climate. A series of field trials was conducted within an International Atomic Energy Agency (IAEA) coordinated research program (IAEA, 1974). Nitrogen was applied at a rate of 120 kg N ha^{-1} (one half broadcast at planting and the other half at tillering). A summary of the results is presented in Table 2. Data show that N recovery ranged from 25 to 58% for urea, 24 to 65% for ammonium nitrate, and 26 to 60% for ammonium sulfate.

In Syria, a 2-year field experiment was conducted using ^{15}N-labelled urea to study the mechanism of N losses and uptake of N by wheat under a Mediterranean environment (Abdel Monem, 1986). Seasonal rainfall was an important factor in determining N uptake by wheat. Nitrogen losses from urea were in the range of 11 to 18%, which is relatively low, presumably because of the high clay content and the high cation exchange capacity of the soil. Nitrogen recovery, ranging from 20 to 49% was affected by the seasonal rainfall. Also, the study showed that when wheat growth was limited by available water, a large fraction of the applied N remained in the soil unutilized by the plant. A recent study (Garabet, 1995) conducted at the same location in northern Syria using ^{15}N showed that N-use efficiency ranged between 21 and 63%, and a large portion (>50%) of the applied fertilizer N remained in the top 20-cm soil layer. No N was detected below the 40-cm depth. Nitrogen-use efficiency reached a maximum around anthesis and decreased during the grain-filling period.

Table 2. Nitrogen-15 recovery from various nitrogen sources.

Country	Urea	Ammonium Nitrate	Ammonium Sulfate
	%		
Egypt	52	47	49
Pakistan	58	65	60
Iran	25	24	26
Turkey	48	40	36
Lebanon	52	47	49

In Tunisia, a 4-year field trial involved three wheat varieties, four N levels with ^{15}N-labelled fertilizer, and two N fertilizer forms, i.e., ammonium nitrate and ammonium sulfate. Nitrogen recovery was in the range 18 to 47%, volatilization losses were 15%, and Ndff was 9 and 21%, with no leaching in the dry season (El-Mhiri and Sanaa, 1993). In Morocco, an experiment was conducted for 2 years in a farmer's field in the semi-arid region (Abdel Monem and Ryan, 1991). Precipitation of the first year was 460 mm, while the second year was dry (200 mm). Wheat was fertilized with ^{15}N-labelled urea. In the wet season, recovery of ^{15}N in plant and soil was 53%, and 30%, respectively. Recovery of the second year's crop from the ^{15}N residual was 9%. Residual N remaining after the wet year was not sufficient to sustain optimum crop growth; some of the residual N became immobilized in the organic form and was unavailable to the plant.

To evaluate N balance under different agro-ecological zones in Morocco, another field trial was conducted at two sites representing different environments of the semi-arid region, with 380 and 270 mm as seasonal rainfall (Abdel Monem et al., 1995). Bread wheat was fertilized with ^{15}N-labelled urea at different rates. Total recovery by the plant was 30 and 35%, while it was 40 and 34% in the soil for the dry and wet site, respectively. High loss was estimated in both sites, with an average of 30%. It was postulated that this was due to ammonia volatilization.

In Pakistan, several studies using the 15-N isotope have been conducted. Azam et al. (1986) have shown that wheat plants utilized 64% of the residual fertilizer N and 20% of the residual legume-N. They also reported that 50 to 60% of the N taken up by plants was recovered in the grain and only 4 to 8% in the roots. Later, the same authors (Azam et al., 1989) studied the transformation of 15-N-labelled leguminous plant material in three soils of Pakistan.

In Egypt, where the agricultural system is very intensive, rate of N fertilizers applied is very high. Efficiency of the added fertilizer is an essential issue due to economic and environmental concerns. Use of 15-N enables researchers to evaluate crops and fertilizers under different soil types. Mohamed and Abdel Monem (1994) reported that fertilizer utilization by wheat (variety Sakha 92) was 23%. Under sandy soil conditions, Abdel Monem et al. (1994) reported 28% recovery by wheat. Eid et al. (1974) indicated that an average of 38% of the N applied as ammonium sulfate was recovered by maize. Under flooded conditions, Hamissa et al., (1986) reported that N recovery by rice ranged between 10% and 39%, depending on the method of application. Abdel Monem et al. (1994b) indicated a low recovery by rice from applied labelled urea (22%) added to wet soil, and higher (41%) when added to dry soil. The major cause for poor recovery is the extensive losses of the applied N fertilizer. Losses from applied N to crops in Egypt was found to be high. In sandy soil it was estimated to be as high as 49% (Soliman et al., 1993), while it reached 62% as urea broadcast to rice under flooded conditions (Abdel Monem et al., 1994a; Soliman and Abdel Monem 1994).

Management for Increasing Nitrogen Efficiency

Increasing the efficiency of the applied fertilizer N through different approaches is one of agriculture's highest priorities. This can be achieved through:

1) *Rational approach to N fertilizer recommendation.* This requires a knowledge of three criteria, i.e., the N requirements of crops for expected yield, the mineralization potential of soil organic N, and the amount of residual fertilizer N available from previous applications.
2) *Increasing N-use efficiency through soil and crop management.* This involves applying fertilizer at the most suitable time and using the proper method to increase the relative effectiveness of the N-fertilizers.
3) *Modified N fertilizer concept.* Researchers have attempted to avoid conditions favorable to extensive N losses by inhibiting urease activity which causes ammonia volatization, or inhibiting the nitrification process, which can make N susceptible to nitrate leaching, or coating the fertilizer granules by insoluble or permeable materials to delay the dissolution of the N fertilizers and increase plant uptake.
4) *Bio-fertilizer's approach.* Biological nitrogen fixation could be used to compete or replace the chemical fertilizer inputs.

As difficult as the problems with N in cropping systems are, they are not insurmountable. Clearly, by reducing loss mechanisms, greater efficiency can be achieved from the economical and technical standpoints. There is also considerable potential for biological N fixation (BNF) in legume crops, these contributing to the pool of soil N. Rational fertilization and BNF should be seem as complementary and not alternatives. The use of ^{15}N has an indispensable role in achieving that goal.

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Nitrogen Fertilizer-Use Efficiency Studies by Syrian Atomic Energy Commission Using ^{15}N-labelled Fertilizers

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Abstract

Several studies on different crops using ^{15}N-labelled fertilizers in irrigated and rainfed conditions showed that N-fertilizer-use efficiency varied with crop, growth stage, season, and type of fertilizer and was in the range of 7-55%. The effect of N application on the uptake of soil N was not consistent over seasons; the amounts of soil N in fertilized crops were either more, similar, or less than the unfertilized. Calculating the "A value" (as units of fertilizer N) for the soils where the crops were grown showed that, in most cases, soil inorganic N was greater than total N, though crops responded to N application.

Introduction

Nitrogen recovery by crops is usually measured by *difference* between the N contents of fertilized and unfertilized crops. The recovery is variable because it is highly dependent on crop yield and response to N application. The dynamic nature of soil-labile N and its sources (Dewilligen, 1986) contributes to such variation. However, the uncertainty is greater with legumes, whose N nutrition depends to a large extent on symbiotic N fixation. The erratic rainfall and temperature, especially in dry areas, also cause high variations in recovery due to soil inorganic N turnover.

Introducing ^{15}N-labelled fertilizers permits direct measurement of fertilizer uptake by crops, with no interaction of crop yield or responses to N fertilization. Recovery measured by the isotope method is generally less than that measured by the difference method (Wild, 1988), but differences between the two methods are not consistent. Jenkinson (1985) attributed to these differences and inconsistence of these variations as the *"priming effect"* or *"added nitrogen interactions"*.

This paper briefly discusses the results of several experiments carried out in Syria by the Atomic Energy Commission to measure the contribution of the different sources of N to crop total N using ^{15}N-labelled fertilizers. The calculations used to estimate the different sources of N in plants are based on the assumption that the fractional use of all sources of inorganic N in the soil is proportional to the amount of inorganic N from each of the sources present at the time of uptake (Hardarson, 1990); the following expressions are commonly used to identify the various sources of N in relation to applied N.

1. *N derived from fertilizer (% Ndff) = (% ^{15}N atom excess in plant / % ^{15}N atom excess in fertilizer) x 100;*
2. *N derived from soil (% Ndfs) = 100 - (% Ndfa + % Ndff).*
3. *N derived from atmosphere; (% Ndfa) = 1- (%^{15}N atom excess in fixing crop / % ^{15}N atom excess in non-fixing crop) x 100.*
4. *Soil inorganic N as units of N fertilizer ("A value") = (% Ndfs / % Ndff) x N fertilizer rate.*

Results

Table 1 shows that measured fertilizer N-use efficiency (FUE) by legume and non-legume crops in irrigated and rainfed conditions in different seasons with different rates and types of fertilizers were in the range of 7-55%. The values varied with crops, rates of fertilizer application and seasons. Despite a few discrepancies, there was a general trend that fertilizer use efficiency was lower with higher application rates.

Table 1. Efficient N fertilizer use, total plant N, "A Value", and N applied.

Crop	Stage	N Rate	Fertilizer†	Efficiency	Plant Total N	"A Value"
		kg ha^{-1}		--- % ----	------- kg N ha^{-1}	------
Irrigated						
Faba bean[1]	pod	20	Urea	25	139	68
Bitter vetch[1]	pod	20	Urea	55	149	70
Peas[1]	pod	20	Urea	51	134	68
Rainfed						
Lentil[2]	Seed	20	A.S.	18-22	91-99	360-386
Chickpea[2]	Seed	20	A.S.	8-12	64-152	130-288
Vetch[3]	Flowering	20/60	A.S.	7/18	132/151	219/212
Barley[3]	Flowering	20/60	A.S.	25/17	63/48	232/228
Vetch+barley[3]	Flowering	20/60	A.S.	35/30	188/136	258/180
Wheat[2]	Seed	20/40	A.S.	34/39	157/161	429/365
Irrigated						
Maize[4]	Seed	80	Urea	37-45	117-155	237-336
		160	Urea	23-27	130-175	394-427
Sugar beet[5]	Harvest	120	A.S.	24-43	131-208	212-636
		120	Urea	11-37	190-342	410-2160
Potato[6]	Harvest	120	Urea	22-53	94-144	152-318

† A.S. Ammonium sulfate.
[1] Kurd Ali and Sharabi (1995), [2] Asfary et al. (1995), [3] Kurd Ali and Sharabi (1995), [4] Khalifa and Mohammed (1991), [5] Charanek (1990), [6] Charanek and Audat (pers. comm.).

Seasonal variation of FUE is shown by selected data on spring sugarbeet in Table 2. The experiment was done in three successive seasons on a clay loamy soil with pH 8.2 (saturated soil paste); OM, 1.3-2.3%, and total N, 0.13-0.22%, down to 60-cm soil depth. The differences in total N uptake ranged from 11 to 66% and FUE from 2 to 3 fold in different seasons.

Banding and broadcasting urea showed negligible effects on FUE in all seasons (Table 2). The effect was more pronounced on total N in plant, but not to the extent that the differences were significant, although banding urea increased total N uptake as much as 65 kg N ha^{-1} (31%) in 1987. This could be attributed to high variation between replicate plots with coefficient of variation of 22% in that season.

Table 2. Method of fertilizer application in relation to efficient use of ^{15}N-labelled urea by spring sugarbeet, 1985-87.

Application Method	N Applied	Use Efficiency			Plant Total N			"A Value"		
		'85	'86	'87	'85	86	'87	'85	'86	'87
	kg N ha^{-1}	-------- % -------			---------------- kg N ha^{-1} ----------------					
Broadcast	120	24b	13	36a	315a	233	210	1179	1744	451
Banding	120	28a	11	37a	342a	247	275	1123	2160	630

a, b, refers to significant differences (5%) in rows.

Selected data from a separate experiment (on the same soil type) show that FUE by autumn sugarbeet varied (8-43%) during the growing season, with an increasing trend towards harvest and negligible differences between seasons (Table 3). The FUE was highest at the end of maximum leaf growth, then decreased by harvest.

This decrease in FUE is attributed to two reasons: a) N losses with leaf senescence after that stage, and b) N uptake by the crop (mainly by the storage roots) after final

Table 3. Efficient use of ^{15}N-labelled ammonium sulfate fertilizer by autumn sugarbeet during the 1986/87 growing season.

Growth Stage	N Applied[1]	Use Efficiency		Plant Total N[2]		"A Value"	
		'86	'87	'86	'87	'86	'87
	kg N ha^{-1}	------- % -------		------------- kg N ha^{-1} -----------			
Maximum leaf growth	60	8	10	35	22	360	160
End of leaf growth	120	39	43	208	144	411	212
Harvest (July)	120	24	24	188	131	636	422

[1] N applied was split into 60 kg N ha^{-1} at emergence and 60 kg N ha^{-1} at maximum leaf growth (after sampling).

[2] The decrease in total N at harvest is attributed to losses of leaves (N percentage in leaves was over twice that in roots) although total dry matter yield increased at harvest.

harvest was more dependent on soil inorganic N than earlier in the season (data is not shown here); total N uptake by harvest did not compensate for N losses.

The contribution of fertilizer N to total N in crops varied between 1 and 13% in legumes and between 4-44% in non-legumes, indicating that crops were mainly dependent on soil N and, in the case of legumes, on soil N and symbiotic N fixation. The amounts of soil N in plants (Ndfs) were in the range of 11-26% of total plant N in legumes and 56-96% in non-legumes. These values varied during the growing season and over seasons. Table 4 presents selected data for Ndfs in spring sugarbeet and in wheat from a 2-course crop rotation on a clay loam soil (pH, 8; OM, 1.5%; inorganic N at planting, 20 $\mu g\ g^{-1}$ in the top 60-cm soil layer). The amount of Ndfs in sugarbeet was significantly higher by 117 and 67 kg N ha^{-1} with added urea than without in 1985 and 1986, respectively. In 1987 Ndfs was highest when fertilizer N was banded and lowest when broadcast; the differences were not significant, although they were between 24 and 65 kg N ha^{-1}. This is attributed to the variations between replicate plots, giving a CV of 23%. Similarly, the Ndfs in wheat (averaged over rotations) was higher (by 11-16 kg N ha^{-1}) without N fertilizer than with fertilizer. Lower values of Ndfs in fertilized winter wheat than the unfertilized were reported by Powlson et al. (1992).

The calculated amounts of soil inorganic N (A value) under all crops, except for the first three crops (Table 1) were more (by 30-600%) than crops' total N. These calculated "A values" represent the total amount of inorganic N present in the soil by the time of final crop sampling (the stage of highest expected DM yield or N in crop). It is not known how much was present at the beginning of the season and how much was gradually builtup during the growth of the crop. Also, the "A values" varied during the growing season and over seasons (Tables 2, 3).

Table 4. Interaction of N fertilization with soil nitrogen over three seasons.

Crop	N Applied		Plant Total N	N Derived from Soil			"A Value"
				'85	'86	'87	
	kg N ha^{-1}						
Sugarbeet[1] (spring)							
	0			168	151	190	
Broadcast	120	Urea		285ab	218a	166	
Band	120	Urea		309ab	234a	231	
					1994		
Wheat[2] (rainfed)							
	0		161		161		
Broadcast	20	A.S.	157		150		429
	40	A.S.	161		145		365

a, refers to significant differences (5%) in columns and b refers to significant differences (5%) in rows.
A.S. Ammonium Sulfate, [1] Charanek (1990), [2] Asfary et al. (1995).

Discussion

Total N in crops is determined by crop demand and N supply, which in turn is determined by the amount of inorganic N available in soil and the surface area of contact between the root system and the soil solution (Nye and Tinker, 1977). The N demand is dependent on crop growth, which is determined by genetics, light interception, and other environmental factors (mainly precipitation and temperature). Thus, variation in these factors from season to season will affect crop optimum growth and consequently N requirements.

Accordingly, total crop N will vary whether or not N supply is limiting. Nitrogen uptake by crops followed yields and were higher in 1985 than in 1986, although there were sufficient amounts of labile N (A values) in the soil in both seasons, more so in 1986. The variations of N supply over seasons may also cause variations in N uptake. Total crop N, where fertilizer was banded, was higher in 1985 than in 1987 although crop yield was significantly higher in 1987 than in 1985.

The amount of inorganic N in soil is determined by soil OM, previous crop residues, soil biomass, environmental conditions (temperature and soil moisture) and atmospheric inputs (Dewilligen, 1986; Wild, 1988; Powlson et al., 1992). These factors will affect the rate and amount of mineralization-immobilization turnover of soil N during crop growth and over seasons as shown by the "A values" under sugarbeet. Residues of previous crops may add a substantial amount to soil labile N and crop N uptake. Powlson et al. (1992) found that winter wheat following potatoes took up about twice as much soil N as wheat following oats.

Atmospheric annual inputs, both wet and dry, may add to soil N an average of 5 kg N ha^{-1} in areas far from industrial and urban centers (Wild, 1988). Measurements in the Netherlands show that values may increase near industrialized areas to 50 kg N ha^{-1} (Dewilligen, 1986). These deposits seem to be location-dependent, and part of it might be absorbed directly by plants. Therefore, they add another source of variation to the estimates of different N sources in crops. In Syria, there is no such measured value that could be used, but one would expect it to be in a similar range.

The surface area of contact between the root system and the soil solution is determined by the root length and soil moisture content and will affect the rate and amount of N uptake by the crop, especially during periods of rapid growth, and consequently of high N demand. This is because transport of N by diffusion is an important transport mechanism even for the NO_3 ion (Asfary et al., 1983). Thus, when soil moisture content is less than field capacity, the surface contact will be less and the distance of ion transport to root surface will be longer in the top 30 cm soil layer. Also, under drier conditions and with small root densities in soil layers below 30 cm, the distances will become longer with the increasing tortuosity of the pathway and the movement of the diffusive ion will be slower which could be a limiting process (Nye and Tinker, 1977). This might be an explanation why crops respond to N fertilization, although the soil inorganic N (A value) is more than crop total N. When crops fail to satisfy their N requirements from the soil, a response to N fertilization is expected and total N in crops would increase as shown with sugarbeet (Tables 2, 4). On the other hand, if the crop's N requirements are satisfied by soil N, applied N may have a small effect on total crop N, as with sugarbeet in 1987, where N was applied broadcast, and with wheat.

Once fertilizer N is applied to soils, it can be immobilized into organic forms; the rate of this process may be high enough to transform all the N from the fertilizer to the organic form in a short time (Dewilligen, 1986). The immobilized N fertilizer is usually considered an easily mineralizable N source during crop growth and might be a major N source for crops when high rates of N uptake are required. Asfary et al. (1983) reported that mineralization rates of soil organic N (1.3-1.7 kg N ha^{-1} day^{-1}) were about ⅓ those of N uptake (4-5 kg N ha^{-1} day^{-1}) during the rapid growth of potatoes (4-9 weeks after emergence). The difference was taken up from the applied N on the basis that the excess amount (100 kg N ha^{-1}) of inorganic N in soils measured at emergence on the fertilized plots than on the unfertilized were from the applied fertilizer (150 kg N ha^{-1}) and the immobilized amount was more easily mineralized than native N. However, they suggested the use of ^{15}N-labelled fertilizer to test this possibility. The apparent recoveries (FUE) measured in this experiment were 50 and 71% without irrigation and 73 and 79% with irrigation, reflecting the effect of variation in seasonal precipitation during the crop growth.

Fertilizer-use efficiency is therefore dependent on the size of the soil labile pool and the turnover of the immobilization-mineralization of soil and fertilizer N during crop growth and over seasons. The contribution of fertilizer N to the labile pool is highest just after application; thereafter, crop uptake of fertilizer N decreases its contribution to the pool because its supply is limited to the applied amount. However, the rates and amounts of the turnover of any source of N in the pool determines the proportion of fertilizer N to soil N at any time of N uptake.

Using the data in Table 3 at the beginning of maximum leaf growth for sugarbeet and at the end of maximum leaf growth in both seasons enables the estimate of the N proportions. The proportions of inorganic N from fertilizer to that of soil at the time were (%): 35 and 26 in 1986, and 79 and 50 in 1987 at these stages, respectively. The proportions under wheat (Table 4) were 14 and 5% for the 20 kg N ha^{-1} and 27 and 11% for the 40 kg N ha^{-1} at planting (initial soil N was 148 kg N ha^{-1}) and harvest, respectively. These values are calculated for the dates of plant sampling and/or N application, and they do not represent the limits of the values that may have occurred during those periods, but they show a range of variation. Also, these proportions are not uniform down the soil profile or across the field, and they represent an average value of the field conditions under those crops.

When fertilizers are broadcast on the soil surface, incorporated to a depth of 15-30 cm, or banded they interact with the labile N in a small volume of soil compared to the volume the roots of crops would extend to (> 75 cm depth). On the other hand, most of the soil N and ≥ 30% of the crop roots are in that layer, which may balance to a certain extent the effect of distribution. Besides split application will have an immediate effect on this proportion which may be diminished later on when the applied N is mixed with greater volumes of soil or immobilized. Even distribution of rainfall, higher precipition and irrigation would improve the distribution of N fertilizers in soils and increase uptake from a greater soil volume. Light showers of rain may not penetrate below 30 cm and may enhance N uptake from that layer only.

Uneven distribution of crop residues will cause spatial variation in the soil labile N which, in turn, may lead to spatial variations in the Ndfs and Ndff in succeeding crops. Polsown et al. (1990) reported spatial variation in the Ndfs values and attributed that to the uneven distribution of previous residues. Similarly, when organic fertilizers are added to soils they may not be evenly distributed and would have spatial variations that may affect the sources of N in crops especially in the first season of application. The added N interaction (ANI) seemed to be affected by all the factors stated above and may not be consistent over sites and over seasons.

Fertilizer requirements of crops therefore will always be difficult to assess. Seasonal variation is a major source to this uncertainty (Cooke, 1967). The difficulty to get an accurate measure of soil N to the rooting depth is another (Wild, 1988). Also, the amounts of labile N in soil at any time of crop N uptake does not mean that they are readily taken up. Therefore, the concept of N requirements of crops would be more effective if it is related to crop growth during the season and the search for new methods of fertilizer applications to fit into this approach would be very useful.

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Nitrogen Cycling in a Dryland Cereal-Legume Rotation System

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Abstract

Isotopic ^{15}N tracer techniques were used to quantify, over a 5-year period (1991-96), the source and fate of N in a wheat rotation cropping trial, established in 1983 at ICARDA in Syria. Yields of wheat (*Triticum aestivum* L. subsp. *aestivum*) grown continuously were considerably less than when grown in rotation with chickpea (*Cicer arietinum* L), lentil (*Lens culinaris* Medik.) or a fallow. Wheat responded to N fertilizer application (urea and ammonium sulfate), particularly at 30 kg N ha^{-1}, in all seasons. Recovery of N fertilizer in wheat (9-26%) and in the soil (26%) was low, indicating that up to 50% of the fertilizer may have been lost from the soil-plant system. Detailed ^{15}N studies indicated that ammonia volatilization and denitrification were likely to be the major N loss mechanisms. Uptake of N in wheat grain was greater than the N input from fertilizer. Measurements of N fixation by chickpea and lentil in rotation with wheat indicated that there was unlikely to be any net input of N to the soil from these legumes (taking into account N removed in grain). There was no increase in wheat yield or N benefit to wheat growing in rotation with chickpea or lentil compared with fallow. Overall, these data indicate that all four rotation systems lead to soil N depletion.

Introduction

In the drier environments of rainfed agricultural systems, both water and N are major limitations to crop productivity. Agriculture in these areas is dominated by cereal cultivation and the use of annual pastures to raise livestock, mainly sheep (Saxena, 1988). In Syria, in the wettest areas (mean annual rainfall >325 mm), wheat is the dominant crop and is grown in rotation with grain legumes (chickpea, faba bean, and lentil) and summer crops (watermelon or cotton) in areas where N fertilizer is used (ICARDA, 1991). It is often assumed that the use of a legume within the cropping system will lead to an input of N to the system from biological N fixation. Data from Tel Hadya for the 1981/82 season indicated not only an increase in wheat yield in response to N fertilizer (up to 60 kg N ha^{-1}), but also a benefit to wheat following faba bean or lentil compared with wheat following wheat or fallow (Saxena, 1988). Such a

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benefit is attributed to the ability of the legume to fix atmospheric N, some of which remains as residual N for the following crop. Therefore, the inclusion of grain legumes in cropping systems may provide an alternative or complement to N fertilizer, thereby reducing the risks associated with using a high-cost input (N fertilizer) in areas of uncertain rainfall.

In order to provide more accurate information on improved farming systems for the region, there is a need for short and long-term rotation experiments in which N budgets are estimated and gains and losses are quantified (Buddenhagen, 1990). Thus, experiments were carried out over a 5-year period (1991-1996), as part of a long-term two-course rotation study in Syria which was started in 1983 by the International Center for Agricultural Research in the Dry Areas (ICARDA, 1990). In particular, we have used ^{15}N to quantify inputs of N from N_2 fixation, to determine the fate of applied fertilizer N, to estimate N losses, and to determine the rate of N turnover in the soil-plant system.

Materials and Methods

A long-term study, involving a range of different cropping sequences, was established in the 1983/84 season at ICARDA's Tel Hadya Research Station near Aleppo. The climate is characterized by cold, wet winters and hot, dry summers, with an average annual rainfall of about 330 mm. The soil is a Calcixerollic Xerochrept, pH 8.2, and contains around 1% organic matter. Four sequences were considered here, namely, wheat after fallow (W/F), wheat after lentil (W/L), wheat after chickpea (W/C) and wheat after wheat, i.e., continuous wheat (W/W). Both phases of the rotation were included, with three replicated plots (0.54 ha) in each phase.

No inputs were used in the first 2 years, but from 1985/86 onwards, fertilizer and weed, pest and disease control measures were applied, and improved cultivars used. Phosphate fertilizer was applied at sowing to the wheat at 50 kg P_2O_5 ha^{-1}. Four N levels (0, 30, 60, and 90 kg N ha^{-1}) were applied in a split-plot design to sub-plots in the wheat phase in order to assess the long-term responses to N and the N benefits derived from the presence of the legumes.

In the 1991/92 season, 4-m^2 microplots were installed in all wheat plots, and were treated with ^{15}N-enriched urea (10.424 atom %) at the same rate of N application as the main plot, in order to measure fertilizer-use efficiency. In addition, in the legume plots 1-m^2 microplots were treated with ^{15}N-enriched ammonium sulfate (10.189 atom %) at a rate equivalent to 30 kg N ha^{-1} in order to estimate the rate of N fixation. In the two subsequent years, ^{15}N-enriched ammonium sulfate (10.289 atom %), rather than urea, was applied to both phases of the rotation.

At final harvest dry matter, total N and ^{15}N enrichment of plant samples and soil samples were determined. The proportion of N in the plant or soil derived from fertilizer was calculated from the ratio of the enrichment of the plant or soil to that of the fertilizer; the proportion of N in the legume derived from fixation was estimated from the ratio of the enrichment of the legume to that of the wheat (Wood and McNeill, 1993).

Results and Discussion

Nitrogen Response Fertilizer and Rotation

Data for three seasons during the early stage of the experiment (1987-89) indicated a response of wheat to N fertilizer at this site (Table 1). The rainfall during the first season was equal to the long-term average, and in the second and third seasons approached the upper and lower extremes, respectively (ICARDA, 1990). Data from later three years (1991-94) showed that the dry matter yield of the W/W rotation was consistently lower than that of the other rotations (Table 2), and there was no yield benefit from the presence of chickpea or lentil in the rotation compared with the fallow treatment. The rainfall in all three seasons was within 10% of the long-term average.

Table 1. Mean dry matter yield of wheat in response to nitrogen fertilizer, and rainfall.

Season	Applied N (kg N ha^{-1})			Rainfall
	0	30	60	
	kg ha^{-1}			mm
1986/87	4600	5,100	5700	333
1987/88	7800	10,000	12300	485
1988/89	3700	5,800	5900	238

Source: ICARDA (1990).

The data in Table 1 indicate a benefit in terms of yield derived from an input of N to this system. If the legume component was providing an input of N to the soil, a difference would be expected in the ^{15}N-enrichment values of the wheat in the different rotation treatments, specifically, the enrichment of the wheat in the W/L and W/C treatments should be lower than that of the wheat in the W/W and W/F treatments (due to isotope dilution). However, the data in Table 3 show no evidence of a N benefit to wheat in the legume-based W/C and W/L rotations.

Table 2. Mean dry matter yield for wheat in different rotations.[1]

Season	Previous Crop				Rainfall
	Wheat	Fallow	Chickpea	Lentil	
	kg ha^{-1}				mm
1991/92	5997	6698	6183	6558	352
1992/93	5172	7231	7576	6239	289
1993/94	3979	6284	3880	6544	365

[1] Fertilized at 30 kg N ha^{-1} in wheat phase.

Table 3. Enrichment of ^{15}N in wheat in different rotations.[1]

Season	Previous Crop			
	Wheat	Fallow	Chickpea	Lentil
1991/92	1.275	1.434	1.674	1.432
1992/93	1.068	0.876	0.946	0.866
1993/94	1.098	1.044	1.455	1.264

[1] Fertilized with 30 kg N ha^{-1} as urea (1991/92) and ammonium sulfate (1992/93, 1993/94).

Fertilizer N Recovery

Isotope ^{15}N analysis indicated that the recovery of N fertilizer in the above-ground parts of wheat was low, ranging from 8.7 to 26.4% (Table 4). This could be due to (a) immobilization of N fertilizer in the soil and/or (b) loss of N by leaching, denitrification or volatilization.

Table 4. Fertilizer recovery of N in wheat in different rotations.[1]

Season	Previous Crop			
	Wheat	Fallow	Chickpea	Lentil
	%			
1991/92	19.6	22.2	26.4	22.9
1992/93	12.6	11.5	15.7	10.5
1993/94	8.7	11.3	11.8	15.6

[1] Fertilized with 30 kg N ha^{-1} as urea (1991/92) or ammonium sulfate (1992/93, 1993/94).

Data for the recovery of ^{15}N-labelled fertilizer in crop and soil applied at sowing (Table 5) indicate that, although approximately 26% of the applied N remained in the soil at harvest in 1992 and 1993, the total recovery was only 38-49%. There were therefore large losses of more than 50% of the fertilizer. Harmsen (1984) suggested that ammonia volatilization is likely to be the major loss mechanism of N in soils of northwest Syria. These soils, which are mainly calcareous and of high pH, would favor loss of ammonia, especially if the fertilizer is applied as urea or ammonium salts. Leaching is unlikely to be significant in this area where, even at sites with an annual rainfall of up to 500 mm, water does not penetrate much below 1.5 m depth. Less than about 5% of the fertilizer was recovered at 20-40 cm depth in this soil (Table 5).

Table 5. Fertilizer N recovery in wheat (whole crop) at harvest and in soil layers in the wheat-fallow rotation.

Fraction Recovered	Labelled N Applied			
	1991/92		1992/93	
	Sowing	Tillering	Sowing	Tillering
	%			
Wheat	23.6	12.3	11.5	9.8
0-20 cm soil	20.4	55.1	22.7	33.1
20-40 cm soil	5.3	4.8	3.9	4.2
Total recovery	49.3	71.9	38.1	47.1
Unaccounted for	50.7	28.1	61.9	52.9

[1] 60 kg N ha^{-1} as a split dressing at sowing and tillering, 30 kg N ha^{-1} on each occasion, but labelled with ^{15}N at either sowing or tillering.

Recovery of ^{15}N from urea, ammonium or nitrate applied at sowing (Table 6) indicated that, within 12 days after application, up to 50% of the fertilizer was unaccounted for, and presumed lost. Losses from urea were greater than from ammonium sulfate. Recovery of ^{15}N in the soil ammonium pool was lower following application of urea than ^{15}N-labelled ammonium sulfate, indicating that volatilization may have occurred from urea following hydrolysis. However, losses from ^{15}N-labelled nitrate were greater than losses from ^{15}N-labelled ammonium (Table 6). The labelled fertilizer could not be completely accounted for in the organic fraction of the soil, indicating that immobilization is unlikely to be responsible for the loss. Therefore, denitrification remains as the only possible significant cause of loss of N from the soil; only 42% of the applied nitrate fertilizer was recovered as nitrate 12 days after application (Table 6). This requires further study to demonstrate by direct measurement the extent of denitrification in soils in the region. Data on split application of fertilizer (Table 5) indicate greater overall fertilizer N recovery following spring application of fertilizer when conditions should be less suitable for denitrification.

Table 6. Recovery of N fertilizer forms in soil 12 days after application[1] at sowing.

Soil N Fraction	Urea	Ammonium	Nitrate
	%		
Ammonium	11	36	0
Nitrate	18	22	42
Organic	15	18	15
Urea	6	not determined	nd
Total	50	76	57

[1] ^{15}N-labelled fertilizer was applied at a rate equivalent to 30 kg N ha^{-1} as urea or ammonium nitrate labelled either on the ammonium-N or the nitrate-N (1994).

Nitrogen and Outputs

Studies with ^{15}N isotope have enabled the different N sources for crops to be quantified, and N budgets to be created for the different rotation treatments at Tel Hadya. The trial has accumulated data on N contained in wheat grain in the different rotation treatments from 1986 to 1993, all of which received 30 kg N ha^{-1} fertilizer in the wheat phase. The values range from 10 to 100 kg N ha^{-1}, with a mean of 45 kg N ha^{-1}. If the wheat grain only is removed from the land, then the average seasonal input of N required to sustain this level of productivity is 45 kg N ha^{-1}. In most seasons and in most rotation treatments the offtake of N in grain was greater than the input of N in fertilizer, therefore the soil N was being "mined".

However, this assumes that all of the N fertilizer applied remains available for uptake by the wheat. The data in Table 7 indicate that the fertilizer N recovered by the crop in the season of application only accounts for about 10% of the offtake in the grain. Residual fertilizer N in the soil could provide for no more than 40% of the N offtake in the grain in subsequent wheat crops. Therefore, a continuous wheat cropping system fertilized with 30 kg N ha^{-1} is sustainable neither in the short term (during a single season) nor in the medium term (over about 10 seasons).

***Table* 7. Source and amounts of N in different parts of the soil-plant system at harvest for the wheat/fallow treatment.**[1]

Season	Grain N	Fertilizer N in	
		Crop	Soil
	kg ha^{-1}		
1991/92	41.5	6.7	10.4
1992/93	49.1	3.5	18.3
1993/94	35.6	3.4	13.2

[1] Fertilized with 30 kg N ha^{-1} in wheat phase, and sampled at 0-40 cm depth.

The data presented in Table 3 indicated no consistent residual benefit from the legume in terms of N supply to wheat growing in rotation with chickpea or lentil. The net input of N to the soil from these legumes must take into account the amount of N removed from the land in grain. The data in Table 8 show that the N contained in chickpea grain varied from 22 to 71 kg N ha^{-1}, but the amount of N gained by the whole plant from N fixation was less than this value in two of the three seasons. Therefore, the chickpea crop did not provide a net input of N into the system. A similar conclusion is reached for lentil, particularly if the lentil straw, which is considered a valuable animal feed, is removed from the land together with the grain. These data indicate that the inclusion of these grain legumes in rotation with wheat may reduce the rate of depletion of soil N compared with a continuous wheat crop, but is unlikely to yield a positive N balance. It must be concluded therefore that these particular grain legume/wheat rotation systems do not offer the immediate prospect of a sustainable cropping system.

Table 8. Source and amounts of N in different parts of the soil-plant system (0-40 cm) at harvest for chickpea and lentil.

Crop/Season	Grain N	Straw N	N Fixed[1]
	kg ha^{-1}		
Chickpea			
1991/92	70.7	12.2	21.3
1992/93	31.7	25.0	47.7
1993/94	21.5	2.1	18.5
Lentil			
1991/92	65.5	15.3	39.3
1992/93	27.7[2]	19.0	
1993/94	75.9	29.6	96.5

[1] Soil sampled at 0-40 cm; [2] data is for grain plus straw.

Conclusions

The data presented here have quantified the balance between inputs and outputs of N in four different wheat-cropping systems, and have highlighted the net depletion of N which is likely to occur in all of these systems. Of particular concern are 1) the large losses of N fertilizer which occur soon after application, and consequently the very low recoveries of N fertilizer in the wheat crop, and 2) the lack of a net input of N to the cropping system from chickpea and lentil. The wider importance of this point in the Mediterranean region is limited at present as grain legumes are grown on only 3.5% of cropland (Buddenhagen, 1990). Although these factors can be discussed in terms of the sustainability of improved crop rotations, consideration must also be given to socio-economic factors when assessing the overall sustainability of farming systems in the region.

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Changes in Organic Matter and Nitrogen with a Cereal-Legume Rotation Trial

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Abstract

Farming systems in West Asia - North Africa involve rotations of cereals with fallow or food/forage legume crops depending on location and rainfall. Barley (*Hordeum vulgare* L. subsp. *vulgare*) tends to dominate in the drier zones and wheat (*Triticum aestivum* L. subsp. *aestivum*, and *T. turgidum* L. subsp. *durum* (Desf.) Husn.) in the more favorable areas. Sheep and goats are integral parts of the systems, particularly those dominated by barley. ICARDA is developing improved cultivars and management practices and needs to critically examine the merits of several systems in terms of efficiency, costs and sustainability. Therefore, a long-term trial was established in 1983/84 at ICARDA's main research station at Tel Hadya, near Aleppo in northern Syria, to evaluate the productivity of systems in which durum wheat is rotated with vetch (*Vicia sativa* L.), lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), medic pasture (*Medicago* spp.), wheat, watermelon (*Citrullus vulgaris* L.), and fallow. Various N levels (0, 30, 60, 90 kg ha^{-1}) and intensities of grazing stubble (heavy, moderate, none) were imposed on the wheat phase. Both the wheat and the alternate phase were included each year. While seasonal rainfall, which ranged from 210 to 486 mm, and residual soil moisture after the alternate phase dictated the magnitude of wheat yields, N increased water-use efficiency. Soil N levels (mineral, total) varied with the system and were highest for medic and least for wheat and fallow. Similar differences were evident for organic matter, which also tended to increase with increasing N level. Though the trial needs to continue for several more years, the impact of some crops (i.e., medic) on soil quality is already apparent.

Introduction

Concern about providing sufficient food for the world's burgeoning population is an ever-present one. The prospect for the Mediterranean area of West Asia and North Africa (WANA) being able to come close to self-sufficiency are gloomy indeed (Oram, 1988). This region is largely characterized by highly variable seasonal rainfall, which is low and often erratically distributed. While irrigation has increased in extent, opportunities for further expansion are very limited. The farming systems of the region are, and will remain, predominantly rainfed cropping in association with small

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ruminants, i.e., sheep and goats. Barley, bread wheat and durum wheat are the principal crops. These are grown in the "wet" period, i.e., from October to May-June, in rotation with fallow and/or food or forage legumes (Cooper and Gregory, 1987) but are increasingly cropped continuously. As rainfall, and therefore soil moisture, is invariably the most limiting factor in crop production (Cooper et al., 1987), the greatest challenge is to improve water-use efficiency. Research in the region has shown that nitrogen (N) (Harmsen, 1984; Ryan and Matar, 1992) and, especially in drier areas, phosphorus (P) can contribute to increased yields and more efficient use of water (Cooper, 1983; Matar et al., 1992).

Livestock, principally sheep and goats, are an integral part of the systems, providing buffering against income fluctuations due to the season-to-season variability in crop yields. Importantly, they also provide a substantial proportion of the dietary protein of farm families in the form of milk, cheese and yoghurt. The barley-dominated systems of the drier areas are essentially livestock production systems in which barley, either as a green crop, or stubble, or stored straw and grain, constitutes the major feed source. In the wetter areas, sources of income and feed are more diverse, but wheat residues provide grazing for both resident and transhumant flocks of small ruminants.

The systems approach to agricultural research adopted by the International Center for Agricultural Research in the Dry Areas (ICARDA) has centered its attention on the potential benefits of integrating common rotations, N fertilization and grazing management. Detailed descriptions of the various kinds of rotations in the Mediterranean area are found elsewhere (Harris et al., 1991). To evaluate new or adapted technologies within the farming systems that ICARDA deals with requires long-term trials. Such trials are costly, require relatively large areas of land, and expert and consistent management, and must be run for many years in order to detect meaningful differences in soil properties, or validly assess the economic benefits of the system being studied. Few regional institutions can meet such criteria. It is hoped that this long-term trial by ICARDA will go a long way towards answering issues of sustainability of relevance to northwest Syria and serve as a model for the entire Mediterranean region.

Materials and Methods

A two-course rotation trial with seven crop sequences was established in 1983-85 in Tel Hadya on land that had been cropped in cereal-based rotations since 1978. (Harris, 1995). The 23-ha site is gently sloping, depth of the soil, a Calcixerollic Xerochrept, ranging between 1 to 2 m with a few shallower patches. The cropping sequences are durum wheat following: fallow (W/F), summer crop, i.e., watermelon (W/SC), lentil (W/L), chickpea (W/C), vetch (W/V), medic (W/M), and wheat (W/W). These are replicated three times, and both phases of the rotations are included each year. Individual plot size is 0.54 ha, and each rotation therefore covers 3.24 ha.

In the first two years no inputs were used, but from the 1985/86 season onwards fertilizer has been added, and weed, pest and disease control measures have been applied, and improved cultivars introduced. Two ancillary treatments are superimposed in a split-strip plot design. Four levels of nitrogen (0, 30, 60, and 90 kg N ha^{-1}) are applied to sub-plots in the wheat phase for the dual purpose of assessing the long-term reliability of N responses and evaluating the capability of the legumes to supply N to the systems. The wheat stubble is subjected to three management treatments: heavy grazing, moderate grazing and no grazing or stubble retention, which form the sub-sub-plots.

Trial Management

Tillage and Planting

Since 1987/88, primary tillage in the wheat phase has been carried out with a tyned cultivator after the first rain of the season, and this is followed by a pass with a spike-toothed harrow for seed bed preparation. In the first two seasons (1985/86 and 1986/87), the traditional planting method of broadcasting seed on to ridged land and covering it by splitting the ridges was used. However, since 1987, seed has been drilled -- wheat with a locally built seed drill at 17.5 cm row spacing following seed bed preparation as above, and other crops (vetch, lentil, chickpea, and wheat in the alternate phase) with a zero till planter directly into wheat stubble at 30 cm row spacing. Medic seed was broadcast in 1983 and 1984, and now pastures regenerate annually. Watermelon, is established as single plants on a 3x3 m grid according to local practice. Wheat and the legumes are normally planted in the second half of November and early December, respectively, following the initial rains. Watermelon is sown in mid-April on land that is fallowed to that time, providing the soil is wet to a depth of 1 m. Seed rates are: chickpea and vetch, 120 kg ha^{-1}; wheat and lentil, 100 kg ha^{-1}; and melon, 1.5 kg ha^{-1}.

Cultivars

The improved durum wheat, Cham 1, has been used throughout the trial. ILC 482, a cold-tolerant chickpea cultivar, with tolerance for *Aschochyta* blight (*Aschochyta rabiei* (Pass.) Lab.), released in Syria as Ghab 1, was selected for the early-sowing strategy used in the trial. It was replaced in 1991/92 by Ghab 2. Syrian local small lentil, used for the first two years, was replaced by a newly released cultivar, Idleb, in 1987/88. The vetch and watermelon are both locally used strains. Thirty kg ha^{-1} of 48 ecotypes of 12 species of medic was originally sown, with the objective of studying the species population dynamics under grazing. The pastures are now dominated by local ecotypes of *Medicago polymorpha* L., *M. noeana* (L.) All., and *M. rigidula* Boiss., but most of the species have survived and are represented in the swards.

Fertilizer

Phosphate fertilizer was broadcast over the whole area in the first two years at 60 and 90 kg P_2O_5 ha^{-1}, respectively, to raise the fertility level. It is now drilled with the wheat at 50 kg P_2O_5 ha^{-1}. The N is hand-broadcast, half at planting and the remainder at the tillering stage of wheat growth.

Crop Protection

Weeds are controlled in the crops by the use of appropriate pre- or post-emergence herbicides, while fallows are maintained weed-free by a combination of cultivation and herbicides. Grazing normally provides adequate weed control in the vetch and the medic pastures. Diseases, insects and rodents are controlled by routine seed dressing, and strategic use of chemicals when necessary.

Grazing Management

As is the practice in the farming systems of the region, the sheep graze from approximately 7:00 to 17:30 h each day and are housed overnight. Medic pastures are grazed throughout the year for as long as they will support 8 to 10 ewes (and lambs) per hectare. Vetch is used as a high-quality feed source for weaner lambs in the spring and is grazed at 25-30 head ha^{-1}. Wheat stubble is grazed by temporarily fencing sub-plots and introducing a large flock (400-600 ha^{-1}) for one or two days.

Yield Determination

Approximately 20% of the area of wheat and chickpea is harvested with a plot combine to determine grain yield, usually in the first half of June. The harvest index is estimated from 5 x 1-m row samples per sub-sub-plot and total dry matter and residue yields are estimated from the grain yield and the harvest index. The same proportion of lentil plots is hand-harvested (late April/early May), dried and threshed, and seed and residue yields are measured. The 'yield' of the vetch and of medic pastures is estimated as grazing days per year (number of days x stocking rate) and as animal products, lamb liveweight gain and milk yield.

Seasonal Conditions

Total season rainfall in the first two years (1985-87) was close to the long-term average (330 mm), i.e., 326 and 333 mm, respectively. The following year, 1987/88, had the highest rainfall (486 mm) while both 1988/89 and 1989/90 were exceptionally dry, with only 235 and 221 mm, respectively. The latter years were closer to normal. These seasonal amounts cover a large part of the range shown in the historical record for the area. Most years were characterized by erratic rainfall distribution; the 1991/92 season was extremely cold with several snowfalls.

Soil Analysis

The soil has been sampled more or less on a yearly basis since 1989. That year, five surface samples (0-20 cm) were taken from each sub-sub-plot, bulked and analyzed for mineral N, and total N (Black et al., 1965). In addition, selected plots were sampled in

20-cm increments to 1 m, i.e., the heavily grazed plots with 0 and 90 kg N ha^{-1} applied in the wheat phase in the W/F, W/C, and W/M rotations. Detailed soil moisture measurements are made on these plots; organic matter was also measured on the soil samples.

Results and Discussion

Crop Production

While the focus of the paper is with aspects of N and organic matter associated with the trial, some brief overview of the general trends for yield data are pertinent. A dominant feature has been the inter-annual variation in yields due to varying rainfall. For example, mean wheat grain yield ranged from 0.83 t ha^{-1} in a dry year (1988/89, 235 mm) to 3.62 t ha^{-1} in a wet year (1987/88, 486 mm); in the latter year, potential yields of 4.5 to 5.0 t ha^{-1} were achieved by adequate N fertilization. Crop sequence had a strong and consistent effect on total biomass and grain yields of wheat. The ranking, according to the preceding phase, is wheat ≤ medic ≈ chickpea < vetch ≈ lentil < melon ≈ fallow, which largely reflects residual soil moisture after the preceding phase. There is little evidence to show that legumes contribute significant amounts of N to the cereal phase, except that wheat after medic shows no N deficiency at tillering, whereas deficiency symptoms are usually visible in all other sequences at zero and low N levels. With some exceptions, there is a response to 30 kg N ha^{-1}. The exceptions include a response to 90 kg N ha^{-1} in the wet year, 1987/88, and to 60 kg ha^{-1} in the rotations with fallow, both related to a greater availability of soil moisture, and no response in dry years. Another exception is that after the third cycle of medic pasture the wheat grain yield without N fertilizer has equalled that where 30 kg ha^{-1} N is applied.

Soil Nitrogen

While the 2-course wheat-based rotation has been described in detail before (ICARDA, 1990, 1993), reporting of its soil and crop N status has previously been limited to preliminary observations on data obtained for the first time in 1989 (ICARDA, 1991). Since then we have had limited sampling of the plots in 1990 and a complete sampling after the 1990/91 season. This included determination of mineral N (NO_3 + NH_4), and total N, i.e., Kjeldahl N, which accounts mainly for the organic N fraction in the soil -- normally the largest one.

Mineral N concentration was consistently greatest in the medic rotation, while wheat after wheat or lentil tended to have lowest values (Table 1). Few differences were apparent between the other rotations. The same trend was again evident when measurements were made after each phase, i.e., wheat or alternative crops. The impact of N fertilization was consistent after the wheat phase, but less obvious after the unfertilized alternate phase. The data reflect residual fertilizer N after the wheat phase, but this was apparently used up by the alternate-phase crops or, more likely, incorporated into soil organic forms.

Table 1. Topsoil (0-20 cm) mineral nitrogen concentration with rotations.

Year	Crop Rotation[1]						
	W/F	W/W	W/L	W/C	W/S	W/V	W/M
	ppm						
1989	10.2	9.9	9.7	9.8	11.1	11.9	15.8
1990	9.5	-	-	10.3	-	-	11.0
1991	10.6	7.9	8.3	10.4	10.4	10.3	14.9
1992	16.2	13.6	-	11.7	-	-	21.0
1993	19.8	14.7	17.7	17.8	17.2	18.7	20.8
1994	21.5	21.9	17.8	17.1	17.0	19.5	25.0
1995	9.7	8.2	10.4	10.1	11.5	14.8	18.3

[1] W Wheat; F Fallow; L Lentil; C Chickpea; S Watermelon; V Vetch; M Medic.

As organic N is the dominant N fraction in soils, total soil N is an important observation. Again, the rotation with medics had significantly enriched soil N contents compared with wheat after either fallow, summer crop or wheat -- none of which added to soil N (Table 2). Total N values for the other N-fixing crops -- vetch, chickpea and lentil -- exceeded those where no legume was present, but whether this represents N enrichment or N saving is not yet clear. When the rotation effect was separated into phases, soil N values were consistently higher after the alternate crops. Nitrogen fertilization, at the 60 and 90 kg N ha^{-1} rates but not the 30 kg rate, tended to increase total N values also. This can be explained in relation to crop yield. The initial increment of N produced a proportionally larger yield response and was completely taken up by the crop; additional increments had less effect on yield and the unused N remained in the soils as residual N. The low rainfall of 1988/89 and 1989/90 exaggerated the effect.

Table 2. Topsoil (0-20 cm) total nitrogen concentration with rotations.

Year	Crop Rotation[1]						
	W/F	W/W	W/L	W/C	W/S	W/V	W/M
	ppm						
1989	686	698	737	716	668	739	806
1990	697	-	-	737	-	-	812
1991	688	678	718	696	651	738	792
1992	771	752	-	785	-	-	914
1993	745	752	787	802	715	823	905
1994	728	768	765	790	710	813	930
1995	737	796	786	831	732	873	970

[1] See notation in Table 1.

Data for mineral N from the first sampling (Nov 1989) indicated that the fertilized plots (90 kg N ha^{-1}) had most residual N in the profile, while values after the wheat were higher in the chickpea and medic plots. Wheat in the latter rotations was most severely affected by the prevailing drought and clearly was unable to use available nitrogen because of lack of water. In the alternate phase, there was little difference between the rotations, with fallow, as might be expected, having somewhat more than the rest. In all cases, the greatest mineral N concentration was in the top 0-20 cm decreasing with depth. When the impact of wheat stubble grazing and N rate were considered, total mineral N levels were greater, in general, where high-intensity grazing was imposed, especially with the W/F, W/C and W/M rotations. This possibly represents a carbon limitation to incorporation of N into the soil biomass when little residue is returned.

Organic Matter

Topsoil OM contents are presented in Table 3 as a function of the overall effect of the different rotations. In theory, the process of inducing changes in organic matter by varying management is relatively slow. However, there was evidence that some differences had arisen in the 10 years since the trial began. Notwithstanding the limited data for 1990, there was a general consistency for the years under consideration. When the crop rotations were considered, it was clear that the lowest values were associated with wheat after wheat and with wheat after fallow or summer crop. Among rotations that include legumes, that with medics produced the highest organic matter content, followed by rotations with vetch, chickpea, and lentil which were similar. Reasons for this pattern are not simple. More mineralization of OM might be expected in the fallow and watermelon phases, due to greater availability of water. Accumulation with medic pasture could arise from inefficient use of dry matter due to trampling and soilage during grazing, deposition of some 400 kg ha^{-1} yr^{-1} of dung, and an extensive root system which measurements of soil water indicate is a characteristic of medic.

Table 3. Organic matter in the top 20 cm of soil with rotations.

Year	Crop Rotation[1]						
	W/F	W/W	W/L	W/C	W/S	W/V	W/M
	%						
1989	1.03	1.05	1.12	1.09	1.02	1.13	1.26
1990	1.00	-	-	1.11	-	-	1.22
1991	1.03	1.05	1.09	1.07	1.02	1.14	1.21
1992	1.22	1.20	-	1.25	-	-	1.44
1993	0.98	1.01	1.05	1.12	0.97	1.12	1.23
1994	1.12	1.14	1.08	1.20	1.08	1.19	1.39
1995	1.14	1.17	1.13	1.23	1.11	1.32	1.46

[1] See notation in Table 1.

Nonetheless, these do not appear to satisfactorily explain the difference between the rotations with medic and the other legumes. The input during grazing of vetch could be expected to be much the same as that from medic, as total grazing days were similar in both rotations. Vetch does, however, have a sparser root system. Chickpea, on the other hand, has an extensive root system and all crop residues are returned during harvest. Lentil resembles vetch in having a small root system and all above-ground biomass is taken at harvest. In the other phase of the rotations, wheat after lentil and vetch produces more above-ground biomass, and thus presumably more roots, than wheat following medic or chickpea.

The dynamics of organic matter changes are obviously complex and it will need basic studies of carbon and N cycling to elucidate them. An interesting feature of the data (Table 4) was the apparent increase in organic matter content with increasing rate of N application. This is probably attributable to enhanced root growth from the applied N, a hypothesis further supported by data on water use which show greater drying of the soil profile by fertilized crops.

Table 4. Organic matter in the top 20 cm of soil with nitrogen fertilization.

	Fertilizer N (kg ha^{-1})			
Year	0	30	60	90
	%			
1989	1.06	1.07	1.12	1.14
1990	1.06	-	-	1.16
1991	1.05	1.08	1.11	1.11
1992	1.21	1.25	1.30	1.35
1993	1.03	1.04	1.10	1.11
1994	1.13	1.15	1.21	1.21
1995	1.20	1.18	1.26	1.26

Conclusions

As yet, only the most tentative of generalizations can be made regarding the effect of rotations on soil N and organic matter. Notwithstanding the dominant effect of soil moisture and the positive influence of fallow and short-season crops on subsequent cereal yield, some effects were already evident after the first sampling. Organic matter appeared to have increased with the medic-cereal rotation. These differences were similar at the second sampling. Where there was no legume in the rotation, organic matter levels were always lower. With time it will become apparent what is the maximum or equilibrium level of organic matter that can be produced by these rotations in this type of environment and to what extent, if any, such levels influence properties such as aggregation and water-holding capacity. Preliminary work indicates that this is beginning to happen. The increase in soil N from the medic rotation should benefit the companion cereal crop when moisture is not too limiting. Similarly, the increased cereal grain and straw N content after medic, and therefore improved food and feed nutritional quality, are additional factors, the value of which it is not easy to quantify.

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Biological Nitrogen Fixation by Cool-Season Legumes: Impact on Wheat Productivity in Syria and Lebanon

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Abstract

Legumes, grown for food and forage or pasture, are important not only for their own grain or biomass yields, but also for their impact on soil nitrogen and the companion cereal crop. The results for the period 1991-1994 from Tel Hadya and Terbol indicated that forage legumes were, in general, more efficient than grain legumes in biological nitrogen fixation, although the actual values are greatly affected by environmental conditions. Highest yields of fixed N were around 100 kg N ha^{-1} in Terbol and nearly 60 kg N ha^{-1} in Tel Hadya and were obtained with *Vicia villosa* subsp. *dasycarpa*. Wheat yields following the legumes were at a par with yield of wheat following fallow and significantly higher than the yield of wheat following wheat.

Introduction

In the dry, rainfed farming systems of West Asia and North Africa region, the cropping system is dominated by cereals. Continuous cereal growing, necessitated by increasing population pressure and expanding demand for food and feed, is leading to decline in productivity because of the build-up of pathogens and pests and depletion of soil fertility. One of the major objectives of ICARDA's research is to arrest this decline in productivity by devising alternative, more sustainable cropping systems through the introduction of annual forage and food legumes in the cereal-dominated rotations. There is a range of annual forage and food legumes that can be grown in the rainfed Mediterranean environments. Some of these are adapted to high rainfall areas whereas others can do well in limited moisture situations. ICARDA is attempting to enhance the adaptation of these legumes to different cropping systems under varying moisture supply.

One of the major roles that the annual forage and food legumes play in the dry rainfed farming systems (which are invariably *subsistent* and have few monetary inputs) is the influx of combined nitrogen in the system through biological N fixation. In the Mediterranean region, where most of the cool-season annual food and forage legumes have evolved, there has been co-evolution of the microsymbiont—*Rhizobium*—along with the macrosymbiont—the host legume plant. However, the association is not always optimum in the stressful environments where microsymbiont might have evolved more for survival rather than for efficient symbiotic fixation. There is, therefore, a need for quantification of symbiotic N fixation by different food and forage legumes in contrasting agroecological conditions in the Mediterranean region. It is also important to identify how some of the agronomic/management variations would affect symbiotic N fixation. Finally, it is of value to assess the residual effect of these legumes on the subsequent cereal crop so that one could identify a range of rotational options for these areas.

Methods and Materials

A trial was started at Tel Hadya, Syria in 1990/91 in which a series of food and forage legumes were grown in a two-course rotation with durum wheat. A 'fallow-wheat' and a 'wheat-wheat' rotation were included for comparing the effect of incorporation of legume in the rotation on the performance of wheat. The rotations are shown in Table 1. Both phases of the two-course rotation were planted each year. The ^{15}N dilution technique was used to estimate the symbiotic N fixation (Fried and Middleboe, 1977). The experiment is being conducted under rainfed conditions; the long-term average rainfall at Tel Hadya is 328 mm/year.

A similar study was started at the Terbol and Kfardane stations of ICARDA, in the Bekaa Valley of Lebanon. The trial at the Terbol site, which has a long-term average rainfall of >550 mm and is cooler than Tel Hadya because of its elevation of nearly 1100 m, started in 1990/91. The trial at the Kfardane site, which has long-term average rainfall of about 350 mm and is also cooler than Tel Hadya because of its elevation of nearly 980 m, started in the 1993/94 season.

A couple of agronomic variables (inoculation with *Rhizobium* and winter sowing in chickpea and the use of Promet seed treatment to control *Sitona* larvae damage to nodules in lentil and peas) were included in the legume phase because they were earlier identified as affecting the performance of these legumes and hence possibly their biological N fixation. Total seasonal rainfall (mm) for Terbol and Tel Hadya was 531 and 290 (1990/91), 860 and 353 (1991/92), 664 and 290 (1992/93), and 475 and 373 (1993/94); only the mean (353 mm) was available for Kfardane. From 1991 to 1994, the numbers of yearly days of frost were 53, 72, 91 and 66 for Terbol, and 35, 57, 48, and 19 for Tel Hadya, respectively.

Results

Results from Tel Hadya and Terbol sites are now available for three seasons, and from Kfardane for the first season. It will indeed take several years before the effect of the weather conditions on the biological N fixation by legumes and trends in their effect on soil fertility and cereal productivity in the two-course rotations become clear. The available results show that productivity of the legume crops is being affected not only by rainfall but also by the thermal regimes. The cooler the winter with more frost days, the lower the yield at a given location. Also, the lower the rainfall, the lower was the yield. Among the three sites, yields were highest at Terbol, intermediate at Kfardane, and lowest at Tel Hadya, following the pattern of seasonal rainfall and the length of the cropping season. The total N yield showed the same trend.

Table 1. Details of cropping treatments used in on-station trials.

Treatment[3]	Terbol		Tel Hadya		Kfardane	
	Cultivar	Seed Rate[1]	Cultivar	Seed Rate	Cultivar	Seed Rate
Wheat (+40 kg N)	Lahn	120	Sham-3	120	Lahn	120
Lentil	Talya-2	100	ILL-4401	100	Talya-2	100
Lentil (+Promet)	Talya-2	100	ILL-4401	100	Talya-2	100
Winter Chickpea (-)	Janta-2	100	ILC-482	44[4]	Janta-2	100
Winter Chickpea (+Strain CP-39)	Janta-2	100	ILC-482	44[4]	Janta-2	100
Spring Chickpea (-)	Janta-2	100	ILC-482	44[4]	Janta-2	100
Spring Chickpea (+Strain CP-39)	Janta-2	100	ILC-482	44[4]	Janta-2	100
Faba Bean	FLIP-85-98	150	[2]Syrian small	22[4]	FLIP-85-98	150
Dry Pea	Television	100	Syrian (Acc#8)	44[4]	Television	100
Dry Pea (+Promet)	Television	100	Syrian (Acc#8)	44[4]	Television	100
Vicia dasycarpa	Acc#683	80	Acc#683	80	Acc#683	80
Vicia narbonensis	Acc#67	120	Acc#67	120	Acc#67	120
Vicia amphicarpa	-	-	Acc#2650/ (Sel#2571)	100	Acc#2650/ Sel#2571	100
Lathyrus sativus	Acc#347	100	Acc#347	100	Acc#347	100
Fallow (-Weeds)	-	-	-	-	-	-
V. sativa (1/3) + Oat (2/3)	-	-	-	-	Acc#32541	100
Vicia sativa	-	-	-	-	Local Oat	100

[1] Seed rate: kg ha^{-1}. [2] Local Syrian cultivar; [3] and - refer to with and without inoculation; [4] seeds m^{-2}.

Tel Hadya

Average seed yields of legumes, and wheat are shown in Figure 1, and the yield of plant N derived from fixation (Ndff) and plant N derived from soil (Ndfs) in legumes and total N yield in wheat are shown in Figure 2. Winter chickpea gave higher yield than spring chickpea and inoculation only marginally improved the winter chickpea seed yield. *Vicia narbonensis* and lentil treated with Promet (Furathiocarb) gave next best seed yields after winter chickpea. Yield of fixed N was highest in *Lathyrus sativus*, *Vicia dasycarpa*, and lentil treated with Promet. Promet seed treatment in lentil and pea increased yield of fixed N indicating the beneficial effect of protecting the nodules of these legumes from damage by *Sitona* weevil. Also, winter-sown chickpea had higher yield of fixed N than the spring-sown crop. Inoculation did not have any effect, suggesting that the native *Rhizobium* in the soil is as efficient as the one introduced through inoculation.

The proportion of plant N derived from fixation (Table 2) did not exceed 70% and was considerably lower in the 1991/92 season which was exceptionally cool with 57 frost days in the growing season, although the rainfall was adequate. Promet seed treatment tended to increase % Ndff in lentil and pea. Winter sowing of chickpea in contrast to spring sowing also increased %Ndff, perhaps because of better thermal and moisture regimes available to the winter-sown crop for symbiotic association. Wheat grain yields following all the legumes (Fig. 1) were higher than the yield of wheat following wheat. However, the wheat yields following fallow were the highest. Yields of wheat following faba bean, *Vicia narbonensis*, lentil, pea with Promet seed treatment and winter chickpea were higher than the yields following other treatments having legumes. Thus, these legumes are a good alternative to fallow for introduction in the cereal-based cropping system in areas with rainfall around 350 mm.

Nitrogen yields by wheat (Fig. 2) were the highest following fallow and *Vicia dasycarpa* and only marginally smaller following *Vicia narbonensis*, and inoculated spring chickpea. These values were higher than those following wheat. Yield of N in wheat following other legumes were either similar to those following wheat or were slightly better, e.g., following winter-sown chickpea, lentil, and faba bean. Because of limited symbiotic N fixation, legumes tended to take up around 20 kg N ha^{-1} from soil during good season and nearly 40 kg N ha^{-1} in the season that particularly restricted symbiotic N fixation (Fig. 2). Faba bean tended to take lowest amount of soil N.

Terbol

Among the legumes, *Vicia narbonensis* gave highest seed yield followed by faba bean, field pea, lentil and winter chickpea (Fig. 1). Winter sowing of chickpea increased seed yield conspicuously over spring sowing. Effect of Promet seed treatment was not very clear, indicating that *Sitona* weevil was not much of a problem at this site. Yield of fixed N (Table 2) exceeded 100 kg ha^{-1} in *Vicia dasycarpa, V. narbonensis*, and pea in 1990/91, in *Lathyrus sativus* in 1991/92 and in *V. dasycarpa* in 1992/93. Yields of fixed N in general were higher in 1990/91 and 1992/93 than in 1991/92. The 1991/92 season was excessively wet (>860 mm rainfall) and cold (>72 frost days), which should have limited the symbiotic N fixation. The Ndff did not exceed 60% in 1990/91, 62% in 1991/92 and 76.7% in 1992/93. *Vicia dasycarpa, V. narbonensis*, and lentil tended to have higher % Ndff than other legumes. Relatively lower % Ndff at Terbol, in contrast to Tel Hadya, may be attributable to higher total soil N content in Terbol: it was 1018 ppm at Terbol as against 614 ppm at Tel Hadya.

Wheat yield following legumes (Fig. 1) was higher than the yield following wheat and was generally at par with the yield following fallow. In fact, the wheat yield following lentil was higher than wheat yield following fallow in all three years. Winter chickpea, pea, *Vicia narbonensis*, as preceding crops also resulted in average wheat yields being higher than those of the crop following fallow. Total N yield of wheat following legumes was generally higher than the yield following fallow. The results of N yield in wheat showed that winter chickpea, pea, faba bean, *Vicia dasycarpa* and *V. narbonensis* are good preceding crops under Terbol conditions.

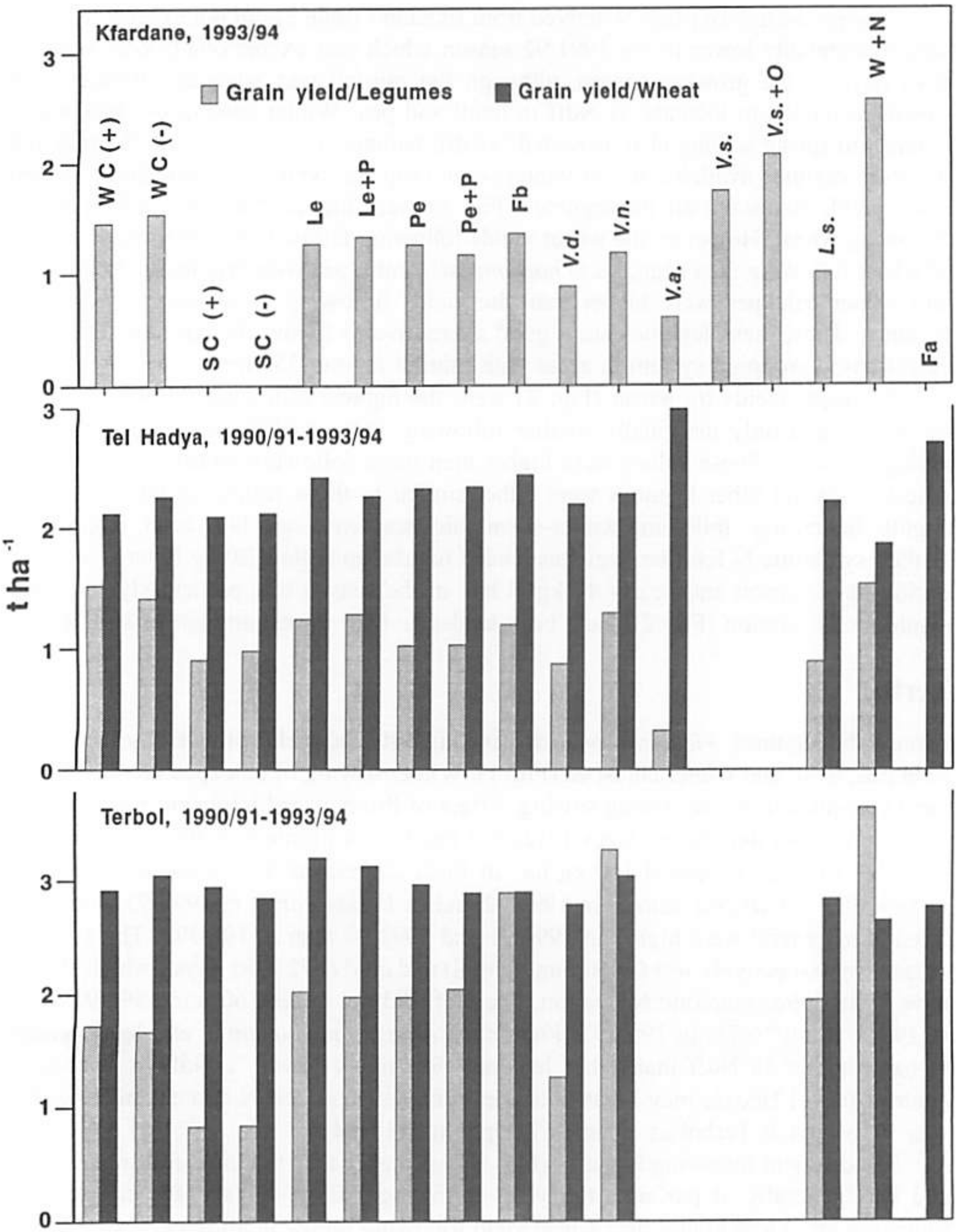

Fig. 1. Grain yield of legumes and wheat in the rotation at three stations.

(Notations: WC,SC+/-:winter and spring chickpea, with/without inocculation; Le=lentil; pe=pea Le+P or P=lentil/pea+Promet; Fb=faba bean; V.d.=*Vicia dasycarpa*; *V.n.*=*Vicia narbonensis*; *V.a.*=*Vicia amphicarpa*; *V.s.*=*Vicia sativa;* V.s.+O:*V.sativa* (1/3)+Oat (2/3); *L.s.*=*Lathyrus sativus*; Fa = fallow; W + N = wheat+nitrogen.

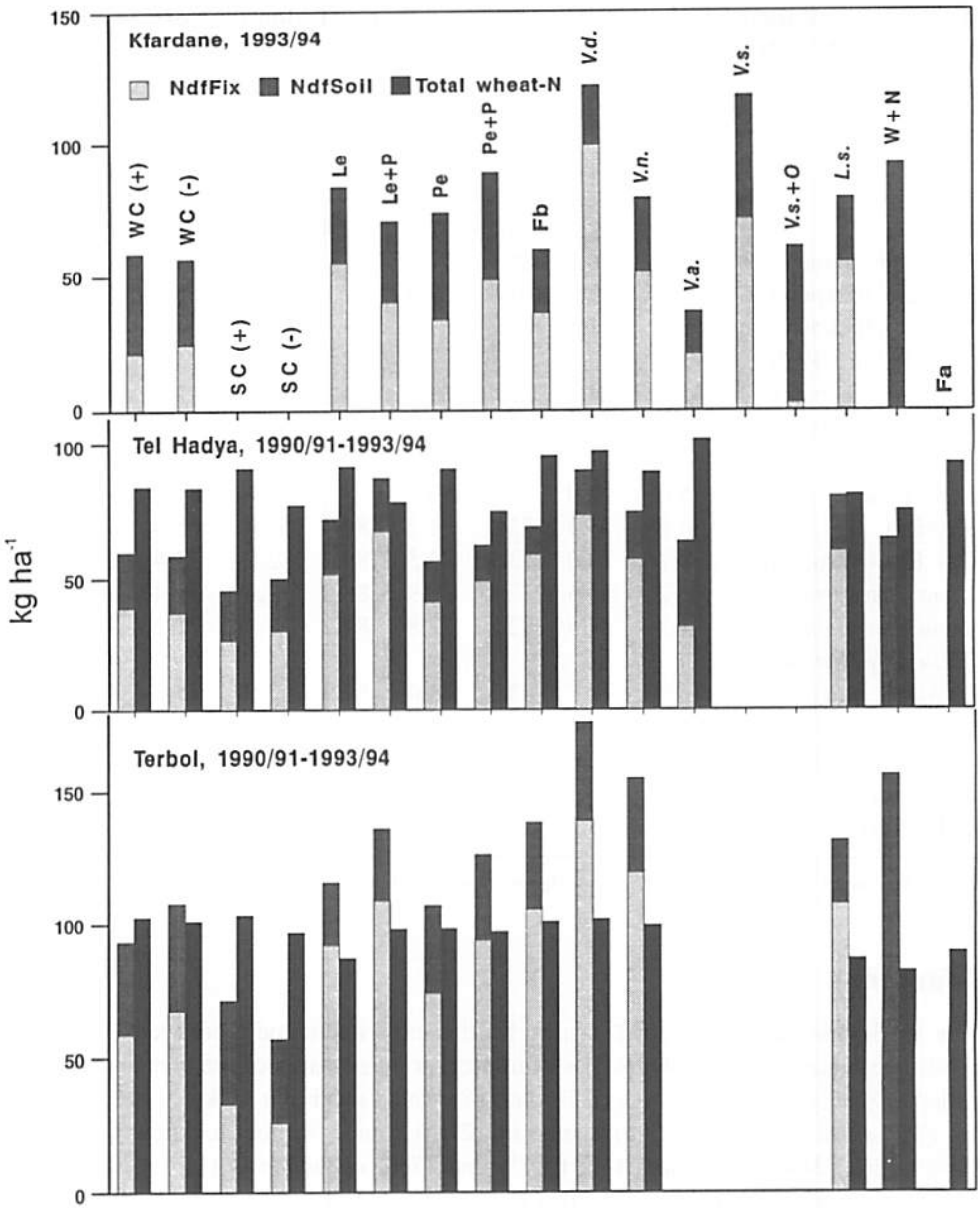

Fig. 2. Nitrogen derived from fixation by legumes, from soil and uptake by wheat in rotations at the stations. (For notations see Fig. 1.)

Table 2. Percentage of plant nitrogen derived from fixation (%Ndff) in different legumes at ICARDA stations.

Treatment[1]	90/91		91/92		92/93		93/94		
	TR	TH	TR	TH	TR	TH	TR	TH	KF
Lentil	72.5	72.5	81.2	72.4	82.4	62.7	78.2	81.0	65.8
Lentil (+Promet)	78.1	78.2	85.7	72.3	85.3	69.9	71.8	87.9	56.7
Winter Chickpea (-)	57.8	53.2	61.9	67.4	-	52.5	68.0	75.3	38.3
Winter Chickpea (+Strain CP-39)	56.5	71.8	68.2	67.4	-	43.6	64.3	74.0	35.9
Spring Chickpea (-)	55.6	64.2	32.1	63.7	-	50.2	-	66.1	-
Spring Chickpea (+CP-39)	51.1	59.8	35.3	70.8	-	40.8	-	61.3	-
Faba Bean	75.0	79.0	-	80.0	-	82.4	81.1	87.6	61.1
Dry Pea	66.5	75.3	73.0	71.3	84.4	59.4	65.0	81.6	46.5
Dry Pea (+Promet)	68.2	79.0	73.9	73.5	85.2	82.2	73.4	81.9	54.1
Vicia dasycarpa	71.2	81.5	77.4	72.9	88.0	72.4	79.4	88.8	80.8
Vicia narbonensis	71.2	74.5	82.2	72.8	87.7	77.4	71.2	83.5	64.5
Vicia amphicarpa	-	-	-	-	-	-	-	47.1	56.5
Lathyrus sativus	78.9	74.4	83.7	73.0	87.9	67.9	75.3	82.6	70.1
Vicia sativa (1/3) + Oat (2/3)	-	-	-	-	-	-	-	-	4.8
Vicia sativa	-	-	-	-	-	-	-	-	60.8
LSD (5%)	13.2	16.2	14.3	19.1	11.0	21.8	12.4	14.1	15.3

[1] and - for chickpea refer to with/without inoculation. Stations: TH= Tel Hadya; TR= Terbol; KF= Kfardane.

Kfardane

The 1993/94 season was the first season for this experiment and there were some crop rotation establishment problems. For example, spring-sown chickpea was damaged by rodents. Seed yield was highest (2.57 t ha^{-1}) in wheat receiving 40 kg N ha^{-1} followed by *Vicia sativa*, oat + *Vicia sativa* mixture (2.071 t ha^{-1}), winter chickpea (1.5 t ha^{-1}), faba bean (1.364 t ha^{-1}), peas (1.2 t ha^{-1}) and *Vicia narbonensis* (1.18 t ha^{-1}). *Vicia amphicarpa* gave the lowest seed yield (884 kg ha^{-1}). The data on %Ndff and on total biological N fixation show that forage legumes, in general, gave higher % Ndff than the grain legumes; *V. dasycarpa* gave the highest value for this parameter. This reflected in the highest yield of biologically fixed N by this legume at Kfardane.

Reference

Fried, M., and V. Middleboe. 1977. Measurement of amount of nitrogen fixed by a legume crop. Plant Soil 47: 713-715.

Field Estimates of Nitrogen-Use Efficiency by Irrigated and Rainfed Wheat in a Mediterranean-type Climate

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Abstract

The extreme variation in moisture and temperature on the typical Mediterranean farming conditions poses constraints for our understanding of nitrogen use by crops and its dynamics in the soil. In this field study, we used $^{15}NH_4(SO_4)_2$ to examine N fertilizer-use efficiency (NFUE) by wheat for two seasons with different total rainfall, i.e., 325 and 273 mm. In addition to natural rainfall, supplemental irrigation was also considered in assessing N behavior. In general, NFUE reached a maximum around anthesis (65-75%) and decreased during grain-filling period, particularly under rainfed conditions. Thus, while NFUE is highly dependent upon measurement date, values were higher by the *difference* method (28-95%) than by the *direct* method (21-63%). As no "priming" effect was apparent in either year, the discrepancy between the two methods was attributed to soil mineralization/immobilization turnover (MIT) process. A large proportion (>50%) of fertilizer N remained in the top 20-cm soil layer as organic N. No significant re-mineralization occurred. While NUE increases with higher rainfall and supplemental irrigation, N losses under Mediterranean conditions are minimal. Thus, the inefficiency induced by organic N immobilization adds to total soil N, which can potentially be used by future cropping.

Introduction

Water, nitrogen (N) fertilizer, and phosphorus (P) are costly inputs for crop productivity in arid and semi-arid areas of the world, and in the West Asia-North Africa (WANA) region. Efforts to improve N fertilizer-use efficiency hinge upon a thorough understanding of N dynamics of the soil-plant system in the field under diverse climatic and geographical situations. Fertilizer N response and rainfall (or irrigation) are closely related (Sharma et al., 1990); efficiency of N fertilizer use by the crop is dependent upon the amount of rainfall in the region (Harmsen et al., 1983). Specific information on the fate of fertilizer N applied to soils of this region is necessary to determine the complete economic benefit of N fertilizer by ensuring reasonable crop production and minimizing environmental pollution, particularly under irrigated conditions.

Nitrogen-fertilizer use efficiency (NFUE) by crops is calculated by *difference*, i.e., N uptake between crops in fertilized and unfertilized plots, and is based on the assumption that addition of fertilizer N does not affect the availability or uptake of the native soil N, and that crops use the same amount of soil N in fertilized and control plots (Powlson and Barraclough, 1993). Isotopic tracer methods are also used to directly determine NFUE. With fertilizer ^{15}N, it is possible to distinguish between N derived from enriched fertilizer and that from the soil pool. The *direct* method, based on ^{15}N-enriched N fertilizer and ^{15}N recovery by crops growing in fertilized plots, assumes that neither plants nor soil microbial populations discriminate between ^{15}N and ^{14}N and use both in proportion to their amounts present (Barraclough, 1991).

Estimates of NFUE based on ^{15}N uptake are usually lower than those calculated by the *difference* method (Harmsen and Moraghan, 1988). While the extent of such differences vary depending on the crop and experimental conditions, Westerman and Kurtz (1974) showed the overestimation to be 23 to 35% for sorghum (*Sorghum bicolor* L.) and Ayoub (1986) reported a 27% increase for wheat (*Triticum aestivum* L. subsp. *aestivum*). The most plausible explanation for the discrepancy between the two methods is that fertilizer N may increase N availability in fertilized soils, i.e., "*priming effect*" or stimulation of soil organic matter decomposition due to addition of N or fresh organic matter (Westerman and Kurtz, 1973). Another hypothesis is that ^{15}N added to the soil is immobilized by the mineralization-immobilization process (MIT) due to soil microbial activity, which may cause pool substitution between fertilizer and soil organic N, i.e., "*apparent added N interaction*" (Jenkinson et al., 1985). Thus, the process of pool substitution could explain the different values obtained by the two methods. Therefore, comparison of the two methods may give an indication of the dynamics of N (or the MIT) in this cropping system.

Under dryland conditions, NFUE at harvest ranges from 20 to 80% depending on fertilizer type, time and method of fertilizer application, soil type and climatic conditions (Abdel Monem, 1986; Malhi and Nyborg, 1992). Most NFUE studies using ^{15}N are presented as N-balance sheets at crop maturity or harvest, e.g., Syria (Abdel Monem, 1986), Sudan (Ayoub, 1986), and Morocco (Soltanpour et al., 1987). However, efficiency of N uptake by plants during the growing season is not well described for the WANA region. Thus, the aim of the ^{15}N labelled experiment described here was to measure yield and N uptake by rainfed and irrigated wheat throughout the season, to compare fertilizer N recovery under field conditions by the *difference* and *direct* methods. Soil mineral-N and organic N were also measured at several occasions to follow the different soil/fertilizer N dynamics and pathways.

Materials and Methods

The study was conducted at the ICARDA's Tel Hadya experimental station in northwest Syria, southwest of Aleppo over a 2-year period, i.e., 1991/92 and 1992/93 growing seasons. Wheat was planted after lentil (*Lens culinaris* Medik.) in Year 1, and after wheat in Year 2. The soil at the site is a deep (<1.5-2.0 m) clay, and is a fine montmorillonitic, thermic, Calcixerollic Xerochrept. The pH was about 8.0, while EC ranged from 0.5 to 0.6 mS cm^{-1} throughout the profile. The $CaCO_3$ content was about 20% in the surface layer and increased with depth to about 26% in the 100 to 120-cm layer. Total soil N ranged from 0.05% in the upper layer to 0.03% at about 1-m depth.

The climate is typical for the semi-arid Mediterranean winter rainfall area, with a long-term mean annual rainfall of 327 mm. In 1991/92 the seasonal rainfall (323 mm) was close to the long-term average; early season rain was relatively high with little or no rain in March and April. In the second year, rainfall (275 mm) was about 10% below the long-term average. Crops suffered from moisture stress during the long dry spell from mid-March to early May, when late rains brought relief just in time to save the harvest.

The 16 treatments comprised combinations of four irrigation regimes, or water levels, and four N application rates in a randomized complete block design with four replicates. During both years, supplemental irrigation was applied in April (heading) at three rates represented by the W notation: W3 represented the maximum amount of irrigation water to compensate for the total water consumption or evapotranspiration and reach 100% field capacity; W1 and W2 received 33 and 66% of the water added to W3; while W0 represented rainfed conditions alone. In 1991/92, the respective irrigations were given on 11 April (28.5, 56.9, 85.4 mm) and 6 May (26.4, 52.8, 79.2 mm), giving a total amount of water applied of 54.9 (W1), 109.7 (W2) and 164.6 mm (W3). In 1992/93, three irrigations were given, i.e., 12 April (27.3, 54.6, 82 mm), 26 April (25.3, 50.6, 76 mm), and 12 May (15, 30, 45 mm) giving a total of 67.6 (W1), 135.2 (W2), and 203 mm (W3).

Nitrogen was applied as $(NH_4)_2SO_4$ at 50, 100 and 150 kg N ha^{-1}. Micro-plots (2 x 1 m) were marked in the fertilized plots where $(^{15}NH_4)_2SO_4$ at 2.5, 2.0, and 1.0 atom % ^{15}N (for 50, 100 and 150 kg N ha^{-1} rates) was evenly distributed as solution by a washbottle. Phosphorus, which was deficient but not a variable, was applied as a basal dressing each season as a triple superphosphate at 40 kg P ha^{-1}. A local wheat cultivar (Cham 4) was sown at 120 kg ha^{-1} in 4 x 5 m plots and 20-cm rows (20 Nov., 1991; 8 Dec., 1992). The crop was harvested in the first week of June each year. All plant samples were dried 48 h in an oven at 68°C, ground, and then analyzed for total N and N isotope ratio.

Moisture-Nitrogen Monitoring

Within the main experiment, in some treatments (rainfed and full irrigated, zero N and 100 kg N ha^{-1}) with four replicates, soil moisture was measured by a Wallington neutron probe at 180-cm soil depth to monitor the profile water depletion and calculate the water needed for each irrigation. Plant samples were taken periodically from three 70-cm rows at 15-day intervals during the two seasons. At harvest, three 3-m rows were cut to root level, and grain and straw were separated by hand with yields of both recorded and analyzed as above. Soil samples were taken four times each season to monitor N dynamics in selected treatments. Nitrogen concentrations were calculated on an area basis by multiplying %N by the soil mass in the respective layers.

Analyses

In duplicate soil samples, inorganic N was determined in 150 ml of 2 *M* KCl (NH_4^+) and of deionized water (NO_3^-) per 30 g of fresh soil after shaking for 1 h. Both $^{15}NH_4$-N and $^{15}NO_3$-N in these extracts were separated with MgO or Devarda's alloy (Buresh et al., 1982). The ammonia was trapped in 0.01 *N* H_2SO_4 and the solution evaporated to dryness in glass vials. The $^{15}N/^{14}N$ ratio analysis and total N (expressed on an oven-dry basis at 105°C) were determined by a CN-Roboprep mass spectrometer. Also, total soil and plant-N were measured by the Kjeldahl digestion (Buresh et al., 1982).

Interpretation of Total N and ^{15}N Data

The proportion of N derived from fertilizer (%Ndff) was calculated as follows: atom %^{15}N in sample/atom %^{15}N in fertilizer, multiplied by 100. The resulting percentage was multiplied by the total N quantity found in the N pool (soil or plant) to get a value for Ndff (kg ha^{-1}). Percent N fertilizer-use efficiency was calculated as follows: *difference* method [N uptake (kg ha^{-1}) in fertilized plots - N uptake (kg ha^{-1}) in control plots]/[applied N (kg ha^{-1})] x 100, and *direct* method [atom % excess ^{15}N in crop x total N uptake in fertilized plots (kg ha^{-1})]/[atom % excess ^{15}N in fertilizer x applied N (kg ha^{-1})] x 100.

Results

Dry Matter Production and Grain Yield

During both years, dry matter and grain yield production naturally increased with N fertilization, since land used for the two experiments were low in available N. Also, during both years, yield production was increased by supplemental irrigation; this was more emphasized in the second (dry) year (Fig. 1). In Year 1, total dry matter (12.5 t ha^{-1}) with the highest N fertilizer rate (150 kg N ha^{-1}) was 59% greater than that of unfertilized treatment averaged over all irrigation levels. This increase corresponded to 46% in the second year. Similarly, average total dry matter for the highest irrigation level in the first season (12.4 t ha^{-1}) was 43% greater than that of rainfed treatment compared with more than 97% in the second season, indicating a higher response to N in the first year (wet) than in the second year. By contrast, total dry matter response to irrigation was larger in the Year 2 (dry) than in Year 1. Also, the proportion of grain *yield* to total dry matter (harvest index, HI) was more effected by irrigation during the second year, when a large increase in HI was observed under the low irrigation level, while a negative effect of N fertilization was obvious under the rainfed conditions.

Seasonal Assessment of Nitrogen Fertilizer Use Efficiency

Measurement of NFUE varied with the method, i.e., *direct or difference*, and varied with the season (Fig. 2). However, differences due to irrigation were only evident in the drier year (1992/93). Irrespective of the year, values from the *difference* method exceeded those of the *direct* method by about 30%. During the two growing seasons, N uptake was low at early growth period (February and early March) because of the low crop N demand. Values reached a maximum in late April after a period of rapid

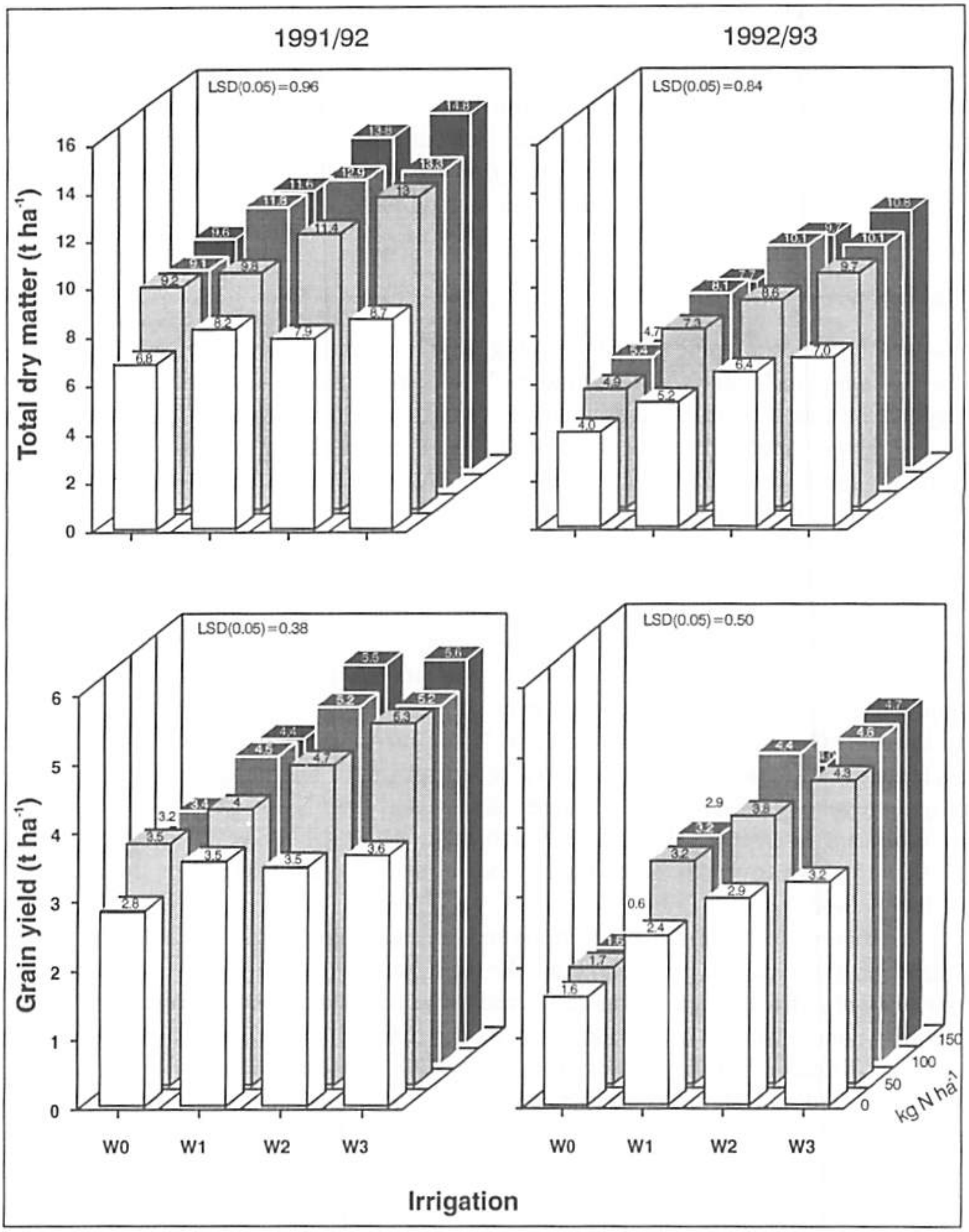

Fig. 1. Total dry matter and grain yield in the two years.
(W0 = W3 Irrigation treatments, see text.)

growth in March-early April, but either stabilized or declined after that time depending on the method of NFUE assessment. A noteworthy feature was that NFUE reached a maximum long before harvest in both years. This was followed by a significant decrease in NFUE values in rainfed and irrigated treatments in the first year and only in rainfed treatments in the second year. For both years, applying the first irrigation treatment did not increase NFUE by the *difference* method, but it did show a significant increase in the second year (by the *direct* method only).

Final Harvest

Values for NFUE obtained at harvest (Fig. 3) corroborate those of Figure 2, showing the full range of N and water treatments. While application of irrigation water and N application rate tended to increase NFUE values by the *direct* method, the trend with the *difference* method was less obvious. These inconsistency can be attributed to variation in the control values. The efficiency of fertilizer N in Year 1 ranged from 41 to 95% by the *difference* method compared with 31 and 58% by the *direct* method, and Year 2 it was 42 to 60%, and 21 to 63%, respectively.

The variation of NFUE values was high with the *difference* method (Fig. 3), where the CV was 24 and 30% for the Years 1 and 2, respectively, compared with 11 and 17% for the *direct* method. The *difference* method showed no clear pattern in the first year, while in the second year %NFUE was increased significantly (P=0.05), by applying the first and the second level of irrigation, compared with the rainfed treatment. On the other hand, in Year 1, the *direct* method showed a significant increase in NFUE values with increased N fertilizer rates with a moderate increase by irrigation; while in Year 2, NFUE values increased by both N and irrigation levels, with a significant interaction (P=0.05) between them. During both years the variation in NFUE was high (over 20%) for the *difference* method, which questions the accuracy of the method.

Soil N recovery of mineral N in the soil, as measured at different sampling times, was inversely related to growth and uptake (data not shown). At the end of the season, only 20-30% of the added N was recovered in the soil under rainfed conditions, while virtually none remained from addition of 100 kg N ha^{-1} in the irrigated plots. However, seasonal differences were evident; in the drier 1992/93 season most of the mineral N was recovered as NH_4^+ in contrast to the wetter 1991/92, where both NH_4^+ and NO_3^- occurred in equal amounts. Therefore, nitrification was speeded up by more favorable moisture conditions. Also fertilizer recovered in the soil after harvest as total ^{15}N was 56 and 43% for rainfed and irrigated treatments in Year 1 compared with 73 and 53% in Year 2. In both years, over 80% of the recovered fertilizer was found in the top 20-cm soil layer.

Discussion

Nitrogen fertilizer-use efficiency measurements showed that, generally, the values measured at harvest, as done in many previous ^{15}N studies, underestimate the potential

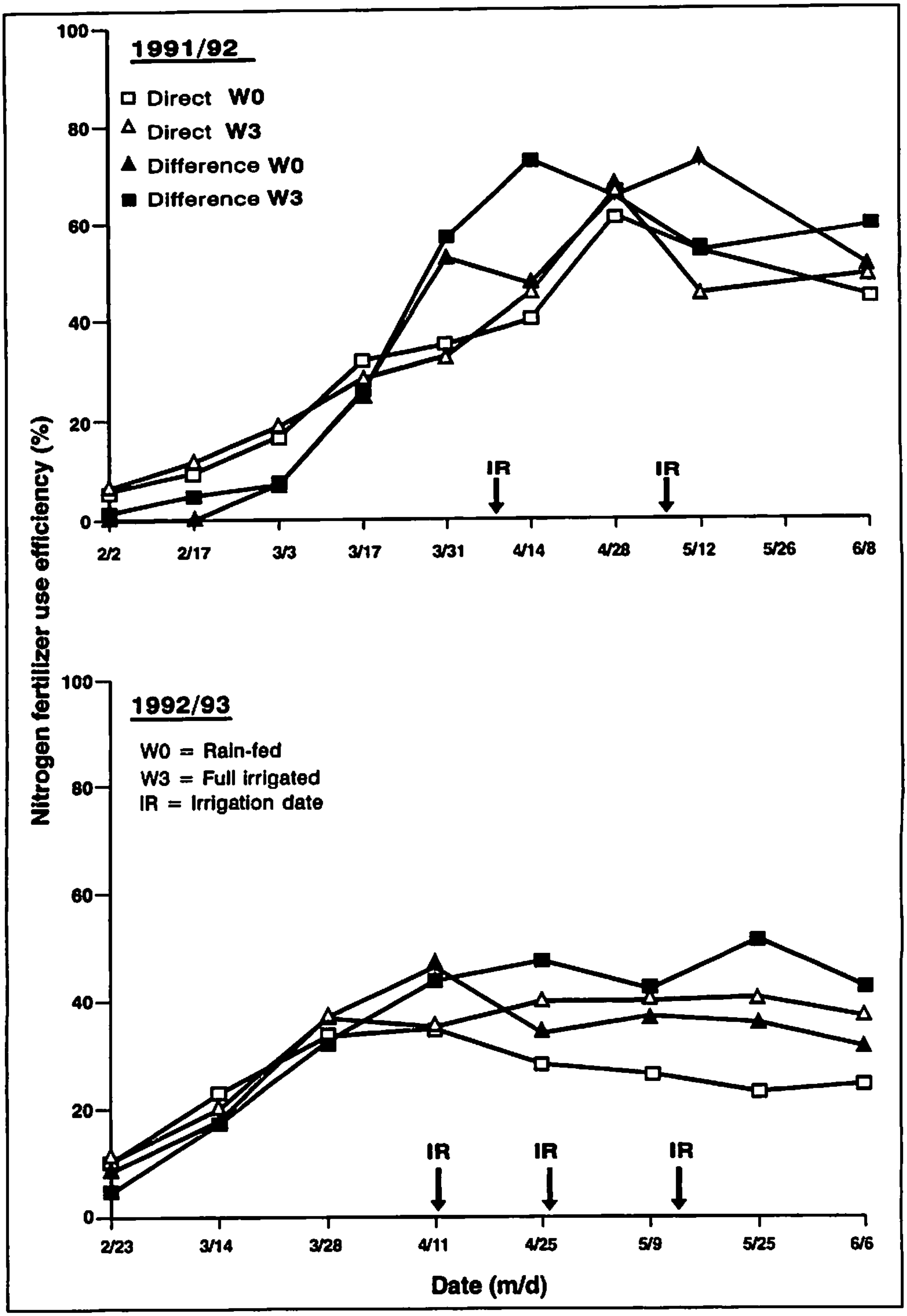

Fig. 2. Nitrogen fertilizer-use efficiency (100 kg/ha rate) by the direct and difference methods at different plant sampling dates for two seasons.

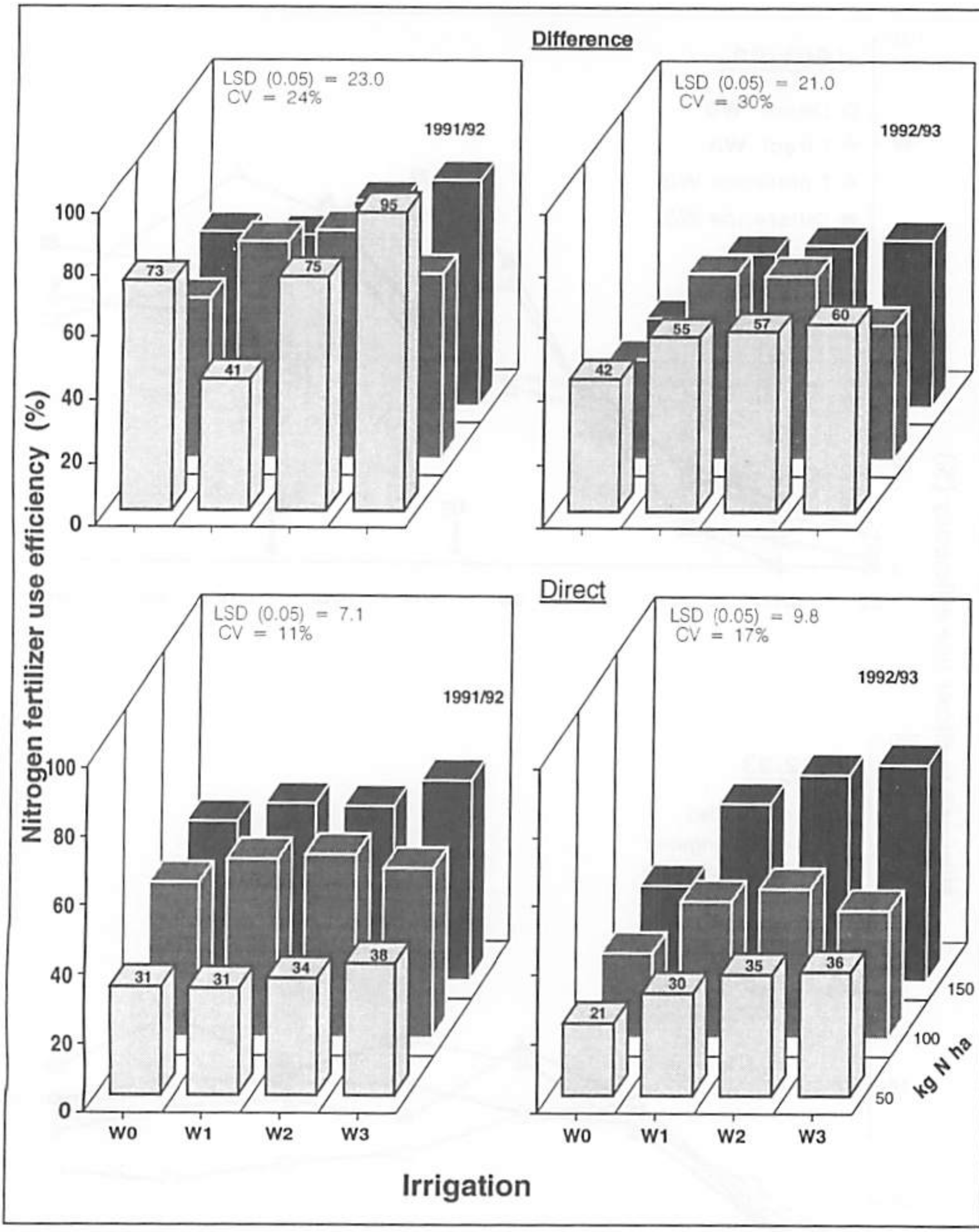

Fig. 3. Nitrogen fertilizer-use efficiency by the *Difference* and *Direct* methods for two seasons.
(W0- W3 = irrigation treatments, see text.)

of fertilizer N uptake efficiency, since, in each year under rainfed conditions, this value was higher before heading time than at harvest. This indicates that the plant must not be considered as a complete accumulative sink for N and that appreciable amounts of N can be lost after heading either by dead leaves or gaseous losses from tops of plants (Mary et al., 1987). Thus, NFUE values recorded are highly dependent on the time or the growth stage selected for evaluation of fertilizer recovery. However, supplemental irrigation, particularly in a dry year, can reduce the decline in NFUE after it has reached a peak, by extending the life of the green leaves and preventing foliage decay.

As reported in literature, NFUE values from the *difference* method were generally higher than for the *direct* method, except at the early growth period (Harmsen and Moraghan, 1988). This is because during early growth, the quantities of inorganic $^{15}NH_4^+$-N in the upper soil layer are large compared with the amount of unlabelled inorganic N in the soil. This may be used by the crop without discrimination between ^{15}N and ^{14}N resulting in a higher NFUE values by the *direct* method than by the *difference* method at a time when crop response to N fertilization becomes low and negligible.

Thus, when available soil N is sufficient to meet the crop's N requirement (i.e., at early growth stages), the *difference* method will underestimate the NFUE (Varvel and Peterson, 1991). In later stages, with increased air temperature and fast plant growth, MIT can play important role in underestimating the NFUE values by the *direct* method as compared with the *difference* method. This agreed with what was illustrated by Harmsen (1986). In the first year, little N was taken up by the crop after applying the first irrigation in April. This was reflected in a negligible increase in NFUE values afterwards, since the low soil N content coincided with high plant N demand.

To identify whether the lower NFUE values obtained in this study by the *direct* method were due to ANI or to MIT, the net soil mineralization of the total soil N was calculated in the selected treatments according to Hart et al. (1986) and Rao et al. (1992) and presented in Table 1. Here, unaccounted for fertilizer-N from the N balance sheet (not shown) was used as the N-loss and the amount of N added through irrigation was calculated as 11.9 and 11.2 kg ha^{-1} for Years 1 and 2, respectively. On average, about 17 kg ha^{-1} more soil N was used by wheat in Year 1 than in Year 2. This was possibly due to either more N mineralized during the first year or to the limited soil volume explored by roots in the second year. Also, more soil N was used by plants in fertilized plots than in unfertilized plots. The latter was not statistically significant (the value was even negative) in Year 3. Therefore, it is concluded that there was no ANI in either year and that MIT was responsible for the discrepancy between the two methods, with the immobilization process being dominant over mineralization.

Furthermore, in this study, increases in soil N uptake in fertilized plots appeared to be related to increases in plant growth, which might have resulted in increased soil N uptake than in unfertilized plots. The correlation between grain yield and soil N uptake (NDFS) gave an "r" value of 0.97 and 0.96 in the first and the second year, respectively (Table 1), suggesting that the increased soil N use in fertilized plots occurred because of a larger root system rather than a "priming effect".

Table 1. Nitrogen source used by wheat at harvest and net N mineralized.

Year	Treatment	Grain Yield	Total N Uptake	N Derived From: Fertilizer	Soil	Net N Mineralized[1]
		kg ha^{-1}				
1991/92	Rainfed	2800	55.1		55.1	36.0
	Rainfed, 100 kg N ha^{-1}	3200	106.0	44.8	61.2	15.2
	Irrigated	3600	66.4		66.4	30.3
	Irrigated, 100 kg N ha^{-1}	5200	125.5	49.1	76.4	-2.0
LSD (0.05) N x W			13.3		11.4	22.6
1992/93	Rainfed	1560	34.9		34.9	-6.5
	Rainfed, 100 kg N ha^{-1}	1650	66.3	24.5	41.8	-22.0
	Irrigated	3200	55.4		55.4	-0.3
	Irrigated, 100 kg N ha^{-1}	4630	98.1	37.1	61.0	-42.0
LSD (0.05) N x W			12.2		11.4	16.9

[1] Net N-mineralized = [TNU + soil inorganic-N at harvest + N-loss] - [initial soil inorganic N + N fertilizer applied + addition through rain or irrigation].

The *direct* method would correctly estimate the NFUE if the difference between the two methods was due to increased mineralization in fertilized plots, but not if MIT caused the difference (Jansson, 1971). Therefore, the *difference* method would be appear to be a suitable method for measuring the NFUE (Rao et al., 1992). This is acceptable only if suitable control plots are used. In this context, it is essential to establish homogeneous plots within replicates, with experimental plots large enough for accurate sampling that reflects the average yield per plot. This may help in getting a better CV for NFUE values by the *difference* method and thus would be an acceptable measurement method for NFUE. This can be supported by the fact that, compared with other studies, the difference between the two methods was not very large in any year (20 and 10% in Year 1 and 2, respectively).

In this study, the process of MIT was immobilization-driven, and considerable amounts (75%) of residual fertilizer were left in the soil at harvest. Part of this fertilizer N was probably present in the crop root system, but this would probably not exceed 5-10% of the amount of N in the above-ground parts of the crop. The high amount of immobilization of $^{15}(NH_4)_2SO_4$ fertilizer seen in both years could be attributed to a higher population of heterotrophic organisms and the presence of readily-soluble C source for microbial activity. The Tel Hadya soil is generally low in organic carbon (C:N ratio was 11.6 and 9.2 in the two season, respectively). With increased dry matter production and increased root development, the amount of decomposable organic C in soils, particularly in the rhizosphere, is likely to increase. Therefore, the total amount of N immobilized in the growing season is likely to increase with increased N, not primarily because of increased N availability, but rather as a result of increased availability of organic carbon in the system. The higher N immobilized and the lower net N mineralized calculated in the fertilized plots of this study confirmed this. However, the rotation system used in the cropping conditions of this study can have a significant influence on the rate of mineralization. For example, this study showed relatively higher net N mineralized under a lentil crop than under a wheat crop.

Fixation of NH_4^+-N by certain clay minerals (e.g., montmorillonite) could occur in Tel Hadya, but may not explain the difference observed between the two methods. Low amounts of fixed-^{15}N were found in the same site and for the same type of fertilizer N (<10%). Therefore, data in this study support the hypothesis that a significant portion of residual fertilizer N was immobilized in the organic fraction of the soil and that the occurrence of MIT in the soil could explain the discrepancy between the two methods, as discussed by Jansson and Persson (1982).

Conclusion

To summarize, this study indicated that the method by which NFUE is calculated can have considerable effect on its rating. The MIT process and the ANI can cause significant uncertainty when N efficiency is measured by the *difference* or the *direct* method. In the *difference* method, this is due to ANI between the soil and fertilizer N. In the *direct* method, it is due to the biological exchange between soil and fertilizer N due to MIT. However, as ANI was not involved in this study, it is concluded that, under the environmental conditions of this study, MIT was the dominant process that controled the N dynamics in the soil plant system. In this context, studies using ^{15}N-labelled fertilizer can define exactly the amount of fertilizer N in the plant and the soil, and particularly, what is lost from the system. Management practices, i.e., supplemental irrigation, that ensure maximum N fertilizer uptake and prevent the subsequent loss would be desirable action with respect to improved NFUE.

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Laboratory Assessment of Nitrogen Mineralization in a Wheat-Based Rotation Trial

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Abstract

The extent to which organic matter is mineralized during the growing season has a major impact on the extent of crop response to fertilization, especially with nitrogen. In long-term trials at Tel Hadya, organic matter and total soil N levels have gradually been influenced by rotations and soil management. In this laboratory study of factors associated with N mineralization, maximum mineral N was produced by incubation at around field capacity at 24 to 30°C. Wetting and drying also increased mineralization. Maximum N mineralization occurred in soil from *Medicago* plots and least for lentil. This study provides the basis for examining mineralization *in situ* in these rotation trials. This should add to our overall understanding of the dynamics of soil N in Mediterranean regions.

Introduction

Effects of long-term rotation trials on yields, nutrient cycling and soil processes have been studied under temperate climates. Normally, yields decrease with continuous cereals while increases occur with addition of farmyard manure or the incorporation of green manure, whether forage legumes or grass (Dyke et al., 1976). In continuous barley, organic amendments, added at a rate of 3 t ha^{-1} of carbon, trebled the organic matter content over 125 years (Jenkinson, 1988). On the whole, the importance of ley or grassland in maintaining and increasing the soil organic matter has been demonstrated (Russell, 1977).

Similar trials are rare in semi-arid conditions and are generally more recent, as in the case of a rotation experiment started in 1983/84 at Tel Hadya, ICARDA's main research station southwest of Aleppo. It is a wheat-based, two-course rotation with seven crop sequences: two grain legumes (chickpea, lentil), two pasture/forage legumes (vetch, medic) in addition to a fallow, a summer crop (watermelon) and, of course, continuous wheat. Further treatments including four N fertilizer levels and three levels of stubble grazing (zero, low and high) were added in the wheat phase in 1985/86. Following three cycles of rotation only, there was evidence of a difference in the organic matter and total N contents between one of the pasture legumes (medic) and the other sequences (Matar and Harris, 1990). After seven years of the trial, some differences in the organic matter contents had developed, the lowest values being associated with wheat, fallow and summer crop sequences (Ryan et al., 1992).

Under the climatic conditions around Aleppo, there were variations in yields between seasons due to the environmental conditions, particularly the rainfall. Little early rainfall delayed germination to January in one season; whereas in other years little effective rainfall during flowering and seed-setting resulted in low yields. It is evident that nutrient build-up, cycling and supply are complex and largely influenced by environmental factors. Therefore, this study aimed at an evaluation of N mineralized from soils of the seven sequences under controlled temperature and moisture conditions. It also involved the determination of the optimum environmental conditions for N release.

Materials and Methods

Soil Properties

The experimental site is located in Tel Hadya, ICARDA's main research station (36° 01' N, 36° 56' E, elevation 284 m), about 35 km southwest of Aleppo. It has a mean annual rainfall of 327 mm. The soil at Tel Hadya is mainly classified as a thermic Calcixerollic Xerochrept. Parent material is alluvium/colluvium deposited on weathered limestone. The soil profile is generally deep, over 2 m. Between 0 and 20 cm depth, it is characterized by a pH 8.0; EC, 0.56 mS cm^{-1}; Olsen-P, 5.0 ppm; $CaCO_3$, 24.6%. Its texture is 65% clay, mainly montmorillonitic, and 32% silt (Garabet, 1995). Because of the swelling/shrinking capacity of this soil, bulk density throughout the profile changes with the occurrence of dry and wet periods in the season. Field capacity is 42% moisture content and the permanent wilting point is at about 26% moisture content.

Incubation Experiments

Soils were taken from seven plots of a wheat-based two-course rotation which were in the "legume phase" (lentil, summer crop, vetch, fallow, chickpea, wheat and medic). For this purpose, plots receiving no additional treatment, neither fertilized nor stubble-grazed, were selected. Each soil sample was a composite of three sub-samples taken between 0 and 20 cm depth.

Nitrogen Mineralization at Three Temperatures

For this experiment, 20 g air-dried soil were mixed with 40 g silica sand, previously cleaned by distilled water, and dried. The mixture was transferred into a 60-ml plastic syringe that served as a leaching tube. At the beginning 25 ml dilute solution (1 m*M* $CaCl_2$, 1 m*M* $MgSO_4$, 1 m*M* KH_2PO_4) was added to each sample. Tubes were incubated at three different temperatures, i.e., 8°C ± 2°, 24°C ± 2°, and 30°C ± 2°.

Mineralized N was recovered from the tubes on a weekly basis over an incubation period of 6 weeks, by leaching with 75 ml dilute nutrient solution in increments of 25 ml. After leaching, the moisture content was adjusted by applying suction (0.25 bar metric suction) for a standardized length of time. Leachates were analyzed for nitrate-N, nitrite-N, and ammonium-N. All treatments were done in duplicate.

Nitrogen Mineralization at Different Moisture Levels

Samples of 50 g soil from the seven crop sequences were put in glass petri dishes. Moisture contents were brought to 25%, 50%, 75%, 100% and 150% of field capacity. Samples were incubated at 30°C for 14 days after which time they were analyzed for mineralized N fractions as described above. Treatments were run in duplicate with a one-week interval between them.

Nitrogen Mineralization in Wetting-Drying Cycles

Samples of 50 g soil from the seven rotations were put in glass petri dishes. Two series of seven were started, but were separated by one week. The samples were moistened to 100% of field capacity, then submitted to 6 successive cycles of wetting and drying at 24°C. Each 4-day cycle consisted of covering the petri dishes for 2 days and removing the cover for the 2 remaining days. Sampling for the determination of N was done at day 5. For both experiments, extraction was done by adding 100 ml 2 *M* KCl solution to 20 g soil followed by shaking for 1 hour at 200-300 rpm, and then filtering.

Nitrogen Determination

The N fractions were determined by steam distillation using heavy magnesium oxide for ammonium and Devarda's alloy (50 Cu : 5 Al : 5 Zn) for nitrate and nitrite . The distillate was collected in saturated boric acid and titrated to pH 5 with dilute sulfuric acid (0.01 *N*). Statistical analyses involved the analysis of variance, slopes comparison, and the Krushkal-Wallis test or analysis of variance by ranks.

Results and Discussion

Nitrogen mineralized varied between treatments and temperatures. At 8°C most crop sequences had a small flush of mineralization by Week 1, while at 24°C and 30°C there was a net peak at Week 3 (Fig. 1). The small flush of the first week has been found in air-dried soils after re-wetting, hence the suggestion of some workers to consider the first week as a pre-incubation period (Christensen, 1987).

Cumulative mineral N by the end of 6 weeks' incubation varied among samples (Fig. 2). Temperature had a significant effect as was also evident in the comparison of the slopes of the linear relationships between the square root of time and cumulative N. Higher rates of mineralization were found in the medic sequence at all three

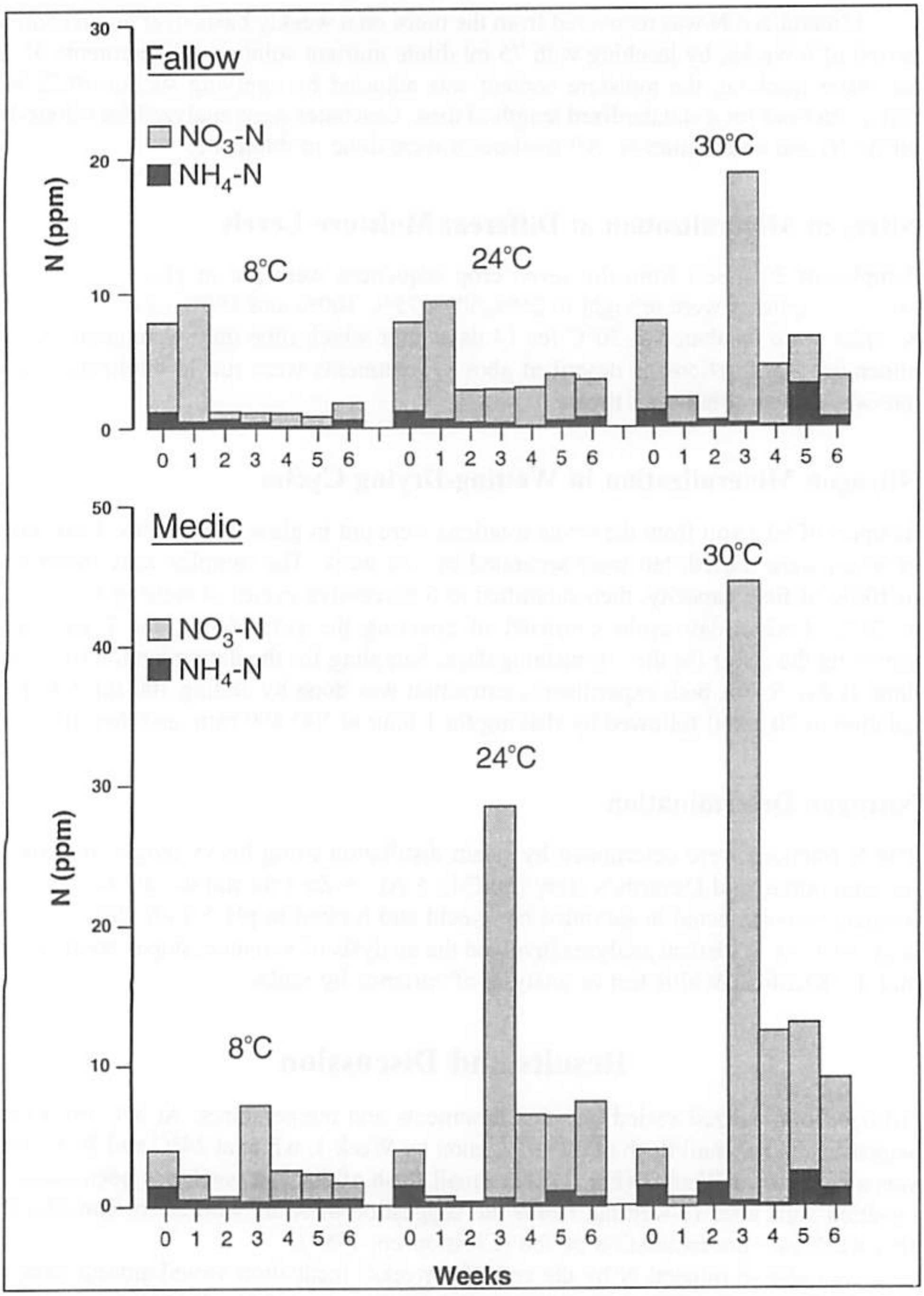

Fig. 1. Mineral nitrogen in soils from fallow and medic crop sequences incubated at three temperatures.

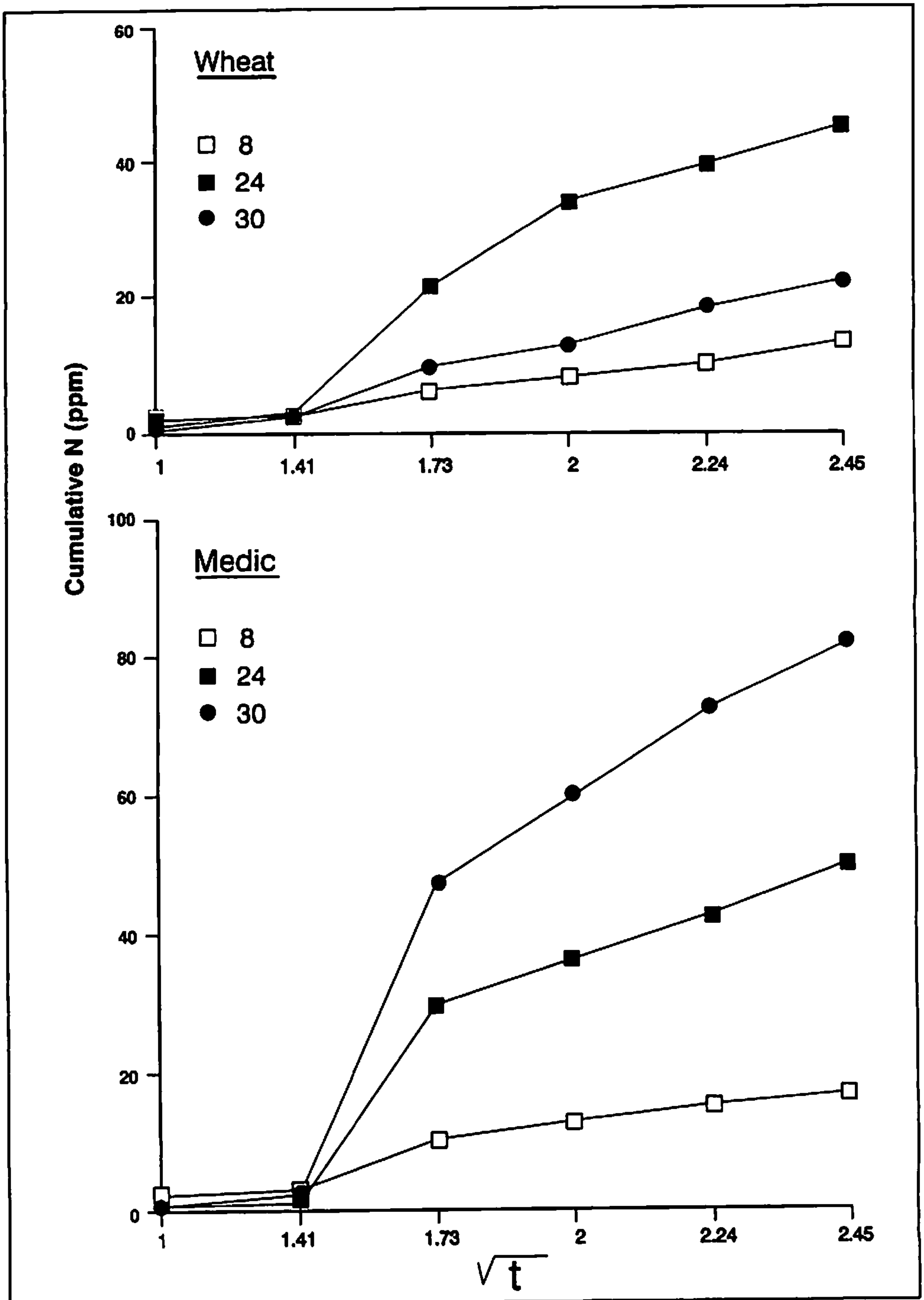

Fig. 2. Cumulative mineral nitrogen mineralized in soils from two rotations incubated at three temperatures.

temperatures. Vetch and chickpea occupied an intermediate position, while the smallest rates were for summer crop, fallow and lentil (Fig. 3). Wheat showed high rates at 8°C and 24°C, similar to the medic, whereas it dropped at 30°C giving decreasing values. Between 24 and 30°C, slopes almost doubled for vetch, summer crop, fallow and medic but not for lentil which showed a small increase (Table 1). This could not be related to either the organic carbon or the total N contents.

Table 1. Slopes of the linear relationship between the square root of incubation time and mineralization potentials from treated soils.

Treatment	Slope			R			Mineralization Potential		
	8°C	24°C	30°C	8°C	24°C	30°C	8°C	24°C	30°C
Lentil	4.67^{b}	10.71^{ab}	12.52^{abd}	0.98	0.96	0.93	30.4	69.6	81.34
Summer Crop	2.64^{a}	8.59^{a}	16.23^{ab}	0.97	0.97	0.97	17.2	55.8	105.5
Vetch	4.72^{b}	14.03^{b}	30.64^{cde}	0.97	0.98	0.92	30.7	91.2	199.2
Fallow	3.32^{ab}	9.01^{a}	21.93^{a}	0.98	0.98	0.97	21.6	58.6	142.5
Chickpea	5.03^{bc}	21.62^{c}	29.64^{c}	0.97	0.97	0.97	32.7	140.5	192.7
Wheat	6.52^{cd}	28.24^{cd}	13.01^{ad}	0.97	0.97	0.98	42.4	183.6	84.6
Medic	9.27^{de}	31.4^{d}	52.32^{e}	0.97	0.96	0.97	60.3	204.1	340.1

Slopes followed by the same letter are not significantly different for any one temperature.

From the linear relationship between cumulative mineral N and time ($t^{1/2}$), mineralization potentials for shorter incubation periods were found as follows: slope x 6.5 (Stanford et al., 1974). This assumes that as time increases the amount of N mineralized approaches of an asymptotic value. In fact, it implies an eventual exhaustion of the mineralizable pool of soil N, which does not in fact occur (Broadbent, 1986).

Successive cycles of wetting and drying for 4 days led to higher mineralization compared with the incubation at the same temperature under constant moisture levels (Fig. 4). This difference was most pronounced for four of the six cycles. By Week 3 at constant moisture, due to the peak of N release, cumulative levels were similar . This could also be associated with the decrease of organic compounds and dead microorganisms. Overall, the variations in mineral N followed a similar pattern to the soil moisture (Fig. 5). In field conditions, intermittent rain would cause a comparable release of N; this burst would last as long as the easily degradable carbon compounds persisted.

Incubation at five moisture contents, corresponding to five levels of field capacity generated different quantities of mineral N. For the six moisture treatments, the optimum level was at 100% of field capacity and was higher for the vetch than for the lentil rotation (Fig. 6). In the case of fallow and wheat crop sequences, the comparison of means indicated significant differences between 75% moisture content and 100%, whereas the two higher values, 100 and 150% presented no differences, due possibly to the negative effects of saturation at 150%. Lentil treatment was, once more, an exception, as the optimum was at 150%.

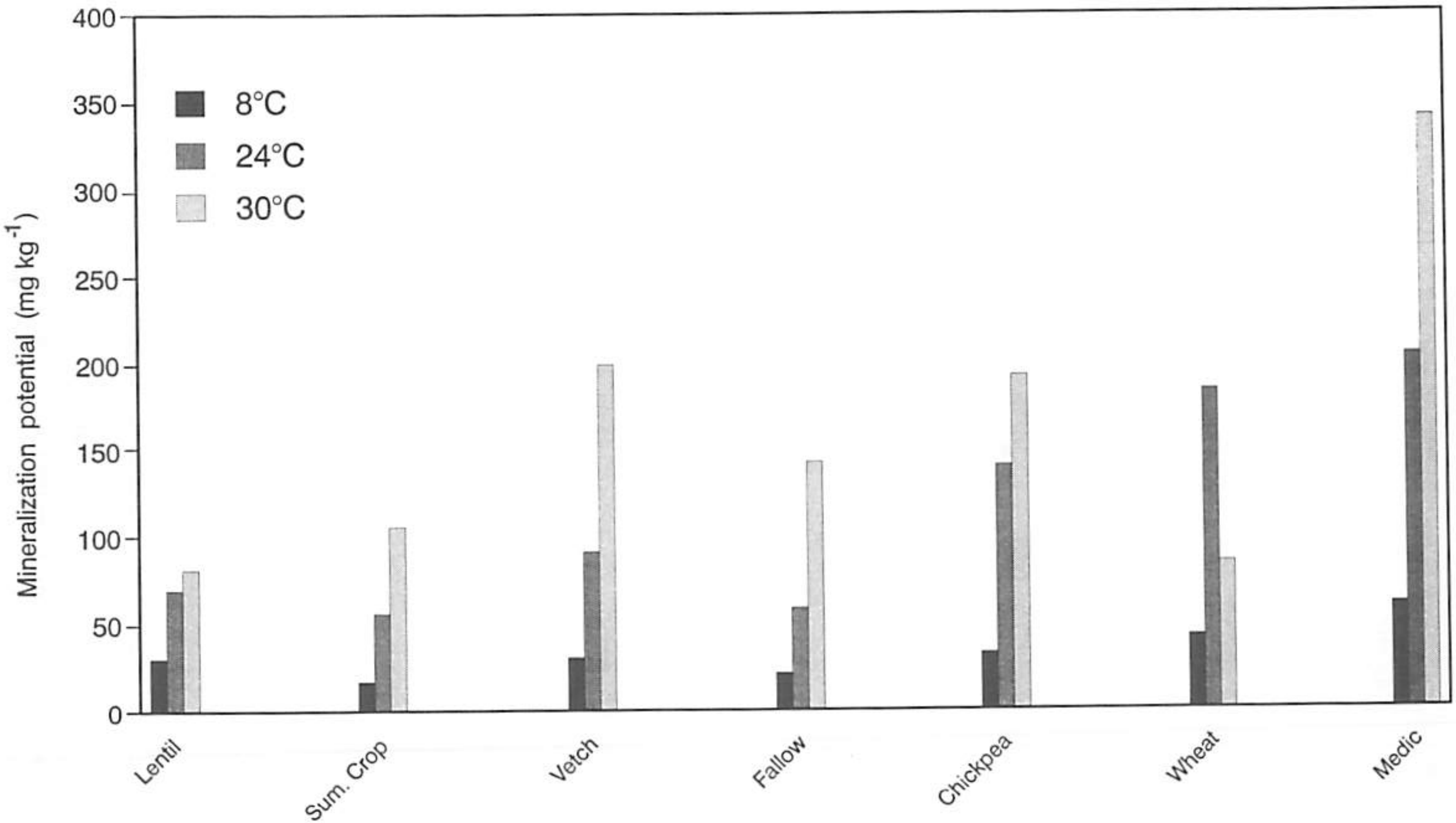

Fig. 3. Nitrogen mineralization potentials of soils from seven crop sequences in a two-course rotation at three temperatures.

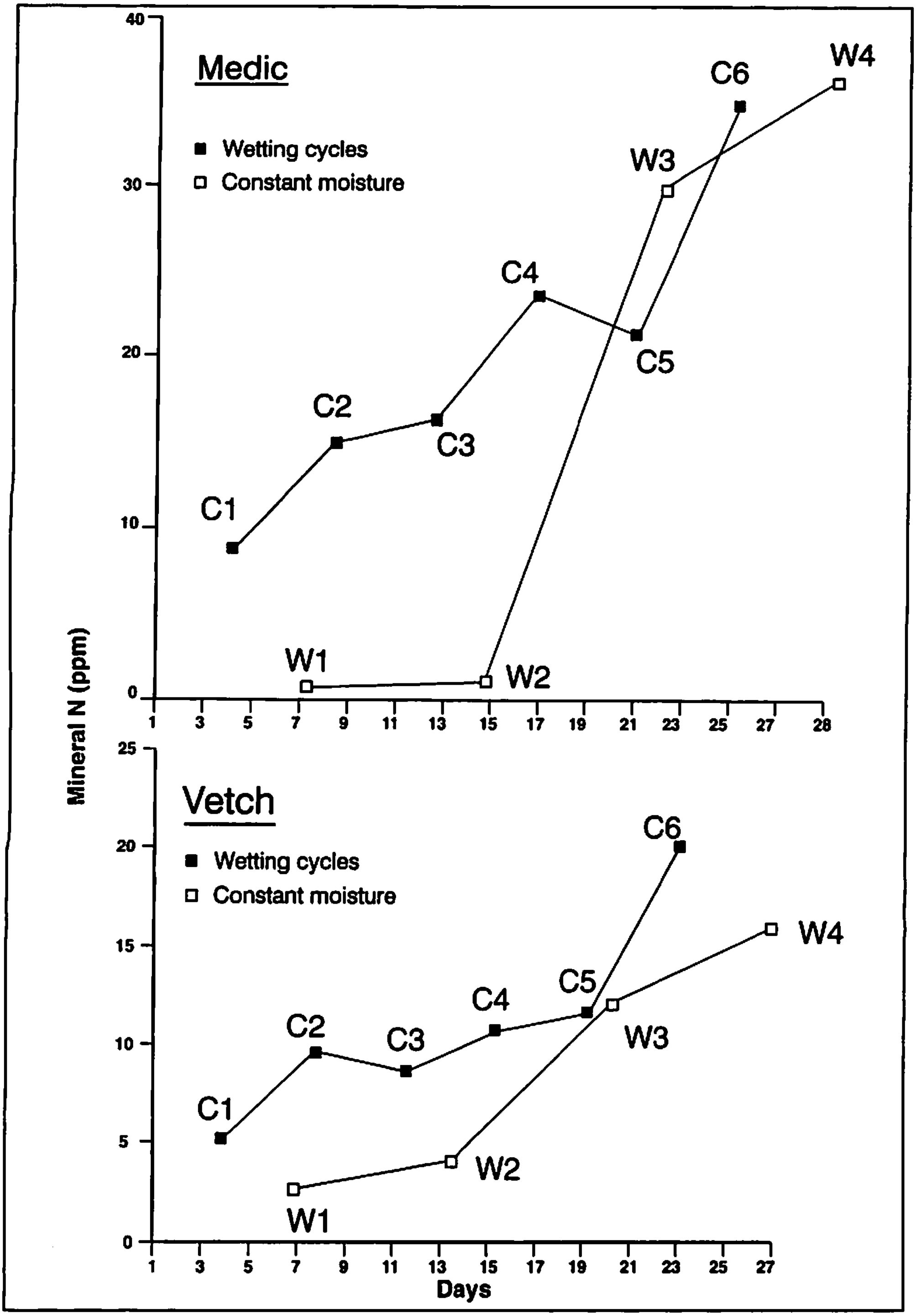

Fig. 4. Cumulative nitrogen mineralized from soils of vetch and medic crop sequences with six cycles of wetting and drying and 4 weeks incubation at 24°C with constant moisture.

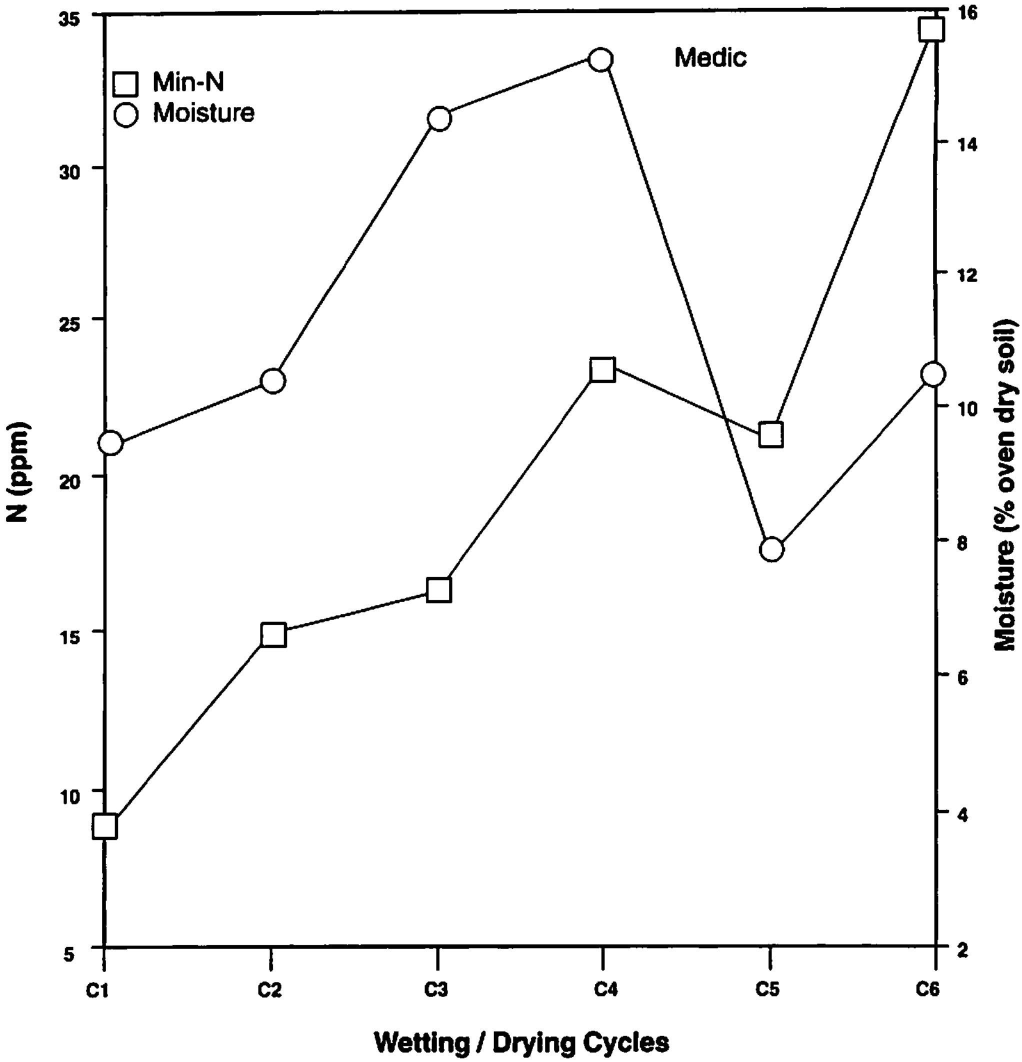

Fig. 5. Nitrogen mineralization and moisture levels in soil from medic crop sequence under six cycles of wetting and drying.

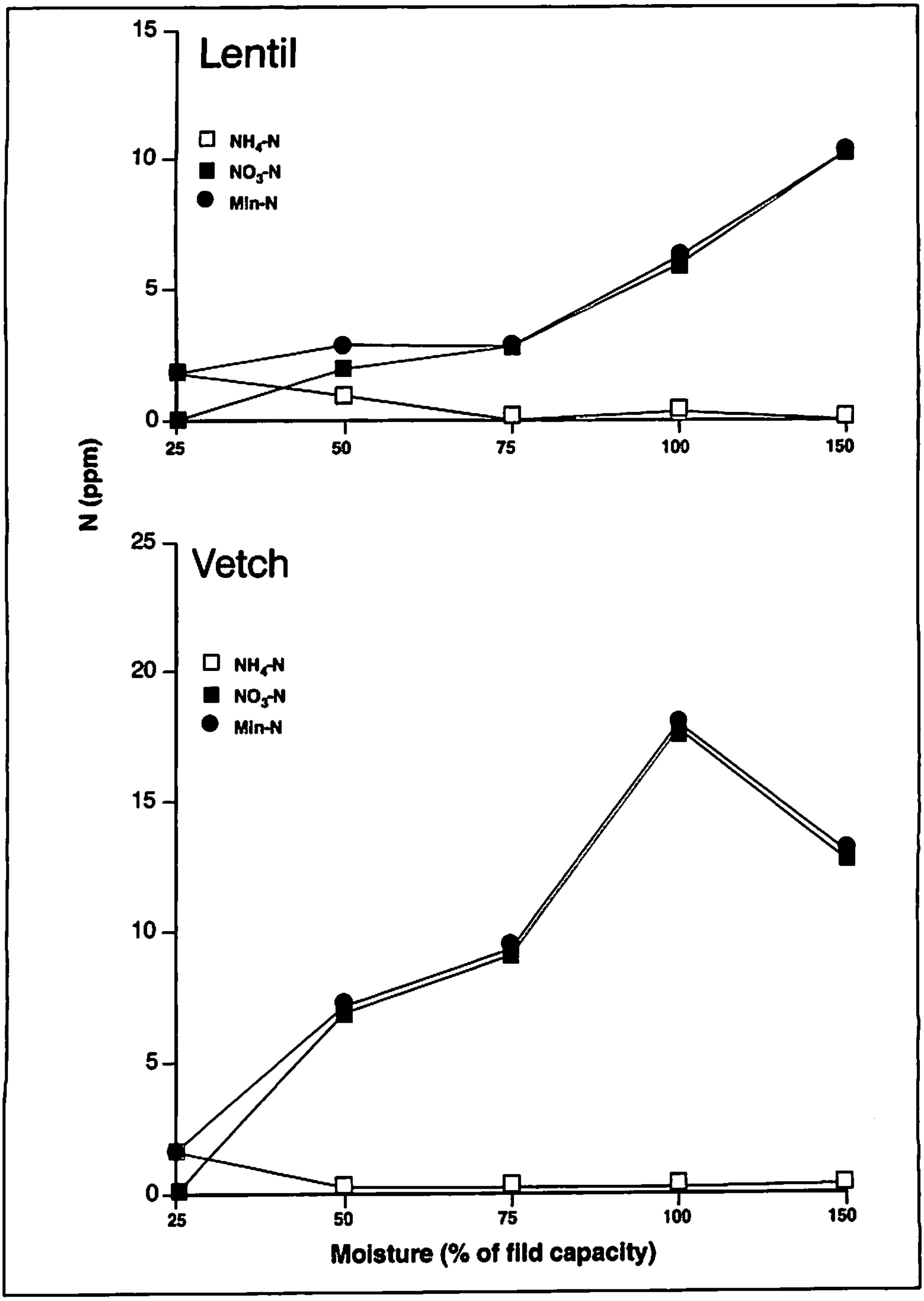

Fig. 6. Nitrogen mineralized (ppm) in soils from two crop sequences incubated for 14 days under different moisture levels at 30°C.

Based on the mean values for total N contents of the seven crop sequences between 1989 and 1994, the proportion of N mineralized was determined. At 8°C, the smallest value was 0.78% for summer crop and the highest 1.81% for wheat. Lentil mineralized least at 24°C (2.08%) and wheat the most (6.18%). At 30°C lentil had the smallest (2.54%) and medic had the highest N content (9.12%). Considering all crop sequences for one temperature, this indicated a difference in the proportion of N mineralized. Thus, mineralization is not directly proportional to the quantities of N present, but is also dependent on the degradability of the N compounds. At 24°C, with the exception of wheat, by increasing proportions the treatments could be classified: lentil, fallow, summer crop, vetch, chickpea and medic. It is obvious that in optimal moisture conditions (100% of field capacity) the main factor influencing the amount of N released is the quantity of N present and its degradability.

In the field, temperature and moisture conditions vary greatly and are usually below optimum. Records from the wheat and medic plots at different soil depths indicated that between January and May moisture levels, down to about 30 cm, decrease from 32 to 22%. During the same period temperature increases from about 8 to 16°C with diurnal fluctuations. Therefore, at the time of the year with the highest N requirements, environmental conditions would be such as to limit mineralization, i.e. low temperatures and limited moisture. The interest of incubation experiments is, rather than a simulation of field conditions, an understanding of the mechanisms determining N dynamics in soils. In fact, these were not independent from crop rotations, as N uptake was not inversely proportional to yields in fallow and medic rotations, due possibly to the N contribution from the legume (Ryan et al., 1992).

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Evolution of ICARDA's Long-term Cereal/Pasture and Forage Legume Rotation Trial

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Abstract

ICARDA's research on long-term rotation trials is of great value to the Mediterranean region. The Farm Resource Management Program (FRMP) invests most of its rotation trial effort on food crop rotations and agronomy, while the Pasture, Forage and Livestock Program (PFLP) uses its rotation trials to compare pasture and forage legumes in rotations with cereals to commonly used alternatives such as fallow, continuous cereal and lentil. The PFLP rotation trial experiment is the subject of this paper. Started in 1985/86 as a wheat-based two phase rotation, the trial evolved over the years in response to the findings of the trial. For example, the treatment wheat/medic (*Medicago rigidula*) was consistently lower in cereal yield than wheat following fallow, watermelon, lentil, or vetch; the hypothesis being that medic regrowth following grazing used additional water compared with the other treatments, reducing the amount of water available to the following wheat crop.

In 1991/92 and 1992/93, strips of barley were introduced into the trial to see whether its shorter time to maturation would result in better performance when paired with medic and compared with the other treatments. Indeed, medic/barley was one of the most productive treatments, so in 1993/94 the entire trial was converted to a barley-based rotation trial. After the first 6 years, medic and vetch (*Vicia sativa*) showed a positive accumulation of total nitrogen and organic matter in the soil (White et al., 1994). In addition, economic analysis showed that only the highest medic grazing pressure (4, 7 and 10 sheep/ha) was economically competitive with the other treatments. The low and medium medic stocking rate treatments were converted to vetch so that we could economically compare vetch grazed by lambs and vetch for hay with vetch grown for seed and straw. The watermelon treatment was discontinued, as it was similar to fallow, and was replaced by continuous cereal, more in keeping with existing dryland farming systems.

Finally, to provide recommendations on least-cost ration formulations for sheep, we needed to know more about how to mix and feed the various available feeds to reduce the high costs of purchased supplemental feeds during autumn and winter when there is no grazing. Our hypothesis was that the N accumulating under the medic and vetch crops would be partially taken up by the barley, possibly making the straw more desirable to sheep. Preliminary results from 1994/95 suggest that it is too early as yet to draw any solid conclusions from these feeding trials.

Introduction

One strategy for increasing agricultural production and maintaining the resource base in West Asia and North Africa (WANA) has been to introduce legumes into the cropping rotations. Benefits of this strategy to both animal and cereal production, in the short term, have been well demonstrated in rainfed agricultural systems (Puckridge and French, 1983). Research on legumes in rotations from the USA, Europe and Australia suggests that, in the long term, sustainability of the system may be enhanced through increases in total soil N, organic matter and improved soil structure. There is, however, little data on the long-term effects of legumes on the N content of the soil in WANA, particularly for rainfed farming systems that include grazing animals.

The unique management systems within WANA make it difficult to apply data obtained from outside the region. The exploitative crop harvesting and animal grazing practices, in particular, are likely to limit the inputs from legumes into the soil as most of the plant material is removed at harvest. A comprehensive understanding of the net flows of N within particular farming systems is therefore necessary to quantify the contribution of legumes to the soil and the nutrition of subsequent cereal crops. Since pasture and forage legumes are two groups of plants that are known to increase soil fertility, the objective of the current trial was to examine how best to manage these rotations so they will be profitable and useable on farms in WANA compared with crop production practices that are commonly used.

Materials and Methods

The experiment described in this paper has evolved over time and the treatments have been changed (Table 1). There are three distinct periods that will be considered: (1) the wheat-based period; (2) the transition period comparing wheat and barley; and (3) the transformed trial in its current state as a barley-based rotation trial.

Wheat-Based Trial, 1985/86 to 1990/91

Both phases of the rotations were present each year. Hence, plots sown to wheat in the first year were in the non-wheat phase in the second year and plots in the non-wheat phase in the first year were sown to wheat in the second year. Plots in the wheat phase were split, half receiving N fertilizer and the other half receiving no N, using either 0 or 60 kg N ha^{-1} (divided into two applications of 30 kg at planting and in spring before tillering). Fertilizer N was not applied to plots in the non-wheat phase. There were three replicates with treatments being randomly allocated within blocks.

Initial site preparation involved chisel-plowing to 30 cm and seed-bed preparation with a spiked-tooth harrow. Lentil, vetch and wheat were sown at 80, 100 and 120 kg ha^{-1}, respectively. Plot sizes for the lentil, melon and fallow were 0.3 ha and for the vetch was 0.17 ha.

Medic plots were sown at 30 kg ha^{-1} (scarified seed) in the first or second year only. The medic plots were not cultivated prior to the regeneration of the pasture. A standard flock size of 5 sheep resulted in plot sizes of 1.25, 0.71 and 0.50 hectares for the M-low, M-medium and M-high stocking rate treatments, respectively. Grazing management ensured that sufficient seed (200 kg ha^{-1}) remained at the end of each pasture phase for its regeneration in the next pasture phase following the intervening wheat crop. Medic pasture botanical composition was > 80% *Medicago* spp. throughout the experiment. Grazing usually started in February or March each year and continued until the medic seed-bank in any one plot fell below 200 kg/ha. At this time animals were transferred to the cereal plots to graze stubble.

Table 1. Evolution of a rotation trial at Tel Hadya, Syria (rainfall, 330 mm).

Trial	Treatments	Time
Wheat Based Trial		
W/F, W/L, W/SC		1985/86
W/M4, W/M7, W/M10		1990/91
W/VSS		
	a. All plots split for +/- N	
	b. W seed rate=120 kg ha^{-1}	
Transition Trial Comparing Wheat vs Barley		
W/F, W/L, W/SC	B/F, B/L, B/SC	1991/92
W/M4, W/M7, W/M10	B/M4, B/M7, B/M10	1992/93
W/VSS		B/VSS
	a. All plots split for +/- N	
	b. B&W seed rates of 80,120,160 kg ha^{-1}	
Transformed Trial Converting Wheat to a Barley-Based 2-Phase Rotation		
B/F, B/B, B/L, B/VH, B/VSS		1993/94
B/M10, B/VG30		to present
	a. All plots split for +/- N	
	b. B seed rate=120 kg ha^{-1}	

Codes: Wheat (W), Barley (B), Watermelon Summer Crop (SC), Lentil (L), *Vicia sativa* (V) for seed and straw (SS), *V. sativa* for hay (H) or *V. sativa* for grazing (G) by lambs, *Medicago rigidula* (M). Numbers following M or VG represent stocking rates (4, 7, 10 ewes ha^{-1} or 30 lambs ha^{-1}).

Watermelon was grown as a sparse (single plants on a 3 x 3 m grid) spring-sown crop on water stored in the soil profile during the winter. In common with local practice, it was planted only when the depth of wet soil in mid-April was judged sufficient to produce a crop (approximately 100 mm of plant available moisture in the 180-cm profile). Plots were deep-plowed (30 cm) using a disc-plow each year in November, followed by 1 to 2 cultivations with a 'ducksfoot' cultivator in spring to control weeds and conserve water. This cultivation regime continued even if the watermelon was not sown. It is important to note that in three seasons (1988/89, 1989/90 and 1990/91) the watermelon crop was not planted and thus the land remained fallow. Annual rainfall totals for the first 6 years (1985/86 to 1990/91) of the trial were 316, 358, 504, 234, 233 and 294 mm, respectively.

Fallow plots were cultivated (to about 10 cm) whenever necessary (2 to 3 times per year) to kill weeds and conserve moisture. Grass weeds in vetch and lentil were controlled with herbicides. Throughout the trial the rate of fertilizer application and method of harvesting varied depending on the type of crop and the seasonal conditions. Soil samples from all plots were taken prior to establishing the trial and in late summer each year thereafter (except vetch plots, which started in the second year). Cores (8-16, depending on the size of the sub-plot) were excavated to a depth of 20 cm. Total N, NH_4^+ and NO_3^- were determined. Further details on materials and methods can be found in White et al. (1994).

The Transition Period with Barley Versus Wheat

Based on data from 1985/86 to 1990/91 (not presented) which showed that rotations including medic reduced wheat yields, we decided to compare wheat and barley with in the rotations during 1991/92 and 1992/93. A split-split-plot design was used to compare three wheat and barley seeding rates (80, 120 and 160 kg ha^{-1}) within the cereal phase of the established rotation. Cereal grain and straw yields were estimated from mature plants cut to ground level just before combine harvesting. Rainfall totals were 353 and 290 mm during these two years.

The Transformed Barley-based Trial 1993/94 to Present Modifications

Since 1993/94 the rotation experiment has been a barley-based trial. Treatments were changed (Table 1) based on the economic analyses so that the trial could be refocused on meaningful issues. For example, the three medic stocking rates were reduced to one (medic high: 10 ewes ha^{-1}) because the high grazing pressure was the most economic (Nordblom et al., 1994). We felt justified in exchanging the physical location of the treatments because the total N levels of the soil in plots were not significantly different, and neither were the medic seed banks. We wished to increase our precision for measuring ewe and lamb performance on medic plots and to do so we needed more animals per replication.

The plots for the high, medium and low stocking rate treatments were 0.5, 0.71 and 1.25 ha, respectively. Therefore, we used 12 ewes on the 1.25 ha plots to arrive at the single 10 ewe/ha stocking rate. The medium stocking rate plot was converted to vetch used for seed, straw and hay; the high medic stocking rate plots were converted to vetch for lamb fattening (grazing); the original plots with vetch were dropped from the trial. The watermelon treatment was also eliminated and replaced with continuous barley so as to document the decline in fertility of the soil, increase in pests and diseases, and to monitor the rate of decline in cereal yields.

In the economic analysis of the trial, the biggest expense in keeping sheep was feeding them in winter. In 1995/96 a new set of marginal land plots was added to the trial to provide a place for sheep to graze during the autumn and winter when they would normally be eating supplementary rations in the sheep shed. This change will greatly reduce our winter feed costs and will demonstrate the value of integrating this type of grazing as a pasture treatment in the experiment.

Feeding Trials

In 1993/94, a year with 373 mm precipitation, the seed, straw and hay produced in the trial were labelled and stored in covered facilities and during the winter, these conserved feeds were fed to sheep to determine a least-cost feeding strategy for the critical indoor period. Ewes from the trial were randomly grouped in the sheep shed and offered straw from barley that followed medic, vetch, lentil, fallow or barley to determine if the rotation treatment affected the intake of the straw.

Results and Discussion

Nitrogen Cycling in Wheat-based Rotations, 1985/86 to 1990/91

Six years' results from the wheat-based portion of this rotation experiment demonstrated the total soil N dynamics, when medic pasture (3 stocking rates), vetch, lentil, fallow or watermelon, are managed in two-year rotations with wheat (White et al., 1994). Rotations including medic pasture or vetch increased total N concentration in the soil by 15-20% from about 550-650 ppm to 700-800 ppm total N levels between 1985/86 and 1990/91. In contrast, the total soil N concentration remained unchanged in the lentil, fallow and melon rotations. The rotations examined in this experiment had clear and markedly different effects on the soil. Lentil and fallow had no effect on total soil N content. The changes in soil properties have implications for the long-term productivity of the different rotations and have highlighted the importance of retaining legume material for maintaining fertility.

The large increases in total soil N and organic matter in the medic rotations indicated that there were large inputs of organic N into the soil. Most of this N came from the return of the legume shoots to the soil. The turnover of shoot material was largest in the low and medium stocking rates where the pasture was under-utilized. It is important to mention that the heavy cracking clay soil (Calcixerollic Xerochrept) in the experiment provided every opportunity for herbage disappearance, pushed by sheep or wind into large cracks, which, starting in May and June, can commonly be 10 cm wide and more than 100 cm deep.

The urine and dung of grazing sheep also returned N to the pasture. This represents only about 20% of the total N returned directly with the shoots and roots; however, in a related experiment, about 55% of N consumed by sheep grazing medic pasture was removed from the field in the form of milk or dung and urine deposited in the night-holding areas. Perhaps, of the N returned to the soil, more than 50% of the N in the urine may have been volatilized.

Differences in the return of N in shoot or root residues may also have caused the different rates of soil N accretion between the vetch and lentil rotations despite the management of both crops being the same. The entire shoot of both species was harvested by hand and removed from the soil, leaving little shoot residue in the field in most years. Leaf drop was not measured during the first 6 years of the experiment described here, but results from the 1991/92 season showed that there were substantially more leaves dropped by the vetch than by the lentil near maturity. Differences in the amounts of N in the roots were not determined but may also have been an important difference between species.

Transition Phase: Wheat vs Barley (1991/92 to 1992/93)

Results from 1985/86 to 1990/91 led us to believe that medic pasture used more water than lentil, vetch, watermelon or fallow when in rotation with wheat. This is not surprising because grazing causes regrowth of medic while the other crops go through a normal phenological progression to maturity. As a result, wheat yields after medic were on average as much as 33% lower than after fallow and 13% lower than after vetch or lentil. A similar trial conducted during the same period of time and located adjacent to the experiment discussed in this paper included neutron probes for the measurement of water balance under various two-phase wheat rotations. Results show that lentil, being a month earlier in maturity than either wheat or chickpea, does not dry the soil to the same extent as other crops. Some water remaining in the soil is frequently retained through the summer, becoming available to wheat during the next phase. In contrast, chickpea and medic dry the soil throughout the 180 cm of the measured profile to at least the same extent as wheat, so that in rotations with these legumes each phase is entirely dependent on the rainfall of a given season (Harris, 1995).

In the first 6 years of the trial, average wheat grain yields were highest (2.1 t ha^{-1}) after watermelon or fallow, about 0.5 t ha^{-1} lower after lentil or vetch, and a further 0.2 t ha^{-1} lower after medic. Wheat/lentil was the most profitable rotation, mainly because of the relatively good prices for these crops, low cost of family labor for hand-harvest of lentils, small size of holdings, and the value of lentil straw for sheep feeding. Nordblom et al. (1992, 1994) reported that an increase of wheat grain yields on the order of 0.6-1.0 t ha^{-1} would make the medic rotation competitive with wheat/lentil. This magnitude of increase did not seem feasible with wheat, so we decided to evaluate the potential of better results with barley, a plant with a shorter growing period.

Statistical analysis for the comparison of wheat and barley in 1991/92 and 1992/93 for both grain and straw showed the following main interactions: (1) N x cereal, (2) N x rotation treatment, and (3) legume system rotations x cereal (Table 2). The fertilizer N response for cereals was greater for barley than for wheat. Application of 60 kg ha^{-1} N increased barley yields by 1.03 t/ha while for wheat it was only 0.26 t ha^{-1}. The harvest index of barley was also considerably higher than that of wheat.

For the N interactions with rotation, the summer crop and fallow continued to out-yield the legume options in both cereal systems; however, the fallow produces a crop only once every 2 years. The watermelon was grown in the 2 years under question after

3 years in a row when it was too dry to plant. In the analysis we compared the fallow system (i.e., fallow and watermelon) with the legume systems (i.e., lentil, vetch and medic). We found differences between and within both systems (P<0.01) with watermelon superior to fallow. We further analyzed the legume system comparison to the level of wheat and barley to answer the hypothesis posed at the beginning of the experiment, i.e., that cereal grain yield after medic *is* reduced when grown with wheat, but not with barley. The barley grain and straw yields after medic were clearly superior to both lentil and vetch.

Table 2. Statistically significant results (P<0.05) to compare wheat and barley grain and straw yields in the rotations.

Nitrogen and Cereal Effects

	N kg ha^{-1}	Wheat t ha^{-1}	HI --%--	Barley t ha^{-1}	HI --%--
Grain	0	2.49	37.3	3.38	51.1
	60	2.75	32.9	4.41	47.1
Straw	0	4.19	3.23		
	60	5.62	4.95		
Total	0	6.68	6.61		
	60	8.37	9.36		

Nitrogen and Rotation Effects

		Fallow System		Legume System		
	kg N ha^{-1}	F	SC	L	V	M
Grain	0	3.18	3.85	2.34	2.56	2.87
	60	4.56	4.93	3.24	3.05	3.09
Straw	0	3.91	5.00	2.67	3.02	3.78
	60	6.34	7.12	4.33	4.10	5.04

Cereal and Legume System Effects

		Legume System		
		L	V	M
Grain	Cereal	2.36	2.37	2.22
	Barley	3.22	3.25	3.74
Straw	Wheat	3.94	4.01	4.70
	Barley	3.06	3.10	4.13

Codes: Medic (M), Vetch (V), Lentil (L), Fallow (F), Watermelon Summer Crop (Sc) and Fallow (F), Harvest Index (HI).

Sheep Feeding Trials

As mentioned above, organic matter and total nitrogen were accumulating in the soil of vetch and medic rotations; however, improved soil physical and chemical conditions are not easily given a value by the farmer. We analyzed the straw and grain of barley grown in the various rotations to see whether there was a difference in the amount of nitrogen taken up (Table 3). No significant differences were detected; however, for straw, the trends in crude protein values matched what was shown in the field, except for the high values found in the barley straw grown after fallow.

In the van Soest analysis of feeds (Maynard et al., 1979), acid detergent fiber (ADF) analysis provides for a sequential separation of the digestible and indigestible portions of the plant carbohydrates. Acid detergent fiber is what is left after the cell contents, pectin and readily degradable hemicellulose and some of the cellulose are removed from plant tissue, leaving mostly lignin and a large part of the cellulose. Barley from plots that followed legume rotations was lower in this fibrous fraction than the barley following barley, watermelon or fallow. Nevertheless, intake of the same straw was lowest from barley following medic or fallow, although not significantly so. Our hypothesis was that soil N would eventually be picked up by plants and increase the intake of straw by sheep. However, the results to date are inconclusive, and the trial will be repeated for at least one more year.

Table 3. Crude protein concentration in the grain and straw in the rotations.

Treatment	Grain CP	Straw CP	Straw ADF	Straw Intake
	%	%	%	kg day^{-1}
B/M	9.97	1.76	51.9	0.57
B/V	9.89	1.66	50.1	0.67
B/L	10.40	1.57	51.0	0.69
B/B	9.85	1.53	52.0	0.68
B/SC	10.25	1.44	53.4	0.64
B/F	10.07	1.95	52.6	0.59
SE	±0.336	±0.140	±0.52	±0.030
P>F	0.83	0.22	0.013	0.081

1. Straw fiber as determined by van Soest's acid detergent fiber (Maynard et al., 1979) analysis and intake of barley straw by Awassi ewes.
2. Barley was grown in rotation with the following crop alternatives: Barley (B), Medic (M), Vetch (V), Lentil (L), Watermelon summer crop (SC) and Fallow (F). P>F: Probability of greater than observed values in the cases where there were no differences among rotations.

Conclusions

This rotation trial changed over time in a process of discovery that was designed to identify the conditions where pasture and forage legume rotations with cereals would be economically competitive with other rotations commonly used by farmers in rainfed agricultural systems in Syria. Analyses of soil from each rotation treatment quantified the accumulation of organic matter and total N in the medic and vetch treatments. However, at the same time, agronomic trials on the research station demonstrated persistently lower yields of wheat following medic compared with wheat after lentil and vetch. We hypothesized that medic was extracting too much water from the soil profile for the water requirements of the following wheat crop to be satisfied. This led to a test of wheat versus barley because of the shorter maturation of the barley, and we demonstrated that, indeed, medic performs superior to lentil and vetch when paired with barley. Furthermore, we can confidently say that the barley grown in the two years of the transition study responded much better to N fertilizer than did wheat, suggesting that the Tel Hadya location might really be better classified as a barley-growing zone -- the Sryian government currently suggests that wheat be grown in this area.

Primarily driven by the assumptions used in the economic analyses, we improved our techniques and measurements. For example, estimates of dry matter from herbage clipped from inside quadrats were twice as high as offtake calculated as grazing days x intake per head, bringing into question the intake assumptions or the over-estimation of production using quadrats. If the latter was true, crop yields were being over-estimated in the economic analysis compared with the pasture rotations. To fix the potential bias we began experiments to verify the actual sheep intake, and began harvesting much bigger samples to get more realistic assessments of crop productivity.

We also changed the treatments to make them more in keeping with the relevant agricultural questions that currently require answers. Three medic stocking rates were reduced to one and the plots were rearranged to accommodate the inclusion of barley/barley, and two more utilizations of vetch in addition to its traditional use as seed and straw, i.e., as hay and as a grazing source for lambs. Finally, the economic analysis demonstrated that winter feeding costs are the most expensive part of the medic rotation; therefore in 1995/96 we introduced marginal land into the trial so that we could demonstrate the advantages of rehabilitating marginal land as a way to decrease our concentrate feed bill, as shown by Osman et al. (1991, 1994); and Osman and Cocks (1992).

Finally, in the search for optimum economic ways of feeding all the materials produced from the trial, we evaluated the quality of the straw and sought to determine whether the N taken up by barley and fixed in its fibrous fraction might be more palatable to sheep. The preliminary results suggest that a more complicated process is occurring that will require further time to reach a solid conclusion.

Acknowledgments

This trial was conceived in 1985/86 by Alan Smith, Phil Cocks and Nerses Nersoyan in consultation with other ICARDA researchers. Nerses Nersoyan, Faik Bahhady and other

technical assistants are responsible for the day-to-day management of the experiment. Peter White was responsible for the nitrogen-cycling work. Anthony Goodchild and Euan Thomson advise on the sheep management and feeding. Ahmed Osman and Gus Gintzburger are pasture and range researchers who have helped with the integration of this component into the trial. Murari Singh has taken responsibility for the statistical analyses. Tom Nordblom and Farouk Shomo provide the economic analyses. Scott Christiansen and Nerses Nersoyan share overall responsibility for the trial and reporting of data.

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Soil and Crop Management Research for Sustainable Improvement in Agricultural Productivity[1]

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Abstract

In this paper a broad holistic view of soil fertility which embraces physical, chemical and biological components is presented. Specific examples are given in relation to tillage and crop rotation trials as well as fertilizer response in relation to site and weather conditions. The role of nitrogen and water economy of legume/barley rotations is highlighted. A plea is made for soil scientists to be broader based and more field-oriented.

Introduction

The productivity of an arable cropping system depends on the four broad factors: Yield potential of crop germplasm, Meteorological conditions, Crop management (planting conditions, pest control, etc.), and soil production potential, and many important interactions between them. The focus here will be on soil 'production potential' or 'fertility'. In English, soil fertility is often used narrowly to mean just chemical fertility -- the availability of nutrients -- but, more correctly, it takes in the physical, chemical, and biological components of the production capacity (or potential) of the soil. This paper very briefly reviews the scope of these components, and then goes on to give a number of research examples drawn from ICARDA experience, to suggest a broader perspective for research in this discipline.

Soil Production Potential

Physical Components

Certain basic properties of an arable field, like soil depth and soil texture (relative proportions of sand, silt and clay), cannot be changed either by farmer or researcher -- except negatively, by allowing erosion. Quite different, however, are the structural

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properties, which are a function of how the individual sand, silt and clay particles (with a little help from the organic matter) stick together, forming crumbs or peds (aggregates). The strength of this adhesion and the proportion of the soil material so aggregated determines such properties as soil infiltration capacity, permeability, aeration and, more generally, what we may call the 'crop-friendliness' of the soil as a production environment: How easy is it to prepare a seedbed? Is surface crusting a problem? Is the soil a good rooting medium?

However, the degree of aggregation varies according to how the soil is managed. It can deteriorate under poor management or be improved (within limits imposed by texture and clay type) by good management. What constitutes poor management is difficult to generalize, but too frequent (and too deep) mechanical disturbance and inadequate return of organic residues are major factors in many environments. Conversely, minimum tillage and the input of crop residues, manures and composts will usually help to create and maintain better structural conditions. However, changes in soil structure, whether positive or negative, usually occur quite slowly. Research into soil physical constraints on sustainable crop production therefore requires long-term monitoring of the soil in fields that have well-defined management or within specially designed long-term trials.

Chemical Components

The chemical (or nutritional) components of soil fertility tend to be more dynamic than the physical ones; and this fact often encourages the view that, if necessary, farmers can always add fertilizers to overcome any inconvenient nutrient deficiency. But this ignores the probable economic constraints. In any case, the reality of fertility management is not as simple as that.

First, depending on soil type, there are certain intrinsic soil properties that determine how crop nutrients, both native to the soil and added from the fertilizer bag, need to be managed. The control exerted by the presence of free calcium carbonate on the availability to plants of phosphate (and other nutrients) is one example of this. Another is the relative inability of sandy soils to hold nutrients in the root zone, lack of cation exchange sites and the rapid through movement of water encourage heavy leaching losses. Since neither the soil content of calcium carbonate nor the soil texture can be substantially changed, the management of crop nutrition must take account of such factors.

Management is a key word here. Arguably, supplying nutrients to the crop as mineral fertilizer represents a failure -- a failure of the farmer and of his scientific advisers to manage the soil sufficiently well to provide for crop needs from the soil's own native resources. This is an extreme view, especially when one considers the naturally meagre availability of plant nutrients in many WANA soils. Nevertheless, there is a point here. Soil fertility needs to be managed -- positively -- in such a way that its nutrient content, native and acquired from previous fertilizer addition, is kept as available as possible to match crop requirements, and so minimize the need for further fertilizer application.

Positive fertility management requires a more determined and integrated application of a number of already well-known approaches. These include:

- Nutrient cycling (through the return of residues and manures; and, in some situations, the use of deep-rooting crops to retrieve nutrients leached below earlier crops).
- Rotation with legumes (with perhaps more attention given to their net N contribution to the system).
- Matching fertilizer form to actual need (how much K from NPK sources is added annually to soils already adequately supplied with this nutrient?).
- Matching fertilizer rate to actual need, and particularly taking account of residues from previous applications (concepts of maintenance dressings and rotational fertilizer strategies).
- Soil testing (by which actual needs, at farm level, may be estimated).

Research for the first four of these necessarily requires trials of two-year or longer duration; and the fifth needs a spatial approach, with trials or samplings spread over the target area.

Biological Components

Soil biology is a rather undeveloped field, particularly in the WANA environment. Many agriculturalists and even soil scientists appear happy to regard the soil as an inert medium -- or, at best, a biological "black box" to which one simply applies water and fertilizers, and from which, as a result, vigorous crops emerge. The reality is a seething underworld of macro-, meso- and micro-flora and fauna engaged in processes in many cases having important influences on physical and chemical aspects of fertility.

One exception to the general disregard for soil biology is nitrogen fixation. The N-fixing role of rhizobia on the roots of legumes is well known and a popular research topic worldwide. Yet the beneficial function of mycorrhizae -- the association of vesicular-arbuscular mycorrhizal (VAM) fungi with plant roots -- though in many ways analogous, is much less well appreciated, even though this symbiosis can greatly increase the efficiency of crop root uptake of P and water. In part, this neglect is because past attempts to inoculate soil or crops with effective mycorrhizae have usually failed. However, most crop roots are naturally infected with indigenous VAM fungi. The more promising research opportunities, therefore, appear to lie in (i) exploiting the apparently large variability in crop genotype susceptibility to VAM infection, and (ii) managing the size and composition of the indigenous population of VAM fungi in the soil (e.g., through crop rotation and genotype selection) to optimize its efficiency to promote crop growth.

Such research requires microbiological, more precisely mycological, expertise working within ongoing agronomy and crop improvement activities. Strategically, managing the soil microflora (mycorrhizae as well as rhizobia and other N-fixers) should be seen as an integral part of the overall management of soil fertility -- with the long-term goal of optimizing nutrient availability with the minimum of inputs. The following examples illustrate the concepts highlighted above.

Tillage: Soil Aggregation and Rainfall Infiltration

As reported by Harris (1995), a trial was set up at Tel Hadya in the 1978/79 season to compare 5 combinations of type and timing of tillage within a wheat-lentil rotation. The primary interest in this trial was in the tillage effects on the weed flora and on crop yields, but topsoil samples were taken after 9 years for physical measurements. Dry sieving was used to separate soil aggregates into six size classes.

In plots that were always tilled while the soil was still dry, the proportion of medium and large aggregates (1-5 mm) was small, and the proportion of fine aggregates (< 0.5 mm) was large, relative to other treatments, particularly those where all tillage was carried out after rain. At the same time, infiltration of simulated rainfall was measured in the field plots following the hand-harvest of lentils, in terms of the time for the surface soil to become saturated. Plots routinely tilled after rain were less liable to flood, that is they had better infiltration, than plots routinely tilled before rain. This finding is consistent with the difference in the size distribution of soil aggregates; one may expect better infiltration where aggregates are larger. (However, the reasons for the slow infiltration in zero-till plots are not known.) These results, as Harris emphasizes, are only exploratory. Nevertheless, they illustrate how the physical properties of even a well-structured soil like that of Tel Hadya may evolve under different management. There are indications here that dry tillage may lead to structural deterioration.

Rotational and Crop Management Soil Structural Properties

As reported by Masri and Ryan (1995), soil samples were taken, prior to planting in November 1992, from the plow layer of field plots at Tel Hadya under both phases of long-term wheat-medic (annual *Medicago* spp.) and wheat-fallow rotations, established in the 1983/84 season. Sampling was designed to take account of the effects both of crop rotation and of different N fertilizer and stubble-grazing treatments applied to the wheat phase.

Several indices of soil aggregation provided by analysis of those samples show essentially the same treatment effects. Aggregate stability was generally greater in the rotation of wheat with medic. Aggregates from the wheat-fallow rotation were more likely to swell and disperse in the presence of water; and the amount of clay dispersed by shaking soil aggregates in water was approximately twice as great in samples from wheat-fallow as in samples from wheat-medic rotation. Somewhat surprisingly, aggregate stability was apparently improved by heavy grazing of the wheat stubble relative to the ungrazed treatment; and N fertilization of the wheat crop also had a positive effect.

The positive effect of N is attributed to greater growth of wheat roots and thereby a greater contribution of organic residues to the soil. More generally, the better physical condition of the soil under the wheat-medic rotation is attributed to a better organic matter status that is presumed to have arisen from the return to the soil of medic roots, leaves, and the feces and urine of the sheep grazing the medic. The mean organic matter content of the wheat-medic plow layer is 1.44% compared with 1.22% under wheat-fallow. In fact, these figures alone are only indicative, not conclusive. Soil organic matter is a very complex material, and different components of it contribute differently to soil properties. Aggregate stability has often been found to be associated with the soil polysaccharide component. It is therefore significant in the present case that the relative amounts of polysaccharide extracted from these soils quite closely mirror the pattern of the aggregate stability. We may note here that the soil polysaccharides, which contribute to the adhesion of soil aggregates, are a byproduct of microbial activity stimulated by the return of organic residues. Thus the physical and biological components of fertility -- and fertility management -- are closely linked.

Site and Weather Effects on Crop Response to Fertilizer

As noted already, chemical components of soil fertility are more dynamic than the physical ones. They also tend to be more spatially variable, differing even from field to field, according to cropping and management history. This is why it is often misleading to derive fertilizer recommendations from results obtained only on research stations. Ideally, recommendations should be based on results obtained from trials conducted across a broad sample of farm conditions in the target areas or should be made specifically for each field on the basis of individual soil-test values.

An example of the on-farm trial approach was given by Jones and Wahbi (1992). Data from 75 barley fertilizer trials, conducted over four years on farmers' fields across northern Syria, were pooled to produce regression equations of the form:

$Y = aN + bP + cNP + dN^2 + eP^2 + fQ + gQ^2 + hQN + iQP + \text{constant}$ where Y is yield, N and P represent rates of applied N and P, Q is total seasonal rainfall and a, b .... i are derived constants.

Such equations (or 'static models'), which account for 60-70 % of the actual yield variance, may then be used to describe crop response to fertilizer in a variety of ways, particularly in relation to site conditions, e.g., soil type, initial soil status of available P and mineral-N, previous crop, rainfall. For instance, grain yield response varied according to rainfall and whether the field had been fallowed or cropped the previous season. While response to added fertilizer was affected by initial topsoil content of available N and P, differences were greatest under low rainfall. Based on long-term rainfall data, one may go on to predict responses to fertilizer, on a probabilistic basis, across a production zone.

Nitrogen and Water Economy: Barley/Forage Legume Rotations

As rainfed cropping in the dry barley zone intensifies, the replacement of fallow -- not with more barley -- with successful, productive forage legumes becomes more urgent. One research issue is which legume is potentially the most useful to farmers? Another, related, issue is which is the best way to harvest that legume -- as green grazing, as hay, as seed and straw -- within existing barley-livestock production systems, to maximize benefits and minimize any loss of barley production.

Between 1986 and 1994, ICARDA conducted eight simple two-year agronomic trials at two sites in the dry barley-growing areas of Aleppo Province to examine the effect of mode (or time) of harvest of common vetch (*Vicia sativa*) on unfertilized barley yield in the following year. Results showed a consistent trend. In all cases, highest barley yields were obtained after green-grazed vetch (statistically significant in four trials), with barley yields after hay harvest tending to be greater than or similar to those after mature vetch harvest. The initial hypothesis was that different harvest times of vetch would leave different amounts of water in the soil and thereby influence productivity the following year. However, it was later recognized that vetch harvest times might also influence N availability to the following crop. Regrettably, resources were not allocated to the monitoring of water and N in these trials, which were only exploratory in nature. However, the study of these factors was eventually taken up within two long-term rotation trials, at Tel Hadya and Breda.

Mean yields of grain and straw over the three seasons, 1991-94, were 10-15% higher where barley was grown after vetch that was green-grazed rather than grown to maturity; and at Tel Hadya, though not appreciably at Breda, the relative enhancement of the total N content of the barley was even greater. This suggests, though does not prove, that the immature harvest of the legume left more N to the following crop. In the Breda trial, soil water use was also monitored, and the results showed that barley following green grazing was, on average (over 3 years), able to utilize 11 mm more water than barley following the mature-harvested vetch. This represents water not used by the green-grazed vetch but stored at depth in the soil over the summer. It is not a large amount, but it represents about 70% of the moisture similarly conserved by a bare fallow. Mean barley total dry matter production at Breda after mature-harvested vetch, green-grazed vetch and fallow was 4.08, 4.55 and 4.61 t ha^{-1}, respectively. Thus vetch, particularly green-grazed vetch, may be introduced into the system to replace fallow without appreciably reducing barley yields.

Discussion

Each of the pieces of research summarized above has its own particular importance, which need not be elaborated here. Rather, there is a more general message to be drawn. It concerns the role of soil scientists in agricultural research. Worldwide, too many soil scientists limit themselves simply to analyzing soil (and plant) samples from other scientists' trials, and to running annual fertilizer trials, to derive yet more standard fertilizer recommendations. It is time to preach revolution against this too-narrow role. Soil scientists should cast their interests and responsibilities wider. Four points towards a new soil science manifesto are:

1. Soil management is an essential component of agronomy. More soil scientists should escape from their laboratories to become soil fertility agronomists. That is, to become more proactive in the planning of crop and crop management trials, establishing equal partnerships with crop scientists and field agronomists in deciding the factors to be tested and the analyses to be undertaken.
2. Crop production is a dynamic process: each year, on each field, a bag of seed

evolves into a deep swathe of vegetation, as, from year to year, crop follows crop. The soil that supports this process is also dynamic, internally, with countless interacting physical, chemical and biological mechanisms, each with its own rhythm. Ideally, the study of an agricultural soil is the study of these mechanisms, how they match to crop processes and how they may be beneficially influenced. Some may be studied in the short term, in laboratory, greenhouse or annual field crop. Others are slower -- involving the residual effects of one season on the next or the gradually evolving changes (in organic matter, structure, fertilizer build-up) that need to be monitored over many seasons. All field programs of soil research should have a strong time dimension planned into them.

3. Agriculture and the soil on which it depends are spatially distributed and spatially variable. Sampling and experimentation need to be spatially conducted if widely useful solutions to soil problems that constrain production are to be identified. Results obtained solely on research stations are rarely directly transferable to the real farm situation.

4. Not least, soil is an essential resource. In many places it is also a threatened resource. Threats come, variously, from erosion by wind and water, from urbanization, and from contamination. The soil scientist has a major role to play here, in quantifying the damage and informing the world.

Conclusion

There are many soil scientists who describe and classify soils, and many others who analyze soils. But agriculture, I suggest, needs more soil scientists who concern themselves with the management of soils, in the broadest possible sense: who go broader, to integrate physical, biological as well as chemical processes into their thinking; who go deeper, to study soil processes, mechanisms and their relation to crop-growth processes; who go longer, to look at sequential and long-term effects; who go spatial, off the research station to factor the farm situation into their work; and who see themselves as one of the main caretakers of the soil as a natural resource. Out of this, the final message is perhaps: less soil in our laboratories, more mud and dust on our boots.

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Use of Models to Enhance Nitrogen Use by Wheat

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Abstract

Wheat is mostly grown between 300 and 600 mm rainfall zones of northwestern Syria. Inefficient use of water and nitrogen is widespread in the area, but field experiments are limited to recommend optimum use of these resources. Thus, the CropSyst simulation model in combination with GIS technology has been utilized for durum wheat production and its probability under supplemental irrigation and rainfed conditions and its N requirements across agroecological zones of nortwestern Syria after calibration of the model with 3-year data set for Cham 1 durum wheat cultivar under three levels of supplemental water (rainfed, 60% and 100% of crop water requirements) and 2 levels of N (0 and 100 kg N ha^{-1}). Water need was found to be 250 to 300 mm for more than 40% of the total cropped area of the study region to give about 6.5 t ha^{-1} mean yield under supplemental irrigation when the crop is provided with about 100 kg N ha^{-1} fertilizer. Growing wheat is risky in relatively drier rainfed areas and N fertilizer can be used more efficiently ranging from 5 to 100 kg N ha^{-1}, taking the rainfall distribution into account. These results are in good agreement with experimental results in some parts of the area, thus crop models can be used in decision-making for water and N application in larger areas and can assist in prioritizing research for management practices for wheat.

Introduction

The rainfed farming systems of the West Asia and North Africa (WANA) have developed over centuries in areas receiving annual rainfall between 200 and 600 mm associated with temporal and spatial variability. This variable and often chronic deficiency of rainfall is coupled with widespread nutrient deficiencies and improper soil and crop management (Cooper et al., 1987). Cereals are the principal crops grown in the region, with wheat (*Triticum aestivum* subsp. *aestivum* and *T. turgidum* subsp. *durum*) covering about 50% and barley (*Hordeum vulgare* subsp. *vulgare*) 20% of the cropped land (FAO, 1994). In Syria, wheat is grown from the wettest to the driest areas. In dry areas, where barley predominates, wheat is produced mostly for subsistence.

Under continuous cropping systems, almost all extractable water is used by crops every year and further evaporation during the summer decreases soil water far below the wilting point. Therefore, sowing of crops is mainly dependent on receiving sufficient precipitation in autumn for crop emergence and canopy development. The impact of water and N availability on productivity, two critical resources for growing crops in the region, cannot be analyzed independently of weather, soil characteristics, field hydrology, crop characteristics and rotation, among other factors. Therefore, in order to develop improved management practices, it is necessary to integrate these factors into a comprehensive cropping systems approach. Field experiments are the best tools to assess the effects of water and N as well as other management practices on crop performance and production. However, they are usually conducted for shorter durations in limited number of locations, and they are also expensive.

To produce reliable results for analysis of the production risk, a minimum of 30-year data are needed in most cases. In this respect, crop simulation models are possible alternative tools for such studies, provided they have preliminary calibration. In addition, Geographic Information Systems (GIS) are the tools for overlaying climate, and soil maps of a region that can be used in integration with crop models for mapping inputs and crop production outputs for a wide region which cannot be covered with field experiments, thus making better decisions, and prioritizing research for the welfare of the farmers. Therefore, the objectives of this study were determination of the yield potential of durum wheat with its N requirement under supplemental irrigation, and rainfed conditions for different agro-climatic zones through utilization of the CropSyst model in combination with GIS technology to assess the regional productivity in the long-term and to increase input use efficiency in northwestern Syria.

The Models

There are several simulation models available for simulating wheat growth, such as CERES-wheat with N sub-routine (Godwin, 1987), SIMTAG (Stapper, 1984), SUCROS1 and SUCROS2 (van Laar et al., 1992), depending on the soil and weather conditions of a given region. However, examples will be given only from the CropSyst because of involvement of soil and crop management including water and N management within a crop rotation systems. CropSyst is a multi-year and multi-crop daily time step simulation model. It has been developed to serve as an analytical tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant N budget, crop canopy and root growth, dry matter production, grain yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, N fertilization, tillage operations and residue management.

Details on the technical aspects and use of the CropSyst model are reported elsewhere (Stockle et al., 1994; Stockle and Nelson, 1994). The water budget was used to estimate the crop water use as evapotranspiration and the N budget for crop N uptake. Daily crop growth, expressed by biomass increase per unit area, was calculated on the basis of the minimum of four limiting factors: light, temperature, water and N. The Priestley-Taylor model (Priestley and Taylor, 1972) was used for evapotranspiration throughout the season with daily weather data of precipitation, maximum and minimum temperatures, and solar radiation.

The Model (CropSyst) Performance

The field data used for model evaluation were obtained from a line-source sprinkler experiment conducted at ICARDA headquarters, Tel Hadya Research Station, during 1989/90, 1990/91, and 1991/92 seasons using a strip block design with 3 replications. Cham 1, an improved durum wheat cultivar, was tested under 3 levels of water (W0=rainfed, W60=60% of crop water requirement, and W100=100% of crop water requirement) and 2 levels of N fertilizer (0 and 100 kg N ha^{-1}) in a wheat-chickpea rotation. Details are given elsewhere (Pala et al., 1996). The CropSyst model was found to track changes in crop growth, its water use and N uptake throughout each growing season reasonably well compared with the experimental data points, thus encouraging us for the reliability of the model, when correctly calibrated, in predicting these quantities at harvest time, which is usually the information utilized in the long-term analysis of management practices.

Observed and simulated above-ground biomass, grain yield, cumulative ET and cumulative N uptake at harvest were compared, with R^2 of 0.84, 0.81, 0.85 and 0.96, respectively, as well as statistical analysis of this information (Table 1). These simulated outputs for Cham 1 followed closely the 1:1 line when plotted against the experimental data. The statistical analysis confirmed that the CropSyst model predicted the outputs reasonably well, showing a high index of agreement (d) and root mean square errors (RMSEs) corresponding to 9 (cumulative ET) and to 25 (grain yield) % of the observed mean values. The observed and simulated mean values of these parameters for the 16 data points of Cham 1 cultivar were very close.

Integration of CropSyst with GIS Technology

As a result of a good performance of the CropSyst model for predicting above-ground biomass, grain yield, cumulative ET and N uptake of durum wheat reasonably well in one location of northwestern Syria, it was integrated with GIS technology for assessment of input use efficiency for wider areas of the same region.

The Study Area

The soils of the study area are diverse; four major soil groups recognized on the FAO/UNESCO soil map of the world are found in northwest Syria. These calcareous soils, formed from limestone residuum, predominate in the area, with very variable texture, depth, slope and stoniness. Organic matter levels are generally low, and structural stability is poor in some soils.

Syria has been divided to six agricultural stability zones based on mean annual rainfall (Watson, 1979). Five of these stability zones transect the study area as mentioned above. However, closer intervals of mean annual rainfall isohyets have been used in simulation to identify changes across rainfall zones (Pala et al., 1992). A total of 24 meteorological stations was used for generating the weather data for pre-defined rainfall isohyets with 20 mm intervals; 11 had daily rainfall, maximum and minimum temperatures data from 12 to 29 years, 6 stations had daily rainfall data from 13 to 28 years, and 7 stations had only monthly rainfall data from 15 to 24 years.

Table 1. Statistical summary comparing simulated vs. observed data for Cham 1 durum wheat cultivar (n=16).

Parameter	Biomass	Grain Yield	N Uptake	ET[1]
	------------------ kg ha^{-1} ------------------			-mm-
Slope	0.94	0.70	1.05	0.93
Constant	244	877	1	7
Adjusted R^2	0.84	0.81	0.96	0.85
Observed mean	7310	2180	67	311
Simulated mean	7090	2410	72	298
RMSE [2]	870	550	8	29
RMSE/Observed mean	0.12	0.25	0.11	0.09
Index (d) [3]	0.96	0.92	0.98	0.95

[1] ET is evapotranspiration.
[2] RMSE is abreviation of root mean square error which describes the average difference between predicted and observed data.
[3] Index of agreement (d), as defined by Willmott (1982), where $0<d<1$, with a value of 1 indicating perfect agreement between observed and predicted data.

About one third of the dryland area lies in northwest Syria. A two-year crop rotation is almost universally practised with wheat as the main crop, mostly preceded by chickpea or lentil depending on the location. Cham 1, which is an improved durum wheat cultivar highly adopted by farmers in the study area (Pala and Rodriguez, 1992), was used in the present work.

Supplemental Irrigation and Nitrogen vs. Durum Wheat Yields

Obviously there is not much effect of rainfall on wheat yield since the irrigation takes care of the water deficit in drier areas (Fig. 1). About 42% of the total cropped area needs 250-300 mm, about 27% needs 300-400 mm, another 25% of the area needs 200-250 mm and the rest (about 6% only) needs less than 200 mm irrigation. This shows that the majority of the area needs more than 250 mm irrigation water to achieve the potential yield. Supplemental irrigation requirement decreases from about 400 mm in the 250 mm rainfall zone to 100 mm beyond the 500 mm zone. Scarcity of water resources, however, allows minor percentages of the area to be supplemented by irrigation, thus water should be used efficiently. When we calculate the probabilities of the irrigation amount needed in contrasting rainfall zones, we can see that in 20% of the cases, about 500, 400, 300, and 100 mm irrigation water would be required in 250, 350, 450 and 530 mm rainfall areas, respectively. In 80% of the cases, around 350, 250, 200, and 100 mm irrigation water would be needed in 250, 350, 450, and 570 mm rainfall zones, respectively.

This shows that more water would be needed to achieve the potential yield of wheat in drier areas, therefore relatively more drought-tolerant barley should be grown

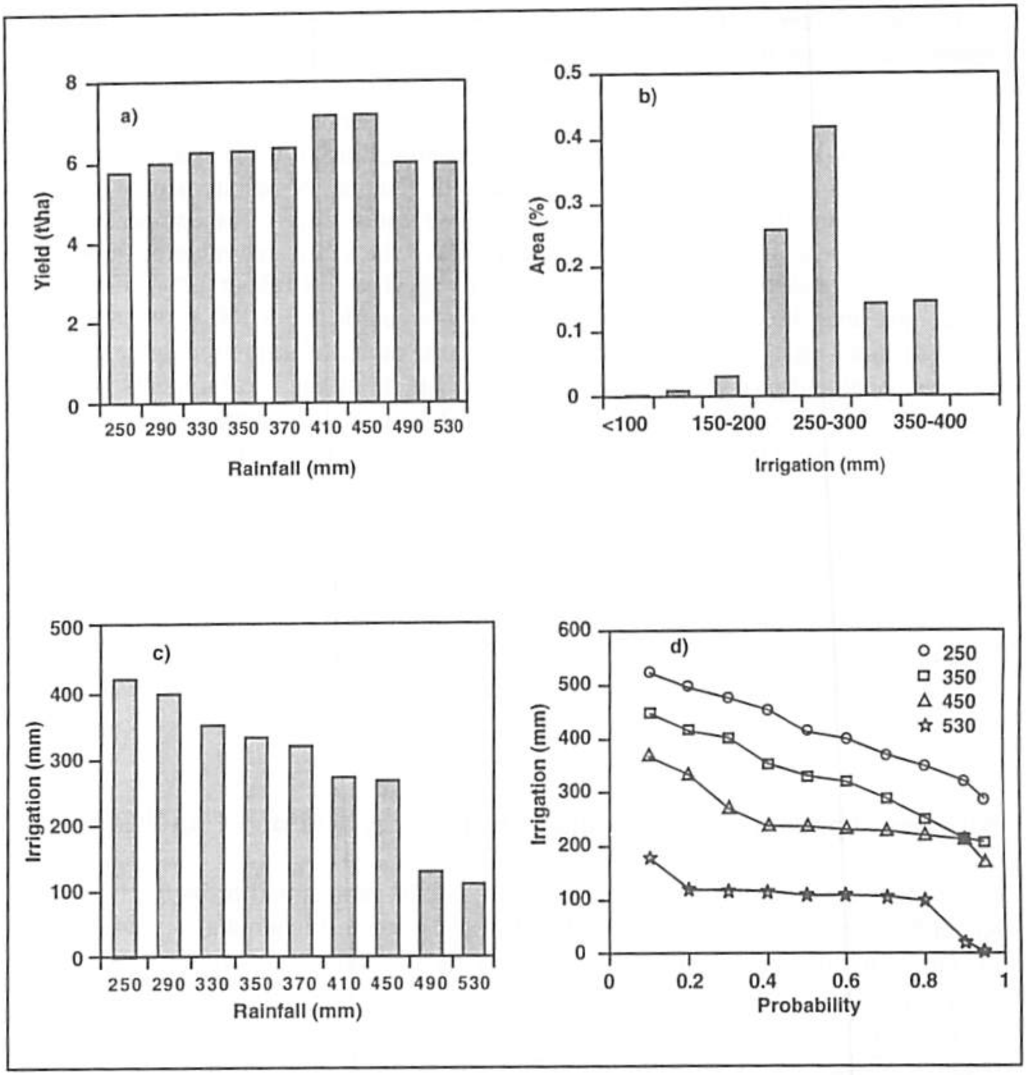

Fig. 1. Mean durum wheat yield across rainfall regions (a) percentage area of ranges for irrigation requirement (b) irrigation requirement vs. rainfall (c) and probability distribution of irrigation requirement (d) under supplemental irrigation conditions.

in drier areas under rainfed conditions and available water should be allocated to other suitable cash crops for its efficient utilization. However, farmers in the region are stilll applying more water than necessary to increase the wheat production (Pala and Rodriguez, 1992). Thus, farmers' water management strategies have to be re-considered by researchers and decision-makers for efficient utilization of these sparse resources.

Parallel to yield levels under supplemental irrigation, N requirement is also not affected by rainfall since more irrigation applied under drier areas compensates the water deficit (Fig. 2). About 10, 30, 25, and 17% of the study area requires 90-95, 95-100, 100-105, and 105-110 kg N ha^{-1}, respectively. The rest (about 22%) of the area needs more than 110 kg N ha^{-1}. Average N requirement is about 100 kg N ha^{-1} under supplemental irrigation conditions depending on the rainfall distribution in the growing seasons. These results are in agreement with data from field experiments studying wheat response to supplemental irrigation and N application in the same study area (Oweis and Pala, 1994; Perrier and Salkini, 1991) showing a usefullness of crop models to extrapolate the results from a few experiments to a wider region. In 20% of the cases, N requirement is about 100, 110, 130 and 140 kg N ha^{-1} in 250, 350, 450 and 570 mm rainfall zones, respectively. In 80% of the cases, N requirement is about 75, 90, 105, and 115 kg N ha^{-1} in 250, 350, 450 and 570 mm rainfall areas, respectively. These results indicate that N use cannot be recommended as blanket application for large areas, thus it should be modified according to agroecological conditions of a given area with the optimum supplemental irrigation if water is available for increasing input use efficiency.

Nitrogen Application on Durum Wheat under Rainfed Conditions

Yield increases linearly from about 0.5 t ha^{-1} in 250 mm rainfall areas to about 5.5 t ha^{-1} at 530 mm rainfall, and then levels off with the increasing amount of rainfall (Fig. 3). This is in good agreement with a study on the assessment of environmental factors on wheat response to N fertilizer (Pala et al., 1992). About 65% of the area needs 50-80 kg N ha^{-1}, about 17% of the area needs 20-50 kg N ha^{-1} and 18% of the area requires 80-120 kg N ha^{-1} for more efficient fertilizer use for wheat production. Nitrogen requirement of wheat also follows the yield increase and ranges from 25 kg N ha^{-1} in the 250 mm rainfall zone to 110 kg N ha^{-1} in 500 mm areas, showing a good agreement with previous on-farm wheat fertilization study (Pala et al., 1992). Therefore, using modeling in combination with GIS technology would be recommended as a useful tool to extrapolate limited experimental data to a larger region for efficient use N fertilizer.

Looking at the probabilities of obtaining yield, in 20% of the cases it is about 1.5, 3.0, 5.0, and 6.0 t ha^{-1} in 250, 350, 450, and 570 mm rainfall areas, respectively. In 80% of the cases, yield is about 0, 1.0, 2.5, and 3.5 t ha^{-1} in 250, 350, 450, and 570 mm rainfall zones, respectively. This shows that production of wheat is risky in <300 mm rainfall areas. Thus it should leave its place to more drought-tolerant crops such as barley in drier areas.

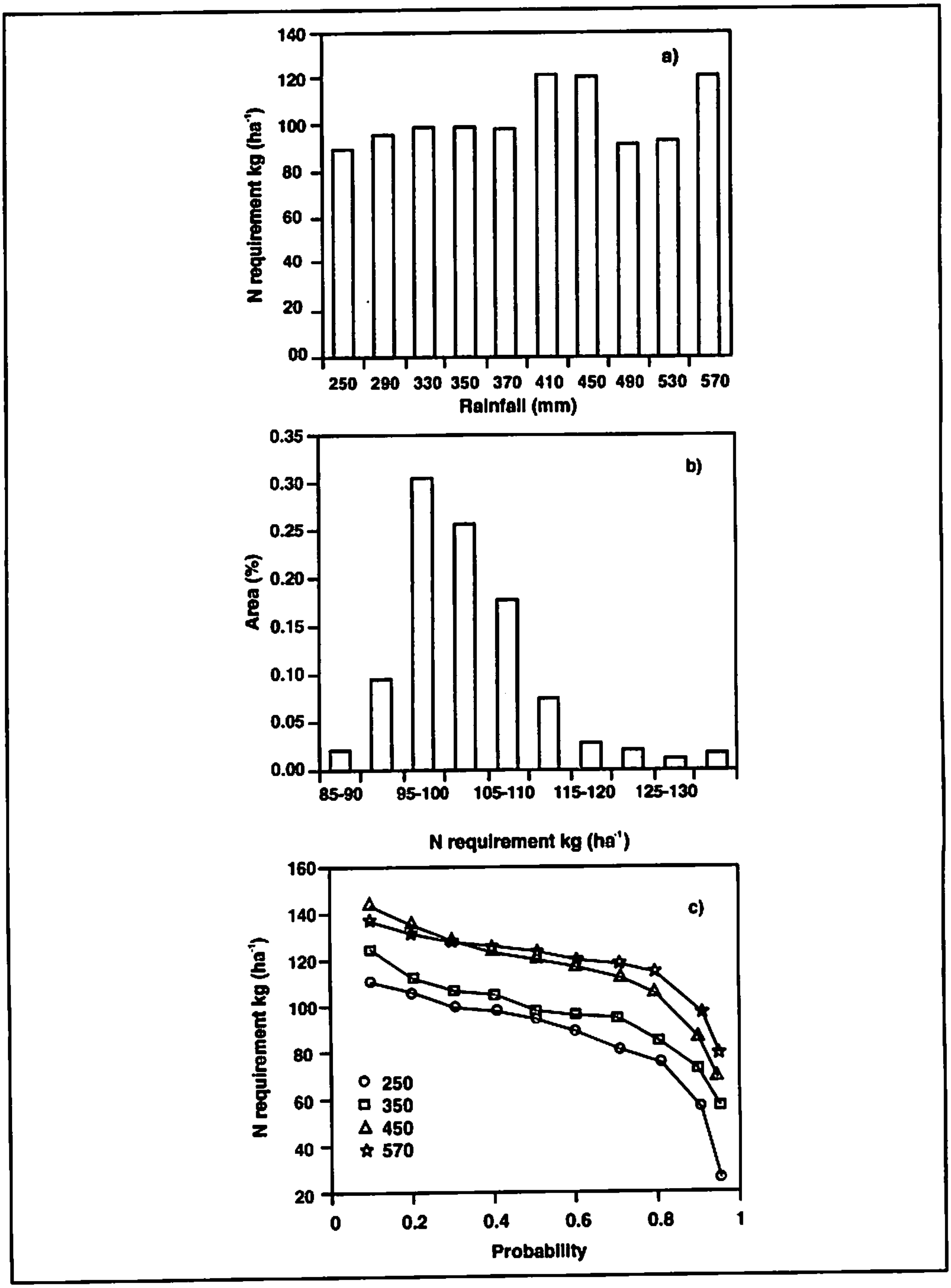

Fig. 2. Nitrogen requirement of durum wheat under different rainfall areas (a) percentage of area for ranges of N requirement (b) and their probability distributions (c) under supplemental irrigation conditions.

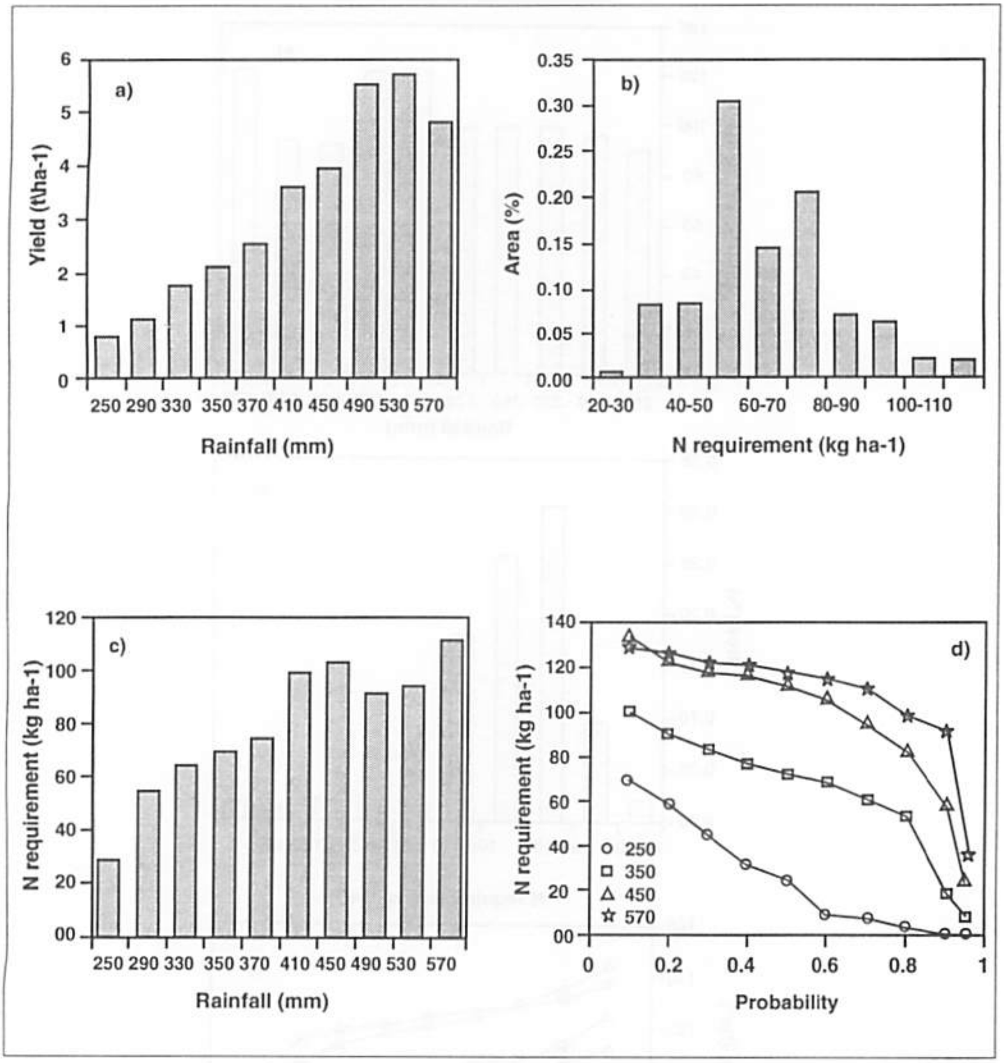

Fig.3. Mean durum wheat yield across rainfall areas (a) percentage area of ranges of N requirement (b) N requirement vs. rainfall (c) and probability distribution of N requirement (d) under rainfed conditions..

In 20% of the cases, N requirements are about 50, 80, 120, and 120 kg N ha^{-1} in 250, 350, 450 and 570 mm rainfall areas, respectively. In 80% of the cases, N requirements will be around 5, 50, 85, and 100 kg N ha^{-1} in the respective rainfall zones, respectively. These results show that N use in <300 mm rainfall areas is an uneconomical option for producers and should be adjusted according to rainfall events later in the season.

Conclusions

Good agreement of the simulated yield and N use with observed data under supplemental irrigation and rainfed conditions has positive implications of cropping systems simulation models as complementary tools for field trials in the region. With this point in mind, improved models can assist in identification of cropping systems with respect to water and N use in the areas where no field trials have been conducted. These models show promising results in assessing the impact of climate variability in combination with soil characteristics on crop production of different regions in relation to water application N fertilization which is very important for decision-making in deciding water management and fertilizer allocation as well as their efficient use. Thus, the productivity of cropping systems and the probabilities of range of yield levels can be predicted under different management options with N use in multi-year sequence to make better decisions and help in research priorities in this area. However, promising models need to be validated for other regions before being utilized extensively.

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3. Phosphorus in Dryland Agriculture

Future Direction of Phosphate Fertilization in the Mediterranean Area

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Abstract

Research in the West Asia-North Africa region has already established the reliability of the Olsen P test in monitoring the availability of soil P, and has set 6 ppm P as the threshold value for response to P by cereals and legumes. Application of this norm, in combination with machine-drilling of the seed and fertilizer, can substantially increase food and feed production in the region. It is argued that particular care needs to be taken for soil fertility to be sufficiently high in the high-rainfall years in order to secure high yields in such years. The time it takes for available P buildup after regular P applications, which may reduce or eliminate the need for P fertilizers, needs to be precisely determined. This will indicate how often the soil should be analyzed and what P rate is required to maintain a desirable soil P threshold value. In irrigated crops, localized irrigation, particularly with drip systems, enables the application of part of the fertilizer or even all the fertilizer through the irrigation stream (fertigation). This new technique requires further research. Finally, it is proposed that application of farmyard manure to dryland crops should be tested for supplying N, P, K and micronutrients, and improving the physical properties of the soil. This will, additionally, facilitate the disposal of the increased amounts of manure that are expected to be available in future.

Introduction

It is readily acknowledged that in the Mediterranean environment rainfall limits crop yields. However, it is not usually recognized that low soil fertility may often be more limiting than rainfall. Indeed sufficiently high soil fertility is required to enable farmers to take full advantage of whatever rainfall occurs. In Cyprus, for example, yields of barley over a 12-year period are expected to be in the classes: *good, slightly above average, slightly below average* or *bad* in the same frequency, i.e., each class prevails in three years (Orphanos, 1994). Of the total yield over the 12-year period, three quarters was produced in 6 years. Conversely, only one quarter of the total yield was produced in the remaining 6 years. This emphasizes the importance of maintaining high fertility in order to fully exploit the high-rainfall years. Critical stages are often invoked in relation to rainfall, but they have not been sufficiently proven (Hadjichristodoulou, 1982). In Cyprus, where barley may suffer moisture stress at any time throughout the season, high yields are associated with adequate rainfall, more correctly soil water, throughout the season. As the water requirement of the crop has been determined to be 240 mm, i.e., it closely matches the average rainfall (Metochis and Orphanos, unpublished). So successful growing of barley in Cyprus is simply due to the rainfall meeting the water requirement of the crop rather than drought tolerance of the crop other than its ability to survive dry periods.

It is usually thought more than proved that bare fallowing in semi-arid areas will enable two seasons' rainfall to be conserved for growing a single crop. However, Orphanos and Metochis (1994) showed that only in a high rainfall year can a sizeable amount of water be conserved. For this stored water to prove useful the crop, the year must be dry. So essentially a potentially high-yield year is sacrificed for a questionable yield increase in a dry year. A long time ago, Littlejohn (1946) recognized that the main effect of fallow was not conserved water but increased N, and possibly P, supply. He reported continually grown, and fertilized, wheat to yield twice as much as wheat grown unfertilized after fallow and four times as much as wheat grown continually without fertilizer. It appears that a suitable crop rotation with sufficient fertilization and good management, including machine-drilling, will promote substantially increased food and feed production in the region.

Soil Fertility

Brief reference to soils in the region has been made by Matar et al. (1992). In short, the soils are predominantly calcareous, but they are rather diverse. Fertility-wise, they are low in organic matter, N and P, but are mostly well supplied with potassium. Typically, for Cyprus, for example, organic matter is about 1%, N 0.1%, P 4 ppm (Olsen P), and K 250 ppm (NH_4OAc-extractable). Crops need to be supplied with N and P, but usually not with K. However, for high-value irrigated crops, farmers often need to apply some K. Also, research in the region, and in other parts of the world, has shown the reliability of the Olsen P test and the NH_4OAc-extractable K test in assessing the P and K-supplying power of the soil, respectively, and in guiding fertilization recommendations. In contrast, soil testing for N is still unsatisfactory, in addition to being cumbersome both with regard to soil sampling and analysis.

Soil Phosphorus

Most soils in the Mediterranean region are inherently low in P (<4 ppm Olsen P), and therefore respond markedly to applied P. In extreme cases (very low P) the response is modified by other limiting factors, e.g., N (Krentos and Orphanos, 1979), and becomes an interaction-type response governed by the most limiting factor (Liebig's Law of the Minimum). The chemistry of soil P is extremely complex. A brief account of what is to be expected in Mediterranean soils is given by Matar et al. (1992) and Torrent (1992). The two most important practical aspects of this complexity are that *P moves very little in the soil*, and it *interacts with the clay fraction and calcium carbonate*; its availability is thereby reduced. Montmorillonite is the predominant clay mineral in Mediterranean soils (Torrent, 1992), but $CaCO_3$ contributes clay-size particles in direct relation to its concentration (Gal et al., 1974). For example, in a highly calcareous soil in Cyprus which contained 40% clay and 50% $CaCO_3$, one third of the clay fraction was clay-size $CaCO_3$ (Orphanos and Kokkinos, 1983).

It is often assumed that calcareous soils are inherently of reduced productivity. This does not seem to be true. However, excess water conditions promote lime-induced chlorosis. Particular care is therefore required in irrigating calcareous soils. With the new methods of localized irrigation, water application can be easily manipulated to prevent such chlorosis and secure very high yields. In this respect, two notable examples from Cyprus can be quoted: one is the high yields of rainfed grapes (up to 25 t ha^{-1}) on soils containing up to 80% $CaCO_3$, and the other is the high yield of citrus (80 t ha^{1}) on soils containing up to 50% $CaCO_3$.

Responses to Phosphorus Fertilization

Threshold Values

Sufficient work has already been carried out in the region to illustrate the P/yield relationships. Results from the different countries have set 6 ppm Olsen P to be a valid threshold value with regard to response to P by cereals and legumes. Work in the region has also established a P-rainfall relationship. At slightly less than 6 ppm Olsen P, response to P is only obtained if rainfall is low (Matar, 1977; Krentos and Orphanos, 1979; Harmsen et al., 1983; Orphanos, 1996). However, this may have caused some confusion at a time when certain countries were still considering and wondering about the need to apply P. Moreover, the significance of this may have been over-emphasized.

In a year of low rainfall, yield is low, and even a relatively high response to P will still leave yield at a low level. Conversely, a small relative response to P when rainfall is high may cause a higher yield increase than at low rainfall. To show this, more refined experimental work is required. In any case, Matar et al. (1992) aptly suggested that for cereals and legumes a threshold value of 10 ppm Olsen P should be aimed at to cater for the range of soils and climatic conditions of the WANA region.

In considering P fertilization--indeed fertilization in general--a clear distinction needs to be made between annual and perennial crops. In the latter, their permanent structures (branches, trunk, roots) serve as a store for nutrients, which buffers them against temporary nutrient deficiencies. Thus, well-nourished trees will continue to produce high yields for a few years after fertilization is discontinued. Thus, annual crops need to be considered separately, as rainfed or irrigated. Reference to rainfed cereals and legumes has already been made. Irrigated crops produce larger and higher-value yields; hence the promptness of farmers to apply even excess fertilizer, including P, and the tendency of fertility experts to recommend higher threshold values. As with rainfed crops, there seems to be an interaction between response to P and irrigation. Thus, out of 21 potato experiments reported by Krentos and Orphanos (1979), response to P was obtained in four experiments, in two of which soil tests were 8 ppm Olsen P or less, but in the other two the soil tested 34 and 56 ppm P. In the latter two, irrigation was traced to be deficient and erratic. More recent work with potatoes has set a threshold value of 17 ppm Olsen P (Maier et al., 1989).

Residual Phosphorus

It is not usually appreciated that, despite fixation, available soil P builds up fairly quickly. Work in the region has shown this (e.g., Jones and Matar, 1990), and soil P surveys confirm it. For example, in Tunisia 84% of the surveyed soils contained more than 10 ppm Olsen P (Gharbi et al., 1990). Results from a long-term experiment in Cyprus (Orphanos, 1996) indicate the course of soil P over an 11-year period (Table 1) and demonstrate the residual effect of fertilizer P on yield of barley. Moreover, a P balance made after five annual applications of 30 or 60 kg P ha^{-1} showed that 29 and 26% of applied P, respectively, could be accounted for as P removed in the extra yield and as increased Olsen P. As yield was essentially the same with 30 or 60 kg P ha^{-1}, the almost identical percent recovery of P also reflects the increased P concentration in the harvested dry matter.

In the above-mentioned study the soil was a sandy loam containing 20% $CaCO_3$. In another study with a highly calcareous loamy soil (75% $CaCO_3$), typical of the rainfed vine-growing areas of Cyprus, a similar course of soil P was observed: The initial P level of 6 ppm increased to 24 ppm after 10 annual applications of 40 kg P ha^{-1}. For the next 6 years without fertilization, the value declined to 15 ppm, while with an annual dressing of 30 kg P ha^{-1}, the value increase to 31 ppm P. It is fortunate that the inherently available soil P (initial P value) is strongly buffered, i.e., it remains constant after long years of cropping (Halvorson and Black, 1985; Selles et al., 1995).

Table 1. Olsen P values as influenced by five annual applications (1980-84).

Sampling date	Fertilization	P Rate (kg ha^{-1})		
		0	30	60
		ppm		
29/1/80	Yearly	4.0	4.0	4.0
18/11/83		4.3	15.0	30.0
23/9/85	Discontinued	4.0	15.5	24.8
10/6/87		3.9	7.1	12.4
10/11/88		5.1	7.4	10.4
22/10/89		2.9	4.6	6.7
23/10/91		3.1	4.1	5.4

Application Methods

Band application of P has been extensively shown worldwide to be more efficient than broadcast application. However, this need not be over-emphasized because, on the one hand, annual crops must be sown by machine, which automatically permits banding the fertilizer, and, on the other hand, the soil is usually cultivated and therefore residual P is mixed with the soil, irrespective of mode of application. Then for irrigated crops, application of the water through pressurized systems facilitates applying, if not all, at least part of the fertilizer dissolved in the irrigation water (fertigation). It could be argued that sowing machines and pressurized irrigation systems alike are expensive. They are, but machine-sowing will pay back quickly. Then pressurized (closed) irrigation systems, on one hand, almost eliminate conveyance and application losses and, on the other hand, enable very high yields to be obtained, thus vastly increasing water-use efficiency (yield produced per unit of available irrigation water).

Phosphorus Carriers

For machine-drilling, the fertilizer needs to be in granular form, and since N also has to be applied, a compound or mixed fertilizer must be used. This restricts the accuracy with which one of the elements can be applied on the basis of soil analysis because compound fertilizers of only a few N:P ratios can be available on the market. So compromises will have to be made. As pointed out by Matar et al. (1992), farmyard manure has not been tested in the region for its immediate and long-term power in supplying P. Manure also supplies other nutrients, including micronutrients, and influences the physical properties of the soil. With the expansion of livestock production, the increased quantities of manure will need to be disposed of, irrespective of their nutritional worth. In Cyprus, farmyard manure has long been considered highly beneficial for rainfed cereals, but it has not been tested in field experiments. However, its value for citrus (irrigated) has been shown (Orphanos et al., 1986) to be equal to that of chemical fertilizer, supplying the same amounts of N and P.

Future Direction

Total soil P comprises 0.05 to 0.10% of the soil, i.e., it is 100-fold more than that available for uptake by crop plants (Al-Abbas and Barber, 1964). Recent developments in genetic engineering have sparked hope that genetic manipulation of crop plants may enable the plant to exploit soil P sources hitherto unavailable for plant uptake. Such manipulation was recently discussed at an international meeting at ICRISAT; Johansen et al. (1995) indicated that mycorrhizal association and exudation could be promising lines for research. However, any practical results from this research area are not envisaged in the near future. So the region will continue to rely on the use of fertilizer P by applying the established norms and pursuing further research along traditional lines.

In pursuing soil testing the region has tacitly agreed to follow the "sufficiency" approach *vis-a-vis* the "building-up and maintenance" approach. As Olsen et al. (1987) have indicated, soil testing is a science only if it employs the *sufficiency* concept. This leads not only to more efficient use of fertilizer but also to reduced environmental pollution, and avoidance of induced deficiencies of zinc and manganese.

Application

The present state of our knowledge allows confident recommendations for P fertilizing. The factors building this confidence are: 1) a reliable soil P test (Olsen test), 2) the slow change of available soil P with time, and 3) the establishment of threshold values for response to P. For best results, other management practices must be improved. For rainfed cereals and legumes, combined machine and fertilizer drilling is indispensable. In any case, sound P fertilizing is possible in the region. The appropriate strategy will have to be developed in each country to cater for soil analysis, and making the recommendations and securing their implementation.

Research

Research will always be required to back up any fertilizer-use strategy. Following the adoption of the Olsen P test and the arrival at threshold values, the course of available soil P with time resulting from P application, or after P fertilizing is discontinued, will need to be determined. To this end, long-term experiments will be required under farmers' conditions. The practical answers sought are: how often should the soil be analyzed? What annual P rate is required to maintain a desirable soil P threshold value? What is the response to P in high rainfall years in relation to soil P?

When localized irrigation, particularly drip irrigation, is used, only part of the soil volume is wetted (usually around 30%) and thereby exploited for nutrients. However, the root system is more profuse in the wetted layer, presumably foraging for nutrients more efficiently. In any case, the expected expansion of trickle irrigation in the region warrants experimentation for the P requirement under these conditions. In addition, Olsen et al., (1987) proposed that soil sampling depth, the state of the soil (moist or dry) to be analyzed and the way to sample under no-tillage conditions need to be researched. However, the region does not need to go into these issues in the near future as it will benefit from work to be carried out in other parts of the world.

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Potential Benefits of Phosphorus Fertilizer on Marginal Lands

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Abstract

An experiment which has been carried out over 12 years (since 1984/85) at Tel Hadya, in northern Syria, showed that broadcast application of superphosphate to non-arable lands (also called *marginal lands*, because grazing is the only possible use), which contain annual legumes, stimulated leguminous growth and reduced nitrogen deficiency, leading to increased herbage production. Phosphate fertilizer was applied at three levels: 0, 11 and 26 kg P_2O_5 ha^{-1} every year for a 7-year period (1984-1990). Annual applications of 11 and 26 kg P_2O_5 ha^{-1} raised the Olsen-P values in the soil from approximately 7 mg kg^{-1} to about 20 and 40 mg kg^{-1}, respectively, by the end of the seventh season (July 1991). The direct effect of P application was observed in improved legume and total herbage yields, and in improved productivity in sheep grazing the pasture. Also, significant effects of residual P have been recorded long after the initial application of fertilizer. The response to P in drought when drought was more accentuated suggests that a higher critical level for available P should be considered for low moisture-regime situations. The study clearly shows the value of using P fertilizer, even at modest levels, for forage production in marginal land.

Introduction

Mediterranean pastures in West Asia and North Africa (WANA) can be classified, based on climatic and edaphic factors, into: a) *badia* or *steppe* pastures, which are characterized by flat lands with deep soils that can be cultivated for growing cereal crops (barley), but due to the erratic rainfall the probability of harvesting a crop is one in every 10 years; and b) *marginal land pastures*. The latter types are non-arable lands within the cereal zone (edaphic more than climatic factors are most important). They are controlled by individual or groups of villages and provide grazing primarily in the spring, although sheep continue to graze them through the summer. These pastures constitute a considerable proportion of the total surface area of many countries in West Asia, i.e., 30 to 50% in Syria and Lebanon, and over 350,000 ha in Jordan. Marginal lands are intensively grazed by sheep and goats, and normally suffer from severe overgrazing and soil erosion.

Despite all these difficulties, marginal lands are considered important for people using them. For example, a study by Nordblom and Thomson (1987) demonstrated that farmers with access to marginal land grazing could own more sheep and would have more profitable livestock enterprises than farmers without such access. Marginal land pastures are heavily utilized in the spring, but because marginal land is not productive in its present condition, livestock owners must use large quantities of supplementary feeds (barley grain, cereal and legume straw, and crop by-products). Improving the productivity of marginal pasture is therefore expected to reduce the need for supplementation and improve their carrying capacity.

Soils

Mediterranean pastures in West Asia are associated with diverse soils, but calcareous soils are predominant. Calcium carbonate has a great influence on the chemistry of these soils and deficiencies of major elements such as N and P are widespread (Velk et al., 1981; Cooper et al., 1987). Soils which contain less than 10 mg P_2O_5 kg^{-1} ($NaHCO_3$ extract) do not provide the 0.2 mg P in the soil solution which is necessary for maximum plant growth (Andrew, 1962; Asher and Lonergan, 1967). A survey on marginal lands in Syria (Ehrman and Cocks, unpublished) indicated that 25% of the pastures has P levels less than 10 mg kg^{-1}, while in another survey (Turk, 1988), the figure was 40%.

Vegetation

Vegetation cover on Mediterranean pastures consists of annuals grasses and legumes, but perennial species can also be found in areas with high rainfall. The most common legumes on marginal land pastures are species of *Medicago* and *Trifolium*. Mediterranean pastures are found in other parts of the world, such as North and South America and Australia, where productivity has been improved as a result of P application and seeding with suitable medic and clover species (Donald, 1970; Jones et al., 1970).

In the present study, the effects of three rates of P and two stocking rates were investigated in northern Syria, to test the hypothesis that application of superphosphate to marginal land containing annual legumes could stimulate the legumes and eliminate N deficiency, and so lead to increased production, and that the effect of fertilizer will continue beyond the years of application. Significant effects of residual P have been reported on succeeding crops in many countries of the Mediterranean basin (Kacar, 1972; Orphanos, 1988; Abdel Monem et al., 1990).

Materials and Methods

The experiment was conducted at Tel Hadya farm (35° 55' N,36° 55' E, altitude 362 m) of the International Center for Agricultural Research in the Dry Areas (ICARDA), 35 km south of Aleppo in northwest Syria. Tel Hadya has a mean annual rainfall of 330 mm and an average growing period of 6.5 months. The climate is Mediterranean, and rain falls normally from October to May.

The experiment was conducted on undisturbed native grassland. The predominantly annual vegetation included a few low shrubs, perennial grasses, and herbs. The soil is calcareous, with pH ranging between 7.8 and 8.4. Soil organic matter and available P averaged 3.5% and 5.8 mg kg^{-1}, respectively. The slope is moderate (3.7 to 7.2), while 30 to 40% of the ground is covered with stones and the soil depth varies from a few centimetres to about 50 cm. In the original experiment, triple superphosphate, supplying 0 (referred to as P_0), 11 (P_{11}) and 26 (P_{26}) kg P_2O_5 ha^{-1} was applied annually in September, and two stocking rates, low and high, were tested. The experimental design was a randomized complete block with three replications, and the *total area* of the experiment was 85.5 ha.

Initially, five ewes aged 2 to 6 years grazed the plots of 6.5 ha or 3.0 ha, representing the low (0.8 sheep ha^{-1}) and high (1.7 sheep ha^{-1}) stocking rates, respectively, in each of the fertilized treatments. In the fifth season, two more ewes (one 3 and one 4-year old) were added to each plot, raising the stocking rates to 1.1 and 2.3 sheep ha^{-1}, respectively. The ewes grazed the plots for the whole year, from early morning to sunset, and were sheltered at night. Sheep were fed a supplement of barley grain during pregnancy and early lactation, and in July and August each year in preparation for mating. Barley and hay were also provided whenever the live weight of individual ewes fell below 43 kg. The lambs were weaned at 8 weeks of age.

Results and Discussion

Available Phosphorus

Available P was less than 10 mg kg^{-1} (i.e., ppm) at the beginning of the study in all treatments, but was significantly improved as the result of P application (Table 1). Surprisingly, there was no increase between 1986 and 1987, although there was a large increase in 1988. There was a gradual decline in P after 1990 following the cessation in annual fertilizer application. Also there was a steady decline in available P in the control treatment until 1988; the level remained below 10 ppm throughout the period of the study.

Herbage and Seed Yield

Total herbage production from the beginning of December is shown in Figure 1, and that of legume component in Figure 2. Significant differences due to application of P were recorded every year, though the difference between P_{11} and P_{26} was not significant except in years of severe drought (1988/89 and 1989/90). Differences in total herbage yield were greatest in spring, which also reflected both applied P rate and total rainfall, highest yields being at the highest P rate in 1987/88, when total rainfall was approximately 500 mm.

Herbage yield of legumes showed a similar pattern of total herbage productional though there were more sharp differences in favor of the P treatments over the control (Fig. 2). The responsiveness of pastures to P_{26} compared with P_{11} in 1988/89 and 1989/90, when available P at P_{11} approached or exceeded 20 mg kg^{-1}, suggests that a critical value of 10 mg kg^{-1} is far too low. If this is true, most grasslands in Syria suffer from P deficiency.

This also suggests that the critical level of 10 mg kg^{-1}, considered appropriate for cropped land, with high rainfall or supplemental irrigation cannot be used to

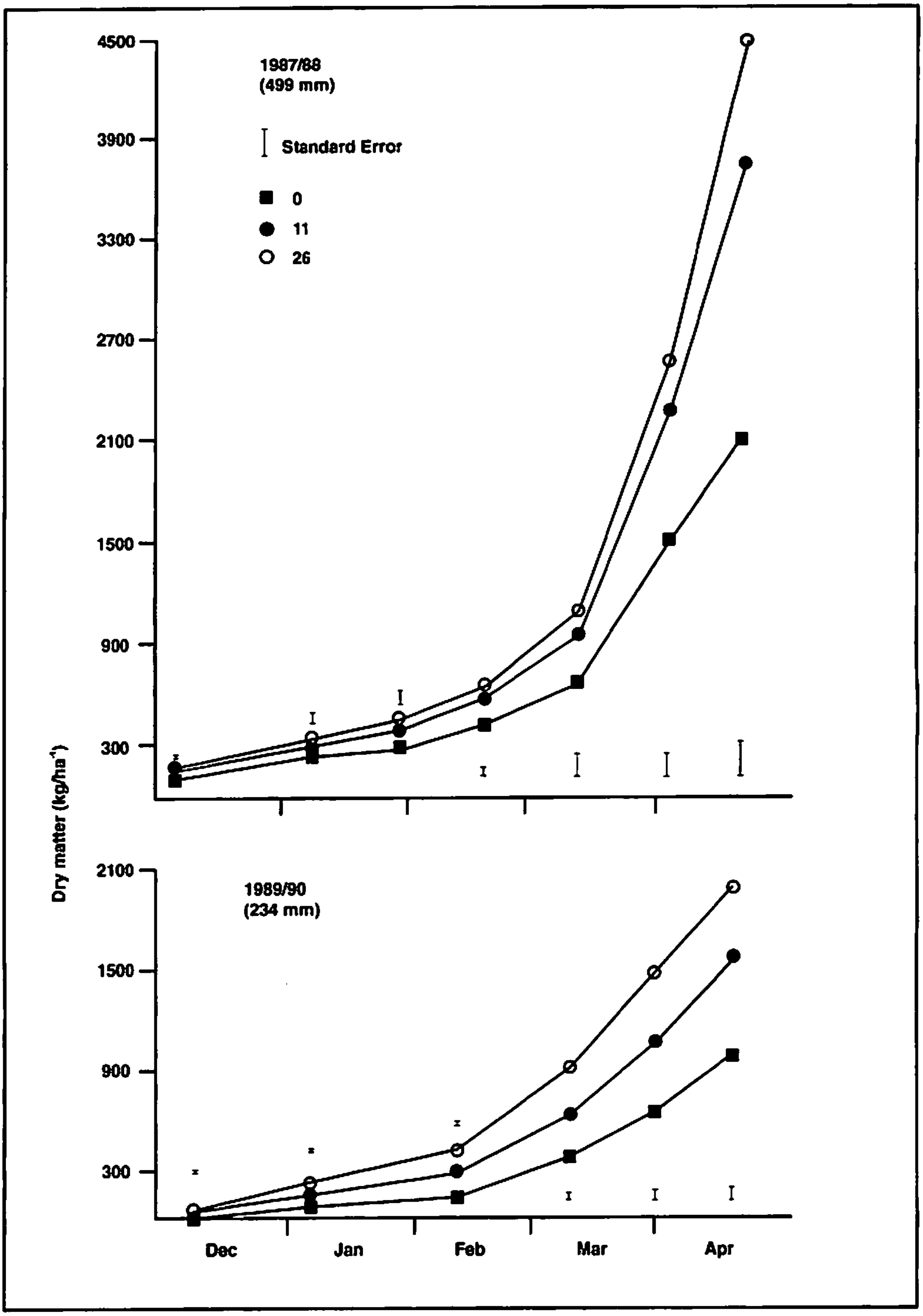

Fig.1. Total herbage production (legume + grazed + other species) at Tel Hadya after phosphorus fertilization in seasons of varying rainfall

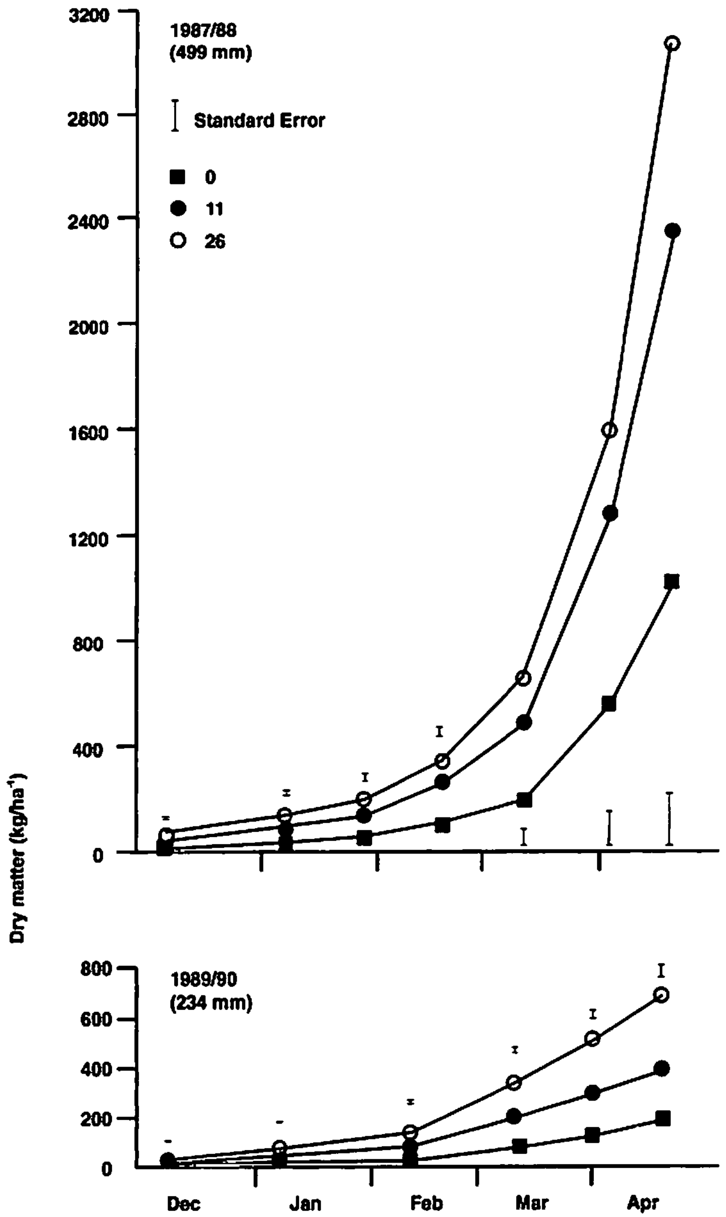

Fig.2. Total herbage yield of legume in grazed pasture at Tel Hadya after phosphorus fertilization in seasons of varying rainfall

Table 1. Available soil phosphorus under three phosphate treatments.

Year	Since Last Application	Phosphate Applied (kg P ha^{-1})			SE ±
		0	11	26	
	------ months -------	----------	mg kg^{-1}	----------	
1984	-	7.9	6.6	7.2	0.95
1985	-	8.3	13.2	26.8	2.30
1986	-	8.1	12.3	17.9	0.84
1987	-	5.0	9.4	16.2	0.88
1988	-	4.6	24.4	58.1	2.50
1989	-	7.1	19.0	41.8	2.69
1990	-	5.9	20.6	42.4	1.73
1991	8	6.5	20.8	40.1	1.56
1992	20	7.3	23.4	38.2	2.07
1993	32	7.2	12.8	24.8	1.29
1994	44	9.3	15.2	21.5	1.19
1995	56	8.3	13.2	26.8	2.30

Measurements made in May each year.

generalize for pastures on non-arable lands, where rainfall is the only source of moisture. According to Göbel (ICARDA, pers. comm.), the probability of having a season with less than 250 mm rainfall based on the last 17 seasons at Breda, Tel Hadya, and Jindiress is 23%, 46%, and <1%, respectively. The average rainfall for the above sites during the same period was 264, 329, and 446, respectively.

Residual effect of the P on herbage yield is shown for 1995 (Fig. 3), where the total herbage yield of legumes and all species showed similar trends as in previous seasons: a high accumulation of biomass at both P_{11} and P_{26} over the control, the difference being significant for legumes in April ($P<0.05$) and highly significant ($P<0.01$) for all species in the spring--February to April (Fig. 3). The differences between P_{11} and P_{26} were not significant, which is consistent with previous seasons, when rainfall exceeded 300 mm (Osman et al., 1991).

Conclusions

The experiment which has been carried out for 12 years suggests that the degradation of communally owned land in West Asia can be reversed by the use of P fertilizer, conservation and utilization of native legume populations. The direct effect of P application in this study has been observed in improved legume and total herbage yields (Osman et al., 1990, 1991; Osman and Cocks, 1993) and in improved productivity in sheep grazing the pasture (Bahhady et al., 1988; Osman et al., 1994). Results also showed that the annual applications of 11 and 26 kg P_2O_5 raised the Olsen-P values

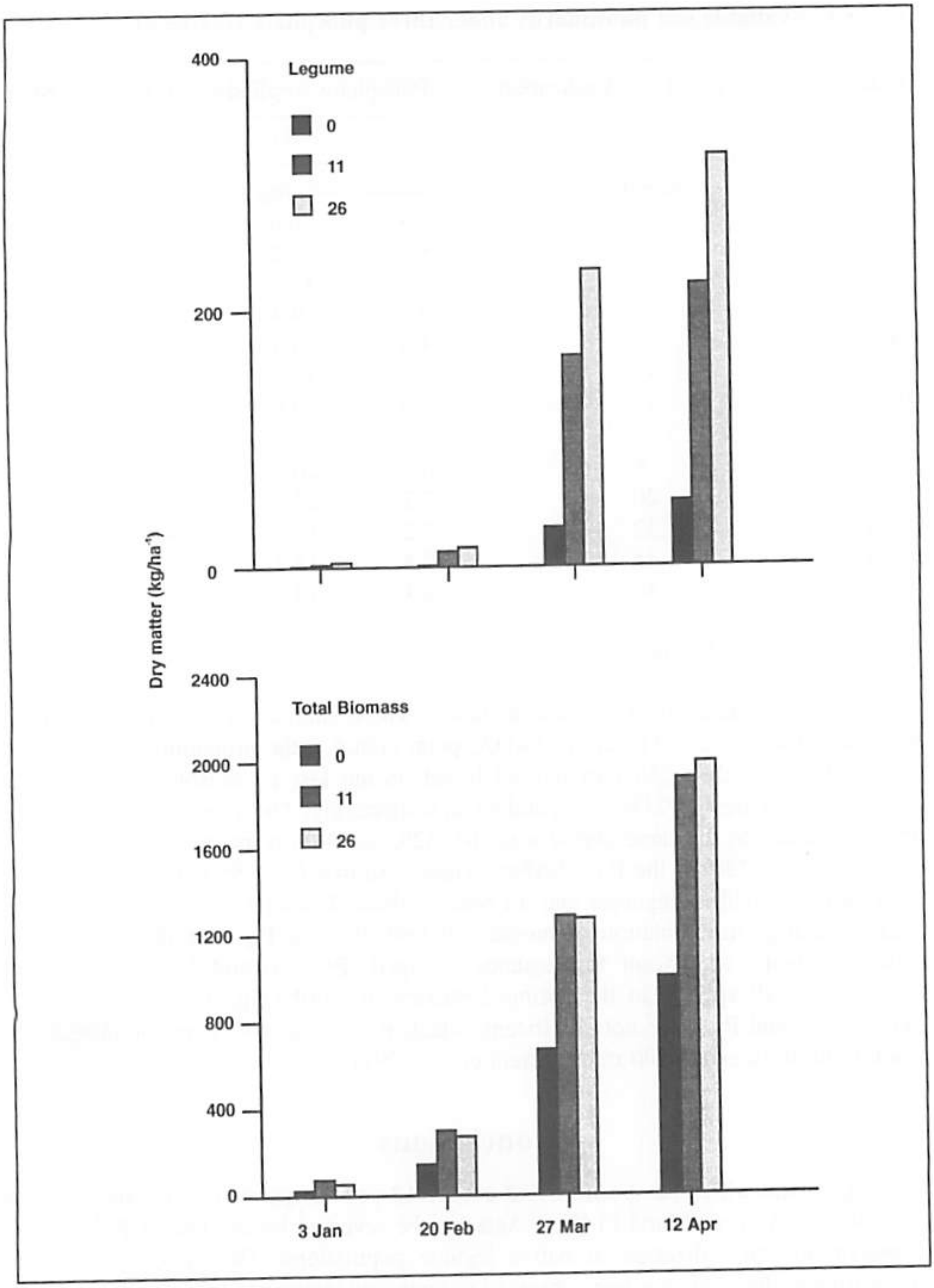

Fig. 3. Cumulative legume and total biomass as affected by residual phosphorus 1995 (312 mm)

in the soil from approximately 7 mg kg^{-1} to about 20 to 40 mg kg^{-1}, respectively, by the end of the seventh season (July 1991). Apart from the direct effect of the P, the residual effect of the fertilizer seems to carry on the positive effect long after the fertilizer application has stopped.

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Optimizing Phosphorus Nutrition for Dryland Cereals

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Abstract

While moisture is the major factor limiting crop growth in the rainfed Mediterranean zone, moisture also has a significant effect on the behavior of P in the soil and its relationship with the crop. Limited moisture restricts P mobility and positional availability. This paper reviews two novel approaches to improving P availability under rainfed conditions, i.e., banding or placement of fertilizer P with respect to the seed, and the use of vesicular-arbuscular-mycorrhizae which can potentially enhance the root's effectiveness to absorb soil P.

Introduction

Phosphorus fertility management is a major concern of farmers in dryland wheat regions. Soil moisture is an especially crucial factor that limits P mobility in areas with aridic and xeric moisture regimes. This places great emphasis on the proper assessment of soil management options for maximizing P availability during periods of water stress. The conventional method of shallow placement of P fertilizers in the surface layer of soil, which is widely practised by most farmers in dryland areas, is appropriate for supplying needed P to plants only if wheat is grown under adequate water supply. However, in low rainfall regions the surface layer of soil becomes dry and limits P movement and availability to plants. This suggests that alternative P placement strategies are required to keep the P fertilizer more available to plants during most of the growing season. In aridic and xeric moisture regimes, the soil surface layers often lack sufficient moisture during a major part of the growing season to maintain shallow root growth (Matar and Brown, 1989). In addition, the diffusion of nutrients of limited soil mobility, such as P, is greatly reduced as the surface layer dries. Under these conditions, plants become increasingly reliant on subsoil moisture and nutrients during later developmental stages.

Mycorrhizae: Their Potential Significance

An important consideration in the optimization of P nutrition of wheat is the growth and development of the plant root system and its ability to access and absorb nutrients. Symbiotic relationships between mycorrhizal fungi and plant roots have been demonstrated for a number of crop species (Jasper et al., 1989). Traditional agricultural practices such as monoculture, long fallowing, and heavy use of fertilizers have contributed to the decline in the native mycorrhizal populations in the soil. The possibility of enhancing the native population or introducing new vesicular-arbuscular mycorrhizal (VAM) species to enhance plant growth may be an important component of sustainable agriculture. These VAM fungi improve plant growth, primarily by increasing uptake of P and micronutrients from nutrient-poor soils.

Research conducted mostly in greenhouse experiments with sterilized soil has shown an increase in uptake of P and yield of wheat following VAM infection. Since P ions in the soil are relatively immobile, plant roots must expend considerable energy producing enough root biomass for adequate P absorption in soils with low P levels. The improved P uptake of mycorrhizal plants often results in a considerable increase in plant growth.

Responses to mycorrhizal symbiosis in the field are notoriously difficult to predict, partially because the majority of studies to date have been conducted with sterilized soils and almost exclusively in greenhouse pot experiments. Under these conditions, the effects of the soil microflora and other field conditions are not evaluated. Since most studies to date have examined the re-introduction of mycorrhizal fungi into sterilized soil, little information is available on the role of these mycorrhizae on the growth of plants under natural field conditions. It has been documented that mycorrhizal plants absorb more Cu and Zn and less Mn and Fe than non-mycorrhizal plants (Kothari et al., 1991). The mechanisms mediating Mn and Fe assimilation or exclusion by VAM fungi are not known. Several mechanisms have been suggested by researchers to explain the decreased Fe and Mn uptake by VAM infection. The most common explanations are:

- The uptake and translocation of Fe and Mn can be antagonized by P, Cu, and Zn (Pacovsky, 1986; Olsen, 1972).
- Nutrient requirements, tolerance or interactions may have changed for VAM-colonized plants (Gildon and Tinker, 1983).
- Changes in the pH in the mycorrhizosphere may have altered the oxidation states of Mn (Dacovsky, 1986).
- Low concentration of available Fe and Mn probably occur in VAM hyphae to avoid the precipitation of insoluble mineral phosphate or the complexation and inactivation of organic phosphates (Dacovsky, 1986).
- Mycorrhizal plants were found to decrease the Mn potential of rhizosphere soil because of the lower number of Mn-reducing bacteria (Kothari et al., 1991).
- Manganese is toxic to VAM (Hepper and Smith, 1976; Lambert and Weidensaul, 1991).

Micronutrient absorption by VAM plants is still unexplored, and it is potentially an important area to mycorrhizal research. More work is required to determine under what conditions these effects operate and how general these effects are. There is still debate whether or not the mycorrhizal plants can utilize the unavailable sources of soil P. Most researchers believe that the mycorrhizal and non-mycorrhizal plants utilize the same sources of P. Therefore, the conclusion was made that the mycorrhizal plants do not utilize unavailable P sources (Gerdmann, 1975; Barrow et al., 1977). Some researchers found no evidence that the fungi can dissolve insoluble forms or release fixed P. Several mechanisms have been suggested by which mycorrhizal plants can enhance the absorption of P and some micronutrients. Mycorrhizal plants can: 1) explore a greater volume of soil beyond the zone of P depletion, 2) lower the threshold concentration for absorption from soil solution, 3) produce exudates which enhance the availability of P, 4) alter the rhizosphere pH as a result of anion and cation absorption by mycorrhizal plants, and 5) solubilize organic P by the production of phosphataze enzymes.

The availability of nutrients in the soil depends not only on their concentrations in the soil solution (nutrient intensity factor), but also on the *buffering ability* of the soil to replenish and maintain their concentration (Marschner et al., 1987). If *diffusion* is the main process by which a plant nutrient is transported to the root surface, the concentration of a nutrient at the root surface is strongly affected by the *diffusion coefficient* and rate. Therefore, static measurements of nutrient concentrations in the soil solution are not representative of bioavailability. Diffusion kinetic parameters also determine nutrient availability to plant roots (Yang et al., 1991). The mycorrhizal fungi mainly increase the uptake of the nutrients that move by diffusion even when grown in dry soil where the diffusion rates of the nutrients are limited. It has been suggested that ion exchange resins, which combine measurement of nutrient *intensity* and *quantity*, be used to predict responses and dependence of crops to the mycorrhizae (Ojala et al., 1983).

Wheat Responses to VAM Inoculation of Eroded Soils

Symbiotic relationships between mycorrhizal fungi and plant roots have been demonstrated for many crop species (Jasper et al., 1989). The mycorrhizal association usually increases the growth of plants by enhancing water and nutrient uptake, especially P (Kucey and Janzen, 1987). For example, the biomass of maize and wheat were increased 306% and 220%, respectively, by mycorrhizal associations (Menge, 1983). The effect of VAM on increasing P uptake is generally more pronounced for plant species with coarse roots and sparse short root hairs. As a result, most studies of VAM have concentrated on P nutrition of plant species with coarse roots such as those of citrus and legumes (Hayman et al., 1975; Hayman and Mosse, 1971).

Information on the VAM influence on P nutrition and growth of wheat is limited and contradictory. Positive influences of VAM colonization on wheat yield in P-deficient soils have been reported (Hayman, 1970; Khan 1975; Dodd and Jeffries, 1986). A low level of available P in soil was compensated by a strong VAM colonization before the grain-filling period (Stoppler et al., 1990). When colonization occurred before anthesis, the biomass and grain yield were increased compared with non-colonized plants (Ellis et al., 1985). In addition to P, VAM enhanced the acquisition of relatively immobile micronutrient cations, particularly Zn and Cu by cereal crops (Kothari et al., 1991). When the topsoil is severely disturbed, the indigenous populations of mycorrhizal fungi are reduced. Under these conditions, Moorman and Reeves (1979) found that only non-mycorrhizal species were able to establish successfully, and that plant growth was greatly stimulated by mycorrhizal inoculation of these soils.

An experiment was carried out by Mohammad (1993) to characterize the pattern of VAM infection of field-grown winter wheat under dryland conditions and to determine if wheat responds to VAM inoculation under field conditions. The impact of soil microflora and field conditions on the successful establishment of the introduced species was assessed in non-sterilized soil. It was found that the VAM inoculation caused a rapid increase in infection at late tillering when the soil temperature had increased. The rate of increase was higher by inoculation when P was not added. Based on this, he concluded that VAM inoculation can increase dryland winter wheat production. He also indicated that this may lead to a further conclusion that the mycorrhizal population can be enhanced in the field and restored after their decline due to monoculturing, fallowing, and heavy use of chemicals. In addition, VAM inoculation can be used to compensate in part for the addition of P fertilizers and decrease the need for the use of chemical fertilizers.

Deep Phosphorus Placement in Dryland Wheat Production

Optimization of P nutrition is a critical component of dryland cereal production. Sub-optimal soil moisture limits P uptake of crops growing in aridic and xeric moisture regimes, i.e., arid and semi-arid areas. Proper assessment of soil management options is required for maximizing P availability during periods of water stress. Shallow placement of P fertilizers in the surface layer of soil, which is widely practised in the dryland areas, is appropriate for supplying needed P to plants when wheat is grown under adequate water supply; however, as the surface soil dries, P movement and availability to plants is limited. In addition, the surface layers often lack sufficient moisture during a major part of the growing season to maintain shallow root *growth* and activity. Under these conditions, plants theoretically become increasingly reliant on subsoil moisture and nutrients during later developmental stages. Pothuluri et al. (1986) suggested, from column experiments in the greenhouse, that if available P is inadequate in the surface layer of the soil, the crop (in this case, sorghum) will take most of its needed P from the subsoil layer.

The significance of the late-season dependence on subsoil fertility was suggested in a recent study of an eroded soil (Pan and Hopkins, 1991). Available P in the subsoil was extremely low, and barley was observed to decrease in above-ground P during grain-filling, despite shallow P placement at planting. These observations provided indirect evidence of a late season P deficiency due to inadequate subsoil P. The decrease in the above-ground plant growth suggests that P fertilizer should be placed deeper to be in the region of the active root zone for improved P availability throughout the growing season. The need for P nutrition during later growth stages has been debated for over 70 years. In the 1920s it was reported that small grain crops take up all their P during the first 4 weeks of the growing season (Gericke, 1925). It was concluded then, and it became a common belief, that P applied later and taken up during the late growth stages would not enhance crop yield. More recently, the late application of P was observed to delay senescence and increase shoot dry matter and the P content of the grain, but this did not cause an increase in grain yield of wheat cultured in sand (Batten and Wardlaw, 1987; Stuart and Wardlaw, 1988). It has been shown by other researchers that the time that P is supplied to the plant is an important factor influencing the growth of wheat, and that maximum grain yield production occurred when P was applied through the early grain formation stages.

The rapid sorption of P by soil colloids prevents P movement from the application point, and therefore P placement becomes critical for optimizing P availability. The effects of deep P placement have been inconsistent and controversial. In addition, the experiments have had complications of tillage effects and the absence of suitable control treatments. These factors confound the interpretation of experiments on deep P placement (Alston, 1980). Several researchers have reported yield or late season P uptake responses to deep P placement. The yield or P content of wheat and sorghum increased when the subsoil was fertilized. Increasing the depth of P application (15 cm below the seed) for field-grown wheat increased grain yield compared with the placement with the seed or at a 5-cm depth (Singh, 1961; McConnell, 1986). In other experiments, incorporation of P and K into the subsoil increased potato yields by 16% and barley yields by 20%, but the yield of wheat was not affected (McEwen and Johnston, 1978).

Available P in the surface layer of soil is mainly used by the nodal roots of cereal crops (Cornish, 1987). Thus, shallow-placed P should be banded beside or below the seed to be positionally available during early growth stages. Banding P fertilizer has usually resulted in greater yield response in corn compared with broadcasting when P application rates were low (Yao and Barber, 1986). Compared with broadcasting, banding reduces soil-to-fertilizer contact, resulting in less P fixation by soil. One of the disadvantages of the banded fertilizer placement is the lower probability of root interception, which is believed to be the key factor in determining the efficiency of P uptake from banded P (Barber, 1984). Broadcast-incorporation of P fertilizer improves *the* probability of interception between roots and P fertilizer and also improves the early access to P. A combination of both broadcast and banded application may provide optimal P availability.

Experiments were carried out by Mohammed (1993) at two sites for dryland wheat in semi-arid and sub-humid environments to determine if subsoil P placement alone or in combination with shallow P placement provides better P availability than either P placed with the seed or as a shallow band. Results of these experiments at the two sites showed that P placed in the subsoil or at an intermediate depth below the seed increased grain yields at both sites compared with the P placed with the seeds. He concluded that deep placement of P with sub-soiling equipment increased the late-season P fertility. The late-season availability of water was also enhanced by the deep P through a stimulation of root growth in the subsoil. Deep P availability is important to the growth and development of wheat grown in winter-rainfall climates. The results illustrated that the increase in the subsoil fertility by deep P placement enhanced wheat growth and grain yield. This indicates the benefit of subsoil P application, when the topsoil P becomes positionally unavailable to plants during later stages of growth due to water stress.

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Soil Fertility Research in Yemen: Nitrogen and Phosphorus

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Abstract

Wheat and barley cultivation comprize 12 and 6.1%, respectively, of the total cultivated area in Yemen. Their cultivation is mostly concentrated in the northern highlands, central highlands and southern uplands, which have different climatic conditions. Many fertility experiments have been conducted to find the proper fertilizer application rates in different agro-ecological environments. These experiments were started in the early 1970s, and have had different supervision and expertise. This review has shown some weakness in the approach, and unrecommended findings. The overall fertility research needed to be clarified and streamlined.

Introduction

In Yemen, wheat and barley are grown throughout the whole country, but are mostly concentrated in the northern highlands, central highlands, and eastern arid regions (Al Jawf, Marib, Seiyun). The cropped area averages 11.8 and 6.14% of the total cultivated area for wheat and barley, respectively. Both crops are grown at different latitudes and moisture regimes, mainly in the summer under rainfed conditions, but 10-20% of the wheat is grown under irrigation, especially in the winter season. The spring season for both crops starts in February, while it is in July for the summer season for the highlands. In the lowlands (eastern arid regions), there is only one season for growing both crops, and it begins in October.

Although about 40 local wheat varieties are grown in the country, the most common ones are Bawni, Ahmar, Masri, Samra, and Maisani. The main local varieties of barley are Sagla, Aswad and Masdus. The improved wheat varieties that have been released in the past 15 years by the Agricultural Research and Extension Authority (AREA) are Sonalika, Pavon, Seri, and Very. Other varieties are expected to be released in the near future. All these varieties are for irrigated cultivation and none of them has proved to be drought-tolerant. However, the production rate for wheat is quite low and ranges between 0.8 and 1.2 t ha^{-1} for the local varieties and 2 to 4 tons for the improved varieties, while it is even lower for barley.

The irrigated wheat area has not changed very much in the past 15 years, despite the encouraging policy of the Ministry of Agriculture to increase production areas. Many reasons and obstructions have contributed to this, including disease epidemics, frost, climate changes, poor genetic potential, inadequate cultural practices contributed by weak linkages with extension media, unavailability of the suitable cultural packages, and, lastly, the availability of cheap imported wheat on the market.

Fertilizers are still not playing an effective role in Yemeni agriculture. James and Halverson (1988) mentioned that the use of inorganic fertilizers was unknown in Yemen until the late 1960s, after which the usage has increased dramatically, but fluctuated from one year to another. For example, the amount of fertilizers imported for the North Governorate was 31,005 tons in 1982, only 1416 tons in 1984 and 1404 tons in 1986, but 20,000 tons in 1985 and 16,487 in 1990--dropping again in 1991 to 9859. The major reason for this fluctuation is the unplanned policy for importing these materials from abroad.

Climate

Due to its location and the influence of the Red and Arabian Seas, Yemen has a variety of agroclimatological zones. The annual rainfall varies from as low as 50 mm in the coastal regions to around 1000 mm in parts of the southern uplands. The major climatic factors affecting wheat and barley cultivation are low and there is erratic rainfall, temperature and humidity.

The wheat and barley growing areas receive varying amounts of seasonal rainfall. The average summer seasonal rainfall is 60, 160, and 451 mm for the northern highlands, central uplands, and southern highlands, respectively, while the spring seasonal rainfall is 41, 180, and 263 mm for the same areas. The production of both crops varies from one year to another as shown in Table 1.

Table 1. Total cultivated area and cereal production with annual rainfall.

	Wheat		Barley	
	1991	1992	1991	1992
Sana'a (Northern Highlands)				
Total area (ha)	39,953	46,745	24,552	28,726
Total production (t)	30,532	56,851	12,427	31,103
Annual rainfall (mm)	49.0	72.1	--	--
Dhamar (Central Highlands)				
Total area (ha)	14,441	14,542	10,215	3,547
Total production (t)	21,447	34,314	10,155	5,969
Annual rainfall (mm)	248	458	--	--
Ibb (Southern Uplands)				
Total area (ha)	8,923	9,191	3,378	3,547
Total production (t)	14,893	15,829	3,077	5,969
Annual rainfall (mm)	705	985	--	--

Source: Statistical Yearbook, 1992.

Soil Types and Fertility

Soils differ in their origin and parent material but in many cases in Yemen they are of limestone origin. Their fertility is generally low, especially in the regions of low rainfall. Table 2 shows the chemical and the physical characteristics of selected soils from the wheat- and barley-growing areas. Due to the topography of Yemen, in which high mountains co-exist with deep valleys, soil formation processes are complex and cause large variation in soil texture of the plowing layer, even within the same field. Soil pH mostly ranges from slightly to moderately alkaline. Organic matter content is very low (less than 1%) in most areas, except in the terraces of the mountains, which receive more moisture, where it could reach 4%. Consequently, the N content is quite low and is less than 0.1%. So, many crops have shown a positive response to N application. The available P content is marginally low and does not exceed 7 ppm except in the areas that receive high application rates of P and in which residual P has accumulated. Therefore, P addition has given crop yield responses, especially under irrigated conditions. Available K ranges between 150 and 300 ppm in most soils, but in some cases it reaches higher levels (700 ppm), so that most crops do not show any response to K application.

Table 2. Chemical and physical properties of two depths for some Yemeni soils.

Soil Property	Southern Highlands		Central Highlands		Northern Highlands	
	0-20	20-40	0-20	20-40	0-20	20-40
pH (1:1)	7.8	7.7	7.6	7.2	7.8	7.9
EC ds/m	0.40	0.42	0.15	0.15	0.25	0.34
Sand %	47	27	68	72	48	34
Silt %	43	61	18	16		2628
Clay %	10	12	14	12	26	38
Soil texture	L	Si	SL	SL	SCL	CL
$CaCO_3$ %	15.3	4.5	25.0	32.5	27.4	14.9
Organic matter %	1.7	0.6	1.0	0.5	0.9	1.3
Available P ppm	12	7	3.6	6.5	19.5	22.4
Available K ppm	290	200	152	113	189	155

Previous Research Activities on Fertility

Wheat

Many experiments have been done to test wheat response to different rates of N, P, and K in different locations and moisture regimes. Most of these experiments received recommended application rates without any preliminary soil tests. In the early 1970s, Qassim and Dewan (1975) conducted many experiments to examine the response of local wheat varieties to fertilization under rainfed conditions in some southern upland areas, which are characterized by their relatively high seasonal rainfall (over 400 mm). They found a significant response to N at the rate of 60 kg ha^{-1}, but little or no response to either P or K. Later, in the early 1980s, Chaudri (1982) found that Sonalika responded significantly to a combined application of N and P (80 kg N, 80 kg P_2O_5 ha^{-1}) in Ibb area, which has high rainfall, while the response was from 80 to 120 kg ha^{-1} in the Kitab area, which receives a lower amount of rainfall. In another experiment, Pavon variety was tested for its response to different rates of N and P. The highest yield was found to be with a combined dose of 120 kg N and 80 kg P_2O_5 (Chaudri, 1983). One year later, Amer (1984) reported that Pavon did not show any response to NPK fertilization in the same area.

In the Central Highlands, some experiments have been conducted by Farnworth and his colleagues during 1979-1983 under rainfed and irrigated conditions. Under rainfed conditions, the local variety Ahmar has received different rates of N and responded significantly, on grain and straw basis, to N application, even though yield was low (Farnworth and Said, 1983). On the other hand, many varieties have been examined to their response to fertilizer under irrigated conditions. Sonalika was tested with fixed rate of NPK (100 kg) in the summer season of 1979. The variety responded significantly to N and P application either individually or in a combination application (Mawly et al., 1980a). Also, the variety Cno-Bb-Cal has shown a significant response to N application; the rate of 100 kg N ha^{-1} was the optimum rate (Farnworth and Said, 1983d).

In another winter season experiment, Sonalika did not responded significantly to different rates of N; that was probably due to the infection of plants with rust (Farnworth and Said, 1983c). Red River wheat variety has been examined for its response to N and irrigation frequencies (Farnworth and Said, 1983e). There was no significant effect of either variable, but this was attributed to the heavy weed infestation (*Lolium temulentum*) of the experiment. In other two separate experiments, Red River wheat expressed a significant response to N application, the optimum dose being 100 kg N ha^{-1}, while for the P application the optimum rate was 80 kg P_2O_5 ha^{-1}. Other studies by Farnworth and Said dealt with fertilization of Bota wheat (1983b) and both wheat and barley (1983g).

Barley

Under rainfed conditions, most of the experiments conducted on barley were concentrated in the Central Highland areas. Qassim and Dewan (1975) examined the response of a local barley variety to different rates of N, P and K at two locations. This variety responded significantly to N and P only at the rates of 60 kg N and 60 kg P_2O_5 ha^{-1}. They mentioned that the addition of K depressed the combination effect of both nutrients. On the other hand, Sagla variety has shown some response to lower rates of both nutrients. The grain yield reached 1.6 t ha^{-1} with the combined treatment (30 kg N + 30 kg P_2O_5 ha^{-1}) in comparison with 1.2 t ha^{-1} of the control (Bisset, 1982).

Under irrigated conditions, Giz-120 yield showed no significantly differences to

N applications which ranged from 50 to 200 kg N ha^{-1} in the winter season. The yield was very low and that was probably due to the attack by aphids and leaf rust (Farnworth and Said, 1983f). On the other hand, the variety Atlas Kindred responded significantly to P addition in the summer season. The optimum rate used was 60 kg P_2O_5 ha^{-1}, but the yield was low due to the attack of beetles and rust. In another two separate experiments designed to test the response of Masdus variety to different N levels and combined N-P rates, the variety responded significantly to the application of both nutrients in the two experiments. In the first experiment, the proper application rate of N was 120 kg with a basal dose of P equal to 50 kg P_2O_5, while in the second experiment the combined treatment (100-100) was highly responsive on grain and straw basis (Mawly et al., 1980b). Also, response of the Masdus variety to different rates of P was tested, with a basal rate dose of N. Although the yield was low due to rust attack, the variety responded significantly, the optimum application rate was 80 kg P_2O_5 ha^{-1}.

While most attention was given to wheat and barley under both rainfed and irrigated conditions, some limited work was done on triticale (Farnworth and Said, 1983a, 1983f). The variable pattern of N or P response was also evident--again for the same reasons, i.e., lack of consideration of soil test values for both N and P.

Conclusions

Despite the many fertility experiments that have been conducted on wheat and barley, there is still a need for further studies to clarify the ambiguous and uncertain findings. Nearly all the experiments were directed towards finding the appropriate application rates of N, P and, to limited extent, K. The findings are inconsistent and sometimes conflicting, which reflects the weakness of the fertility programs.

This weakness, from my point of view, is due to many reasons which include: 1) shortage of qualified national personnel that could lead continuous well-planned soil fertility programs; 2) conducting these experiments of different supervisors that come for short periods; and 3) conducting these experiments in different agro-ecological environments (locations and soil types) and mostly for one season. In addition to these, and in the absence of correlative soil tests, many of these experiments have been conducted in experimental fields that been used for other activities under which they received ample fertilizer application.

In view of these unexplainable factors there is a urgent need for further studies under more controlled and better designed conditions in order to clarify these findings and examine the effect of different fertilizer sources and timing of application in relation to soil tests. Since most of the cultivated areas are under rainfed conditions, the role of fertilizers under this conditions should be more focused as part of an improved national program.

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Residual and Current Effects of Phosphorus in Rotational Trials

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Abstract

The importance of P for crop production in the dryland West Asia-North Africa region is well documented. Response to fertilizer invariably occurs when soil test levels are low. The long-term trial sought to examine the effect of residual P and yearly "maintenance" P applications in a cereal/legume relation at three sites over a rainfall gradient. Surprizingly, there were few responses to P application; evidently, the critical P level is lower in such clay soils. Residual P disappeared after 4 years. Other aspects included monitoring of available P in all plots as well as distribution of total and organic P with depth.

Introduction

Phosphate deficiency is a major constraint in agriculture throughout the world; the semi-arid rainfed lands of the vast area of West Asia-North Africa (WANA) are no exception to this generalization. As soils of this dryland zone are predominantly calcareous, they are prone to low levels of plant-available P (Matar et al., 1992). Additionally, a number of socio-economic factors have contributed to low P fertilizer inputs, e.g., traditional small-scale farming, poorly developed infrastructure, uncertain returns due to drought hazard.

However, in the past decade, research conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA) in collaboration with the various national programs has demonstrated the potential of judicious fertilization to increase crop yields (Ryan and Matar, 1992). In general, where Olsen (0.5M $NaHCO_3$) soil P test levels were less than about 6 mg kg^{-1}, a response was likely for rainfed crops. When test values were above this critical level, fertilization was normally not recommended.

Soil testing could therefore pinpoint on-farm P fertilization needs. However, given the initial responses to applied P, the subsequent concern is with the long-term effects of fertilization in soils of a xeric Mediterranean environment with alternating cereal and legume rotations. Thus, the normal reversion or transformation of P fertilizer in soils (Afif et al., 1993) may be modified with time by concomitant biological and climatic as well as soil factors.

The dynamics of residual P are normally studied in incubated laboratory experiments or in pots in the greenhouse. Most researchers reported long-term field are from temperate regions, and none have assessed P within the context of cereal-legume rotations. Such trials could establish how long the effect of P fertilizer will last and how much is needed to maintain adequate P levels.

Some details of the long-term trial reported here have been presented in a previous report (Matar et al. 1991). However, only soil test values were shown for the first four years and no yield data were presented. While the experiment is on-going, some of the trends which emerged are worthy of being highlighted at this stage. This multi-year, three-site rotation trial was designed to:

1. measure the impact of residual and currently applied P on crop yields (grain and straw) and on P uptake,
2. monitor changes in available soil P with time,
3. determine the distribution of total, available and organic P with depth, and
4. assess the impact of P fertilizer on adsorption isotherms and P desorption.

Materials and Methods

A long-term P fertilization trial was established in 1986 on a rainfall gradient, at three experimental stations operated by ICARDA in northwestern Syria: its main station at Tel Hadya, near Aleppo (Calcixerollic Xerochrept), Breda 35 km to the east (Typic Calciorthid), and Jindiress, 70 km to the northwest (Chromic Calcixerert). All are deep soils and are representative of their respective areas.

Initially, all sites were low in available P. In 1986/87 a range of soil test levels was established by applying different P_2O_5 rates as triple superphosphate (0, 50, 100, 150, and 200 kg ha^{-1}). In subsequent seasons, annual rates of P (0, 15, 30, 45 and 60 kg ha^{-1}) were applied broadcast and incorporated at planting. All the crop sequences were as follows: Tel Hadya, wheat/lentil; Breda, barley/vetch; and Jindiress, wheat/chickpea (chickpea was replaced by lentil in 1990 because of Fusarium problem on chickpea). Yearly measurements were taken of available soil P levels along with dry matter yield and uptake data. Mean seasonal rainfall (and ranges) were as follows: Breda, 260 mm (183 to 415 mm); Tel Hadya 332 mm (222 to 504 mm); and Jindiress, *447 mm* (334 to 715 mm).

As considerable amounts of P_2O_5 had been added (up to 680 kg P_2O_5 ha^{-1}) and accumulated in the soil after 8 years, selected plots were sampled on the surface, and with depth to 1 m, for analysis of total and organic P. The potential effect of previous P additions on adsorption and release parameters were assessed by isotherms and successive $NaHCO_3$ extractions in the laboratory.

Results

This long-term trial has yielded volumes of data sets: yearly and cumulative values for crop yield and its components, P concentration and uptake, soil test data, laboratory data that characterize profile distribution of the various P forms, and adsorption and desorption characteristics. Therefore, it is only possible in this report to outline the main trends.

Crop Yields/P Response

Despite the low levels of available P at the sites, i.e., 6.0, 4.0, and 2.4 mg kg^{-1} for Jindiress, Tel Hadya, and Breda, respectively, there was no yield response, either in straw or crop responses were frequent, but not consistent with time or whether P was residual or yearly (Table 1). While the residual effect of initial P application was non-existent, yearly application only had an effect in the last three seasons; this concided with declines in control values with continuous cropping. Overall or total yield increases due to fertilization were significant for Jindiress and Breda, but not Tel Hadya. Relative to the control, crop P uptake by grain and straw tended to be higher with P fertilization. There was no obvious differences in response of wheat and the alternate legume crop. Total yield at the stations increased as rainfall increased.

Table 1. Significance of crop biomass responses (cereal/chickpea or lentil) to yearly applied and residual phosphorus.

Station	Application	Year						
		87/88	88/89	89/90	90/91	91/92	92/93	Total
Jindiress		W	CH	W	L	W	L	
	Rainfall	715	354	334	438	425	437	
	Yearly	NS	NS	NS	S	S	S	S
	Residual	NS	NS	NS	NS	NS	NS	NS
Tel Hadya		W	L	W	L	W	L	
	Rainfall	504	234	209	267	311	298	
	Yearly	NS	NS	NS	NS	NS	S	NS
	Residual	NS	NS	NS	NS	NS	NS	NS
Breda		B	V	B	V	B	V	
	Rainfall	415	195	183	244	263	283	
	Yearly	NS	NS	NS	S	S	S	S
	Residual	NS	NS	NS	NS	NS	NS	NS

Residual P_2O_5= 200 kg ha^{-1}; Yearly= 60 kg ha^{-1}; Notation: wheat= W; barley= B; lentil= L; chickpea=CH; vetch=V. Significance (0.05)=S; Non-significant=NS.

Olsen Soil Test Values

Without P and with continuous cropping, test values declined over the 10-year period by 30 to 40% in Jindiress and Tel Hadya, but remained fairly constant in Breda (Fig. 1). Available P tended to increase with time and in proportion to the amounts applied, especially in the Breda soil; the 15 to 30 kg rates generally maintained P values at their initial levels.

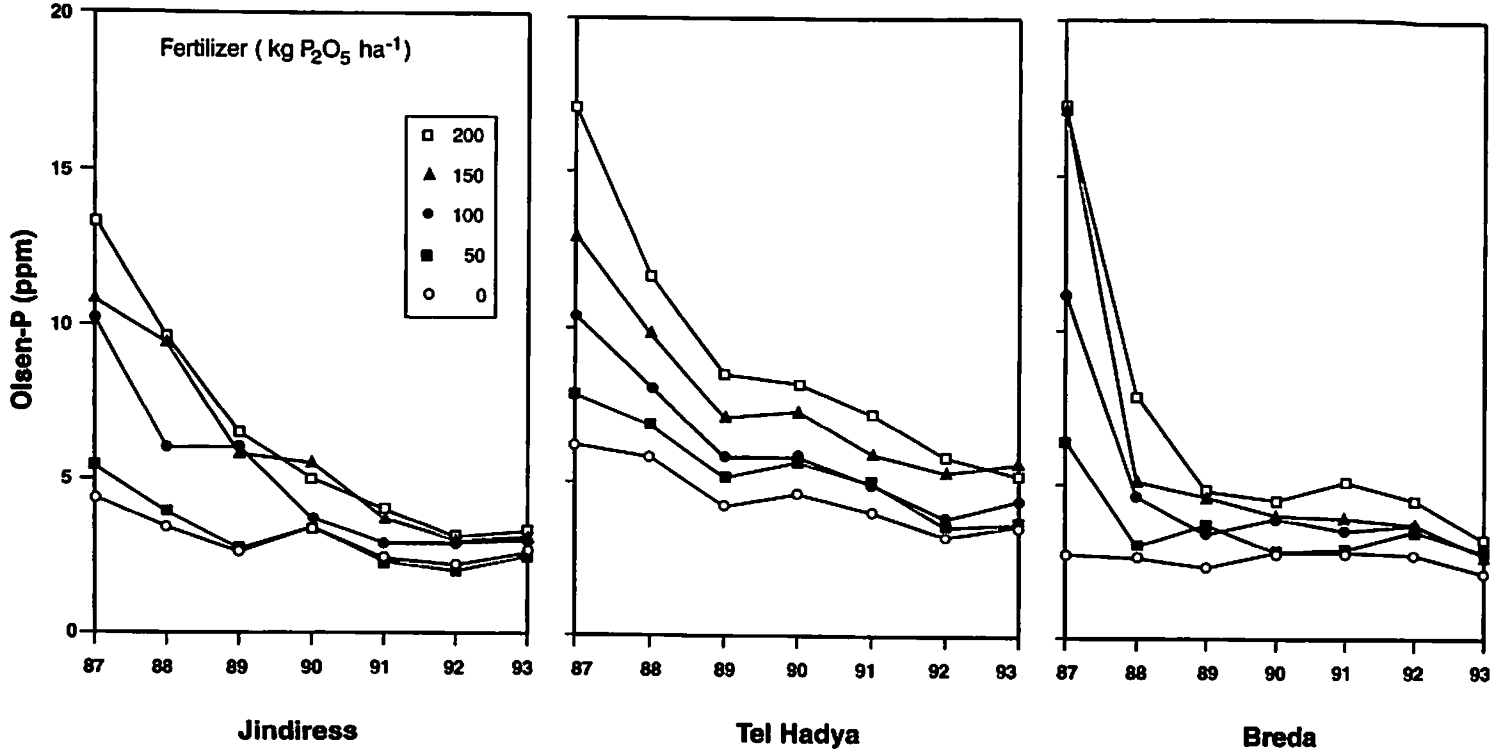

Fig. 1. Actual change in residual Olsen P after the initial fertilizer addition (sampled at 0 to 20 cm soil depth).

When one considers the amount of P removed by cropping and that added to the soil (Table 2), it was clear that continuous cropping without P "mined" or reduced the soil reserves, while modest applications of P (30, 60 kg P_2O_5 ha^{-1}) resulted in a positive balance at all sites. The initial or residual P application raised test values, which then declined exponentially; after 2 to 4 years, there were little difference from the control. Residual P persisted longer in Jindiress and Tel Hadya than in Breda.

Total and Organic P

While the amount and pattern of total P profile distribution varied with the site, no effect of fertilization was detected with depth. Organic P values ranged from 55 to 90 mg kg^{-1}, i.e., about 10% of total P, and tended to increase with depth for Jindiress and Tel Hadya, but were relatively constant for Breda.

Adsorption/Desorption

Differences between soils were relatively small; adsorption conformed to the Langmuir isotherm. Adsorption was somewhat less in samples that came from yearly fertilized plots. The measured P requirement, at 0.2 mg L^{-1} solution, was lower in previously fertilized samples. Cumulative extraction with $NaHCO_3$ indicated no resiual effect of the initial P application, but did show a buildup of available P with yearly application.

Table 2. Phosphate balance in soil after 8 years' fertilizer use.

Station	Application Rate, P_2O_5		
	0	30	60
	------------------------kg ha^{-1}------------------------		
Jindiress	-107	+27(13)	+165(39)
Tel Hadya	-89	+81(38)	+228(54)
Breda	-78	+87(41)	+261(62)

[1] Percentage change in paretheses.

Conclusions

Critical values are lower than the norm for the region's rainfed soils, which is considered to be around 6 ppm. The reasons for this discrepancy have to be clarified. The effect of normal P application does not persist longer than 3 to 4 years. With regular P application of 30 kg P_2O_5 ha^{-1} or more, available P levels build up with time. Operation of long-term P trials in Mediterranean environment is confounded by variable yearly rainfall.

In conclusion, this long-term P trial at ICARDA's three stations over a rainfall gradient has shown how added P declines in solubility with time, but with repeated application on a yearly basis, P fertility levels tend to buildup with time. The initial heavy P application was not large enough to produce any long-lasting residual effect. The crop response data from the trial need careful scrutiny to reconcile with data from other P experiments at these sites.

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Use of Radioactive Phosphorus in Soil Fertility Research: Mobility in an Acidified Soil

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Abstract

The use of isotopes has added greatly to our knowledge of the agricultural sciences. Much of the detailed knowledge of soil reactions resulting from fertilizer phosphorus applications, as well as rates of uptake by plants, have been attributed to radioactive P. This element is invariably deficient in agricultural soils and has to be rectified by chemical fertilizer application. However, P fertilizer-use efficiency is low largely due to adsorption/precipitation reactions that, in turn, cause limited mobility and positional availability for plant uptake. This study illustrates the use of ^{32}P to evaluate mobility in acidified sandy loam soil in columns. Though acidification is unlikely to be of relevance in dryland areas of WANA, the process may be pertinent to fertilizer application from point-sources, as in drip irrigation. The quest to improve P use efficiency is a daunting one. The data showed that localized acidification promoted considerable P movement. The implications are potentially important for the region's agriculture.

Introduction

While much is known about phosphorus in soil and its reactions with added fertilizer sources, there are still seemingly unsurmountable problems to be overcome. The advances in our knowledge of the complex chemistry of P have not provided practical solutions to the intractable obstacle of P "fixation", i.e., conversion to insoluble forms, and consequently limited movement in the soil from point of application. As a consequence, the efficiency of fertilizer P is rarely greater than 10 to 15%. The problems assume even greater significance with changes in agricultural fertilizer such as drip irrigation and direct drilling. However, during the last few decades, changes in fertilizer technology and the use of non-conventional soil amendments offer some hope for a solution to limited P mobility.

Soils of arid regions, which are mainly calcareous, are generally deficient in plant available P, the Middle East region being no exception (Matar et al., 1992). With the production of excess sulfuric acid from copper mining operations, due to scrubbling of waste gasses in response to stingent environmental legislation in the 1970s, interest was re-kindled in using this amendment to reclaim sodium soils and improve water penetration (Miyamoto and Ryan, 1976), reduce volatile loss of ammonia from irrigation systems (Miyamoto et al., 1976) and enhance solubility of native P (Ryan and Stroehlein, 1979) and micronutrient cations (Ryan et al., 1977).

Some developments which led to new P fertilizers have also raised the possibility for improved P mobility, and therefore more efficient use. An acid-generating material, urea phosphate, was shown to be effective in improving water penetration and reducing the adverse effect of sodium in calcareous sodic soils (Ryan and Tabbara, 1989; Ryan et al., 1988a) as well as being an excellent source of both N and P. The indirect effects on iron solubility in calcareous soils (Ryan et al., 1988b) was an additional potential benefit. New organic sources of P were found to be more mobile in soils (Rauschkolb et al., 1976) than the conventional monocalcium phosphate, i.e., superphosphate, but costs remain a serious obstacle.

Thus, this study sought to evaluate conventional P sources (monocalcium and diammonium phosphate) with experimental material (urea phosphate) together with various degrees of acidification using sulfuric acid. In order to separate the specific effect of P mobility, a treatment using an isotope of phosphorus (^{32}P) was used in order to distinguish between P from soil and from the fertilizer.

Materials and Methods

This column study was carried out in a greenhouse at the University of Arizona Campus Agricultural Center and lasted for 22 days, approximately 1.5 times the half life of ^{32}P. The soil was collected from the Page-Trowbridge Ranch near Oracle, AZ, and is classified as White House sandy loam (fine, mixed, thermic, ustollic, Haplargid). A bulk sample was collected from the top 50 cm, air dried, passed through a 2.0-mm screen, and mixed in preparation for column and laboratory studies. Soil pH, available P (Bray I), and EC were determined according to conventional procedures; the initial soil pH was 6.5, EC 0.3 dS m^{-1} and available P was 13 mg kg^{-1}.

Batches of soil (4.5 kg) were weighed into a 50 x 10 cm column for each treatment. An initial application of 1.25 L tapwater was added to each column, moistening the soil to about field capacity (28% w/w). Three soil acidity levels were obtained by using two different levels of 2.5 *M* H_2SO_4, i.e., 45 and 75 ml per column, so that the surface soil pH would be lowered below 4.0. Three different P fertilizer sources were supplied at 100 µg P g^{-1} soil in each column; fertilizer-grade urea phosphate ($CO(NH)_2H_3PO_4$), reagent-grade monoammonium phosphate ($NH_4H_2PO_4$), reagent-grade monocalcium phosphate ($Ca(H_2PO_4)_2$-H_2O) and a control.

Immediately after the P application, a topical application of 300 micro-curies of carrier-free ^{32}P as $H_3{}^{32}PO_4$ per column was added and uniformly distributed in only one replicate of the experiment. All soil columns were then given the first irrigation at a rate of 200 ml per column. After 21 days from the ^{32}P application, irrigation was terminated. The ^{32}P-treated replicate was prepared for counting as follows: Each column was cut longitudinally using a vibrating saw, and 6.0 cm width slit was made along the soil column, and then removed. Thus, the soil along the soil column was partially exposed. The counting was done with a GM-tube connected to a digital analyzer model 25 scaler-rate meter, model LUDLUM. The tube window was covered with an adjustable shield. Thus, the width of the exposed soil could be controlled. The GM-tube was then connected to a double-gear shaft, driven by an electrical motor. The speed of the GM-tube was adjusted to move down the soil column at a rate of 2.0 cm per minute and a surface area of 12.0 cm^2 per count was made.

All ^{32}P treated columns were subjected to the same procedure, and the activity of ^{32}P along the soil column was measured as soon as possible. The other three replicate columns were sectioned at 4.0 cm depth using a band saw; each soil section was removed, air dried, ground to pass through a 2.0 mm sieve, and tested for pH and available P (Bray I).

Results and Discussion

The primary reflection of any effect of acidity is a change in pH. Thus, when pH values with the 4-cm sections of the columns were examined, it was evident that the H_2SO_4 application significantly reduced values from the original value (Table 1). However, though the depression of pH was related to the acid rate, differences between the two rates were generally insignificant. The effect of the acid was consistent throughout the columns, i.e. pH values around 4.3 for the first level of acid and 3.8 for the second level. The control column also showed a depression in pH of from 5.4 to 5.7 in the top 12 cm, compared to about 6.2 throughout the column. Thus, irrigation with water alone had a slight effect on pH (original 6.5), probably due to leaching of cations down the column.

There was no evidence of any interaction between acid application rate and the P fertilizers on pH, except for urea phosphate. In the latter case pH values were between 0.5 and 1.0 pH unit lower than the control throughout the column. Thus, urea phosphate itself had an acidifying effect on the soil.

Of more direct significance is the effect of the induced changes in pH on available or extractable P. Again it was clear that acidification alone had a significant effect on Bray I - extractable P, with values ranging from about 3-fold higher in the top 0-4 cm to from 5 to 7 times higher down the column (Table 2). Thus, the acid reaction at the point of application had solubilized P from insoluble soil sources and much of it had been moved down the column with the irrigation water. Presumably, with continued water movement from irrigation, the accumulation front would be deeper.

There was an interaction between the distribution of available P from the H_2SO_4 treatment alone and the three P fertilizers. Clearly, the acid treatment facilitated the movement of the P fertilizer into the soil; however, the effect involved only the top 4 cm. The gross effect of acidification was to increase the concentration of P down the profile. Nevertheless, there were differences between the P services. For urea phosphate, values were consistently related to the H_2SO_4 application rate throughout the column, with a maximum accumulation from 4 to 12 cm. For both diammonium phosphate and monocalcium phosphate, the zone of accumulation was wider, i.e., from 8 to 24 cm; the H_2SO_4 application rate influenced the distribution pattern, with the higher rate causing P to move deeper.

Table 1. Soil pH values in soil columns treated with H_2SO_4 and P fertilizers.

Depth cm	Control			UP			MAP			MCP		
	A0	A1	A2	A0	A1	A2	A0	A1	A2	A0	A1	A2
0-4	5.4b	4.3a	4.1a	5.1b	4.1a	4.1a	5.7c	4.1a	4.4a	5.6c	4.3a	4.2a
4-8	5.4c	4.1b	3.7a	5.4c	3.9ab	3.9ab	5.6c	4.1b	3.8ab	5.4c	4.0b	3.9ab
8-12	5.7d	3.7bc	3.4a	5.6d	3.9c	3.5ab	5.8d	3.9c	3.5ab	5.7d	3.5ab	3.6ab
12-16	6.1e	3.5a	3.4a	5.4d	3.8c	3.5a	6.0e	3.6bc	3.4a	5.9e	3.4a	3.4a
16-20	6.2e	3.5ab	3.3a	5.3d	3.9c	3.4a	6.1e	3.6b	3.4a	6.2e	3.5ab	3.3a
20-24	6.3g	3.6cd	3.4ab	5.5f	3.8e	3.3a	3.2g	3.5bc	3.4ab	6.2g	3.7de	3.3a
24-28	6.2e	3.7b	3.4a	5.7d	3.9c	3.4a	6.2e	3.6b	3.4a	6.2e	3.8bc	3.4a
28-32	6.2e	3.9bc	3.5a	5.9d	4.1c	3.6a	6.2e	3.7ab	3.5a	6.2e	4.1c	3.5a
32-36	6.2d	4.2b	3.7a	5.9c	4.2b	3.7a	6.2d	3.9a	3.7a	6.3d	4.3b	3.6a
36-40	6.2e	4.5d	3.8a	6.1e	4.5cd	3.9ab	6.2e	4.1bc	3.8a	6.3d	4.7d	3.8a

Means followed by the same letter within columns are not statistically different ($P \geq 0.05$).

Notation: UP = urea phosphate; MAP = monoammonium phosphate; MCP = monocalcium phosphate; AO= no H_2SO_4; A1= first acid level (45 ml); A2 = second acid level (75 ml).

Table 2. Extractable P in soil columns treated with H_2SO_4 and P fertilizers.

Depth cm	Control			UP			MAP			MCP		
	A0	A1	A2	A0	A1	A2	A0	A1	A2	A0	A1	A2
0-4	16a	49ab	49ab	277f	204e	132d	261f	95cd	83bc	175e	115cd	124cd
4-8	18a	50ab	67b	210d	255be	248e	179cd	169c	177cd	174cd	190cd	177cd
8-12	15a	61b	63b	174d	213a	272gh	150cd	231ef	255fg	146c	289h	230ef
12-16	15a	72b	66b	124c	163d	214e	125c	244f	227ef	124c	288g	210e
16-20	14a	98bc	87b	101bc	140cd	167de	115bc	219fg	175def	88b	247g	197ef
20-24	15a	93bc	97bc	71b	132cd	142d	85b	204e	143d	89b	221e	148d
24-28	18a	72b	108cd	55b	84cd	134d	85bc	130d	126d	85bc	118d	135d
28-32	17a	49ab	118d	48ab	50ab	113d	74bc	76bc	97cd	61b	57b	112d
32-36	15a	23ab	79de	39abc	40abc	70de	41abc	67cde	74de	51bcd	32ab	83e
36-40	14a	19ab	39cdef	31bcd	33bcde	45def	39cdef	51f	42cdef	49f	29abc	48ef

Means followed by the same letter within a row are not statistically different ($P \geq 0.05$).

Notation: UP = urea phosphate; MAP = monoammonium phosphate; MCP = monocalcium phosphate; AO= no H_2SO_4; A1= first acid level (45 ml); A2 = second acid level (75 ml).

Table 3. Relative distribution of ^{32}P in soil columns treated with H_2SO_4 and P fertilizers.

Depth cm	Control			UP			MAP			MCP		
	A0	A1	A2	A0	A1	A2	A0	A1	A2	A0	A1	A2
0-4	78.3	58.9	50.3	74.3	25.1	24.5	37.1	14.2	17.4	47.7	14.4	19.3
4-8	20.3	31.9	30.2	20.8	42.6	27.1	24.2	28.8	18.8	36.8	23.7	20.2
8-12	0.6	2.5	9.3	3.1	23.7	29.1	24.2	26.8	33.7	8.7	26.2	22.8
12-16	0.3	2.8	6.1	1.2	2.9	12.5	11.1	18.0	22.1	3.7	24.4	14.8
16-20	0.2	3.2	3.1	0.5	2.3	3.8	2.5	9.1	5.7	2.3	8.4	12.7
20-24	0.1	0.4	0.5	0.2	1.9	1.5	0.3	1.5	1.6	0.4	1.4	5.7
24-28	0.1	0.1	0.3	0.2	1.1	1.0	0.2	0.4	0.2	0.1	1.3	4.0
28-32	0.1	0.1	0.1	0.2	0.3	0.4	0.1	0.2	0.2	0.1	0.1	0.3
32-36	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
36-40	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Notation: UP = urea phosphate; MAP = monoammonium phosphate; MCP = monocalcium phosphate; AO = no H_2SO_4; A1 = first acid level (45 ml); A2 = second acid level (75 ml).

Where acidification solubilizes soil P and fertilizers add soluble P to the soil pool, it is difficult to separate the effect of each treatment. The addition of ^{32}P was designed to identify such effects. The relative distribution of ^{32}P in counts per minute revealed an effect of both fertilizer source and acidification on P mobility (Table 3). A similar pattern to the gross values of Table 2 emerged. Thus, there was a strong effect of acidification on net P mobility and minor influences of fertilizer source. Nonetheless, even with maximum penetration, between 80 to 90% of the applied P was confined to the top 12 to 16 cm; without acidification, as much as 75% of the applied P was confined to the top 4 cm. Correlation analysis between available P and ^{32}P revealed a reasonably good relationship between the two parameters. Thus, despite its sophistication, ^{32}P has no great advantage over conventional chemical analysis in detecting movement of P in soil columns.

Conclusions

While the beneficial effect of acidification on P availability could have been predicted based on previous research (Miyamoto et al., 1975; Ryan and Stroehlein, 1979), its interactive influence on the mobility of P from various sources could not be so readily explained. Clearly, any P fertilizer will have an effect on the chemistry of the soil solution and adsorption/precipitation reactions at colloid surfaces. Acidification and other induced changes can influence the transformation of sources such as urea phosphate. The circumstances of this study do not allow us to clearly identify the various mechanisms involved.

What is clear is the dominant effect of acidity on P solubility and mobility and relatively minor difference due to fertilizer source. Despite these differences, the ^{32}P data showed that net P mobility is still low. Even the accumulation at 10 to 20 cm was higher than anticipated. The question is how relevant are these findings for the calcareous soils of the WANA region where dryland farming or supplemental irrigation is practised. Clearly, the effect of acid would be much less than in this study due to the buffering capacity. The only case where inorganic P (orthophosphoric acid) was effective was on coarse-textured poorly buffered soils (O'Neill et al., 1979).

While acid amendments are not available in the region, there might be a role for acid materials in specialized production systems such as greenhouses. It was encouraging that conventional extraction procedures and ^{32}P identified a similar pattern of P mobility. Thus, for most circumstances, the former method is more amenable for use. Despite the valuable contribution of ^{32}P to soil P research (L'Annunziata and Legg, 1989), it is not readily apparent how this technique can be further applied to advance our applied knowledge of soil P chemistry in the WANA region.

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4. Micronutrients: Deficiencies and Toxicities

Plant Available Trace Iron, Zinc, Manganese and Copper in Turkish Soils

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Abstract

Trace element studies of Turkish soils began in the early 1970s and have continued increasing since then. The current study is based on the analyses of 1511 soil samples. The results indicate that 50% of Turkish soils are deficient in Zn, 27% are deficient in Fe, and less than 1% are deficient in Mn. The level of Cu seems adequate. Since yield barriers are almost reached, emphasis should now be given to trace elements and related problems so that these are not the yield-limiting factors either in Turkey or in the West Asia-North Africa (WANA) region in general. The WANA region countries that have similar soil and climate characteristics as Turkey are likely to have potentially similar trace element problems.

Introduction

Trace or minor elements comprise seven of the 16 elements now considered to be essential for plant growth. These are boron, copper, iron, manganese, molybdenum, zinc and chloride. Since trace means very small and nutrient denotes food, the term trace element refers to an essential plant food element required in very small amounts for adequate plant nutrition. Although required in very small amounts, trace elements are essential and play major role in plant growth and development. The trend to more intensive crop production, with higher yields and heavier use of nitrogen, phosphorus, potassium fertilizers increases the need for greater consideration and use of trace elements in agriculture. As farmers continuously strive for maximum yields and quality, more attention should be given to trace element needs and problems. As yields increase, the incidence of trace element deficiencies becomes more common because higher yields also involve greater removal of trace elements from the soil. Yield barriers seem to have been reached, thus attention should be given to determine if one of the trace elements is a limiting factor.

One of the most effective means of determining if a particular trace element is limiting yield is the soil test. Trace element soil tests distinguish trace element-sufficient fields or areas from deficient. This information is important for determining whether a soil can supply adequate amounts of trace elements for crop production, as well as for adequate nutrition of humans and animals that may feed on the product. Once information is available about the location of deficient areas, corrective measures can easily be applied. Information about the extent of deficient areas is also important in helping fertilizer manufacturers and governmental decision- makers to determine the amount and kind of trace element fertilizer to be used on a provincial and country scale. This should result in increased income of farmers who are unaware of the problem.

Studies on trace element content of soils started in the early 1970s in Turkey. Zabunoğlu (1973), Zabunoğlu et al. (1978), Hatipoğlu (1981), Aydemir (1982), Kacar (1984), Aktap and Hatipoğlu (1984), Aydeniz et al. (1986), Güzel et al. (1991), and Taban and Kacar (1991) presented data on trace element investigations of Turkish soils. These studies generally involved a limited number of samples in relatively limited areas. The number of soil samples never exceeded 20 to 40. The largest general study to date was that conducted as the part of a global survey by the Food and Agriculture Organization (FAO) with 250 soil samples from Turkey (Sillanpaa, 1982). The work of Sillanpaa was also mainly concentrated in Central Anatolia. All these studies suggested the possibility of both Fe and Zn deficiencies in Turkish soils.

Procedure

A total of 1511 soil samples were collected from all over Turkey, so as to represent the widest variation in soil and climatic conditions, taken from a 0-25 cm soil depth with a stainless steel auger. The samples were analyzed for texture, pH, total salt, organic matter and lime content in order to identify the relationship of these factors with plant-available trace element status of the soils. The elements Fe, Cu, Zn, and Mn were determined by using a DTPA extractant (0.005 *M* DTPA + 0.01 *M* $CaCl_2$ + 0.1 *M* TEA, pH = 7.3) proposed by Lindsay and Norwell (1969, 1978). The procedure involved 20 g soil samples shaken with 40 ml of the extractant for 2 hours, after which the suspension was filtered, and the micronutrient the content was measured by an atomic absorption spectrophotometer (Perkin-Elmer 1100 B, air-acetylene flame). The results were evaluated based on critical values proposed by Viets and Lindsay (1973), i.e., 4.5, 0.2, 0.5, and 1.0 ppm are the critical values for Fe, Cu, Zn, and Mn, respectively. The areas with sample values below these critical values are estimated as the probable deficiency areas for the related trace elements.

Results and Discussion

In this current study, soil samples were collected from all the existing major soil groups in Turkey and represent a very wide soil conditions; pH varied from very acidic to very alkaline, texture varied from sandy to clay, lime content varied from none to very high, organic matter (OM) varied from very low (<0.1%) to high (> 68%) and salt content varied from trace to slightly saline (Table 1).

The distribution of plant-available or DTPA-Fe in Turkish soils is given in Table 2. A considerable proportion (26.9%) of the soils had below the critical value of 4.5 ppm. Thus, Fe deficiency is estimated to occur in almost 7.5 million ha of agricultural land. The relationship is expressed as $Y = 113.68 - 13.81\ X$ ($r = -0.616^{**}$), $Y = 14.82 - 0.36\ X$ ($r = -0.306^{**}$), and $Y = 4.36 - 4.03\ X$ ($r = 0.242^{**}$) and was significant between the plant-available Fe content and pH, lime ($CaCO_3$) and organic matter

Table 1. Range and mean values for relevant soil properties.

Soil Properties	Minimum	Maximum	Average
Water Saturation %	18.0	113.0	52.6
Total Salt %	Trace	0.3	0.7
pH	4.3	10.8	7.4
$CaCO_3$ %	-	71.6	10.6
Organic Matter %	0.1	6.6	1.7
DTPA (ppm)			
Fe	0.2	151.4	11.1
Cu	0.3	46.5	2.1
Zn	0.06	12.7	0.8
Mn	0.7	331.0	24.8

content of the soils, respectively. The DTPA-Fe content decreased as the pH and lime content of the soils increased, but increased as the organic matter increased. No significant relationship was found between salt content and Fe content of the soils. The multiple regression, expressed as Y = 100.17 - 23.03 (% total salt) - 12.09 (pH) - 0.11 (% $CaCO_3$) + 2.05 (% OM), was significant ($r = 0.402^{**}$) between plant-available Fe content of soils and these parameters.

Iron deficiency was found in every major soil groups, but appears to be more severe in Rhegosols, Red Mediterranean, Brown, Gray-Brown Podzolic, and Colluvial soils in that order. The percentage of the samples below the stated critical value of 4.5 ppm was 63, 50, 42, 39, and 34, respectively, in these major soil groups.

Table 2. Distribution of DTPA-extractable Fe.

Fe Values	No. Samples	Total Distribution
---ppm----		-------- % --------
< 2.50	128	8.5
2.50 - 4.50	18.40	--
4.50 - 9.00	592	39.2
9.00 - 13.00	208	13.8
> 13.00	305	20.2

The distribution of plant-available Zn content in these Turkish soils is given in Table 3. About half (49.83%) of the samples had below the critical value of 0.5 ppm. Thus, Zn deficiency is estimated to effect almost 14 million ha of agricultural land in Turkey. The relationship, expressed as Y = 2.76 - 0.27 X ($r = -0.169^{**}$) and Y = 0.16 -0.36 X ($r = 0.304^{**}$), was significant between the plant-available Zn content and pH, and organic matter content of the soils, respectively. The DTPA-Zn content of the soils decreased as the pH of the soils increased, but increased as the organic matter increased. No significant relationship was found between total soluble salts or lime content with Zn content of the soils. The multiple regression, expressed as Y = 1.42 - 0.16 (pH) + 0.33 (% OM), was significant ($r = 0.101^{**}$) between DTPA-Zn content of soils and these parameters.

Zinc deficiency were found in each of the major soil groups, but it was most severe in Organic (67%), Rhegosols (63%), Chestnut (62%), Reddish Chestnut (57%), and Basaltic (56%) soils in that order.

Table 3. Distribution of DTPA-extractable Zn.

Zn Values	No. Samples	Total Distribution
---ppm---		--------- % ----------
< 0.50	753	49.8
0.5 - 1.0	495	32.8
1.0 - 1.5	127	8.4
1.5 - 2.0	50	3.3
2.0 - 2.5	30	2.0
2.5 - 3.0	15	1.0
> 3.00	41	2.7

The distribution of DTPA-Cu content of Turkish soils is given in Table 4. None of the samples' Cu value was lower than 0.2 ppm. Thus, indicating no copper deficiency problem in Turkey. Almost 70% of the samples had Cu values between 1.00 and 3.00 ppm.

Table 4. Distribution of DTPA-Cu.

Cu Values	No. Samples	Total Distribution
---ppm---		------ % ---------
< 0.20	0	0.00
0.20 - 0.40	10	0.66
0.40 - 0.60	43	2.85
0.60 - 0.80	74	4.90
0.80 - 1.00	101	6.68
1.00 - 1.60	406	26.87
1.60 - 2.20	398	26.34
2.20 - 3.00	252	16.68
> 3.00	227	15.02

The distribution of DTPA-Mn content of the soils in the survey is given in Table 5. A very small proportion of the soils (only 0.70%) were below the critical value of

1.0 ppm. Thus, one can conclude that deficiency of Mn is not very common in Turkey. The relationship, expressed as Y = 30.48 - 86.49 X (r = - 0.108**), Y = 278.90 - 34.21 X (r = -0.699**), Y = 32.96 - 0.77 X (r = -0.305 **), Y = 9.80 - 8.97 X (r = 0.247**), was significant between the DTPA-Mn content and total salt, pH, $CaCO_3$ and organic matter content of the soils, respectively. The Mn content decreased as the pH and $CaCO_3$ content of the soils increased, but increased as the organic matter and total salt contents increased. The multiple regression, expressed as Y = 260.53 + 15.82 (soluble salts %) - 32.26 (pH) - 0.15 (lime %) + 3.12 (% OM) was significant (r = 0.530**) between DTPA-Mn content of soils and these parameters.

Table 5. Distribution of DTPA-extractable Mn.

Mn Values	No. Samples	Total Distribution
---ppm---		------- % -------
< 1	1	0.70
1 - 5	42	2.78
5 - 10	271	17.94
10 - 20	675	44.67
> 20.0	522	33.91

Prospects and Conclusions

The most important trace element disorders in Turkey seems to be those due to Zn and Fe deficiencies. The study thus confirmed indications from the previously reported, though less extensive, surveys dealing with micronutrients. Low organic matter and high $CaCO_3$ content of the soils and high pH values are the indicators. The WANA countries, which have similar soil and climate conditions, are very likely to encounter such trace element disorders.

Although the application of N and P fertilizers is well known by farmers and sometimes even done in excess, farmers are not generally aware of the nutritional problems with trace elements or indeed of their existence. The application of Zn or Fe fertilizers is rarely, if ever, carried out by farmers. Thus, ways to familiarize farmers with the concept of trace elements should be sought, and farmers should be encouraged to use either trace elements directly or trace element-containing fertilizers. This may be achieved by using price support mechanisms.

Research should be initiated to establish crop responses to Fe and Zn as well as the most effective application methods. Excessive P fertilizer application is believed to be one of the causes of Fe and Zn deficiency. Farmers should be discouraged from using excess amounts of P fertilizers--soil testing for P is the obvious strategy. Sometimes the most effective and economic solution to overcome the deficiency problem of Fe and Zn is to select and grow plant genotypes that are Fe- or Zn-efficient. In crop breeding programs of Turkey, and possibly WANA countries, resistance to Fe and Zn deficiency should be considered as one of the selection criteria.

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Nutritional Constraints for Pasture Legumes: Importance of Zinc and Phosphorus Soil Test Values

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Abstract

In the Dryland Mediterranean zone, animal production and cereal growing are complementary. The success with which nitrogen-fixing legumes are established and managed in rotation with cereals depends largely on the presence of appropriate rhizobia and the elimination of nutritional constraints. This 2-year field study in northwest Syria assessed the growth of four annual *Medicago* species [*M. rigidula, M. noeana, M. rotata, M. aculeata*]; two vetch species (*Vicia sativa, V. villosa* subsp. *dasycarpa;* and chickling (*Lathyrus sativus*), with and without inoculation or N (as urea), as well as a range of phosphorus (P) and zinc (Zn) treatments. The soil (Calcixerollic Xerochrept) was low in both available P (2.1 mg kg^{-1} $NaHCO_3$-P) and Zn (0.6 mg kg^{-1} DTPA-extractable) at the first year's site, but higher in P (4.5 mg kg^{-1}) and Zn (1.0 mg kg^{-1}) at an adjacent site the second year.

The primary factors significantly ($P \leq 0.05$) increased yields of both categories of legumes (pasture, forage). However, P had no effect on *L. sativus*, in contrast to *V. villosa* subsp. *dasycarpa* and *V. sativa*. Interactions were more pronounced for medics, with *M. noeana* and *M. rigidula* showing little response to inoculation or mineral N. Both *M. rotata* and *M. aculeata* responded to inoculation. The effect of P was less in the case of *M. rotata* and *M. aculeata*. Zinc consistently increased herbage yield across all P levels. Though the weather in the second year was similar, neither P nor Zn had any significant effect largely due to higher test values. While P as a crop constraint is well recognized in the Mediterranean zone, the impact of Zn deficiency is relatively new, but is easily identified by soil tests and rectified. Similarly, compatibility with indigenous soil rhizobial populations or with introduced effective rhizobia also has to be considered for functional nodulation and high rates of N_2 fixation.

Introduction

In the rainfed farming system that characterizes the West Asia-North Africa (WANA) region with a Mediterranean climate, fallow in rotation with cereals in alternate years is traditionally used to obtain adequate cereals yields, largely due to moisture conservation. With increasing land pressure, the fallowed area has decreased, with inevitable concerns about decreasing soil fertility and the sustainability of intensive cropping and monoculture. The notion of ley farming--integrating annual medics

(*Medicago* spp.) with cereal cropping (Clarkson et al., 1989)--was initially developed in Australia and is being promoted in the WANA region. Ley farming is designed to provide forage in the alternate year--and to benefit the cereal crop through biological nitrogen (N_2) fixation. Despite the capacity to fix atmospheric N_2, the adaptive potential of native medic ecotypes largely depends on the presence of specific rhizobia (Materon, 1991). In such cases, inoculation is necessary (Brockwell et al., 1988). Successful annual legume pasture establishment requires more than microbial adaptation.

As an essential nutrient, phosphorus (P) is deficient in most soils of the WANA region (Matar et al., 1992). In such cases, rainfed cereals and legumes are likely to show yield increases with P fertilization (Osman et al., 1991). In studies with medics in Australia, application of P increased the pasture output of *M. truncatula* (cv. Jemalong) five-fold on a P-deficient soil (Clarkson et al., 1989). Not only was growth of *M. polymorpha* increased with P, but nodulation was enhanced (Del Pozo et al., 1989). Notwithstanding the overall effect of P on medics, differential responses to P have been observed for *M. polymorpha*, *M. noeana*, and *M. rotata* depending on the P concentration in a hydroponic medium (Lorenzetti et al., 1989).

Information from research on P fertilization of medics in the WANA region is limited. Observations by Ryan et al. (1995) in Morocco indicate substantial field responses for *M. scutellata* (cv. Śavá) and *M. truncatula* (cv. Cyprus) but not for *M. polymorpha* (cv. Śerená), which showed ineffective nodulation. In another Moroccan field trial, none of the medics tested responded to applied P, while only one vetch, *V. villosa*, and *Lathyrus ochrus* responded to P (Ryan et al., 1992). An associated, though less known factor, but a potentially important one in crop production in calcareous soils, and, therefore, the WANA region where soils are mainly calcareous, is zinc (Zn) deficiency.

The scant evidence we have indicates that, according to criteria described by Lindsay and Norvell (1978), available Zn is low to marginal in northwestern Syria, i.e., <0.6 mg kg^{-1}. Research on Zn nutrition of pasture legumes has been mainly limited to alfalfa (*M. sativa*) (Stout et al., 1987), and there is virtually nothing on *Vicia* and *Lathyrus* species. Our research with Zn has so far only dealt with medics in a greenhouse experiment. Results indicated that the positive effect of Zn was dominant, especially when combined with P fertilization and adequate N sources (Materon and Ryan, 1995). Thus, in this 2-year field study, we evaluated the impact of inoculation, and N, P and Zn nutrition on a variety of adapted cold-tolerant forage legumes, in addition to the same annual *Medicago* species previously used in the greenhouse study.

Materials and Methods

The experiment was conducted at Tel Hadya on one of the most common red-clay calcareous soil types (Calcixerollic Xerochrept) in Syria's rainfed (200-600 mm yr^{-1}) cereal-producing zone. The soil at the first year's site had low P (Olsen) and Zn (Lindsay and Norvell, 1978) levels (2.1 and 0.6 mg kg^{-1}), while it was a little higher (4.5 and 1.0 mg kg^{-1}) at the adjacent site the second year. The pasture legumes (i.e., grazed) used for this experiment were annual *Medicago* (medics) ecotypes of species which are cold-tolerant and well-adapted and widespread in the Mediterranean region. Because of dormancy and the need to ensure germination, the seed was mechanically scarified before planting. The forage legumes (harvested for animal feed) are also common in the region, as well as being cold-tolerant. Seed rate at planting was based on the germination percentage of seed available for each species. The average seeding rates were 38, 13 and 12 kg ha^{-1} for the medics, *Vicia* and *Lathyrus*, respectively. Seed was placed in rows by hand.

The four medic species were treated with peat inoculum made with an equal mixture of two strains of *Rhizobium meliloti* (ICARDA M15 and ICARDA M53 originating from northwest Syria), both with various degrees of specificity for each of the medics species. Uninoculated controls, with and without mineral N, were included for both trials. The mineral N controls received three split applications of urea after germination, with intervals of 3 weeks between each application. The total N applied was equivalent to 90 kg N ha^{-1}. The P treatments were 0, 15, 45, and 135 kg ha^{-1} mixed with the soils as solid-phase monocalcium phosphate, $Ca(H_2PO_4)_2$. All P treatments were split into a control without Zn and a Zn treatment at the rate of 48.4 kg Zn ha^{-1} (to give about 5 µg Zn g^{-1} soil) added as $ZnSO_4.7H_2O$.

The pasture (medics) and forage (*Vicia* and *Lathyrus*) trials were established separately, each being adjacent to one another and separated by a 5-m buffer zone. Plots were 1.05 x 2.0 (2.1 m^2) with six rows. Rows were 17.5 cm apart. Blocks and plots were separated by distances of 2.0 and 1.0 m, respectively. A randomized complete block design (RCB) with four replications was used.

During the growing period (Nov-May), in 1993/94 and 1994/95 five plants from each plot were collected at random to observe nodulation, vigor and distribution. Herbage production, expressed as dry weight, was estimated based on the harvest of all above-ground plant material from the inner four rows at the flowering stage. Herbage yield data were subjected to analysis of variance for main factors and their interactions, with mean separation using the least significant difference method (LSD) at a 5% probability level.

Results

In the first season (1993/94) each of the main effects, i.e., N, P, Zn, species and rhizobial inoculation, had a significant and consistent effect on dry matter yield of both categories of legumes. However, there were some significant interactions or differential effects between species and these factors, especially for the pasture (*Medicago*) group. Irrespective of treatment, mean yields of the medic species differed being in the order: *M. rigidula* > *M. noeana* > *M. aculeata* > *M. rotata*, respectively. Mean responses to applied P were consistent and significant at all P levels, with yield at 135 kg ha^{-1} being about 60% higher than the control. Overall, Zn application significantly increased biomass yield by about 13.4%. Inoculation of medic seeds with cultures of *R. meliloti* strains increased growth by about 18%, with the effect of N fertilization alone being 27%. Mean yields of the forage legumes were significantly different, with *V. dasycarpa* yielding 4.65 t ha^{-1} compared with 3.38 t ha^{-1} for *V. sativa* and 2.77 t ha^{-1} for *L. sativus*.

With increasing P application rate (0, 15, 45, 135 kg ha^{-1}) mean forage yields increased by 34, 50, and 60%, respectively. Zinc application increased overall herbage production by about 20%, or slightly higher than observed for the *Medicago* species. Inoculation of the forage legumes with cultures of *R. leguminosarum* strains was responsible for a 10% increase in overall herbage yield, which was equivalent to that produced by mineral N alone.

Impressive as the main treatment effects were, the primary concern is how each species was influenced by these factors. Thus, both *M. aculeata* and *M. rotata* responded more strongly to inoculation than *M. rigidula* and *M. noeana* (Fig. 1). However, in most cases, inoculation, which induced nodulation and thus N_2 fixation, was sufficient to meet the plant's N needs as reflected in yields from plants treated with mineral. The N plant scoring for vigor also reflected these differences. Symptoms of N deficiency, such as yellowish stunted plants, were observed in those species which expressed a need for inoculation. While P consistently increased yields with increasing application rates, the degree of response was greater for those species which did not need inoculation and which had a higher growth potential, i.e., *M. noeana* and *M. rigidula*. Similarly, where lack of nodulation or N limited growth, the overall response to applied P was reduced. While Zn application had a consistent effect on each species, the positive response tended to be greater for some species (*M. rigidula*) and less for others (*M. rotata* and *M. aculeata*).

The only significant interactions in the case of forage legumes involved a differential response to P and Zn. Thus, while increasing P consistently increased yields of both *V. dasycarpa* and *V. sativa*, there was no response with *L. sativus*. Though Zn increased the yields of all three forage species, the effect was proportionately greater with *V. sativa*. In the second year (1994/95), there was no significant effect of either P or Zn on growth and yield of either category of legume. Therefore, the data are not presented. As expected, inoculation produced a similar effect as in the previous year.

Discussion

This field study demonstrated that each of the main factors considered, nodulation, N, P, and Zn, was vital for the full expression of growth potential from annual *Medicago* and *Vicia* spp. and *Lathyrus sativus*, major and potentially important pasture and forage crops in the Mediterranean zone. In so doing, it complemented the work of Materon and Ryan (1995), who showed that these factors influenced growth of *Medicago* species to an even greater extent in the greenhouse; responses to inputs are normally greater in the greenhouse than in the field.

Considering the many constraints to successful introduction of the Australian ley farming concept in the WANA region (Puckrige and French, 1983), the variable responses to inoculation depending on the medic species in question, were to be expected. Similarly, with a low-P soil, the positive influence of P was not surprising for the medics or for the forage legumes tested, given the general responses observed for cereals and legumes in the WANA region (Matar et al., 1992).

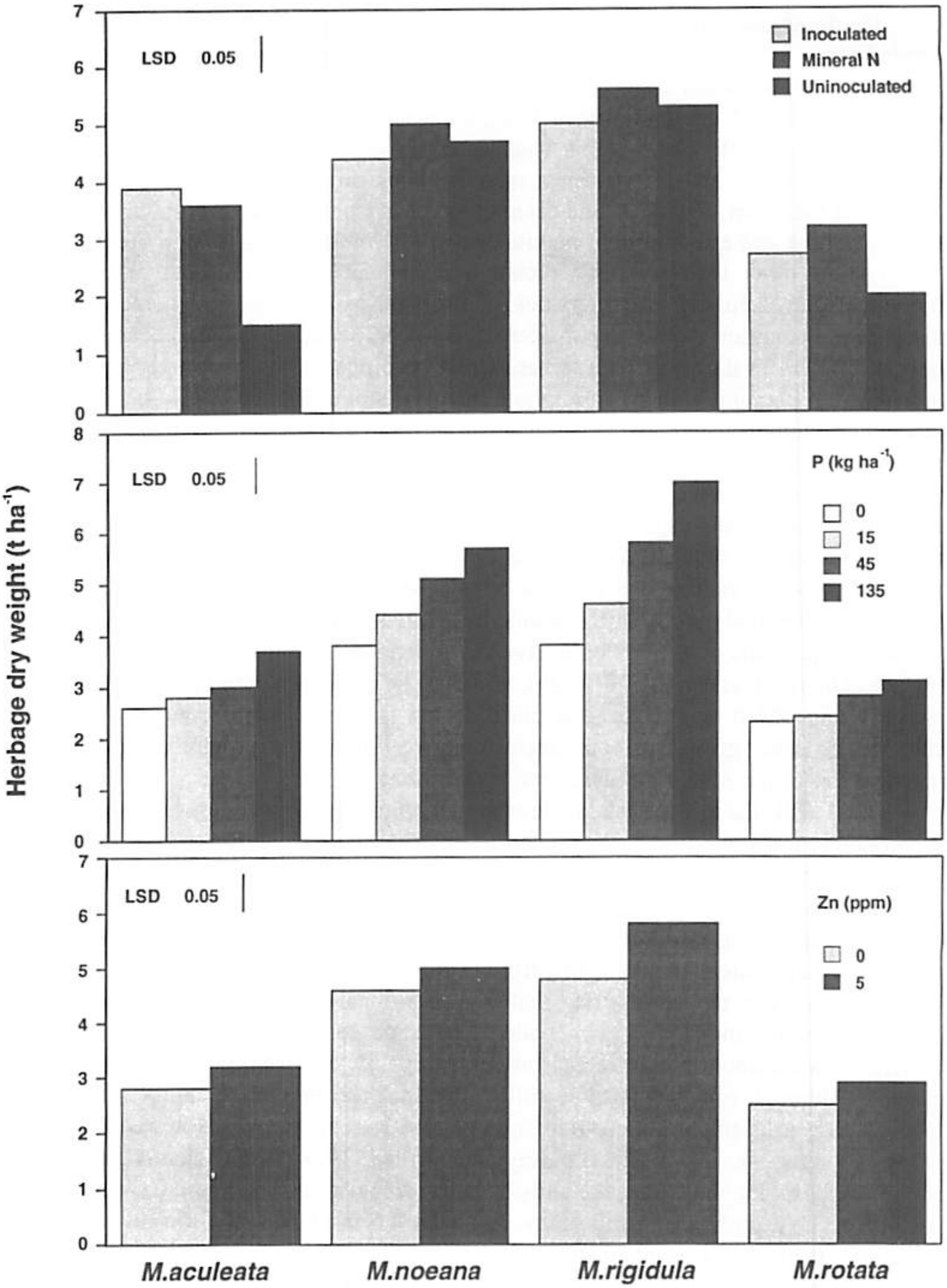

Fig. 1. Responses of the four *Medicago* species to nodulation and applied phosphorus and zinc.

The foremost concern for any legume at any one site is whether inoculation is needed. Two of the four pasture species involved in this study, *M. aculeata* and *M. rotata*, need inoculation for adequate growth and to allow for responses to nutrient inputs. They would, therefore, need inoculation for successful field establishment in soils containing ineffective rhizobia, such as those used here. However, there is a range in both distribution and effectiveness of indigenous rhizobial populations is soils of West Asia (Materon, 1991); so one cannot predict inoculation needs without screening for compatible and effective root nodule bacteria before planting at new sites.

Factors other than soil type dictate whether such rhizobia exist or not. The biological and chemical characteristics of the soil, as well as its legume-cropping history, are important factors to consider. Halse (1993) concluded that inoculation was only a problem in the short term; where strain specificity is an issue, seed should be inoculated at planting with an appropriate rhizobial strain. Remedial post planting soil inoculation should be avoided, as soil-resident rhizobia will strongly dominate inoculant rhizobia in nodule formation (Materon, 1994).

The responses were more consistent to P than to rhizobial inoculation; although all four medic species responded well, potential maximum increases were greatest for *M. noeana* and *M. rigidula*. Phosphorus fertilization of medic, vetches and Lathyrus followed the same trend as observed for cereals (Matar et al., 1992). To incorporate the P fertilizer effectively in the soil, it should be applied during the cereal phase; if it were applied in the medic phase, it would have to be broadcast and would remain on the soil surface. The residual effect of P would, however, be carried over to the grazed legume phase during which no tillage takes place. In the farming systems context, P greatly enhances not only growth of both crops in the rotation, it also promotes survival and regeneration of the medic by increasing pod or seed numbers.

Thus, while the key to sustainable cropping-animal grazing systems is P fertilizers, its economic use should be based on soil testing (Matar et al., 1992)--a concept that is gaining momentum in the WANA region. Although P fertilization programs can be made, it is clear that rainfall plays a large part in dictating the extent of response, since responses vary in the same field from good in a normal "*wet*" year (Ryan et al., 1996) to poor to non-existent in a year of early season drought (Ryan et al., 1992).

The response to Zn suggests that this nutritional factor should be taken into consideration in future work with both pasture and forage legumes. Indeed, as Zn deficiency is common in calcareous soils, it is probably a constraint to cereal-growing as well. Although one can fertilize soils with Zn, breeding for tolerance to low Zn levels is also a feasible option (Graham et al., 1993). Though not calibrated for most crops and soils, the DTPA test (Lindsay and Norvell, 1978) is sufficiently general to serve as a basis for indicating the soils or agro-ecological zones where Zn deficiency is likely to be a problem; in this study, soil with 0.6 mg kg^{-1} was deficient while the site with 1.0 mg kg^{-1} was adequate.

In conclusion, this field study confirmed results from a previous greenhouse study (Materon and Ryan, 1995) and demonstrated the importance of adequate nodulation for *Medicago*, *Vicia* and *Lathyrus* species to express maximum potential when P is deficient. As the addition of small amounts of Zn accentuates the P response, future work will focus on Zn in soils and cropping systems in the region, and on its implication for animal nutrition, i.e., impaired growth and reproduction (C. White, CSIRO, Australia, pers. comm.). Indeed the issue of micronutrients including Zn, in human nutrition is of current concern, with the International Food Policy Research Institute (IFPRI) spearheading a global research project on micronutrient research in human nutrition. Our current work aims at complementing this effort at the soil and plant level and investigation its impact on the grazing animal.

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Boron in Soils and Water in Iraq

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Abstract

Boron is unique in that it can be deficient in soils for growing crops and can also be toxic. One has to consider the levels of B in soils, particularly the available fraction, and the content in irrigation water. A brief outline is given for these aspects in Iraq.

Introduction

The importance of boron in the agronomic sphere could be said to date from the discovery of boron (B) in plant ash in the middle of the last century. Since then, there has been a growing awareness of the beneficial (and harmful) effects of B on plant growth. Irrefutable evidence on the essentialness of this element to higher plants became available during the second decade of this century (Flemming, 1980). We now know that B plays an essential role in many plant physiological processes. Growing points of both roots and shoots cease to elongate when B is deficient, and if severe deficiency continues, the plant dies. There is evidence that B has a role in RNA metabolism. In B deficiency, flowering is inhibited and water relations are abnormal. The germination of pollen grains and growth of the pollen tube are severely inhibited by lack of B. It has an important role in sugar translocation, N metabolism and enzymatic activities (Epstein, 1973; Tidsale and Nelson, 1975).

Boron is unique among the micronutrients in the narrow range of concentrations that occurs in the soil; many crops on a worldscale are affected by either side of this range. A fraction of one part per million may be required, and a few parts per million may be toxic. In this regard there is much variation among soils and crops in identifying the critical limits of toxicity and deficiency. However, yield decrease associated with B toxicity is often compared with that caused by B deficiency.

Boron in Soil

Soil B Content

All the rocks of the earth's crust contain B in concentrations varying with the nature of the rock. Total B content in basic igneous rocks ranges from 1 to 5 ppm, from 3 to 10 ppm in acid igneous rocks, and from 5 to 12 ppm for metamorphic rocks and sedimentary rocks of continental origin. Sedimentary rocks of marine origin have a very high B content which can attain 500 ppm and more. The total B content of soil ranges from 1 ppm in some podzols to 270 ppm in some soils of arid zone areas (Aubert and

Pinta, 1977). For soils of the temperate regions, the total B content ranges from 2 to 100 ppm. Lower values are expected in coarse-textured soils which are low in organic matter and in pH (Alalwan, 1989). Soils of the arid and semi-arid regions generally have high B contents ranging from 25 to 300 ppm. In some areas within these regions where B salts accumulate, values of up to 1000 ppm have been recorded; e.g., from Peru (Fleming, 1980). Soils of the tropical humid regions show lower B concentration limits; total contents range from 0.1 to 4 ppm.

Soil Boron Forms

Four forms of combinations are recognized: Boron in silicate structures (mineral B), B associated with clay minerals and sesquioxides (adsorbed B), organically combined boron, and water-soluble boron (available B).

Silicates

The importance of this fraction stems from the role it plays in controlling the amount of plant-available B in a particular soil. The forms of combinations which exist are essentially complexes of B either as molecular boric acid or as the borate ion.

Organic Boron Compounds

Soils high in organic matter are frequently high in boron. In pure systems, B shows an affinity for alpha-hydroxy aliphatic acids and for ortho-dihydroxy derivatives of aromatic compounds. Boron is also capable of reacting with sugars and diol-type structures.

Water-Soluble Boron

This form represents the readily available fraction to plants. Its composition may be quite variable depending on soil type and reaction. Boron uptake from soil solutions occurs as boric acid, borate and polyborate.

Factors Affecting Soil Boron Availability

Calcium Carbonate

Calcium carbonate reduces B availability and increases B reserves by fixation, as it does with most of the soil micronutrients.

Organic Matter

Organic matter influences B availability, but this role is conditioned by such factors as its degree of decomposition, moisture, and pH. Organic matter helps minimize B loss from soils while at the same time maintaining the element in reasonably available form.

Soil Moisture and Temperature

Boron availability is decreased under dry soil conditions. Boron fixation has been noted when soils are dried. Increasing soil temperature leads to greater B fixation.

Soil Texture

It is evident that there is greater B movement in sandy soils than in those of heavier texture. Light-textured soils contain less available B than heavy-textured soils; B deficiency is more common in such soils.

Interrelationships With Other Elements

Application of fertilizer does not affect B availability, but the increased growth resulting from N addition may induce B deficiency. Boron availability is less in alkaline soils where free Ca ions are present. Plants growing in soils containing very high levels of water-soluble B did not suffer from B toxicity when free Ca ions were present in high concentration.

Some Soil Aspects in Iraq

The area of Iraq may be divided into five physiographic regions, each with specific geological, hydrological and climatological conditions. These regions are: Zagros mountains, Jezira, foothills, Lower Mesopotamian Plain, and the desert area in the west. Geologically, both the Zagros mountains and western desert are composed mainly of limestone. The foothills consist of beds of gravel, conglomerates and sandstone. The Jezira area is the remains of an old inland sea in which mainly gypsum was deposited. The Lower Mesopotamian Plain, as an extensive geosyncline, is filled with shelf sediments on top of which erosion products brought by water streams have been deposited. The climate is continental arid, with hot summers and cooler winters. Rainfall ranges from 50 mm $year^{-1}$ in the southwest to >800 mm $year^{-1}$ in the northeast. Agriculture in the Lower Mesopotamian Plain depends on river water, which is mainly of good quality. In the northern part of the country, crops are rainfed. In some parts of Jezira and desert area, farmers use well-water to grow vegetables. Because of the uniform deep deposits overlying the old sea sediments, the groundwater in Jezira, and Lower Mesopotamian Plain is highly saline.

There is a great variation in soil characteristics in the different physiographic regions and also within each region. Soil organic matter drops from 4% in the northeast to 0.1% in the southwest in accordance with rainfall. The soil in the mountainous area and desert ranges in depth from a few centimeters in the uplands to a few meters in the valleys, while the fine sediments, which form the soil of Lower Mesopotamian Plain, continue to a depth of 2 km (Buringh, 1960). Topography determines the depth of groundwater. Therefore, soil salinization is most likely in the Lower Mesopotamian Plain where the groundwater is high.

Since the parent rocks are calcareous, all soils in Iraq possess a high content of calcium carbonate (20-40%). Consequently, soil pH is alkaline. Most of the area of the Lower Mesopotamian Plain has a heavy texture. Conversely, the soils of Jezira, foothills, and desert area are light-textured. Smectite is the predominant clay mineral in the Lower Mesopotamian Plain with smaller amounts of chlorite, illite and kaolinite. Soil structural stability is very low, and there is always a problem of aeration, poor water infiltration, and excess salinization.

Boron Status in Iraqi Soils

The B content in Iraqi soils is relatively high, which is consistent with background information on the area. Soils derived from recent and marine deposits -- Iraqi soils are an example of such soils -- are known to have higher B concentrations. The arid climate and salinity also contribute to the high B content in Iraqi soils. Some known soil characteristics and environmental conditions regulate the B availability in Iraqi soils and thus prevent B toxicity. The high calcium carbonate content, alkaline pH, clay content, and the dry weather all enhance B fixation. Even when water-soluble B is high, as in some parts of the Mesopotamian plain, the high content of Ca ions regulates or reduces the harmful effects of B ions.

Many studies were carried out in the last two decades on B concentration and behavior in different locations and zones in Iraq (Alalwan, 1989; Amadi and Lazim, 1989; Murtadha, 1982; Pagel and Alzubaidi, 1974). The results are briefly reviewed in this report. In their study on micronutrients status in the northern part of Iraq (Dohuk, Erbil, Sulaimaniya, and Kirkuk), Amadi and Lazim (1989) found that total B varied from 78 to 269 ppm; the mean value was 166 ppm. Hot water-extractable B ranges from traces to 13.3 ppm with an overall average of 2.4 ppm. Boron concentration was higher from north to south in the four governorates, being higher in Sulaimaniya and Kirkuk compared with Dohuk and Erbil; concentrations also decreased with soil depth.

Significant correlations were found between soluble B and total B, organic carbon, clay content and electrical conductivity of the soil. Pagel and Alzubaidi (1974) studied soluble B and other micronutrients in six profiles representing different parts of Iraq, but found no significant correlation between soluble B and other soil properties. However, B decreased with soil depth in each profile and increased from north to south. Murtadha (1982) found that total B in different localities in Nineva governorate (north) ranges from 92 to 364 ppm, with an overall average of 189. He obtained a high positive correlation between total B and calcium carbonate, organic matter and clay content. However, a negative correlation was found between soluble B and these soil properties. Alalwan (1989) studied B status in the southern governorates of Basra, Misan, and Thi-Qar, and found the total B values to range from 84 to 343 ppm and hot water-soluble B to range from 1.8 to 3.5 ppm. There was a highly significant correlation between total B with calcium carbonate ($r = 0.82$), and salt ($r = 0.56$) contents.

Recently, in a study carried out by the Department of Soil Science in the College of Agriculture and Forestry, University of Mosul, soil-soluble B was found to decrease with the increase in the average annual precipitation. Soluble B ranged from 0.17 to 95 ppm with an average of 0.61 ppm in the surface soil (0-25 cm) in the 450-mm zone. In the 350-450 mm zone soluble B ranged from 0.89 to 1.85 ppm, with an average of 1.84 ppm in the 250-350 mm zone.

Boron in Water Resources

Boron contents in water resources in Iraq vary according to the nature of the resource and the location. As with the soil, the B content increases in surface water from north to south. This is because rivers act as a drain for the adjacent soils collecting soil salts as they flow southward. Boron is higher in wells and drainage water compared with rivers. Laboratory analyses during the last 10 years indicated that B concentration in the Tigris and Euphrates ranges from 0.03 to 0.17 ppm upstream and from 0.20 to 1.24 ppm downstream. Boron concentration in well-water ranges from 0.64 to 4.8 ppm in different locations. Drainage water in the Mesopotamian plain contains higher B concentrations than irrigation water, ranging from 0.65 to 2.84 ppm. Boron content in water, and especially in wells and drains, increases during summer and decreases during winter as a result of dilution and concentration during the rain season and dry summer.

One can make a few conclusions regarding B in water of Iraq. According to literature on water quality, river water in Iraq is considered of excellent quality, even for B-sensitive crops. Well-water is not suitable for sensitive crops, but is acceptable to good for tolerant and semi-tolerant crops. Drainage network water is not suitable for most crops, especially in the southern part of the country.

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Differential Responses of Barley, Durum and Bread Wheat to High Levels of Soil Boron

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Abstract

Boron can be phytotoxic, causing yield reduction, when present in slightly above normal concentrations in the soil solution. Boron toxicity, caused by inherently high levels of B in soils or by using irrigation water high in B, has recently been found to occur in many dry areas of West Asia and North Africa (WANA). In view of the importance of barley, and durum and bread wheat in WANA, especially in semi-arid and high-altitude areas, work to identify B-toxicity tolerant winter cereals was initiated at the International Center for Agricultural Research in the Dry Areas (ICARDA) in 1993. Here, I report the results obtained on the differential responses to high levels of soil B in the three crops. Seedlings of advanced lines and germplasm accessions were first screened in a plastic house in tanks of soils mixed evenly with known amount of boric acid. Then lines with low B-toxicity symptoms and B concentrations were grown in pots up to maturity.

There was significant variation in seedling B-toxicity symptom scores and shoot B concentrations in all three crops at high soil B levels, with barley and bread wheat having larger variation than durum wheat. In a barley trial, most of the varieties from West Asia had low degrees of symptoms while the European varieties had high degrees of symptoms. This suggested that B is a factor causing European varieties to be poorly adapted to the region. In general, wheat had less symptoms than barley, and could grow in soils with a higher B level. Tolerant lines grew much more vigorously than sensitive lines under high soil B levels, resulting in large differential grain yield responses to increasing B levels between lines. On average, barley suffered more grain loss than durum, while bread wheat had the least yield reduction. The advantages of exploiting genetic tolerance over soil reclamation are presented. Growing varieties with high tolerance to B toxicity is the only practical approach to increase or maintain yields on inherently high-B soils, where there is no concern about further B build-up.

Introduction

Boron (B) is one of the seven essential micronutrients. In the more humid parts of the world, B deficiency is a widespread nutritional problem that affects high-yielding crops (Gupta, 1979). This tends to lead many of us to believe that B toxicity does not exist.

If present in excess amounts in the soil solution, B can be phytotoxic. There is a narrow range between B levels in soil solution causing deficiency and toxicity when compared with other nutrients. Reisenauer et al. (1973) gave a rough guideline that deficiency may occur when hot water-soluble soil B is less than 1 ppm, and toxicity will occur when it is greater than 5 ppm. Moderate to severe B toxicity leads to yield reduction, besides giving foliar symptoms. In a field study in South Australia, Cartwright et al. (1984) found a 17% difference in grain yield between adjacent barley plants having severe or mild B-toxicity symptoms. Using isolines of barley, Jenkin (1993) also found a yield reduction of similar magnitude between tolerant lines and sensitive lines in a high-B site.

In contrast to B deficiency, B toxicity occurs mainly in arid and semi-arid regions, especially in alkaline soils (Leyshon and Jame, 1993; Marschner, 1986). This is probably because of limited precipitation to leach the bulk of the B down below the root zone. Alkaline soils are able to adsorb more B than acid soils (maximum adsorption of B by soil particles occurs around pH 9), thus allowing a lesser amount of free B to be leached away. Boron toxicity probably was first reported by Christensen (1934) in barley as early as 1933 in USA. But serious efforts on tackling the problem in cereal crops only began after the discovery, in 1983 and later years, of how widespread B toxicity is in South Australia (Cartwright et al., 1984; Wayne, 1986), which has a Mediterranean type of climate and alkaline soils similar to WANA. At ICARDA, research on B toxicity started in 1992, after the visit of a consultant, Dr Tony Rathjen, from the University of Adelaide, South Australia.

There are many reasons for explaining why B toxicity was not more widely realized earlier. One reason is that high soil B concentrations occur commonly in subsoils (Cartwright et al., 1984; ICARDA, 1994), while soil surveys usually sample the topsoil. For example, B concentrations were found to increase substantially at or below 30 cm depth in eight out of the ten profiles sampled at Boueider, which is a dry site (average annual rainfall of 233 mm) in northern Syria and where B-toxicity symptoms had been observed on barley (ICARDA, 1994).

The other reasons for explaining why B toxicity was not more widely realized earlier are: 1) Boron-toxicity symptoms in wheat are not conspicuous. Even when symptoms are easily seen, as in barley, they have been mistaken with symptoms caused by diseases or other stresses. 2) Landraces grown in high-B areas in WANA are tolerant with little symptom expression. 3) Boron toxicity has been confounded with salinity or drought, which are receiving major attention in dry areas. 4) There is less research conducted in dry areas relative to well-watered, fertile regions.

Now it is known that B toxicity in cereal crops occurs in semi-arid areas of many WANA countries. It occurs in Algeria, Egypt (northwest coast and Sinai), and Libya, and probably in Morocco and Tunisia. Many soil samples collected in Iraq, Syria, and Turkey (Anatolian Plateau) had high B levels (Sillanpaa, 1982). The level of tolerance in germplasm accessions indicates that B-toxicity also occurs in Afghanistan, Iran and Jordan. In other parts of the world, B toxicity has been reported in India, Peru and Spain, besides Australia and the USA.

There are many causes leading to high B levels in soil solution (Leyshon and Jame, 1993). In WANA, the two main causes are: 1) soils inherently high in B, such as those formed from sediments of inland seas, and 2) use of irrigation water high in B, often from deep wells. It is not practical or easy to detoxify high B soil by agronomic means (Leyshon and Yih-Wu, 1993). One may leach the soil extensively by using much more water than what is needed to remove soluble salt, but the availability of water in semi-arid and arid areas always is a constraint. Chemicals, such as triisopropanolamine, are expensive and may not work under field conditions. Lime application to increase pH and adsorption by soil particles is not suitable for alkaline soils.

Selecting or breeding crop cultivars with high tolerance or resistance to B toxicity most probably is the only practical approach to increase or maintain yields on high-B soils under rainfed conditions. Much work on screening for B toxicity tolerance and on understanding the underlying mechanisms have been reported for bread wheat (*Triticum aestivum* L. subsp. *aestivum*) and barley (*Hordeum vulgare* L. subsp. *vulgare*) in Australia (Nable, 1988; Moody et al., 1988; Paull et al., 1988, 1991; Jenkin and Lance, 1991), but relatively little has been done on durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.) (Yau et al., 1995). In view of the importance of barley, durum and bread wheat in WANA, especially in semi-arid and high-altitude areas, work to identify and develop B-toxicity tolerant winter cereals was initiated at ICARDA in 1993. In this paper, I shall report the results obtained so far on the differential responses to high levels of soil B in the three crops on foliar symptom severity, shoot B concentrations, growth and yield.

Materials and Methods

Seedlings of advanced lines and germplasm accessions of barley, durum and bread wheat were tested in a plastic house in tanks (2.0 x 0.75 x 0.25 m) of soils mixed evenly with boric acid. The rate of 50 mg B kg^{-1} soil was used for screening barley. This gave a hot water-extract of around 12 ppm, which is similar to the B levels found at 30 to 50 cm depth at Boueider, as mentioned earlier. For wheat, 100 mg B kg^{-1} soil was used. The rates were selected based on previous testing to give the best differentiation between entries in a short time (Yau et al., 1995). Entries were planted as hill plots in a replicated randomized block design with 5 seeds per hill. Foliar B-toxicity symptom scores based on the proportion of leaves affected were taken 4 to 6 weeks after sowing. Growth scores were also taken for wheat seedlings. Shoot B concentrations of selected entries were measured.

Lines with low B-toxicity symptoms and low B concentrations were grown in pots to maturity in a plastic house. There were usually two treatments: control (about 0.4 to 0.8 ppm hot water-extractable B) and +B (mixed with 50 mg B kg^{-1} soil). A split-plot design with 2 to 3 replicates was used.

There are two main reasons for conducting the screening in controlled environments. First, there usually is a large horizontal and vertical variation in soil B levels in the field (ICARDA, 1994; Cartwright, 1984; Graham, 1991), thus making field screening with small plots quite unreliable. Second, B-toxicity symptoms can be easily confused with those of diseases (e.g., scald, net blotch or spot blotch in barley, tan spot in wheat), frost, drought or salinity under field conditions.

Results

Boron-toxicity symptoms first occurred in older leaves. In barley and wheat, B-toxicity symptoms started at or around the leaf tip, then developed along the edges down to the leaf base. Symptoms in barley, which were more obvious than in wheat, consisted of dark brown spots or blotches besides chlorosis. Only chlorosis developed in durum and bread wheat.

There was significant variation in seedling B-toxicity symptom scores in all three crops, with barley and bread wheat having larger variation than durum. In general, wheat had a lower degree of symptoms than barley, and could grow in soils with a higher B level. But some barley accessions (Sahara 3763, 3768 and 3769) did have lower symptom scores than the best bread wheat (Greek G61450). Durum wheat accessions, which could grow in high B soils as vigorously as Greek G61450, have recently been identified.

The most important result came from the screening of a barley trial which included widely grown winter/facultative barley varieties from West Asia and Europe. Most of the varieties from West Asia showed few symptoms, while all the European varieties in the trial had severe symptoms (Table 1).

Table 1. Boron-toxicity symptom scores for two contrasting groups of winter/facultative barley in the Barley High Elevation Adaptation Yield Trial.

Entry Name	Origin	B-Toxicity Symptom Score[1]
Tolerant group:		
Arabi Aswad	Syria	2.25
Baluchistan	Pakistan	1.5
ICB 104041	Afghanistan	1.25
Tadmor	Syria	2.0
Tokak	Turkey	2.0
Walfajr	Iran	1.75
Zarjou	Iran	2.0
Sensitive group:		
Cyclone	Russia (Saratov)	4.0
Lignee 527	France	4.25
Novator	Russia (Saratov)	4.25
Plaisant	France	4.0
Robur	France	4.5
Victoria	Romania	4.0

[1] 0-5 scale: 0=no symptom, 5=severe symptoms.

There was a large variation in shoot B concentration, besides B-toxicity symptom scores, within barley and bread wheat. Table 2 gives the range of B concentrations found in bread wheat, in which a near ten-fold difference was detected. A larger range existed in barley, while durum wheat had less variation.

Besides having a lower degree of B-toxicity symptoms and lower shoot B concentrations, tolerant lines grew more vigorously than sensitive lines under high soil-B levels, and sustained no or low reduction in growth when compared with those plants grown under the control B treatment. Table 3 shows the differential responses in dry matter production at tillering stage by some barley genotypes. Relative to the low-B treatment, the moderately-tolerant cultivar, Galleon, recorded a 60% growth reduction in the high-B treatment, in contrast to the 18% increase in the highly-tolerant accession, Sahara 3763.

Table 2. Shoot B concentrations between different bread wheat genotypes.

Genotype	Shoot B Concentration	B-Toxicity Symptom Score[1]
	-----------ppm-----------	
Zidane 89	907	4.5
C182.24/C168.3/3/...	411	2.5
Halberd (Australia)	447	2.25
Shi#4414/Crow'S' (ICARDA)	272	2.25
Greek G61450 (Greece)	226[2]	1.5[2]
ICDW 7674 (Afghanistan)	169[2]	0.75[2]

[1] 0-5 scale: 0=no symptom, 5=severe symptoms.
[2] from a different experiment, but results adjusted based on the common check Halberd.

Table 3. Shoot dry matter yield at tillering for contrasting barley genotypes grown in soil with low or high B levels.

Genotype	B-Toxicity Symptom Score[1]	Low B	High B	Reduction
		--------g/pot-------		----%----
Galleon (Australia)	4.5	1.17	0.47	60
ICB 108254 (Iraq)	1.25	1.49	1.00	32
ICB 109415 (Iraq)	1.25	1.39	1.28	8
Sahara 3763 (N. Africa)	0.1	1.01	1.20	-18

[1] 0-5 scale: 0=no symptom, 5=severe symptoms.

Table 4 shows the reduction of grain yield in barley, durum and bread wheat relative to the control when grown in a soil high in B. This result was obtained with many advanced lines in a pot experiment. On average, barley suffered more grain loss than durum, while bread wheat had the least yield reduction.

Table 4. Mean B-toxicity symptom score at high soil B level[1], and percentages of grain and straw yield reduction relative to the control.

Crop	B-Toxicity Symptom Score[2]	Yield Reduction	
		Grain	Straw
		----------%----------	
Spring barley (18 lines)	2.7	52.7	10.9
Winter/facultative barley (16 lines)	2.5	50.6	14.6
Durum wheat (15 lines)	2.0	43.6	16.8
Bread wheat (12 lines)	1.7	32.5	5.2

[1] Soil level = 18 ppm; [2] 0-5 scale: 0=no symptom, 5=severe symptoms.

There were differential grain yield responses between genotypes to increasing B levels. This is illustrated using three Syrian durum cultivars (Fig. 1). Plants were grown in pots of soil to which boric acid was mixed at rates of 0, 25 and 50 mg B kg^{-1} soil (giving 0.3, 7.1 and 17.4 ppm hot water-extractable B). Gezira 17, the old cultivar derived from a local landrace, did not suffer any significant yield loss at high soil B levels. On the contrary, the grain yield of Cham 1, the responsive cultivar released in Syria in 1984, was significantly reduced at both high B levels. Cham 3, which was released in Syria in 1987 for drier areas, had its yield reduced only at the highest B level.

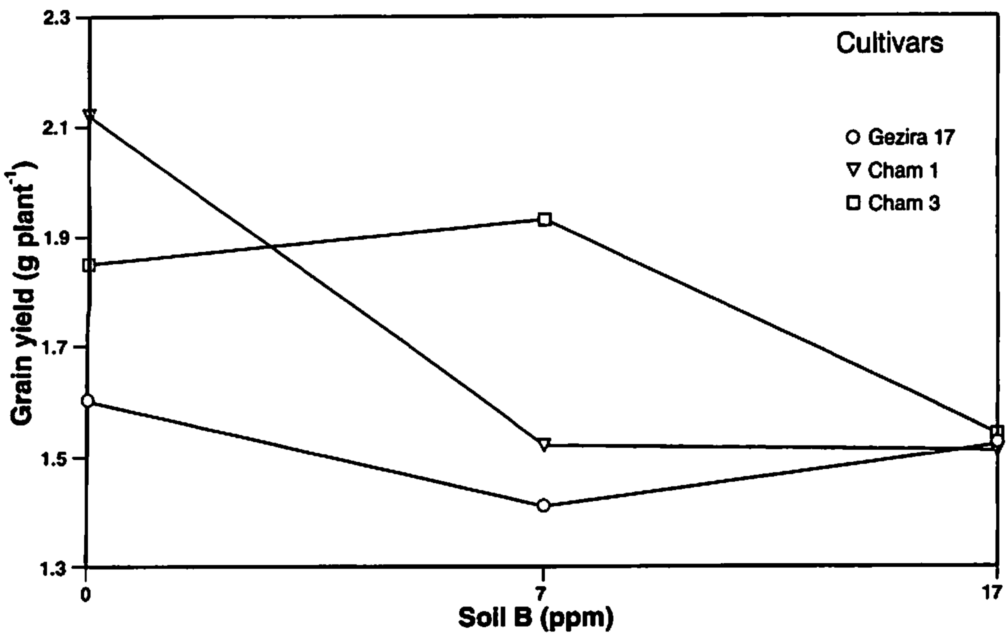

Fig. 1. Differential grain yield responses of three durum wheat cultivars to high soil B levels.

Discussion

I suggest the exploitation of genetic tolerance, but not soil reclamation, as a solution for the problem of high soil B. This is because large-scale reclamation is not feasible in most of the dry, rainfed areas, or in areas where B is added to the soil by irrigation water, due to a lack of good quality water. Besides, leaching B from the soil is not as easy as it is for soluble salts (Leyshon and Jame, 1993). Under this situation, one really should ask the question: "Is it necessary to continue using the expensive orthodox approach of modifying the soil to suit the plants?" I believe the answer is "No!" It is high time that we adopted the more practical approach of modifying the plants to suit the soil.

Results of this study showed clearly that nature has chosen the latter approach because many of the widely-grown barley landraces from the region's dry areas have good tolerance to high soil B. Furthermore, reclamation may create problems. Reclaimed lands may be suitable for B-toxicity sensitive crops, but crops which have a high demand of B, such as sugar beet, alfalfa, and cotton, may suffer from B deficiency.

Some of you may think that the use of B-toxicity tolerant varieties may eventually lead to a build-up of B and crop failure, a situation similar to that of salinity. To clarify this, it is important to distinguish the two main sources of B in the soil. In the vast rainfed areas, where B is inherently present in the subsoil, use of B-toxicity tolerant varieties is not expected to lead to further B build-up in the soil. Build-up of B may occur in areas where high B irrigation water is being used. But this build-up will occur whether B-toxicity tolerant or sensitive varieties are used, and this build-up has probably already occurred in many irrigated areas of WANA. In my opinion, the use of tolerant varieties will give researchers and administrators a longer period to search for the best strategy for farmers to adopt. For those areas where B build-up has already occurred, only tolerant varieties can be grown.

The most important result of this study is that the European barley varieties are very sensitive to B toxicity, while the widely grown landraces in the dry areas of West Asia are mostly tolerant. This finding provides one more reason why European materials are generally not well adapted to WANA countries. It also indicated that natural selection has been so successful that the problem of high B soils has not been realized in WANA and unknowingly neglected in present breeding programs. This study found good sources of B-toxicity tolerance in barley, durum and bread wheat for genetic exploitation. Since inheritance of B-toxicity tolerance in bread wheat is controlled by a few additive genes (Paull et al., 1991), breeding for B-toxicity tolerance is expected to be relatively easy.

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5. Laboratory Techniques and Nutrient Management

Soil Testing and Plant Analysis Methodology for Dryland Research

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Abstract

Almost all soils in the arid and semi-arid fields of West Asia and North Africa are alkaline and calcareous and have low organic matter (OM) contents, and major nutrient deficiencies involving N, P, K, Zn, B, and/or Fe. Fertilization is primarily practised for N and P only, but generally at lower rates compared with actual requirements, and is imbalanced in favor of N. Soil testing and plant analysis are the practical techniques for diagnosing nutrient disorders and, when combined with field trials, formulating sound recommendations for balanced fertilizer use. Besides determining the soil properties affecting nutrient availability, such as pH, $CaCO_3$, OM, texture and salinity, soils are analyzed for extractable nutrient fractions to obtain indices of nutrient availability. Plant analysis, though of lesser use than soil testing, provides useful information regarding actual nutrient status and uptake by the crop plants which can help improve soil fertility management. The paper discusses *soil testing* and *plant analysis techniques* in general use in dryland agriculture as well as *interpretation of analytical data for formulating fertilizer recommendations*. Simpler, more efficient, and/or economical methods of soil testing and plant analysis are suggested for future emphasis in dryland research. The need for micronutrient soil testing and plant analysis is emphasized for balanced nutrient management in dryland agriculture.

Introduction

Optimum plant growth requires adequate and balanced nutrient supply which can be managed by balanced fertilizer use. Balanced fertilization, in turn, is dependent on formulation of fertilizer recommendations based on nutrient requirement of crops and nutrient supplying capacity of the soil on which the crop is to be grown. The diagnostic techniques for assessing soil nutrient status and determining fertilizer needs of crops include: (a) nutrient deficiency symptoms, (b) field experimentation, (c) greenhouse pot experimentation, (d) soil testing, and (e) plant analysis.

Each diagnostic technique has advantages as well as limitations. Deficiency symptoms of some nutrients are useful indicators of nutrient deficiency, but such symptoms may be frequently confused with symptoms of disease or insect damage. It is often too late to manage fertilization of agronomic crops after observing symptoms. Field experimentation is the most reliable approach in determining site-specific fertilizer requirements for crops, but the technique is expensive and time-consuming. Although greenhouse pot experimentation is a useful technique for academic purposes, it is not a practical technique for advisory use as results of pot culture experiments cannot be directly extrapolated to field situations. Therefore, soil testing and plant analysis are the only practical approaches for diagnosing nutritional disorders and formulating recommendations for balanced fertilizer use.

Soil testing is most useful in predicting nutrient requirements and in evaluating salinity problems since the analyses can be performed prior to crop sowing and appropriate fertilizer application can be made in time for balanced nutrient supply to the crop. Use of plant analysis can support and supplement the soil testing information, as the nutrient content of diagnostic plant parts indicates the true nutritional status of the crop.

The crops grown in rainfed dryland areas of the West Asia-North Africa (WANA) region, with a Mediterranean, merging to a continental, climate, include cereals (wheat, barley, sorghum), legumes (lentil, chickpea, faba bean, pea, medics, peanut) and oilseeds (sunflower, vetches) (Matar and Somel, 1987). Various crop species or even varieties of one species have specific nutrient requirements and ability to utilize soil nutrients (native and applied) and thus leave different residual effects in soils. Soils of the WANA dryland area belong to at least six soil orders of the US Soil Taxonomy system: Entisols, Inceptisols, Alfisols, Mollisols, Vertisols and Aridisols (Matar et al., 1992). Most dryland soils are alkaline, calcareous to varying degrees, and low in OM--the most important nutrient deficiencies are those of N and P. Potassium deficiency is rare, but may be of significance in coarse-textured soils and when high yields are harvested continuously without adding K. Sulfur deficiencies are also reported in some dryland soils (NFDC, 1994). However, oilseeds, having high S requirement, may be affected more by S deficiency than are other crops. This subject merits further research.

Among the micronutrients, Zn deficiency is the most widespread and crop response to Zn fertilization has been reported for rainfed wheat, maize, sorghum, rapeseed, and mustard, (Rashid and Qayyum, 1991), but its practical impact in dryland farming has not been felt because of low crop yield levels. Boron and Fe deficiencies are next in importance to that of Zn (Rashid, 1996). It must be remembered that the occurrence of micronutrient deficiencies is more genotype-specific compared with deficiencies of major nutrients. Disorders of Cu, Mn and S are negligible, and the Ca, Mg, and Mo status of dryland soils is adequate.

Fertilizer use in dryland agriculture is more or less limited to N and P and the nutrient use rate is generally lower than actual crop requirements and is biased in favor of N. This inadequate and imbalanced fertilizer use results in nutrient mining of dryland soils. Therefore, accurate prediction of fertilizer requirements in dryland agriculture is highly warranted for sustainable agriculture.

Soil Testing

Soil testing is viewed as the practical application of soil science research because it is the farmer's best guide to wise and efficient use of fertilizers and soil amendments. Soil testing in the customary sense refers to the laboratory analysis to assess plant-available nutrients, salinity, element toxicity, and other soil properties (texture, pH, calcium carbonate, organic matter, EC, SAR, etc.). A soil testing program also includes *interpretations*, *evaluations*, and fertilizer and amendment *recommendations* based on results of chemical analyses and on other considerations. Information gained from soil testing is useful in predicting the probability of obtaining a profitable fertilizer response, and providing a basis for balanced fertilizer recommendations and maintenance of soil fertility for sustainable agriculture. The value of soil testing is both general and specific, as it ensures judicious and economic fertilizer use. Thus, soil testing is an important means of increasing crop production by the rational use of fertilizers in combination with other improved management practices.

In Pakistan, soil analytical data from advisory soil testing laboratories are primarily used for determining gypsum requirement for sodic soils, making soil test summaries to get an idea of the general status of soil fertility, and also for advising farmers regarding fertilizer requirements of their crops. However, use of soil test values for site-specific fertilizer recommendations is very limited because few farmers use soil analysis to get recommendations on fertilizer use (Rashid and Ahmad, 1994).

Analytical Methods

It is necessary to choose the kinds of analyses which are meaningful for the soil to be analyzed. Soil test methods of general use in dryland agriculture are listed in Table 1 and soil test methodologies for fertility evaluation are summarized in Table 2.

There are no widely accepted methods of testing soils for available N (Dahnke and Johnson, 1990). Soil analysis for total N content using the Kjeldahl technique is a futile exercise. Therefore, N fertility status of soils is mostly assessed from organic matter and mineralizable N contents. Organic matter levels in dryland soils are generally low (<1.0%), and mineralizable N provides only a small fraction of the total N required for high-yielding crops. In these situations, a test of soil NO_3-N is good measure of available N (Dahnke and Johnson, 1990; Matar et al., 1990).

Most of the N mineralized in soil obviously comes from a fraction of the soil organic matter that is easily decomposed. Therefore, it is likely that a mild acid or alkaline extractant could make a suitable chemical extractant. Hussain and Malik (1990) proposed the modified alkaline permanganate method of Sahrawat and Burford (1982) for evaluating N fertility status of alkaline soils. Using 35 alkaline soils of Pakistan, they obtained a correlation coefficient (r) of 0.84^{**} between the modified alkaline permanganate method and mineral N from an incubation test, $r = 0.76^{**}$ between permanganate N and N uptake by wheat, and $r = 0.44^{*}$ between permanganate N and wheat dry matter yield. A chemical availability index could have the advantages of being *simple* and *rapid*. Therefore, this method is worth considering for dryland research. However, NO_3-N, e.g., by the AB-DTPA test (Soltanpour and Workman, 1979), and NH_4-N content are considered good indices of N availability when used in conjunction with soil organic matter content. Methods for measuring N in the soil extract mainly involve colorimetry and titrimetry (Keeney and Nelson, 1982).

Among major nutrients, soil testing is most effective for P. The soil test procedures used in the WANA region for evaluating P fertility of dryland alkaline soils include $NaHCO_3$, Bray I, Bray II, Bingham, Truog, Morgan, and AB-DTPA (Matar et al., 1992). In general, the P extracted by acid solution is much less satisfactory than the $NaHCO_3$ method. Therefore, the routine soil test for evaluating P fertility of alkaline soils in most countries is the $NaHCO_3$ method of Olsen et al. (1954). The Regional Soil Test Calibration Network of ICARDA adopted this test as the official soil P test for the WANA region (Matar et al., 1992). The resin method is also very effective for alkaline soils (Ryan and Ayubi, 1981), but it is considered tedious and time-consuming, and hence unlikely for widespread adoption.

Among the methods developed later for alkaline soils, AB-DTPA (Soltanpour and Workman, 1979) has received research attention in some countries, primarily because it can be used for simultaneous extraction of many nutrients--P, K, NO_3-N, micronutrients (Zn, Cu, Fe and Mn) and Na (Jones, 1990). The amount of P extracted by this method is highly correlated with that obtained by $NaHCO_3$ (Rashid et al., 1988, 1992; Azzaoui et al., 1989; Punno, 1993), K with that obtained by neutral normal NH_4OAc extraction and Cu, Fe, Mn, and Zn with that obtained by the DTPA extraction

Table 1. Soil test methods for determining soil fertility, and other soil properties.

Parameter	Method/Extractant	Reference
General Soil Properties		
Texture	Bouyoucos hydrometer	Bouyoucos (1962)
pH	Saturated soil paste, or 1:1 soil-water ratio	McLean (1982)
Organic matter	Dichromate oxidation (Walkley and Black)	Nelson and Sommers (1982)
Free carbonates ($CaCO_3$)	Acid neutralization	Soltanpour and Workman (1981)
Electrical conductivity	Conductivitimetry	Rhoades (1982a)
(Total soluble salts) CEC	Ammonium acetate	Rhoades (1982b)
Exchangeable cations (Ca, Mg, K and Na)	Ammonium acetate	Thomas (1982)
Micronutrients		
NO_3-N	AB-DTPA	Soltanpour and Workman (1979)
P	$NaHCO_3$	Olsen et al. (1954)
	AB-DTPA	Soltanpour and Workman (1979)
K	NH_4OAc	Thomas (1982)
	AB-DTPA	Soltanpour and Workman (1979)
SO_4-S	$CaCl_2$	Williams and Steinbergs (1959)
Micronutrients		
Zn, Cu, Fe, & Mn	DTPA	Lindsay and Norvell (1978)
	AB-DTPA	Soltanpour and Workman (1979)
B	Hot water	Berger and Truog (1940)

Source: Rashid and Ahmad (1994).

Table 2. Soil test methodology for fertility evaluation.

Parameter/adaptability	Olsen[1]	AB-DTPA[1]	NH_4OAc[2]	DTPA[2]	Hot water[2]
Property/Nutrient (s)	P	NO_3-N, P, K, Zn Cu, Fe, Mn,	K, Mg, Na, Ca	Zn, Cu, Fe, Mn	B
Sample size (g)	2.5	10	5	10	
Volume extractant (mL)	50	20	25	20	
Extracting solution	0.5 *M* $NaHCO_3$ at pH 8.5	1*M* NH_4HCO_3 + 0.005 *M* DTPA at pH 7.6	1 *N* NH_4OAc at pH 7.0	0.005 *M* DTPA + 0.01 *M* TEA + 0.01 *M* $CaCl_2$ at pH 7.3	H_2O
Shaking/boiling time (minutes)	30	15	5	120	5
Shaking action and speed	Reciprocating 180+ oscillations/min	same 180+/min	same 180+/min	same 180+/min	-
Extract determination	Colorimetry, 880 nm (molybdenum blue)	P: Molybdenum blue K: Flame emission Zn, Cu, Fe, Mn: AAS	K, Na: Flame emission Mg, Ca: AAS	AAS	Colorimetry (Azomethine-H) at 430 nm
Range in soil nutrient conc. without dilution (kg ha^{-1})	2-200	P, 2-100; K, 5-750; Zn: 0.5-35	K, 50-1000; Ca, 500-2000 Mg, 50-500; Na, 10-250	Zn: 0.5-20	
Sensitivity (kg ha^{-1})	1	P: 2; K:1; Zn: 0.5;	K, 5; Mg, 5; Ca, 10; Na, 2	0.5	
Primary Reference	Olsen et al. (1954)	Soltanpour and Schab (1977)	Schollenberger and Simon (1945)	Lindsay and Norvell (1969)	Berger and Truog (1940)

[1] For alkaline soils, [2] Wide range of soils.

(Jones, 1990). Generalized interpretative guidelines for AB-DTPA soil test data are given in Table 3. Phosphorus in the soil extract is measured colorimetrically using the ascorbic acid molybdenum-blue colour method (Watanabe and Olsen, 1965).

Table 3. Generalized guidelines for interpretation of soil analysis data.

Parameter	Soil Test	Low	Marginal	Adequate
Organic Matter	Walkley-Black	<0.86%	0.86-1.29%	>1.29
		----------------	$mg\ kg^{-1}$	----------------
NO_3-N	AB-DTPA	≤10	11-20	>20
P	$NaHCO_3$	≤7	8-15	>15
	AB-DTPA	≤3	4-7	>7
K	NH_4OAc	<100	100-150	>150
	AB-DTPA	≤60	6-120	>120
Zn	DTPA	<0.5	0.5-1.0	>1.0
	AB-DTPA	<1.0	1.0-1.5	>1.5
Cu	DTPA	<0.2	0.2-0.5	>0.2
	AB-DTPA	<0.2		>0.5
Fe	DTPA	<4.5		>4.5
	AB-DTPA	≤2.0	2.1-4.0	>4.0
Mn	DTPA	<1.0	1.0-2.0	>2.0
	AB-DTPA	<1.8		>1.8
B	Hot water	<0.5	0.5-1.0	>1.0

Source: FAO (1980), Soltanpour (1985), Ludwick (1995), Martens and Lindsay (1990), Johnson and Fixen (1990), Soil and Plant Analysis Council (1992), Matar et al. (1992).

The procedure routinely used to simulate K-supplying capacity of soils is extraction with 1 *N* neutral NH_4OAc (Thomas, 1982). The AB-DTPA procedure for extractable K (Soltanpour and Workman, 1979) is now also common in many labs. Potassium in the extracts is measured by flame photometry or atomic absorption spectroscopy. As extractable K content may tell a little about the soil's K-supplying capacity, interpretation of exchangeable K levels should take into account the K-release rate, subsoil K levels and the influences of other cations (Rashid and Ahmad, 1994).

In Pakistan, AB-DTPA has proved to be quite effective in diagnosing P and K deficiency in rainfed crops, as the data were generally in agreement with plant analyses (Table 4). The generally extractant for SO_4-S in alkaline soils is 0.01 *M* $CaCl_2$ (Williams and Steinbergs, 1959), while SO_4 concentration in the extracts is measured by turbidimetry (Verma et al., 1977).

The routine soil test for micronutrients (Zn, Cu, Fe and Mn) is the DTPA method of Lindsay and Norvell (1978). However, many research labs have now switched over to the AB-DTPA method of Soltanpour and Workman (1979) or are using the latter test along with the DTPA method for comparison purpose (Rashid and Ahmad, 1994). Micronutrient concentrations in the extracts are measured by atomic absorption spectrophotometry. The routine soil test for soil B is the hot-water extraction procedure of Berger and Truog (1940) and subsequent determination by colorimetry using the azomethine-H procedure (Bingham, 1982). However, comparable effectiveness of the HCl method (Ponnamperuma et al., 1981) in determining B fertility of alkaline soils (Rashid et al., 1994, 1995b) suggests further investigations because of simplicity of the technique.

Soil Test Interpretation

Translation of soil test analytical results into fertilizer recommendations is not simple. This is so because the crop harvest obtained by the farmer comes much later than the soil analysis before crop sowing which indicates available nutrient reserves (Decroux, 1990). An evaluation of the analytical results for fertilizer recommendations must be based on field response data obtained under local soil-climate crop conditions. While generalized published criteria provides good guidelines, they cannot be applied to all situations because of variation in soil types, management practices, crop genotypes, and yield targets. Therefore, local interpretive guidelines, based on soil-test crop-response calibration, are needed for meaningful soil analysis data interpretation.

In field experiments Matar et al. (1990) determined that NO_3-N or mineral N (NO_3 + NH_4-N) content in the topsoil at crop sowing was a good index of N availability to dryland wheat in the Mediterranean region. They proposed critical levels of NO_3-N in the 0-60 cm soil layer as 8 mg kg^{-1} for wheat following legumes (lentil or chickpea) and 15 mg kg^{-1} for wheat proceeded with a non-leguminous crop.

The ICARDA's Regional Soil-Test Calibration Network considered 5 to 7 mg P kg^{-1} soil by Olsen procedure as the critical value below which a response is likely (Matar et al., 1992). The proposed critical levels of $NaHCO_3$-extractable P and fertilizer recommendations for rainfed cereal crops (wheat, maize, and sorghum) in Pakistan are presented in Table 5. However, these guidelines are generalized in nature and lack a sound enough basis for site-specific fertilizer recommendations. This is so because in addition to other factors, P fertilizer requirements can be greatly influenced by the soil type (Mahmood-ul-Hassan et al., 1993), crop genotypes (Rashid and Bughio, 1993, 1994), cropping systems (Punno, 1991), previous crop, salinity/sodicity hazard, crops to be grown, and yield target.

Table 4. Nutrient deficiency diagnosis in rainfed soils and crops of Pakistan using soil testing and plant analysis.

District	Locations No.	Nutrient	Percentage in each category					
			Soil[1]			Sorghum[2]		
			Low	Medium	High	Low	Medium	High
Jehlum	140	P	70	26	4	61	39	-
		K	39	41	17	32	66	2
Chakwal	115	P	74	23	3	77	23	-
		K	19	48	33	14	80	6
			Soil[1]			Rapeseed-mustard[2]		
Attock	65	P	74	21	5	74	26	-
		K	25	63	12	29	66	5
Chakwal	55	P	73	25	2	75	25	-
		K	25	44	31	22	71	7
			Soil[1]			Peanut[2]		
Chakwal	76	P	75	20	5	70	30	-
		K	30	44	26	29	71	-
Attock	24	P	71	21	8	67	33	-
		K	29	42	29	25	75	-

[1] Based on AB-DTPA test results; [2] Based on plant analysis data.
Sources: Rashid and Quyyum (1991), Rashid (1993), Rashid (1994).

Table 5. Critical soil P levels and proposed fertilizer rates for rainfed cereals in Pakistan.

Category	$NaHCO_3$-P	Recommended Fertilizer Application Rate	
		Full Technology Adoption	Partial Technology Adoption
	--mg/kg--	kg P_2O_5 ha^{-1}	
Very low	<5	75	60
Low	5-10	50	40
Medium	10-15	40	20
High	15-20	20	--
Very High	>20	--	--

Source: Ahmad et al. (1991).

Interpretation of micronutrient soil test data is, however, restricted to categorization into *deficient, adequate*, or *toxic*. Formulation of micronutrient fertilizer application rates for deficient soils is therefore based on crop requirement information rather than soil test data *per se*. Great care should be exercised in recommending fertilizer rates to avoid toxic (especially B) or excessive levels which may induce deficiencies of other micronutrients. Generalized guidelines for interpretation of soil analysis data are given in Table 3.

Plant Analysis

Plant analysis usually refers to the quantitative analysis of the total nutrient concentration in plant tissue. The concentration of a nutrient in diagnostic plant parts in general indicates the soil's ability to supply that nutrient and is directly related to the soil available nutrient status soil. Up to a certain point, as the plant nutrient concentration increases, yield increases. Plant tissue analysis information can lead to improved fertility management for crop production. When plant analysis is used as a means of evaluating the crop nutrient status, changes in the fertilizer program can often be made immediately, or, if that is impossible, in time for the next crop. Plant tissue analysis can indicate where fertilization will likely result in increased yield, but plant analysis alone is not adequate to guide fertilizer management. Rather, current and past soil conditions as well as agronomic practices and crop conditions must be considered before making appropriate fertilizer recommendations.

Methods of Plant Analysis

Plant tissues are generally analyzed for N, P, K, Zn, Cu, Fe, Mn and B. Total N in plant tissue is analyzed by Kjeldahl digestion. Plant analysis for P and K is performed either by wet-acid digestion using HNO_3-$HClO_4$ or by dry-ashing at 550°C for 6 hours.

Zinc, Cu, Fe and Mn is analyzed by wet-digestion if the tissue is high in silica. However, low-silica tissues such as leaves of leguminous crops and seeds of grain crops can be analyzed for micronutrients by dry- ashing. As total Fe content in plant tissue does not indicate Fe nutritional status of plants (Rashid and Din, 1992), determination of ferrous (Fe^{2+}) iron in fresh leaves by o-phenanthroline extraction (Katyal and Sharma, 1980) is suggested. In our experience, Fe^{2+} content in fresh plant tissues of rainfed chickpea and peanut crops is an accurate indicator of chlorosis severity (Rashid and Din, 1992; Rashid et al., 1997a). The critical level of Fe^{2+} in peanut plant tissue was also estimated (Table 6). Boron in plant tissue is analyzed by dry ashing (Gaines and Mitchell, 1979). The methods of measuring nutrient concentration in plant digests are the same as used for soil extracts, as already shown.

Plant Analysis Interpretation

The content of a particular nutrient below which the crop yield or performance is less than optimum is called the *critical level* and the range of nutrient concentration associated with optimum plant growth and yield is called the *sufficiency range*. Traditionally, plant analysis data are interpreted using critical levels and *nutrient sufficiency range* (NSR) approach. For example, in maize about 0.25% P in the ear leaf at silking time is considered the critical concentration and 0.25-0.50% is the sufficient range (Jones et al., 1991). The physiological age, cultivar, year-to-year climate variation, nutrient interactions, and geographical location can cause variations in plant elemental concentration (Jones et al., 1991). Therefore, traditional interpretation techniques of plant analysis has its limitations.

The Diagnosis and Recommendation Integrated System (DRIS) technique of interpreting plant analysis data is based on a comparison of calculated elemental ratio indices with established norms. Although previously supposed to be a better technique of interpreting plant analysis data, DRIS is no better than the one based on NSR (Beverly, 1992; Beverly and Hallmark, 1992) because, in recent studies DRIS has proved inferior to NSR in diagnosing nutrient deficiencies in apple and corn (Beverly. 1992; Soltanpour et al., 1995). The NSR can be superior to DRIS in situations where: (i) very high level of one nutrient can cause false relative deficiency (inbalance) diagnosis of other nutrients, and (ii) an optimal ratio between two nutrients produces maximum yields only when both nutrients are in their respective sufficiency ranges. Therefore, it is doubtful that the DRIS method will ever be exclusively used in lieu of the more traditional NSR technique. Hence, use of the NSR technique is recommended in combination with an appropriate soil test to avoid poor diagnosis of nutritional disorders.

Plant analysis interpretive values by NSR for selected dryland crops, given in Table 8, emphasize that internal nutrient requirements of crops could vary drastically in different crop species, different plant parts of the same species, and in the same plant part of a species sampled at various growth stages. Moreover, nutrient requirement of varieties of the same species could also very greatly (Rashid et al., 1997b). Therefore, generalized interpretive guidelines are be useful in all situations. Such guidelines for a number of agronomic crops, vegetables, fruit trees and other plant species have been published by Jones et al. (1991) and Reuter and Robinson (1986). However, minimum nutrient concentrations tolerable for adequate growth, given optimum supply of other factors, needs to be determined for local crop genotypes commonly grown for dryland agriculture.

Table 6. Fertilizer P requirements of selected " benchmark" soils in Pakistan.

Soil Series	Subgroup	pH (1:1)	$CaCO_3$	Clay + Silt	AB-DTPA-P	Fertilizer Requirement[1]
			---------- %	-----------	---mg kg^{-1}---	mg P kg^{-1} soil
Rasulpur	Ustochreptic Camborthid	7.6	3.4	4+17	2.50	8
Gujranwala	Udic Haplustalf	7.9	2.0	13+52	0.30	51
Missa	Typic Ustochrept	7.7	6.2	16+58	0.24	83

[1] Amount of P fertilizer needed for 0.2 mg P L in soil solution; Source: Mahmood-ul-Hassan et al. (1993).

Table 7. Effect of foliar sprays of sequestrene on total Fe and Fe^{2+} content of young leaves of chickpea and peanut (on dry-weight basis).

Crop/Cultivar	Total Fe		Fe^{2+}	
	Chlorotic Plants	Green Plants	Chlorotic Plants	Green Plants
	---------------------------- mg kg^{-1}	----------------------------	----------------------------	----------------------------
		Chickpea		
C-44	1100	1000	29	47
C5-1434	800	700	29	47
V6-1122	1100	1200	29	47
CM-88	1100	2000	29	47
		Peanut[1]		
BARD-92	-	-	31	51
BARD-699	-	-	35	42

[1] Critical Fe^{2+} concentration in young terminal leaves of peanut = 40 mg kg^{-1}
Source: Rashid and Din (1992); Rashid et al. (1995a).

Table 8. Plant analysis interpretive guides critical level/nutrient sufficiency range approach.

Nutrient	Low	Sufficient	High	Low	Sufficient	High
	------------	------------	%	------------	------------	------------
	Barley (*Hordeum vulgare*)			Oat (*Avena sativa*)		
N	<1.75	1.75-3.00	>3.00	<2.0	2.0-3.0	>3.0
P	<0.2	0.2-0.5	>0.5	<0.2	0.2-0.5	>0.5
K	<1.5	1.5-3.0	>3.0	<1.5	1.5-3.0	>3.0
	------------	------------	mg kg^{-1}	------------	------------	------------
Cu	<5	5-25	>25	<5	5-25	>25
Mn	-	-	-	<25	25-100	>100
Zn	<15	15-70	>70	<15	15-70	>70
	Wheat (*Triticum aestivum*)					
	Whole shoot, heading from boot			Top two leaves, just before heading		
	------------	------------	%	------------	------------	------------
N	<2.0	2.0-3.0	>3.00	<1.75	1.75-3.0	>3.0
P	<0.2	0.2-0.5	>0.50	<0.21	0.21-0.5	>0.5
K	<1.5	1.5-3.0	>3.00	<1.51	1.51-3.0	>3.0
	------------	------------	mg kg^{-1}	------------	------------	------------
B	<6	6-10	>6	<5	5-50	>50
Cu	<5	5-25	>25	-	-	-
Mn	5-24	25-100	>100	<16	16-200	>200
Zn	<15	15-70	>70	<21	21-70	>70
	Peanut (*Arachis hypogaea*): upper part of plant					
	Sampling time: Prior to or at bloom stage			At early pegging		
	------------	------------	%	------------	------------	------------
N	<3.5	3.5-4.5	>4.5	<3.5	3.5-4.5	>4.5
P	<0.25	0.25-0.5	>0.5	0.2	0.2-0.35	>0.35
K	<1.7	1.7-3.0	>3.0	<1.7	1.7-3.0	>3.0
	------------	------------	mg kg^{-1}	------------	------------	------------
B	<25	25-60	>60	<20	20-50	>50
Cu	<5	5-20	>20	<10	10-50	>50
Mn	<60	60-350	>350	<100	100-350	>350
Zn	<25	25-60	>60	<20	20-50	>50
	Sorghum (*Sorghum bicolor*): third leaf below head					
Sampling time:	At bloom stage (head visible)			Grain in dough condition		
	------------	------------	%	------------	------------	------------
N	<3.3	3.3-4.0	>4.0	<3.0	3.0-4.0	>4.0
P	<2.3	2.3-0.35	>3.5	<0.15	0.15-0.25	>0.25
K	<1.4	1.4-1.7	>1.7	<1.0	1.0-1.5	>1.5
	------------	------------	mg kg^{-1}	------------	------------	------------
B	<1	1-10	>10	<1	1-6	>6
Cu	<2	2-7	>7	<1	1-3	>3
Mn	<10	10-190	>190	<8	8-40	>40
Zn	<15	15-30	>30	<7	7-16	>16

[1] Barley and oat whole plant at head emergence.
Source: Jones et al. (1991).

Seed Analysis

Seeds of crops are generally not used for determining nutritional status of the sampled plants (Jones et al., 1971). However, seed analyses have proven a good indicator for evaluating the N (Goos et al., 1981; Pierce et al., 1977), P (Rashid and Bughio, 1993; Rashid and Din, 1993), S (Fox et al., 1977), and Zn (Rashid and Fox, 1992) supply status of soil. The use of seeds as diagnostic tissue has advantages in terms of ease of sampling, processing, and/or analyzing. Seed analysis only diagnoses past problems. However, it can be used to identify sites where future crops will respond to fertilizer application and regional trends in the nutrient status of crops. Table 9 lists critical concentration of N, P, S and Zn in mature seeds of selected crops.

Table 9. Critical nutrient concentrations in mature seeds of selected grain crops.

Nutrient	Crop Species	Critical Concentration	Reference
		------------- % ---------	
N	Wheat	1.92	Goos et al. (1981)
	Corn	1.53	Pierre et al. (1977)
P	Rapeseed	0.72	Rashid and Bughio (1993)
	Chickpea	0.37	
	Lentil	0.26	
	Wheat	0.22	
	Black gram	0.35	Rashid and Din (1993)
S	Cowpea	0.26	Fox et al. (1977)
		-- mg kg^{-1} --	
Zn	Cowpea	36	Rashid & Fox (1992)
	Corn	18	
	Sorghum	10	
	Millet	15	
	Wheat	15	
	Wheat	10	Riley et al. (1992)

Problems in Laboratory Data Interpretation

Soil testing and plant analysis are generally quite effective in diagnosing nutritional problems. However, at times the best analytical technique may not be helpful in correct diagnosis of the problem. For example, the $NaHCO_3$ soil test performed on 31 alkaline "benchmark" soils of Pakistan failed to diagnose P deficiency in 10% cases and incorrectly diagnosed P deficiency in 13% cases (Rashid and Hussain 1990). Similarly, most appropriate plant analysis methodology and interpretation techniques may fail in correct diagnosis in certain cases. An inaccurate nutrient deficiency diagnosis may not necessarily be because of ineffective analytical technique and/or incorrect diagnostic interpretation. In fact, constraints such as time of fertilizer application, inefficient nutrient application or uptake, nutrient interactions, or drought stress may prevent yield response to a nutrient which is indeed required. On the other hand, applying a nutrient deficiency of which is not diagnosed, might increase yield by indirectly increasing the supply of another nutrient which is in fact required (Beverly and Hallmark, 1992). For example, application of NH_4-N to a calcareous soil might increase the availability of Fe by acidifying the soil through nitrification, whereas Fe fertilization as inorganic Fe salts might not increase Fe availability. Considering the complexity of soil, plant and environmental processes operating between the time of applying fertilizer and measuring yield, apparent errors in the diagnostic system may actually be weaknesses in the data used.

Discrepancies in soil and plant analysis may occur due to the use of same critical levels for evaluating soils which differ in texture, mineralogy, and other characteristics. However, soil and plant analysis can supplement each other for the better interpretation of results for assessing the nutrient status of soils and crops. For example, in our experience, despite some discrepancies between the soil and plant analysis data, soil testing by AB-DTPA and analysis of diagnostic plant parts were generally in good agreement for identifying the extent and severity of P and K deficiencies in rainfed soils and associated crop plants (Table 4).

Future Research Needs

The overall objective of a soil testing and plant analysis program in dryland agriculture cannot be anything else but accurate prediction of fertilizer requirements for balanced nutrient supply to crops. An example of practical utility of such a program is the guidelines developed and used in Colorado for giving fertilizer recommendations for a crop or a group of similar crops in accordance with soil test nutrient levels and a yield target (Soltanpour et al., 1985). The past research efforts under the ICARDA-coordinated Soil Test Crop Response Calibration network in the WANA region have resulted in very useful information. The future soil fertility dryland research may aim at developing similar guidelines by emphasis in the following areas:

Soil Test Methods

Despite the known difficulties in evaluating N fertility of soils, some simple and practical methodology may be agreed upon and adopted for getting a reasonably good idea about the native N fertility of dryland soils and sound prediction of fertilizer N requirements. Although the conventional soil tests, i.e., $NaHCO_3$ for P, are quite affective and well adopted, the advantages of efficiency and economy call for adoption of a multi-element 'universal' soil test such as AB-DTPA for routine soil testing. This switch-over will help achieve a comprehensive picture of soil fertility status in respect of N, P, K, Zn, Cu, Fe and Mn with less effort. The AB-DTPA method may, therefore, be included in all future soil test crop response research programs where such information is still lacking.

In view of widespread B deficiency in dryland soils and crops (Rashid and Qayyum, 1991; Rashid et al., 1995b), soil testing for B may also be included in all research studies. The simpler soil test for B, i.e., HCl method of Ponnamperuma et al., (1981), should be evaluated on a wider range of soils before being recommended for adoption for routine soil analysis.

Plant Analysis

Soil fertility research in dryland agriculture merits more emphasis on plant analysis for getting a better picture of nutrient management. Therefore, nutrient concentrations and uptake should be monitored in all research studies. Development of critical levels and/or sufficiency ranges for the major local crop genotypes is suggested for sound interpretation of plant analysis data. For nutrients such as iron, plant analysis is a requirement rather than an option. Determination of the physiological iron fraction, Fe^{2+}, is suggested by an appropriate extractant like the o-phenanthroline method of Katyal and Sharma (1980), at least in the crop genotypes known to be susceptible to Fe chlorosis.

Micronutrients

Presently, the term balanced fertilization is more or less restricted to N, P, and K use only. However, reports of widespread deficiencies of micronutrients in a number of dryland crops emphasize the need for assuring adequate micronutrient availability to plants. Therefore, more emphasis is suggested on soil testing and plant analysis for micronutrients, particularly for crop genotypes known to be susceptible to the deficiency of a particular micronutrient. As application of micronutrient fertilizers may not be a practical management practice in many dryland agriculture situations, screening of crop germplasm with respect to susceptibility to micronutrient deficiency is suggested by using appropriate plant analysis techniques.

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Soil Nitrate Test for Nitrogen Recommendations for Rainfed Barley

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Abstract

Soil samples for nitrate (NO_3) at 0 to 15-cm depth were taken for 7 years just before sowing barley at two locations with 250 and 350-mm mean rainfall. Grain barley growing in different rotation systems followed fallow, vetch, forage barley or grain barley. Nitrogen (N) was applied at rates of 0, 30, 60, and 90 kg N ha^{-1} to barley in sub-plots. Correlating the total NO_3 supply (soil plus in fertilizer) with the grain yield of barley, critical NO_3 levels were determined with three different methods: *Regression, Cate-Nelson, and Quadratic- Response* and *Plateau model.* Correlation coefficients were low when the relationship was examined over the years, but improved when the site-year and the site-year-rotation were considered. Under the experimental conditions, the low correlation coefficients were attributed to two factors, 1) inconsistency of the onset of rainfall which enchances N mineralization, and consequently the amount of NO_3 present at sampling time, and 2) to the low rainfall and uneven distribution which determine the response of cereals to N supply. The critical level ranged from 30 to 100 mg NO_3-N kg^{-1} with a mean value of 60 mg NO_3-N kg^{-1} of soil. *Soil testing is not an accurate method for N fertilizer rate recommendation*; critical levels established should only be used to indicate responsive and non-responsive sites, considering climatic conditions for mineralization before sampling.

Introduction

The rate of N fertilizer to apply to cereal crops is based on potential yield, soil type, cropping history, and fertilizer and grain prices (Mason, 1989; Ryan et al., 1991), or directly on the soil N supply as measured by soil testing (Taylor et al., 1978; Gelderman et al., 1988) or plant analysis (Papastylianou, 1989). Blanket recommendations of N rates can also be based on long-term N fertilizer studies under specified environmental conditions (Krentos and Orphanos, 1979). The present report deals with soil testing and its applicability for N fertilizer recommendations under rainfed conditions. Soil testing for NO_3 has been shown to be a successful tool on which to base N fertilizer recommendations in some cases (Matar et al., 1987; Ward, 1971), but not in others (Sylvester-Bradley et al., 1987; Gordon and Rickerl, 1992). These contradictions are due to the fact that the crop's N requirements depend on weather conditions (temperature, rainfall) and the status of other nutrients (Anderson, 1985). The amount and distribution of rainfall and temperature are not only critical factors as to how much N fertilizer is needed, but they also determine the release of mineral N from the soil N pool (Rochester et al., 1991; Cassman and Munns, 1980).

Long-term rotation studies offer the possibility to investigate a variety of environmental conditions influencing yield each year at a certain location, as well as the effect of different cropping systems. Within such studies, the relationship between soil NO_3 status at the beginning of the growing season with the final grain yield could also be examined. The long-term rotation studies at two locations in Cyprus offer this background. In addition, the different NO_3 levels present in the soil as a result of varying of N fertilizer application rates, and cropping systems produce a wide range of NO_3 supply so that a full response curve can be obtained.

Materials and Methods

Two rotation trials were established on clay loam soils. The first one was initiated in 1980 at Laxia, an area with an average rainfall of 250 mm per year and the second one at Dromolaxia in 1981, an area with average rainfall of 350 mm. The rotation treatments were *vetch* for hay-*barley* for grain (VB); *fallow-barley* for grain (FB); barley for *hay-barley* for *grain* (HB); *barley* for *grain* - *barley* for grain (B2) and *continuous barley* for grain (BC). The local cultivar of vetch (*Vicia sativa* L.) was sown at the seed rate of 150 kg ha^{-1}. The two-row barley (*Hordeum vulgare* L.) cultivar "Kantara" was sown at the seed rate of 110 kg ha^{-1} for grain and at 175 kg ha^{-1} for hay.

Barley for hay and the first phase of barley for grain (rotation B2) received 60 kg N/ha/year in all sub-plots, while all other barley for grain received the following N fertilizer rates in sub-plots: 0, 30, 60, 90 kg N ha^{-1}. The N was applied at sowing as ammonium sulphate, and P at sowing at 100 kg ha^{-1} as triple superphosphate in all plots. The rotation treatments were randomised in the main plots, which were divided into four sub-plots (6 x 5 m) for the N fertilizer treatments. The treatments were allocated in a split-plot design with three replicates.

The hay were harvested when vetch was at the full pod-formation and barley at the early-dough stage. Barley for grain was harvested at full maturity using an experimental combine harvester to cut two strips, each 8 rows x 4.5 m from the middle of the sub-plots, leaving borders between sub-plots and from the external rows. All cycles had an entry phase so that both phases of the cycle were present every season. The set of data presented in this report are from the first 8 years, by which time each rotation treatment completed 4 and 3 cycles in each entry phase. The first-year data were not included because they were not influenced by the rotation treatments.

Soil samples were taken each year towards the end of October at 15-cm depth. A hole was opened with a spade and soil was taken from the walls throughout the whole depth. Five sub-samples were bulked to one sample from each sub-plot and transferred to the laboratory in open plastic bags, then air-dried, ground and passed from a 2-mm sieve, and analysed for NO_3-N using the ion-selective electrode (Hadjidemetriou, 1982). In plots where N fertilizer was applied, total soil NO_3 was considered to be the amount in the soil at sampling time plus 100% or 50% of the N fertilizer which was applied at sowing. The N fertilizer was converted to NO_3 values on the basis of 1.4 g cm^{-3} bulk density for a depth of 15 cm.

Critical NO_3 levels for optimum grain yield were determined by using regression analysis, the Cate-Nelson method (Cate and Nelson, 1971), and the quadratic-response-and plateau (QRP) model. For quadratic regression analysis between NO_3 and grain yield, the NO_3 level responsible for 90% of maximum yield from the curves was considered to be the *critical level*. The relative yield was estimated in two ways; 1) using check plot yields divided by "maximum" yields obtained for the particular data set and, 2) dividing by the "optimum" yield. The "optimum" yield was defined as the yield which was not statistically different from the maximum according to the Duncan's Multiple Range test for a GLM procedure (SAS, 1990) of the four N levels. A relative yield of 90% was used as the horizontal line, while a vertical line (indicating the critical level) was used to separate most of the values above the horizontal line in the upper right quadrant, leaving in the upper left none or an "insignificant" number of outliers. Values in the lower left and lower right quadrant reflected yield suppression due to N deficiency and N excess supply, respectively.

Critical values with both the regression and Cate-Nelson methods were set on the nearest ten-units, since the line indicating the critical level is drawn arbitrarily when using the Cate-Nelson method. Using the QRP model (SAS, 1990) with NLIN procedure, relative yield was expressed as the percentage of the maximum which was calculated by averaging the highest grain yields from the N fertilizer treatments which were not significantly different at the 5% probability level. Data from plots not receiving N fertilizer were analysed both separately and together with the rest of the N fertilizer treatments.

Results

There was no consistency in year-to-year variation in soil NO_3 in the non-fertilized continuous barley plots, rainfall before sowing, and total seasonal rainfall (Table 1); there were years with high soil NO_3 before sowing, and years in which mineralization does not occur. Rainfall before sowing was also inconsistent; in some years sowing was done in dry soil and others when 40% of the seasonal rainfall had occurred before sowing. The year-to-year variation in soil NO_3 in all fertilizer rate plots and grain yield at the two locations, (Table 2), indicate that yield was not directly related to the amount of seasonal rainfall; in years with similar rainfall, different yields were obtained, indicating the importance of rainfall distribution along with its total amount. The importance of total rainfall is reflected in higher yields at Dromolaxia, where rainfall is higher than at Laxia. Detailed analysis of grain yield of these studies is presented by Papastylianou, (1993).

The coefficients obtained when correlating NO_3 with grain yield within location and rotation treatment and over years were very low (Table 3), and had no value in determining critical NO_3 level for optimum grain yield. However, when the regression analysis was performed within locations and years-over-rotations (Table 4) and for each year-location and rotation system separately, the coefficients improved. In years when the amount and distribution of rainfall played an important role in yield response to N,

Table 1. Soil nitrate in unfertilized plots from continuous barley and pre-sampling and seasonal rainfall.

Season	Laxia			Dromolaxia		
	NO_3-N	Pre-Sampling Rain	Seasonal Rain	NO_3-N	Pre-Sampling Rain	Seasonal Rain
	mg kg^{-1}	------------ mm ---------		mg kg^{-1}	---------- mm -----------	
1981/82	25	18	226	---	---	
1982/83	26	8	207	18	1	234
1983/84	16	1	257	3	0	331
1984/85	28	55	265	15	196	487
1985/86	21	53	259	38	49	282
1986/87	59	29	236	36	16	308
1987/88	28	17	363	34	13	479
1988/89	17	42	282			
Mean	29	26	259	23	45	343

Table 2. Range and mean of soil nitrate and grain yield values in all fertilized plots at two locations.

Season	Laxia				Dromolaxia			
	Nitrate		Grain Yield		Nitrate		Grain Yield	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
	---- mg kg^{-1} ----		------- t ha^{-1} -----		---- mg kg^{-1} ----		----- t ha^{-1} ------	
1981/82	16-72	33	0.06-3.4	1.6	--	--	--	---
1982/83	15-75	31	0.48-2.5	1.0	14-68	30	0.2-2.2	1.1
1983/84	9-56	33	0.30-1.8	1.1	0- 47	16	0.1-1.7	1.0
1984/85	25-153	62	0.37-2.9	1.5	10-161	52	2.1-3.9	3.1
1985/86	14-113	44	0.01-1.6	0.5	28-169	74	1.8-5.5	3.8
1986/87	48-210	101	0.5 -1.7	1.2	24-145	75	0.6-3.3	1.8
1987/88	10-200	78	1.1-4.3	2.6	25-129	51	0.9-3.6	2.5
1988/89	10-47	23	0.9-4.3	2.9				
Mean	20-126	55	0.4-2.6	1.4	16-109	46	0.9-3.5	2.3

R2 values were above 0.6. Yield response to N supply was affected by rotation. Thus, within the same year and location, positive and negative trends were obtained. Negative responses frequently occurred after vetch, indicating excess N supply after this crop, when additional N fertilizer was used.

Table 3. Relationship between nitrate supply and grain yield over 7 years.

Location	Rotation	Intercept	b-Linear	b-Quadratic	R2
Dromolaxia	B2	1541.8 *	8.8 NS	0.08 NS	0.19
"	BC	1231.8 *	27.0 *	-0.12 NS	0.13
"	FB	2241.1 *	-2.3 NS	0.05 NS	0.09
"	HB	1297.0 *	19.6 NS	-0.03 NS	0.21
"	VB	2341.8 *	9.2 NS	-0.02 NS	0.05
Laxia	B2	56.7 NS	27.9 *	-0.10 NS	0.24
"	BC	703.9 *	6.7 *	-0.02 NS	0.04
"	FB	877.6 NS	14.7 NS	-0.06 NS	0.03
"	HB	132.0 NS	27.5 *	-0.10 *	0.25
"	VB	316.9 NS	27.6 *	-0.14 *	0.09

NS = non significant; * = significant at 5% probability level; B2 = barley for grain; BC = continuous barley for grain; FB = fallow-barley for grain; HB = hay-barley for grain; VB = vetch for hay-barley for grain. BC and B2 differ in fertilization.

Table 4. Relationship between nitrate supply and grain yield for the two location and each year over all rotations.

Year	Location	Intercept	b-Linear	b-Quadratic	R2	
					Fertilizer[1] +	Control[2]
1981/82	Laxia	-1246.1 *	76.9 *	-0.41 *	0.59	0.58
1982/83	Dromalaxia	182.8 NS	30.6 *	-0.21 *	0.18	0.34
1982/83	Laxia	286.8 NS	17.1 NS	-0.05 NS	0.32	0.91
1983/84	Dromalaxia	312.6 *	29.6 *	-0.22 *	0.43	0.42
1983/84	Laxia	529.5 *	22.5 *	-0.19 *	0.29	0.30
1984/85	Drom.	2175.3 *	16.5 *	-0.04 *	0.62	0.49
1984/85	Laxia	987.1 *	16.6 NS	-0.11 *	0.18	0.61
1985/86	Drom.	1640.0 *	42.1 *	-0.17 *	0.33	0.46
1985/86	Laxia	105.6 NS	10.4 NS	-0.04 NS	0.08	0.95
1986/87	Drom.	127.3 NS	28.9 *	-0.11 *	0.26	0.21
1986/87	Laxia	763.5 *	6.9 *	-0.02 *	0.19	0.49
1987/88	Drom.	717.1 *	38.0 *	-0.15 *	0.55	0.57
1987/88	Laxia	2452.4 *	6.3 NS	-0.03 *	0.26	0.63
1988/89	Drom.	1250.3 *	55.2 *	-0.32 *	0.59	0.31

[1] Data from all N fertilizer rates plots; [2] Data only from zero-N plots.

Correlation coefficients between soil NO_3 and grain yield in plots of the zero N fertilizer rate where higher than those from all N fertilizer rates (Table 4), but only the linear model was significant; thus, critical levels cannot be estimated as they can with quadratic models. The critical levels obtained from these curves varied within each rotation over the years (Table 5) without having any relationship between these critical levels and rainfall amounts. The critical level obtained ranged between 30 and 100 mg NO_3-N kg^{-1} soil without having any consistency within rotations; the average critical value was 60 mg NO_3-N kg^{-1} soil.

Table 5. Nitrate levels (soil plus fertilizer source) at which 90% of maximum grain yield was obtained in five rotations at two locations.

Season	Laxia					Dromolaxia				
	B2	BC	FB	HB	VB[1]	B2	BC	FB	HB	VB
	---------- mg NO_3 kg^{-1} ----------									
1981/82	60	60	80	60	60	--	--	--	--	--
1982/83	40	50	70	30	40	40	50	40	40	60
1983/84	40	40	50	40	30	40	40	60	30	40
1984/85	50	50	50	60	50	60	60	100	80	80
1985/86	40	40	50	40	40	80	60	60	70	60
1986/87	100	80	100	100	80	90	90	90	90	90
1987/88	40	60	60	60	40	60	60	60	70	60
1988/89	--	--	--	--	--	50	50	40	50	50
Mean	53	54	66	56	49	60	59	64	61	63

[1] For notations, see Table 3.

The critical levels, over all rotations, which were obtained by using three different ways of definition (Table 6) averaged 54 to 80 mg NO_3-N kg^{-1}; the lower values were obtained when the "optimum" grain yield was used to estimate relative yield. With the QRP method, only 5 out of the 14 location-year cases were defined. Values with QRP were at the same range with the other two methods (regression and Cate-Nelson). The results presented are from data which include soil NO_3 plus 100% of the N fertilizer applied. When taking into account only 50% of the N fertilizer added to the soil NO_3, the critical levels were on average 20% lower than values obtained by using 100% of the N fertilizer.

Discussion

In the present study, soil samples were taken from the top 15-cm layer where most of the organic matter exists and where mineralization occurs; any NO_3 in the soil below this depth was ignored. The best correlation between soil NO_3 and N uptake is obtained with the first horizon compared with further depths (Gelderman et al., 1988; Soltanpour et al., 1989). Sampling a shallow depth also has the advantage that the recommendation can be readily applied by the farmers: there is no need for specific equipment and skills for sampling and more sub-samples can be taken giving a more representative soil NO_3 value. When correlating soil NO_3 with final grain yield, all other factors influencing yield are ignored. Thus, in many studies, correlation coefficients between soil NO_3 and yield are often very low (Gordon and Rickerl, 1992). The major factors which influence the low correlation between soil NO_3, from sampling at a particular time, with final cereal grain yield, is dependence of NO_3 release on soil wetting, which occurs with the first rain (Soudi et al., 1990); the actual growing season begins with the onset of the first rainfall which varies from year to year. In many cases, soil sampling for NO_3 is done before the first rains and before mineralization and NO_3 release.

Table 6. Nitrate levels at which 90% of maximum grain yield was obtained over all rotations.

Season	Laxia				Dromolaxia			
	Regression	Cate-Nelson		QRP[1]	Regression	Cate-Nelson		QRP
		Maximum	Optimum			Maximum	Optimum	
	mg kg^{-1}							
1981/82	80	80	60	86	--	--	--	--
1982/83	70	70	40	--	60	60	30	66
1983/84	40	70	40	31	50	50	30	ND
1984/85	50	60	60	49	100	90	60	ND
1985/86	70	70	40	ND	90	80	80	ND
1986/87	80	80	80	105	100	100	80	ND
1987/88	60	70	60	ND	90	80	60	ND
1988/89	--	--	--	--	70	70	40	ND
Mean	64	71	54	67	80	76	54	

[1] Quadratic - response - plateau model. ND = not determined.

When knowing the environmental conditions of a certain area, sampling for NO_3 could be recommended at a period when the peak mineralization has already occurred (Addiscott and Darby, 1991). However, this strategy is not practical for N fertilizer application at sowing time for Mediterranean conditions due to the inconsistencies of *the first* rainfall. Soil sampling later in the growing season, for top-dressing recommendation, could be replaced by NO_3 tissue testing, which is shown to reflect soil N availability (Papastylianou and Puckridge, 1981, 1983; Darby et al., 1986) and it is an easier method to be applied by farmers (Papastylianou, 1989). To overcome the problem of unknown N release after the first rain, some scientists use mineralizable NO_3, which is the potential NO_3 released by the soil, by incubating the soils under certain moisture and temperature (Soudi et al., 1990). However, these artificial conditions do not reflect in the field conditions. In such cases, critical levels established on the mineralisable NO_3 might be misleading for the practice of N fertilizing (Mengel, 1991).

The present study reveals that the previous cropping history of the field influenced the critical levels within the same year. However, cropping history alone was not enough to improve the accurancy of the critical NO_3 level for grain yield; variation of critical levels within a rotation cannot be explained by the season's total rainfall because, under Cyprus rainfed conditions, distribution is more critical than the actual amount, within limits (Hadjichristodoulou, 1982). To estimate NO_3 availability, the actual amount of the fertilizer applied is added to soil NO_3. However, fertilizer use efficiency (FUE) in this environment is only 40 to 60 % (Papastylianou, 1991). Thus, the estimated critical level on soil NO_3 might be higher than if FUE is considered; when it was assumed that FUE was 50% the critical levels were 20% lower. The critical levels might have also been underestimated in some cases because soil sampling was done before the onset of rainfall and the subsequent mineralization. Nitrogen released later was not included in the critical level determination.

The average value of critical NO_3 level of around 60 mg kg^{-1} of soil is in line with the 30 mg NO_3-N kg^{-1} of soil suggested by other studies (Taylor et al., 1978; Krentos and Orphanos, 1979) when considering that, in those studies, samples were taken at 30-cm depth. However, this mean value cannot be given to farmers, due to the high variation within years, and soil analysis cannot be suggested for recommending N fertilizer rates. Farmers have to rely on methods which take into consideration other growing factors. Such methods include: plant analysis (Papastylianou, 1989) or combination of factors as soil NO_3 along with soil type, climate, cropping history, and economics (Mason, 1989). Modelling, which includes most of the factors influencing plant growth and production, might provide the answer in the future; it gives estimates of N requirements before knowing the climatic factors which will follow during the growing season. This might be partly overcome by using long-term rainfall and temperature averages. However, studies by Otter-Nacke and Kuhlmann (1991), using different models to predict N fertilizer requirements, did not recommend modelling as a tool for N recommendation.

The present study, which combines the results of many year-locations, is indicative of the inconsistency which exists in the literature regarding the value of soil testing for N fertilizer recommendations. It is concluded that the relationship between soil NO_3 and grain yield depends on the amount and distribution of rainfall which are responsible for the NO_3 release from the soil N pool and the crop N response. Because these conditions are so unpredictable at the beginning of the growing season, soil NO_3 tests alone are not a reliable method for recommending N fertilizer rates.

The only suggestion which can be made at present for areas with rainfall ranging between 250 and 350 mm, is that, in cases where NO_3-N levels are 40 to 60 mg kg^{-1} soil in the top 15-cm layer, fertilizer application can be delayed, and plant requirements can be further verified by tissue testing at tillering stage, which is the time for N top-dressing. In cases where soil NO_3-N is below 40 mg kg^{-1}, then N fertilization at sowing could be considered, especially when rainfall and temperatures were already favorable for N mineralization. In these cases, 50% of the recommended blank N rates, which are usually based on long-term fertilization studies (Krentos and Orphanos, 1979; Papastylianou, 1993), can be applied at sowing and the rest of the N fertilizer should be decided at tillering stage. Similarly, general recommendations for using soil NO_3 for identification of responsive sites, rather than predicting N fertilizer rates, were given by Fox et al. (1989).

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Variability in Analyses from WANA Soil Laboratories

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Abstract

In dryland farming of the Mediterranean zone, which has rain in winter with long dry summers, inadequate soil moisture is generally the dominant factor limiting crop growth. Nitrogen (N) and phosphorus (P) can significantly and economically increase yields in most circumstances when both elements are deficient. Soil testing can serve as a basis for identifying nutrient deficiencies and, with field calibration, can provide a basis for fertilizer recommendation. Fundamental to such endeavors is the use of appropriate tests and consistency of test results. Thus, a standard soil sample (Calcixerollic Xerochrept), along with a questionnaire, was sent to 50 laboratories in the region which are involved with soil analysis. Of the 36 respondents, most ran tests for available nutrients, pH and EC, but few did tests for total P, boron or sulfur. Most laboratories made some recommendations for clients. Few laboratories were involved with ^{15}N or ^{32}P analysis, while a small number performed clay mineral analysis. Units of measurement varied among laboratories. While most laboratories were close to the normal values for the test sample, others showed wide variation, especially for Olsen P and organic matter. By communicating these findings to survey participants in this workshop, we hope that the sources of such variation can be identified. Analyses can be improved by use of reference samples of known composition. The survey can help broaden and improve communication among soil scientists in ICARDA's Soil Fertility Network and improve the effectiveness of soil and fertilizer use research.

Introduction

The International Center for Agricultural Research in the Dry Areas (ICARDA), established in 1977 at Tel Hadya, Aleppo, Syria, has a mandate for development of rainfed agriculture in countries of the West Asia-North Africa (WANA) region. Though a highly diverse region, it is mainly characterized by a Mediterranean-type climate with variable rainfall in winter and spring and long dry periods during summer and early autumn (Cooper and Gregory, 1987). In most countries, rainfall is relatively low (200 to 600 mm yr^{-1}) and erratically distributed, and thus soil moisture is the main factor limiting crop growth. Though dryland farming has minimal inputs, recent research in the region (Ryan and Matar, 1990, 1992) has shown that yields of cereals, mainly barley (*Hordeum vulgare* L. subsp. *vulgare*), bread wheat (*Triticum aestivum* L. subsp. *aestivum*), and durum wheat (*T. turgidum* L. subsp. *durum* (Desf.) Husn.), can be increased by N fertilizer in most years (Harmsen, 1984). Similarly, where soil levels of available P are deficient, significant and economic responses may also occur with P fertilization (Matar et al., 1992).

The Soil Fertility Network, involving ICARDA and scientists from the region's national programs, has focused on the role of soil testing in an effort to enhance crop production through efficient fertilization (Matar, 1992). Fundamental to this effort is the need for standardize analytical methods, which should be accurate and repeatable. Without such standardization, interpretation of field trial data is difficult, with corresponding barriers to effective communication among scientists.

Laboratories in the WANA region which perform soil analysis for available nutrients are generally operated by Ministries of Agriculture and other state bodies, and by universities. Unlike in the West, commercial laboratories in WANA region are few. Based on our observations and the diversity that exists in the region, soil testing is variable. Similarly, in the USA, for any one procedure, i.e., lime requirement, Follett and Follett (1983) showed a wide range of methods in use. In addition, these same laboratories produced different results and recommendations (Follett and Westfall, 1986; Follett et al., 1987). In the only study of laboratory procedures in the WANA region that we are aware of, Matar (1985) showed that, although all participating laboratories used the $NaHCO_3$ method for available phosphorus (Olsen et al., 1954), results varied widely. This was attributed to modifications introduced by the operators and conditions specific to individual laboratories.

In view of efforts at ICARDA to coordinate soil and fertilizer use research in the WANA region, our objectives were twofold: 1) to ascertain the range of routine tests performed in soil analysis laboratories, and 2) compare analytical data for these tests on a reference soil sample supplied by ICARDA to cooperators involved with these laboratories.

Materials and Methods

A bulk sample of soil was prepared by air-drying and sieving through a 2-mm screen. It represented the dominant soil type (Calcixerollic Xerochrept) at the 948-ha Tel Hadya headquarters station of ICARDA, about 35 km southeast of Aleppo in northern Syria. The area has a Mediterranean-type climate (327 mm yr^{-1}) with rainfed winter cropping, mainly of cereals. Sub-samples (0.5 kg) were sent (October to November 1992) in plastic containers to government and university soil testing laboratories (one commercial laboratory was included) in the following countries: Syria, Jordan, Iran, Iraq, Pakistan, Yemen, Saudi Arabia, Ethiopia, Lebanon, Turkey, Cyprus, Egypt, Libya, Algeria, Tunisia, Morocco, and Spain. A sample was also sent to the USDA-SCS Soil Laboratory in Lincoln, Nebraska, for complete analytical characterization. The data from this laboratory and ICARDA's own laboratory were to serve as the reference standards.

Respondents were asked to submit the sample to routine tests performed in their laboratories and report the results on an accompanying questionnaire. Each questionnaire was coded to preserve anonymity. The following tests were specified in the questionnaire: pH, electrical conductivity (EC), Kjeldahl N, ammonium-N and nitrate-N, organic matter (OM), calcium carbonate ($CaCO_3$), extractable phosphorus (P), total P, cation exchange capacity (CEC), exchangeable cations, extractable micronutrients, and sulfur.

Respondents were also asked to list any other tests which they routinely performed in their laboratories, whether they did isotope analysis, i.e., ^{15}N or ^{32}P, made mineralogical analysis, or made recommendation for clients based on soil tests. For each test performed, procedural details were requested, i.e., air- or oven-drying, soil/solution ratio, shaking time, specific extractant and molarity, determination procedures, instrumentation, units of measurement, and reference methods. A general reminder to return the questionnaires was sent in January to February 1993.

It is hoped that this report will help laboratories to eliminate unacceptable deviations from "true" test values, where such variation exists.

Results

Of the 50 laboratories which received the soil sample for analysis and the questionnaire, 36 have responded. After 22 labs responded initially, a further 14 responded with a second reminder. The results presented are based on these 36 respondents. Actual test results are presented in Figures 1 to 5, while variation in the different methods used are presented in Table 1 for general analysis and in Table 2 for available or extractable nutrients. For convenience, the highlights of each test or group of tests are given individually. Details of the initial response to the survey were reported by Ryan and Garabet (1994). The present report involves the expanded response reported and presented in front of many of the participants who were involved in the survey.

Table 1. Determination variables for soil general properties.

Measurement		Procedure Details[1]
pH, EC	Extractant	: Water (34); $CaCl_2$ or KCl (1)
	Soil/Solution	: 1:1(9), 1:2(1), 1:2.5(13), 1:5(3), 1:10(1), paste (8)
Organic Matter	Wet Oxidation	: Potassium dichromate (35)
	Titration	: Ferrous sulfate (19), Ferrous ammonium sulfate (15)
	Colorimetric	: (1)
Calcium Carbonate	Extractant	: 0.1 *N* HCl (2); 0.5 *N* HCl (5); 1.0 *N* HCl (7); 6 *N* HCl (4)
	Determine	: Weight Loss (2); Acid Neutralization (21), Calcimeter (11)
Cation Exchange Capacity	Saturation	: 1 *N* NaOAc, pH 8.2 (16); 0.4 *M* NaOAc - 0.1 *M* NaCl pH 8.2 - 60% ethanol (4)
	Displacement	: 1 *N* NH_4OAc, pH 7.0 (16); 1 *M* Mg $(NO_3)_2$, pH 7.0 (4)

[1] Number of laboratories in parentheses.

Table 2. Determination variables for soil nutrients.

Measurement	Procedure Details[1]	
Mineral Nitrogen	Extractant	: 2 *M* KCl (12) 1 *M* KCl (2), : 3 *M* HCL (2), 1 *N* K_2SO_4 (1), AB-DTPA (1)
	Soil/Solution	: 1:10 (12); 1:5 (4); 1.4 (2) paste (1) 1:2.5 (1)
	Shaking Time	: 60 min. (12), 15 min. (3), 30 min. (3), 45 min. (1), 10 min. (1)
	Determination	: Distillation (16); Colorimetric (4)
Kjeldahl Nitrogen	preparation	: Digestion (27)
	Digestion Time	: 5 min. to 1 h. (5); 2 to 5 h. (9); 6 to 8 h. (5)
	Determination	: Distillation (24); Colorimetric (2)
Extractable Phosphorus	Extractant	: 0.5 *N* $NaHCO_3$ (29); 1 *M* $NaHCO_3$ (2)
	Soil/Solution	: 1:20 (31)
	Shaking Time	: 30 min. (31)
	Determination	: Colorimetric-Ascorbic Acid (18), Stannous chloride (8)
Exchangeable Cations	Extractant	: Ammonium acetate pH 7.0 (27), pH 8.5 (3), Water (3)
	Soil/Solution	: 1:5 (9); 1:20 (13); 1:45 (1); 1:10 (1); 1:25 (2)
	Shaking Time	: 15 min. (3); 30 min. (15); 60 min. (6); 120 min. (1)
Extractable Micronutrients	Extractant	: NH_4HCO_3 - DTPA (2); DTPA (18)
	pH	: 7.2 (2); 7.3 (15); 7.6 (3)
	Soil/Solution	: 1:2 (19); 1:5 (1)
Sulfate	Barium Sulfate	: Precipitation (7); Turbidimetric (6)

[1] Number of laboratories in parentheses.

Soil Preparation

The samples were prepared by air-drying in all except one laboratory, which used oven-drying (35°C).

pH, EC,$CaCO_3$, CEC

All except one laboratory used water to extract the sample for pH and electrical conductivity measurements; that one used KCl or $CaCl_2$. The soil/solution ratio was mainly 1:2.5; 1:1 or a saturated paste. With a mean of 8.0, pH values ranged from 7.2 to 8.9 (Fig. 1). Similarly, with a mean of 0.39 mS cm^{-1}, EC values ranged from 0.10 to 1.20. Twelve reported as mmhos cm^{-1} and the remainder as dS m^{-1} or mS cm^{-1}.

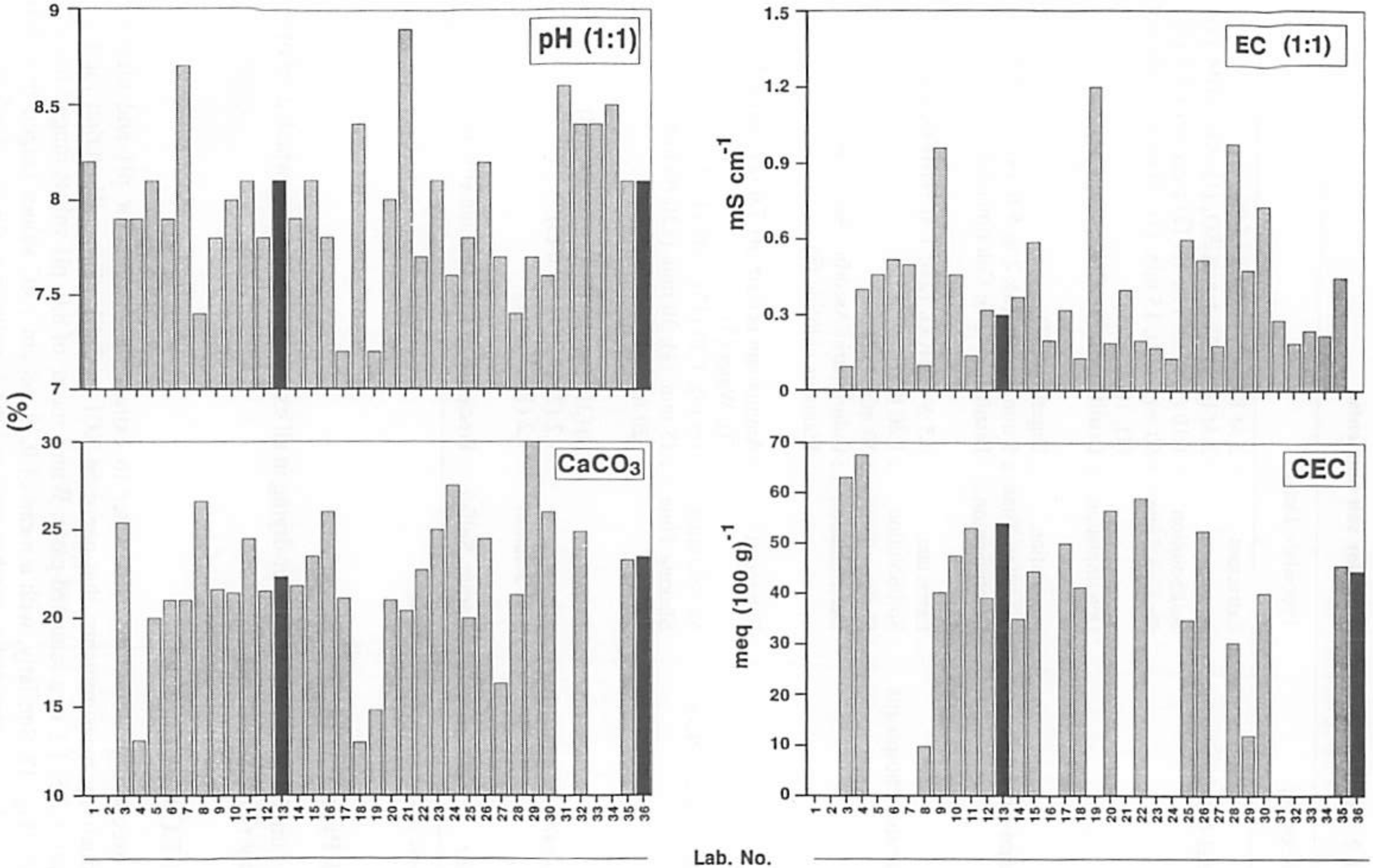

Fig. 1. Laboratory test values for pH, electrical conductivity, calcium carbonate, and, cation exchange capacity.

For $CaCO_3$, most laboratories used acid neutralization with 1.0 *N* HCl or 6.0 *N* HCl followed by either titration with 0.5 or 1.0 *N* NaOH or CO_2 evolution as measured by a Bernard, Collins or Scheiber calcimeter (Fig. 1). Some laboratories used 4 or 6 N HCl, while a few used gravimetric loss from CO_2 evolution. Values ranged from 13 to 30%. However, most were clustered around the mean value (22%).

Most laboratories that measured cation exchange capacity (CEC) used the standard 1 *N* NaOAc, pH 8.2 saturation procedure followed by washing and displacement of exchangeable Na by 1 *N* NH_4OAC, pH 7.0 (Fig. 1). Four laboratories used 0.4 *M* NaCl of pH 8.2 - 60% ethanol followed by 1 *M* $Mg(NO_3)_2$ at pH 7.0. While most values were around 43.7 meq/100 g, four were near 60 and one less than 10.

Organic Matter - Nitrogen Fractions

All laboratories used wet oxidation with 1 *N* potassium dichromate for organic matter determination followed by titration with 0.5 *M* ferrous sulfate or ferrous ammonium sulfate. Values (Fig. 2) ranged from 0.37 to 2.82% with about 50% around the mean (1.13 %).

While the Kjeldahl procedure, which uses concentrated H_2SO_4 with a catalyst mixture of K_2SO_4, $CuSO_4$, Se (100:10:1), is commonly used for measuring organic N, there was no consistency in digestion time among laboratories, i.e., 5 min to 1 h, 2 to 5 h; 6 to 8 h. Most used distillation followed by titration with H_2SO_4 rather than colorimetry. Not surprisingly, many values were considerably above the modal value (0.07%), and the mean (0.10%) value (Fig. 2).

Mineral N, i.e., ammonium (NH_4) and nitrate (NO_3), was measured by 19 laboratories, most of which used KCl (1 *M* or 2 *M*) as an extractant. Most used a soil/solution ratio of 1:10, a shaking time of 1 h, and distillation. However, a range of shaking time and ratios was reported (Table 2). Four laboratories were considerably above the modal (14 ppm) and the mean (15 ppm) values, excluding the abnormal 1000 ppm value for NH_4, while only one was markedly higher in the case of NH_4.

Available and Total Phosphorus, Boron, Sulfate

Virtually all laboratories measured available P using the standard Olsen method with 0.5 *N* $NaHCO_3$. Most used ascorbic acid for color development, while others used stannous chloride as a reducing agent. Most values were close to the mean (7.5 ppm), with some extremes, i.e., 3.8 and 20.2 ppm. Total P was measured in only three laboratories. These used digestion with perchloric acid and color determination with ammonium metavanadate, molybdenum blue, or ascorbic acid. Values ranged from 46 to 646 ppm (Fig. 3).

Boron was also measured in only three laboratories, using the hot-water extraction procedure. However, the values were widely different, i.e., 0.18 to 0.72 ppm (Fig. 3). Sulfate was measured in 13 laboratories by barium sulfate precipitation or turbidimetry. Values were expressed as S or SO_4. Again, results varied widely, i.e., from 10 to 100 ppm with one extreme value "outlier" of 4800 ppm SO_4 (Fig. 3).

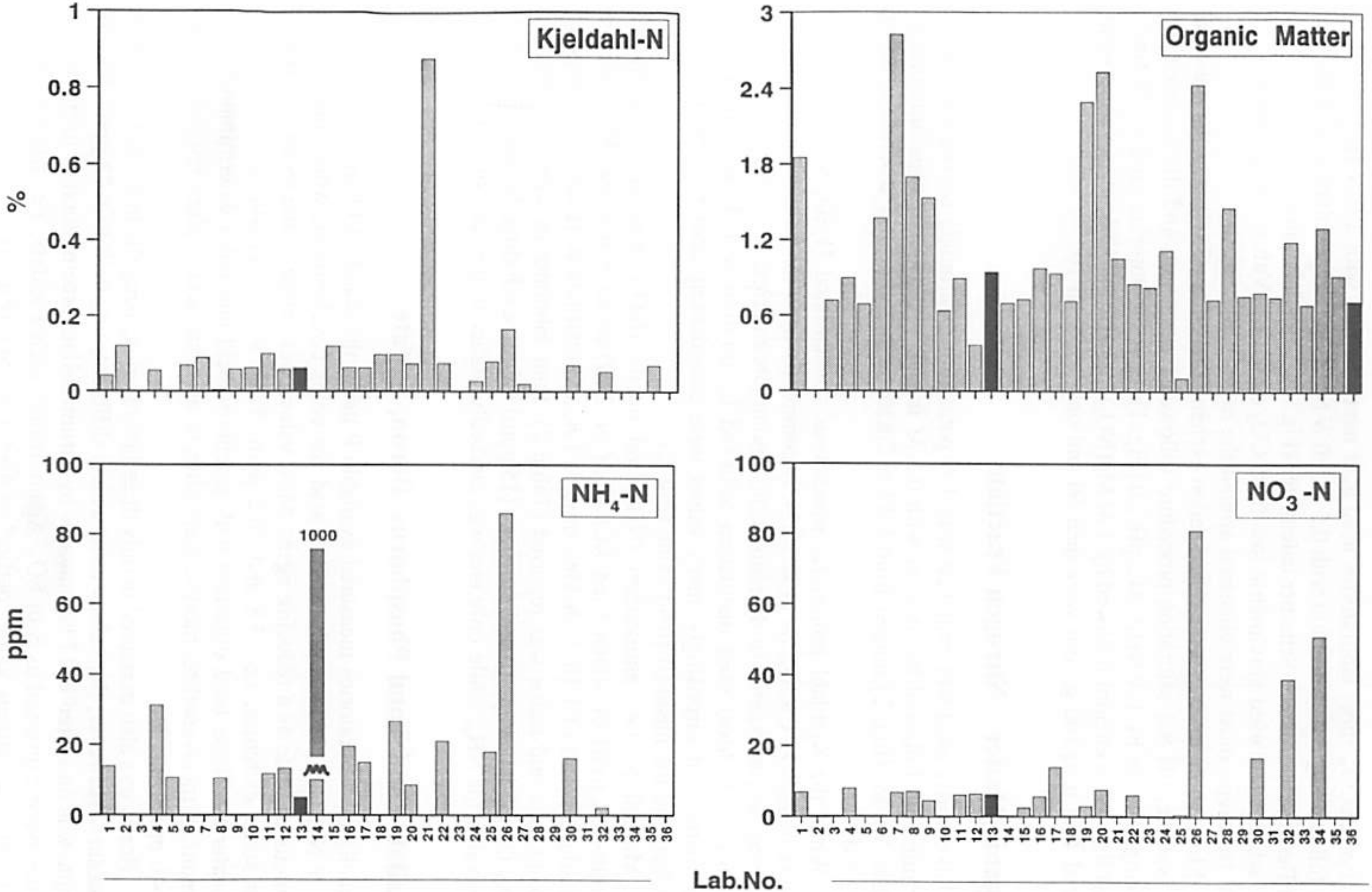

Fig. 2. Laboratory test values for organic matter and various nitrogen forms.

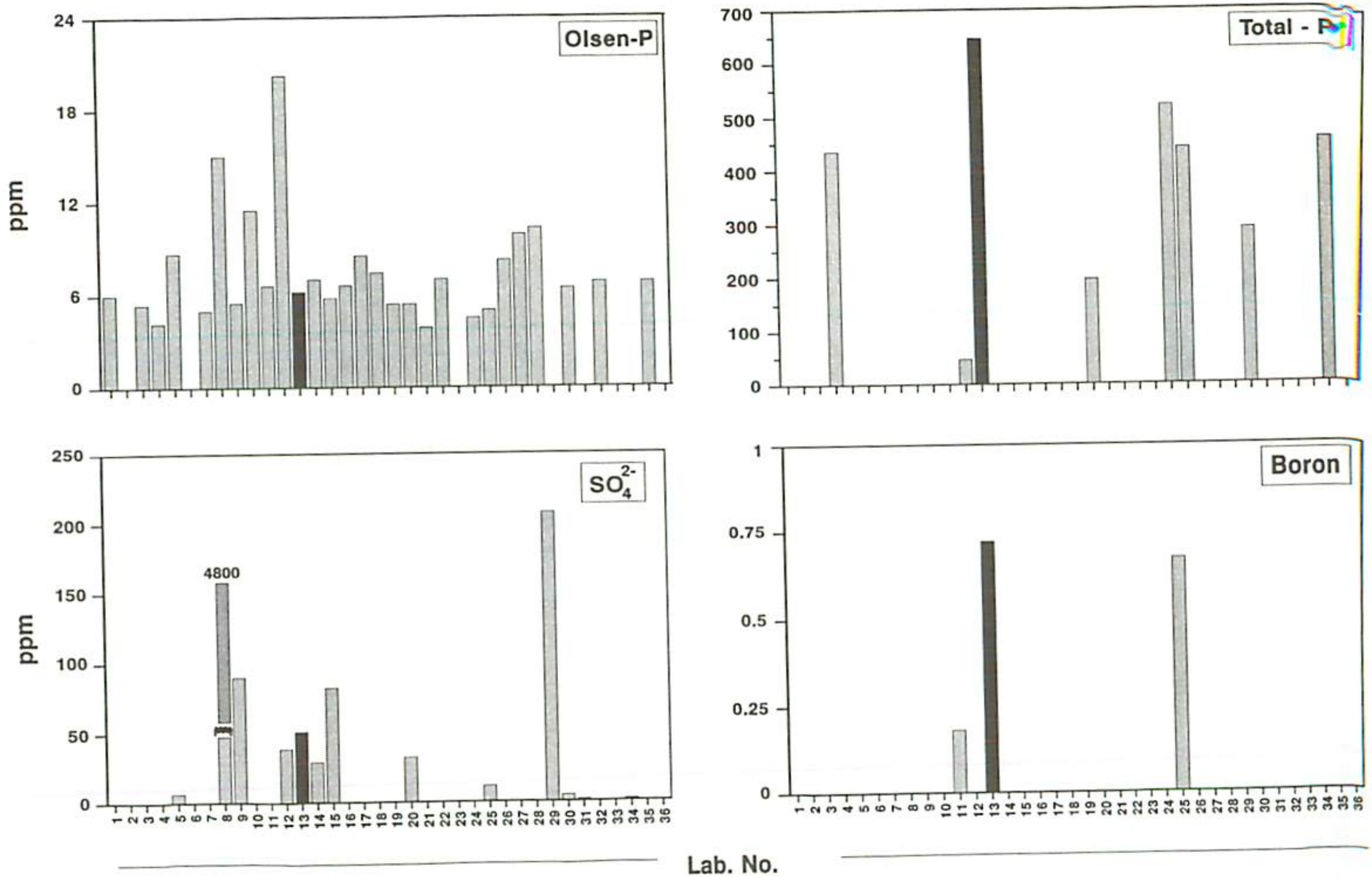

Fig. 3. Laboratory test values for sulfate, boron, and available and total phosphorus.

Extractable Cations

Most laboratories used 1 *N* NH_4OAc, pH 7.0, to extract K, Ca, Mg and Na. Most laboratories determined K, while relatively few did Mg. The K values were generally close to the mean value, with some low values (Fig. 4). Variation in values for the other cations was considerably greater. Most reported determination with flame photometry and a few used atomic absorption spectrophotometry.

Micronutrient Cations

While several laboratories determined micronutrients, all used the simultaneous DTPA extraction procedure of Lindsay and Norvell (1978), or its modification using NH_4HCO_3-DTPA (Soltanpour and Swab, 1977), with measurement of the extracted micronutrients by atomic absorption spectrophotometry. Values for Mn were uniform except for one laboratory, while there was greater variation for Fe, Zn, and Cu (Fig. 5).

Miscellaneous Information

Five laboratories reported doing analysis for gypsum -- two of them for ESP (exchangeable sodium percentage) also. Particle-size distribution was also determined by five laboratories. One reported doing "active" carbonate determination and another was involved with fertilizer analysis. Only one laboratory surveyed did ^{15}N analysis and two measured ^{32}P. A total of eight laboratories indicated that they did mineralogical analysis. All but three laboratories reported some interpretation of results, giving practical recommendations to users based on soil and other test results.

Conclusions

While most laboratories used standard reference procedures for the tests they performed, i.e., USDA Handbook 60 (Richards, 1954) for pH, EC, $CaCO_3$, N in Agronomy No. 9. (Black et al., 1965, now updated by Page, 1982), the Olsen procedure for P (Olsen et al., 1954), and that of Lindsay and Norvell (1978) for micronutrients, the variation in the results suggested that these were due to modifications introduced by the operators and by unspecified factors. Previously, we observed large differences between Olsen-P values on samples analyzed during summer to those assayed in the winter. This difference was attributed to the higher temperatures of the water used to make the extracting solution during the summer.

Sharing the findings of this study with the various laboratories involved should help in identifying causes of unusual deviation from true values for the various tests performed. We will identify the performance of any particular laboratory and provide our standard reference soil sample as a basis for comparison. At the same time, the survey should promote cooperation between ICARDA and the various national research programs in the countries of the WANA region. It should also provide a basis for scientific communication within the context of the region's Soil Fertility Network which is under ICARDA's mandate.

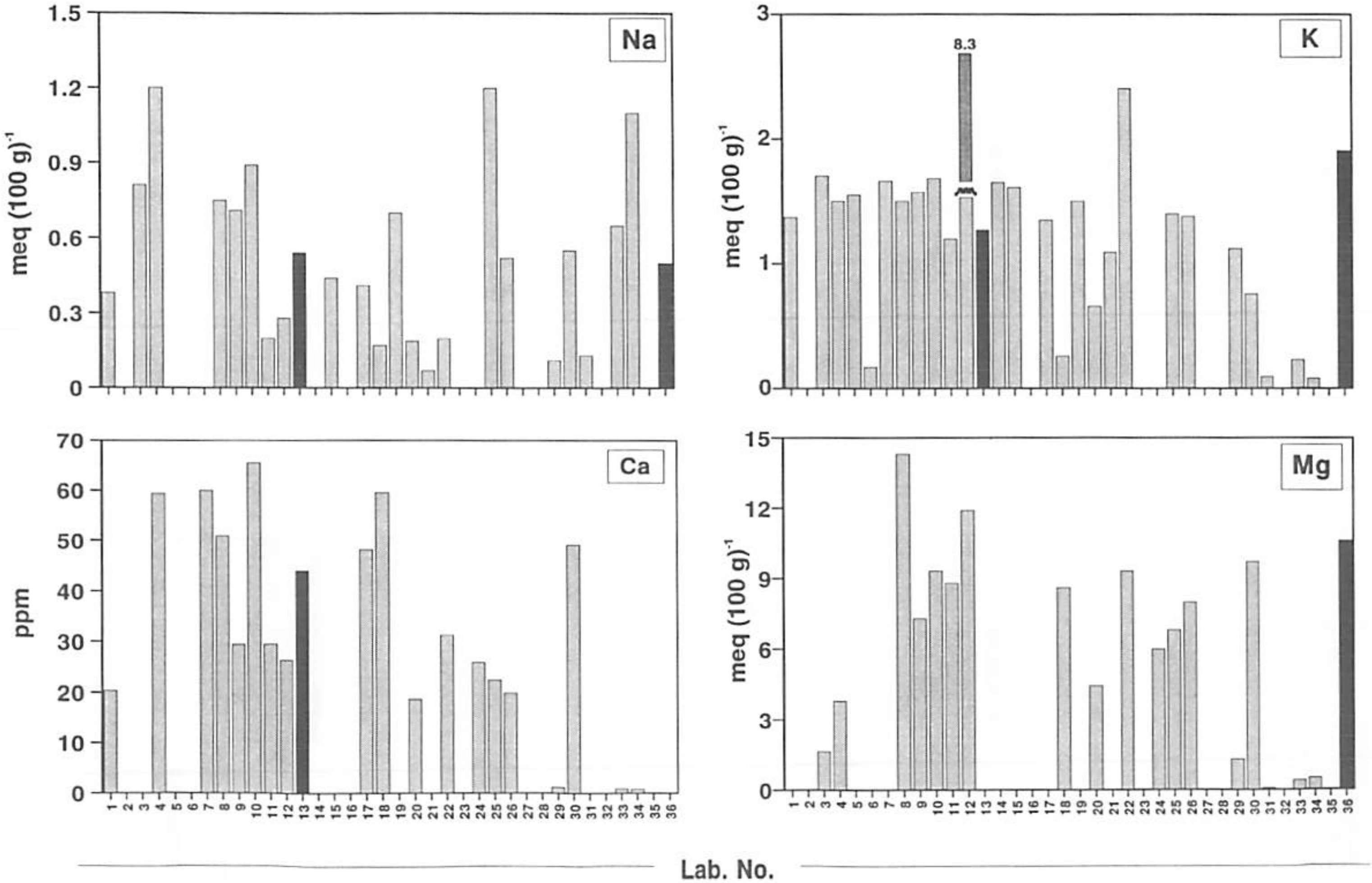

Fig. 4. Laboratory test values for extractable cations.

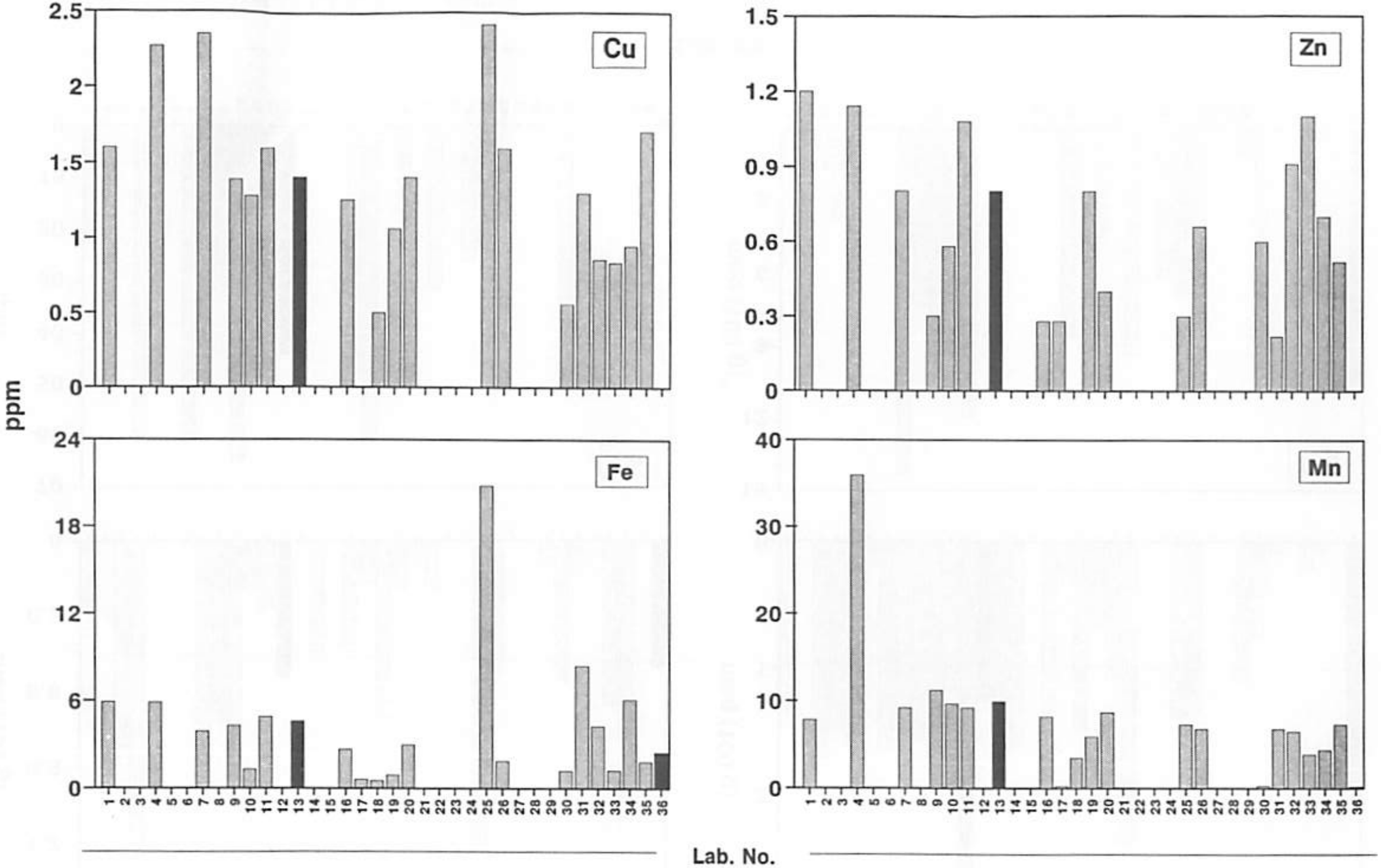

Fig. 5. Laboratory test values for extractable micronutrients.

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Nutrient Balance and Chemical Fertilizer Control in Iran

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Abstract

Adequate nutrition of plants is one of the most important factors in the improvement of the quantity and quality of crops. For appropriate plant nutrition, it is not only essential to provide the required amount of each element to the plant, but to establishment of the correct balance between nutrients is a top priority, because under conditions of imbalance, yield and efficiency of fertilizer will be reduced. Unfortunately in Iran, the ratio of N, P, and K used is often ill-founded, and it may congruent with the requirements of the crop. In addition the time when these nutrients are most required has not been included in the fertilizer recommendation. Thus N fertilizer is generally applied to the crop in one application and, in most cases, in amounts in excess of the plant's need, whereas split applications would be more effective and allow the crop to use the fertilizer gradually.

Persistence of this trend, in addition to causing loss of time and money by farmers, results in leaching of nitrate and pollution of groundwater. It may also result in accumulation of nitrate in hazardous amounts (more than 0.25% on dry weight basis) in the edible parts of vegetables such as spinach and lettuce. Although the needs of plants for P in comparison with N and K are low, our farmers are still extravagant in the use of ammonium phosphate resulting in over use of P with possible deleterious effects on the uptake of other nutrients, especially zinc. Due to excessive application of N and P fertilizer, use of K fertilizers, in tems of crop yield and quality is neglected.

In order to safeguard the equilibrium between soil nutrients, and yield improvement, with due attention to sustainable agriculture, it is proposed that: 1) The nitrate concentration in the 0-60 cm soil layer in the first month of the crop growth period should not exceed 20 ppm and PSNT (pre-side Nitrate Test) method should be applied for cash crops such as corn and potato, 2) The ratio of N, P, and K fertilizer used should be adequate and must not exceed 1:2:1 times that removed by the crops, 3) In fields where large quantities of P fertilizers have been used, applications of this fertilizer should be suspended for a few years especially when available P is around 15-20 ppm, 4) Potassium-fertilizer should be applied to crops which are heavy consumers, and to soils where K has been depleted.

Introduction

Adequate plant nutrition is one of the most important factors in the improvement of crops. In plant nutrition it is not only necessary to place an adequate amount of each nutrient at the disposal of the crop, but it is vital to create a balanced ratio between the nutrients. Unbalanced nutrition, by application of specific nutrients, results in disorders in the growth of plants which ultimately decreases yield. This is the main cause of the relatively low efficiency of chemical fertilizers use in Iran. In 1979, total amount of N and P fertilizers which were used throughout the country was almost 1.0 tons, but a decade later, this amount increased up to 2.0 ton per year. The ideal ratio for N-P-K is about 100-50-40, but in Iran this ratio was 100-80-5. In other words, we used more P fertilizer than the plant's needs. Despite good progress in agricultural production in Iran, especially in the last decade, fertilizer use is still not balanced.

Due to climate and weathering conditions, the dominant type of clay in most soils of Iran is illite, while the amounts of K-bearing minerals are considerable, especially in virgin soils. Since it was believed that weathering of illite released enough K, application of K along with N and P fertilizers was not advised. Sometimes this idea has been spread even to cash crops, such as potato. It is clear that using N and P fertilizers without K decreases K in all potato tissues and lowers yield as well as tuber quality (Soltanpour and Cole, 1978). The continuation of this undesired practice has depleted the K content in some arable soils; the available K in some soils of Damavand and Dezful (Iran) has decreased to less than 200 mg kg^{-1} (Navabzadeh and Malakouti, 1993). Tubers, which are the harvested portion of the potato plant are modified underground stems with internodes greatly extended, use abundant amounts of N, and may accumulate NO_3-N which reduces tuber quality. Although potatoes take up large quantities of K, in some cases, especially in high-K soils, no response to K has been reported. It is clear that lack of response is due to the residual effects of previously applied K or K-released from the soils in question. The critical value for potato, however, varies considerably. Manrique (1992) reported that in K-deficient soils, the amount of K in the petioles was less than 4%.

In recent years, 150,000 tons of K_2SO_4 have been imported; this trend is likely to continue, so that in the next few years fertilization will be more balanced. In prioritizing the methods for eliminating this basic problem, being aware that numerous factors are involved in the decline of production, it appears that assessing the fertilizer requirements of strategic field crops could have been the main bottleneck. In order to accomplish this task, one must not only be aware of the nutrient status and level of soil fertility, but also the water and nutrient requirement of plants, as well as the climatic conditions, level of yield expected, and the manner in which the field is managed.

The soils of Iran, with the exception of a strip in the north, are generally calcareous. Feldspars, mica and illitic clays are the prominent minerals in these soils. Due to the climatic conditions and the lack of leaching of salts from these soils, the available K content is relatively sufficient. However, in consecutive years, by the injudicious use of N and P fertilizers, irreversible damage has been inflicted on these soils and consequently on to the country's agriculture. This happens at a time when the chemical fertilizer requirement of the country is less than its present consumption. The incorrect use of N, P, and K fertilizers, and the lack of inclusion of other plant nutrients in the general fertilizer recommendation, has been the cause of some deficiencies. At present, despite these, the consumption of chemical fertilizers in Iran is greater than the average world consumption. Nevertheless, production per unit area, which is chiefly due to lack of awareness by farmers, accurate knowledge regarding the fertilizer requirement of field crops and proper use of fertilizer supply in accord with demand, is much less than the use yield obtained in the developed countries (Nafisi; 1986, Amir Mokri, 1990).

Since farmers prefer chemical fertilizers, use of organic fertilizers, which is vital for the improvement of the physical, chemical and biological characteristics of the soil has in many instances been forgotten. Lack of use of organic fertilizers (compost, animal and green manures) and unsuitable cropping patterns have caused hardening of arable soils, increasing their bulk densities and lowering their permeability. Since persistence of this trend has been in conjunction with the irregular use of chemical fertilizers, degradation of soil structure has continued.

The amount of mineral nutrients taken up by various field crops during one season with specified yields and the fertilizer recommendations is documented in Table 1 (ILACO, 1981). The time of maximum nutrient uptake by field crops is generally during the second and third month of growth. For example, more than 65% of the nutrients assimilated by corn were taken up during the 26 to 75 days interval after planting. Corn takes up most of its K requirement early in the season, but the need for N and P commences a little later. Either because of lack of root extension in the initial stage of growth or the immediately available P and K in soil, it is recommended that P and K fertilizers be applied prior to planting. However, due to the solubility of N, it should be applied in split application in accordance with the plant's needs. At each stage of plant growth until the commencement of flowering Nitrogen can be readily applied at each growth stage by dissolution in the irrigation water. Otherwise sulfur-coated urea (SCU) should be used as a slow-release N source.

Table 1. Nutrients removed by field crops and optimum fertilizer recommendation.

Crop	Yield	Nutrient Removal			Fertilizer Recommendation		
		N	P	K	N	P	K
	--t ha^{-1}--	kg ha^{-1}					
Wheat	3 grain +3.5 straw	70	15	48	80	20	40
Maize	3 grain +6 stalk	200	35	125	80	30	70
Rice	4 grain +6.5 straw	60	15	70	90	15	30
Cotton	2 seed	90	25	105	80	15	40
Potato	25 tubers	115	20	155	75	30	90
Sugarbeet	40 tubers +10 leaves	150	25	155	90	30	85
Sugarcane	90 stalk	85	25	140	10	35	70
Saybean	2 seed	125	15	30	15	20	45
Alfalfa	80 fresh crop	320	25	140	15	35	120
Citrus	15 fruit	100	10	110	130	35	120
Tea	1 dry leaves	90	7	27	50	15	45

Source: ILCA (1981).

Since farmers have not taken into consideration the amount of nutrients withdrawn from the soil, the only way to attain maximum production is seen with higher use of fertilizer, whatever kind it may be. Since 80% of the fertilizer cost is subsidized by the Ministry of Agriculture, the imbalanced trend between N, P, and K is still visible. This trend used to be observed in some areas of the country, especially in cash crops which are heavy K-consumers, i.e., potato, maize, sugarbeet. Data for fertilizer use show huge variation in amounts applied for any given level of potato yield (Yazdani, 1988). Although a close relationship exists between quantity of available K of soil and yield of field crops, particularly in potato (Navabzadeh and Malakouti, 1993), but in the past, not enough attention has been given to K fertilizers.

In regions where such irregular use of fertilizer is common farmers generally consume water in excess of the crop needs. Therefore some of the N applied is not available to the crop, because it is leached away. For example, the amount of nitrate leached in a corn field where two N fertilizers were used in the vicinity of Tehran was more than 40 ppm even at a depth of 2 m (Jafari, 1992). Excessive use of P fertilizer, because of its relatively low requirement by crop, its fixation in soils, and its interference with micronutrient uptake such as Zn, does not provide any other advantage to the crop and is a waste of the farmers' time and money.

Research suggests that the binding energy of P to the surface of $CaCO_3$ is approximately one fifth less than that to oxides of iron and aluminum (Tisdale et al., 1993). Therefore, it could be expected that despite the speedy fixation of fertilizer P in calcareous soils, in the long term the P "fixed" in these soils becomes available to the crop more readily than in soils where iron and aluminum oxides are dominant. On the other hand, Barber (1984) showed that if the use of P fertilizer ceases, the plant will absorb its P requirements from non-available sources, whereas in the case of consistent use, the plant will adsorb its requirements from readily available sources.

Compared with excessive use of N and P fertilizers, the use of K fertilizer is not customary throughout the country. Continuation of this trend has had a negative effect on the yield and quality of field crops. Potassium, in addition to its effect on increasing yield and quality of wheat and maize grains, plays a positive role in the uptake of other nutrients, especially N. The amount of K needed is equal to or greater than the requirement for N. The soil cannot provide the required amount of K for a protracted period, therefore appropriate use of K is necessary.

Excessive use of fertilizer N is injurious to livestock and humans. In America, cows fed with alfalfa containing 0.21% NO_3-N died. The permissible limit of NO_3-N content in dry feed is determined to be 0.1%. It was reported that children that consumed spinach containing large amounts of NO_3-N suffered from food poisoning due to the higher nitrate accumulation in canned spinach (Lorenz, 1978). In general, accumulation of NO_3-N is greater in some vegetables such as radish, spinach, asparagus, sugarbeet, lettuce, carrot, and cauliflower. Accumulation of NO_3-N rarely occurs in the edible portions of fruits and thus is not a problem with these crops. In canned food products, especially in the case of spinach, beans, tomato, and fruits which have acid-producing properties, NO_3 acts as an oxidizing agent and thus NO_3 accumulation under such conditions could be the cause of poisoning.

Recently, in America, two procedures outlined below, were recommended to economize in the use of N fertilizers and prevent the pollution of groundwater without sacrificing yield:

- The concentration of NO_3-N in soil is tested in late spring (PSNT method) during the cropping season and if it lower than 20 ppm, then N is applied as a side-dressing. Implementation of this method in the corn fields of Iowa resulted in the saving of 300,000 tons from the use of fertilizer N at the cost of only one percent of corn grain yield.
- A chlorophyll meter was used in corn to determine the greenness of the leaves. Comparison of the data obtained with a calibration were prepared using leaf samples of N concentration enabled the estimation of the N concentration in the corn plants. In this way, probable deficiency in the leaves were diagnosed. In studies conducted in the corn fields of Colorado (Soltanpour et al., 1995), a good correlation was observed between the values obtained from the cholorophyll meter and the N percentage in leaves (R^2 =0.95).

Table 2. Permissible nitrate concentration limits in some vegetables on a fresh weight basis.

Nitrate	Leafy Vegetables	Vegetables Tubers	Other Crops
<20	Cabbage, Onion leaves	Onion, Potato	Sweat Corn, Cucumber, Melon, Watermelon, Squash, Tomato
30-50	Asparagus, stalk Lettuce	Carrot	Brocolli, Eggplant
50-100	Sugarbeet leaves, Cabbage leaves, Outer leaves of Lettuce, Spinach Parsely, Radish	Sugarbeet Tuber, Radish Tuber, Turnip Tuber	
>100	Table Sugarbeet petioles, Spinach, Turnip, Radish leaves	Radish, Turnip	

Source: Lorenz (1978).

Conclusion and Recommendations

1. The causes for the accumulation of nitrate in some field crops, and methods for its prevention could be summarized in the following ways:

- Various tests have indicated that the main reason for the accumulation of nitrate in plants is the use of N fertilizers, particularly in the NO_3 form (Minnotti, 1978). Nitrate accumulation can be prevented by using limited amounts of N fertilizers and in split applications to conform to the plants' requirement. In vegetable cultivation, it is recommended that an ammoniacal-N source be used in lieu of NO_3-N fertilizer.

- Since different varieties of plant species exhibit diverse reactions in respect to NO_3-N accumulation, plant breeders need to improve and recommend those varieties which accumulate little nitrate.
- The accumulation of NO_3-N decreases with an increase in temperature. In one experiment, increasing the temperature from 20 to 35°C, decreased the concentration of NO_3-N in tomato. However, in spinach nitrate accumulation was highest at 25°C (Lorenz, 1978). Consequently, accumulation of nitrate in autumn cultivation is greater than spring cultivation.
- Planting vegetables in shady sites should be avoided, and as far as possible they should be harvested in the afternoon because the nitrate concentration is low during this time of the day due to the higher photosynthesis.
- As far as possible, the consumption of stems, petiole, and outer leaves of vegetables should be avoided and if possible these kinds of vegetables should be eaten after cooking.

2. Quantity and time of application of chemical fertilizers should match with the time needed and amount of nutrients removed from the field crops.

3. The establishment and operation of soil and water testing laboratories all over the country will enable the physical and chemical analysis of soil for salinity, pH, organic carbon, total N, available P, and available K, $CaCO_3$, and soil texture prior to cultivation. These results should be supplied with the necessary fertilizer recommendation for a particular crop.

4. The use of ammonium phosphate should be avoided in fields where the available P content is greater than 20 ppm (Olsen method) because of the gradual release of ammonium throughout the growth period, the farmer is inclined to use an amount in excess of plant requirements. In some arable lands the concentration of available P in soil has exceeded 50 ppm; farmers persist in its use as it is a source of N.

5. Determination of NO_3-N in the plow layer of soil at a time when the corn seedlings have attained a height of 25 cm should generally be adopted, so that apart from attaining the desired yield, savings in the consumption of N fertilizers will result.

Finally, it is hoped that with the help of those involved in research, education and extension in the country, our farmers, instead of excessive chemical fertilizers use will switch to utilizing compost, animal or green manure so that, while sustaining an increase in production per unit area, they will safeguard this national wealth for future generations of the country.

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Mineralogical Considerations in Soil Fertility Management in Morocco

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Abstract

In Morocco, as in other Mediterranean countries, the most active part of the soil with respect to nutrients and water supply is made of crystalline layer silicates, humic substances, iron oxides, and clay-sized carbonates. The 2:1 phyllosilicates regulate the dynamics of K^+ and NH_4^+ as a consequence of their high surface area, their charge characteristics, and environmental conditions. The preference of soil smectites for K^+ over Ca^{2+} is controlled by the tetrahedral charge. Recent developments in electron microscopy coupled with energy dispersive detector have shown that smectites may have a great importance on phosphorus adsorption. Phosphate anions are specifically adsorbed by 1:1 layer silicates and iron oxides. Clay-sized $CaCO_3$ reduces the availability of P by its precipitation as P-Ca forms with low solubility. It is demonstrated that humic substances present in soil solution can chelate Ca and Fe and thus prevent the formation of P-Ca and P-Fe compounds. The availability of nitrogen is largely controlled by the amount of organic matter and soil ecological conditions. The pertinence of clay mineralogy needs to be clarified. Although there is evidence that soil mineralogy influences critical nutrient levels to interpret soil fertility analysis, more research is needed to establish quantitative relationships between clay mineralogy and nutrient availability. Detailed characterization of soil clays and reliable quantitative analysis of the clay minerals are necessary to reach this objective.

Introduction

Soil mineralogy-fertility relationships are basic components in our understanding and interpreting the results of fertility experiments. In fact, soils with the same texture (similar clay content) may have different behavior with respect to nutrients and water supply. In these cases, the nature and relative quantities of clay minerals are important to consider. However, establishing quantitative relationships between clay mineralogy and soil fertility is a very difficult task. Difficulties still exist in identification, characterization, and quantification of soil clays (Badraoui et al., 1992).

Many regional surveys in Morocco have shown that the soil fertility status in a given region at a given time is independent of soil type. It depends mostly on the agricultural history (previous crops and fertilizers used) of the plots (Badraoui et al., 1993). Thus, the quantities of fertilizers to be added to a given crop should not be the same on the same soil type. However, soil nutrients critical levels used in interpreting soil analysis depend strongly on soil type (Torrent, 1992). Pertinent soil characteristics in Mediterranean areas are clay content, clay mineralogy, relative quantities of each mineral phase, iron oxides content, organic matter content, and carbonates (Bajwa, 1983; Badraoui, 1988; Badraoui et al., 1992; Torrent, 1992). Theses characteristics largely influence the capacity of the soil to supply nutrients to plants and the kinetics of its ability to replenish the soil solution after the depletion of the rhizosphere (Badraoui et al., 1992; Hinsinger et al., 1992).

The objective of this paper is to demonstrate the importance of clay mineralogy in soil fertility management through a number of recent research studies done in Morocco. It will only focus on the major plant nutrients potassium (K), phosphorus (P), and nitrogen (N).

Mineralogy of Moroccan Soils

The mineralogical composition of the clay fraction (the most active part of the soil) of Moroccan soils, like other Mediterranean soils, is dominated by 2:1 layer silicates (Badraoui, 1988; Badraoui and Bloom, 1990; Badraoui et al., 1992; Torrent, 1992). In general, Moroccan soils have a mixed mineralogy. The dominance of a mineral phase with respect to the others depends on soil type.

Vertisols and vertic subgroups of other soils, locally called "Tirs" soils, are dominated by smectites with small amounts of illite and kaolinites. Detailed characterizations have shown that smectites are mostly high-charged and iron-rich beidellites. The sand and silt fractions of these soils are in most cases quartzitic. Red Alfisols or Fersiallitic soils contain much more kaolinite and iron oxides than 2:1 layer silicates. However, illite is generally present in association with kaolinite. The relative quantities of illite with respect to the other minerals depends on the parent material. Inceptisols and Aridisols have calcium carbonate accumulation in the profile. Their mineralogical composition, although mixed, is dominated by 2:1 clays. Other minerals such as palygorskite may be dominant.

These three categories of soils would have different behavior with respect to the dynamics of N, P, and K. They should be considered when setting up experiments for establishing critical levels of plant nutrients, especially P and K. The following sections will demonstrate how distinctive mineralogical assemblages influence the dynamics of these elements in the soil.

Soil Mineralogy and Potassium Availability

Fixation and release of K are the two major processes controlling the availability of this element to plants. The quantity of K which is immediately available to the plant is that of the soil solution. At any time, a dynamic equilibrium is established between soil solution K, adsorbed K, and fixed K in the underlayer space of the 2:1 layer silicates. This equilibrium is controlled by the clay mineralogy. The effects of mineral content, the total charge, and the location of the charge on K fixation were largely discussed by Badraoui et al. (1992) and Bouabid et al. (1991). The amount of fixed K is strongly related to the tetrahedral charge of the clay which is the distinctive character of soil beidellites (swelling clays). It was suggested, from a practical viewpoint, that both total and tetrahedral CECs of the soil could be used as good predictors of K fixation. In fact, soil K test should be interpreted in relation with the CEC (Quemener, 1986; Ait Houssa, 1989) for soils with different clay mineralogy. For soils with similar mineralogy, clay content is enough to interpret the soil K test.

More recent studies on K-Ca exchange equilibria in Vertisols focused on the relative effects of total charge and tetrahedral charge on selectivity coefficients (Moujahid, 1993). A fraction of the K which is added to the soil as fertilizer will replace Ca in the exchange complex as shown in the following equation:

$$\text{Soil-Ca} + 2\,K^{+} = 2\,\text{Soil-K} + Ca^{2+}$$

The relative affinity of the exchanger (soil clay) with respect to Ca and K depends on its charge characteristics and can be expressed by a selectivity coefficient. Both Vanselow (1932) K_V and Gaines and Thomas (1953) K_{GT} selectivity coefficients are used as follow:

$$K_V = \frac{M^2K\,(Ca^{2+})}{MCa\,(K^+)^2}$$ M : molar fraction of adsorbed K

$$K_{GT} = \frac{E^2K\,(Ca^{2+})}{ECa\,(K^+)^2}$$ E : equivalent fraction of adsorbed K

Five clay fractions extracted from Vertisols (M1, ZR, M16, S, and DK) and one reference clay (SWY-1) were used in K-Ca exchange experiments at 25°C to obtain exchange isotherms and to evaluate their relative selectivity for K. Figure 1 shows that all soil clay isotherms are above the non-preference isotherm. The M1 soil, which is the Chaouia Vertisol, has the highest selectivity for K versus Ca. The reference montmorillonite (SWY-1) shows the lowest preference for K compared with soil clays. Tetrahedrally charged soil smectites have a higher affinity for K than the reference octahedrally charged montmorillonites which are generally used in laboratory experiments to simulate the behavior of soils.

The preference for K compared with Ca by soil clays is also demonstrated by the high values of both Vanselow, and Gaines and Thomas selectivity coefficients. For example, K_V ranges from 400 to 114 mol L^{-1} at low concentration of K in the exchange sites for soil clays. The lowest K_V were obtained for SWY-1 (Fig. 2). Similar results were obtained for K_{GT} (Fig. 3). The preference for K decreased with the saturation of the clays with this element (Fig. 2 and 3). These results clearly demonstrate that the sites having a high selectivity for K are saturated first. The curves of LnK_V versus the equivalent fraction of K adsorbed by clays are necessary for modeling the partition between K in soil solution at equilibrium and K adsorbed on clay surfaces.

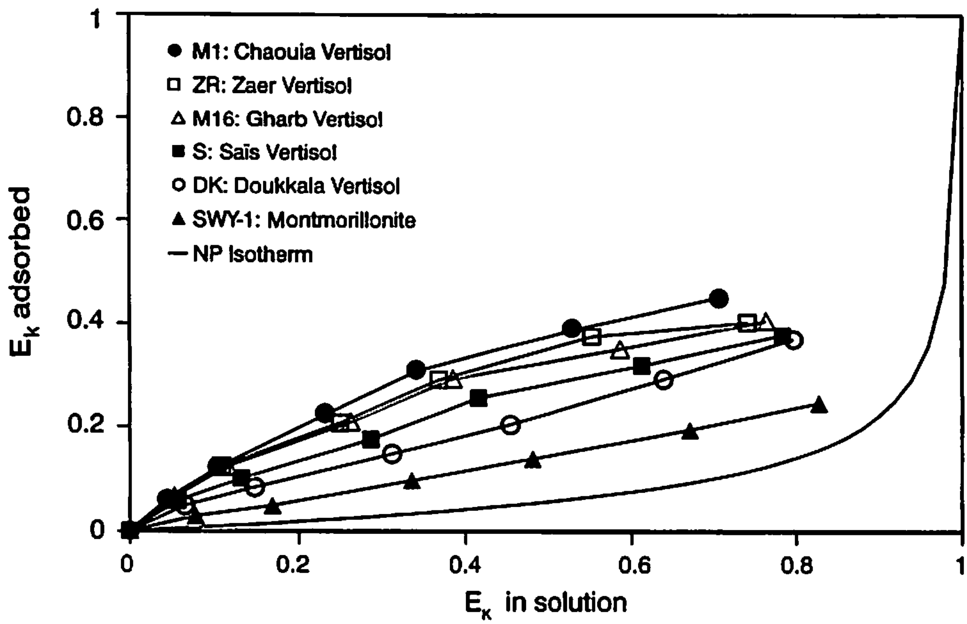

Fig. 1. Exchange isotherms of K-CA in vertisols of Morocco at 25°C.

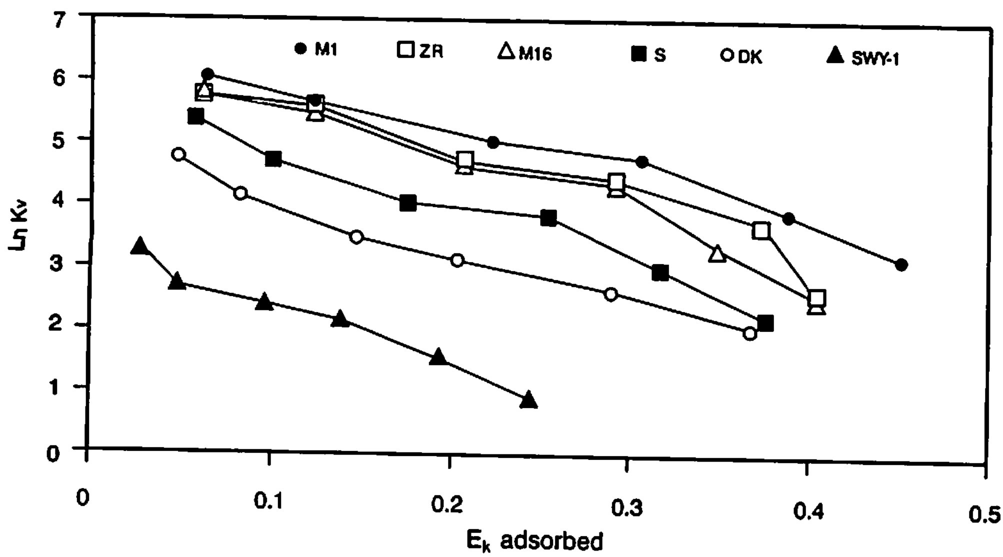

Fig. 2. Changes of Vanselow selectivity coefficients with the saturation of K adsorption sites in vertisols of Morocco at 25°C (see Fig. 1 for sample references).

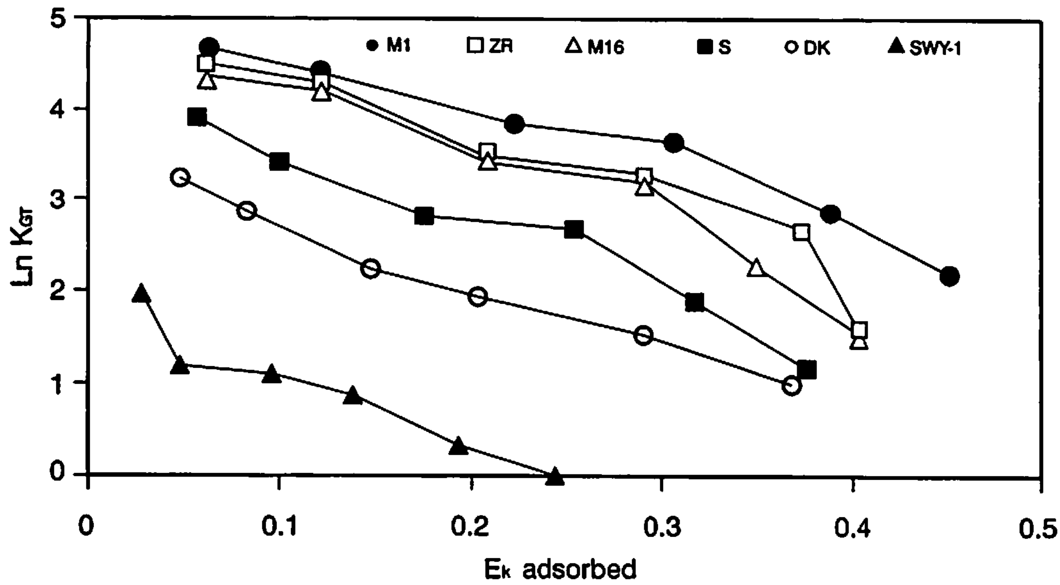

Fig. 3. Changes of Gaines and Thomas selectivity coefficients with the saturation of K adsorption sites in vertisols of Morocco at 25°C (see Fig. 1 for sample references).

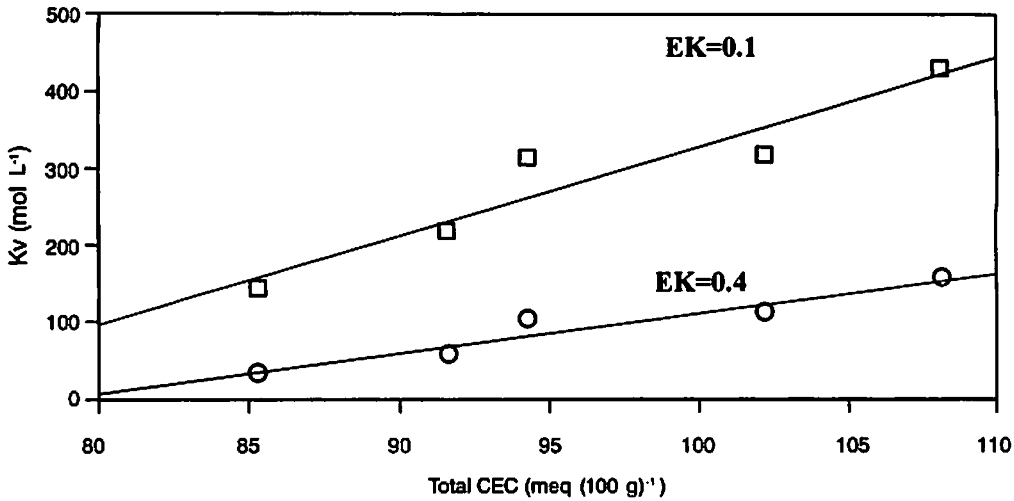

Fig. 4. Relationships between Vanselow selectivity coefficient and total charge of the Clay fraction of vertisols of Morocco for different equivalent fractions of K in solutions.

The relative selectivity for K over Ca by soil clays could be explained by their charge characteristics. Highly significant correlations exist between both total and tetrahedral charges and the selectivity coefficients at any equivalent fraction of K in solution (Fig. 4 and 5). These relationships demonstrate that it would be possible to predict selectivity coefficients of K versus Ca in Vertisols using cation exchange capacity data which are available in soil characterization reports. From a practical point of view, clay mineralogy should be taken into consideration in soils presenting high K-fixation capacity. This phenomenon could give rise to problems of K deficiency or lack of response to K fertilizers in soils low in exchangeable K.

Soil Mineralogy and Phosphorus Availability

Pertinent soil parameters influencing the dynamics of P in the soil are: clay content; the nature of clays, especially iron oxides and 1:1 layer silicates; pH, carbonates, and organic matter (Matar et al., 1992). In fact, P dynamics in the soil is much more complicated than those of K. It is generally known that soil constituents with pH-dependent charges (oxides, kaolinites, and organic acids) control the P availability to the plants. This is the reason why most of the weathered acid tropical soils which are rich in kaolinite and Fe oxides have P fertility problems (Ryan et al., 1985a, 1985b; Soltanpour et al., 1988; Torrent, 1992; Moughli et al., 1992; Matar et al., 1992).

The P availability decreases in calcareous soils because of the precipitation of this element as calcium phosphates with low solubility; $CaCO_3$ in the clay fraction of the soil is the most reactive part of carbonates to be used as an indicator for P availability in calcareous soils (Matar et al., 1992). In Mediterranean soils with homogeneous clay mineralogy, sorption of P is generally correlated with clay content (Moughli et al., 1992; Matar et al., 1992). Kaolinite adsorbs more P per unit area than 2:1 layer silicates because kaolinite has higher surface charge density in the edge faces. Matar et al. (1992) reported that clay-sized carbonates have a higher P sorption capacity than clay minerals but a lower P sorption capacity than iron oxides.

The effects of humic substances (HS), Fe^{3+}, Al^{3+}, and soil clay mineralogy on P availability when added as monocalcium phosphate monohydrate $Ca(H_2PO_4)_2,H_2O$ (MCPM) at pH 5 were investigated on a Vertisol of Fes region in Morocco (Bennani et al., 1993). In both solution and whole soil or clay suspensions, humic substances chelate P and prevent the formation of less soluble forms such as dicalcium phosphate *dihydrate* (DCPD) $CaHPO_4.H_2O$ (Fig. 6). The percent P remaining in solution ranged from 58.5 to 50 when no HS were added. In the clay fraction of the Vertisol (CFV) and bentonite (B) Ca^{2+} - Na^{+} exchange at the clay surfaces decreased the amount of Ca^{2+} in solution and thus the precipitation of DCPD. The Vertisol, however, increased the precipitation of DCPD, compared with solution experiment, because of its Fe content and exchangeable Ca.

The addition of humic substances increased the availability of P in solution (Fig. 6). Linear correlations were found between the amount of humic substances added and percent P remaining in solution:

For CFV: $\% P = 53.87 + 0.113 HS$; $r^2 = 0.99$ ($P < 0.001$)

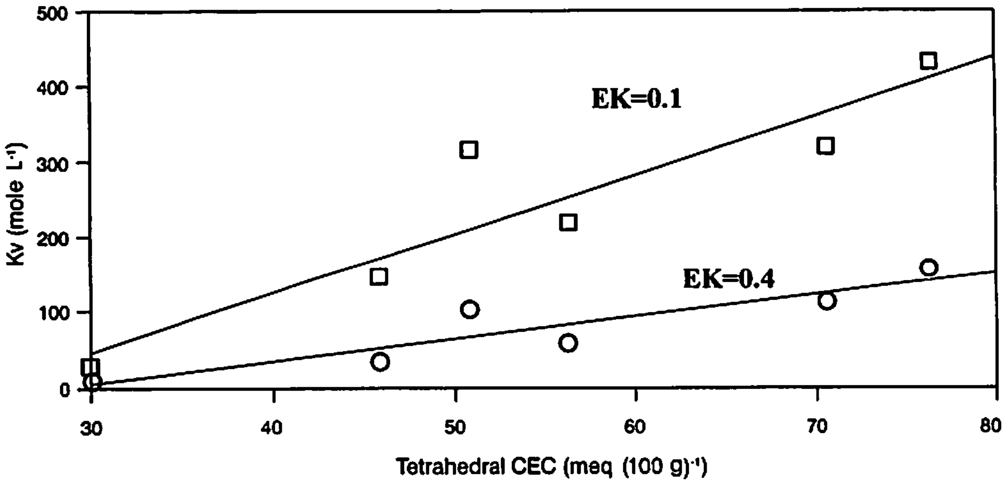

Fig. 5. Relationships between Vanselow selectivity coefficient and tetrahedral charge of the clay fraction of vertisols of Morocco for different equivalent fractions of K in solutions.

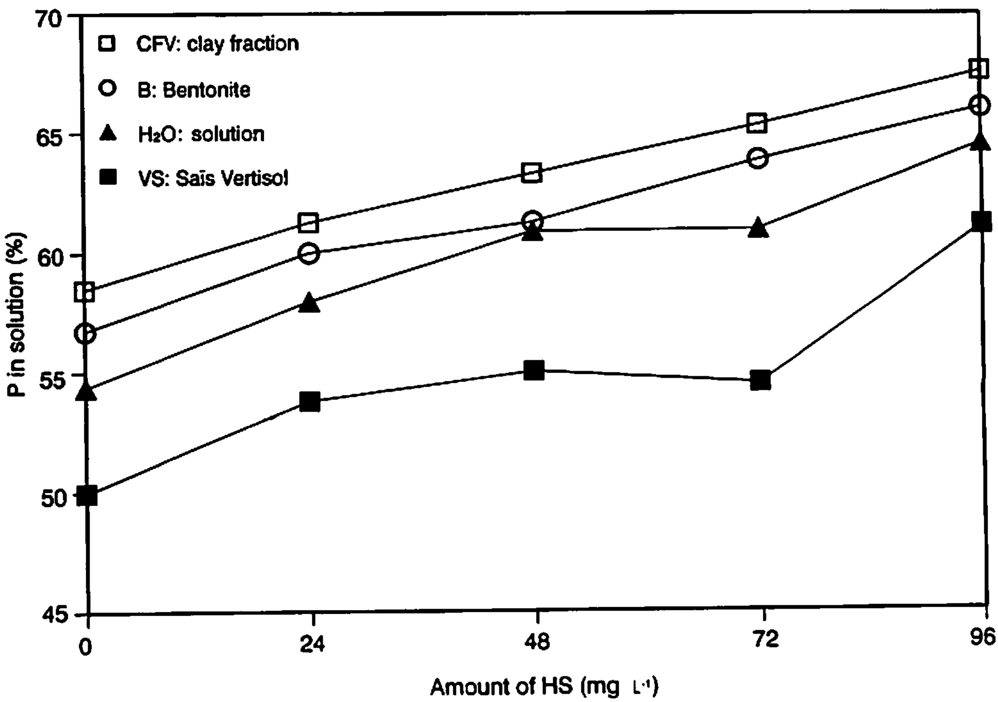

Fig. 6. Dependence of phosphorus which remains in solution on the amount of humic substance added.

For B: % P = 52.97 + 0.091 HS ; r^2 = 0.93 ($P < 0.001$)
For H_2O: % P = 51.76 + 0.087 HS ; r^2 = 0.97 ($P < 0.001$)
For VS: % P = 45.82 + 0.141 HS ; r^2 = 0.99 ($P < 0.001$)

The increase of P in solution per unit of humic substances added is higher for the whole soil (VS) compared with the other treatments. This effect could be explained by the chelating properties of HS for Ca released by MCPM dissolution and for Fe^{3+} and Al^{3+} which could form in soil solution at pH 5. The addition of Fe^{3+} and/or Al^{3+} decreased P availability in solution for all treatments (data not shown). The presence of humic substances before the addition of Fe^{3+} and Al^{3+} reduced this effect. Swelling clays (smectites) can considerably reduce the evolution or reversion of MCPM to DCPD by their high capacity to adsorb Ca, Al, and Fe and thus permit higher concentration of P in solution.

From a practical viewpoint, it is important to maintain a high organic matter content in agricultural soils to reduce the transformation of soluble fertilizer P to less soluble forms and to prevent its specific adsorption by clay minerals. In fact, critical P-level would depend on texture, clay mineralogy, active (or clay sized) calcium carbonates, CBD-extracted Fe (Torrent, 1992).

A new approach to P speciation in soils was developed by Rodier and Robert (1995). It is based on direct observation and counting of P-bearing particles under a transmission electron microscope coupled with an energy dispersive detector. Applied to an acid soil and a calcareous soil from long-term PK fertilization experiments in France, this technique showed that P-Si-Al particles (with Si/Al ratio indicating 2:1 layer silicates) were dominant (>60% of total particles) compared to P-Fe, P-Al, P-Fe/Al, or P-Ca particles in the concentration range between 1 and 15% molar fraction. Above this concentration, P-Fe and P-Al particles were the most frequent in acid soils and P-Ca in the calcareous soil. It was shown that very small clay P-bearing particles contribute greatly to P adsorption. More work is needed using this technique to understand the behavior of fertilizer P after its addition to the soil under in Mediterranean conditions.

Soil Mineralogy and Nitrogen Availability

Relatively little is known about quantitative relationships between soil mineralogy and N dynamics in Mediterranean areas. However, clay minerals would influence N-mineralization, microbial activity, and especially ammonium fixation. In fact, several studies have shown that tropical and sub-tropical soils contain large amounts of native fixed NH_4^+ (Feigin and Yaalon, 1974; Nommik and Vahtras, 1982; Soudi, 1988; Burford and Sahrawat, 1989; Sahrawat, 1995). The NH_4^+ cation, having a size and a charge similar to that of K^+, was considered having the same behavior than K^+ in relation to 2:1 layer silicates. Therefore, quantitative relationships between clay characteristics (total charge and location of the charge) and K^+ fixation could apply for NH_4^+.

Chen (1985) demonstrated that NH_4^+ fixation by smectitic soil clays is largely increased with the increase of total and tetrahedral charges. Soudi (1988) and Soudi et al. (1992) showed that native fixed NH_4^+ by 31 soil samples from Chaouia, Tadla, Gharb, and Zaer regions of western Morocco ranged from 22 to 137 mg kg^{-1} of soil. It represented from 3.2 to 25.3% of total N. No clear relationship between clay mineralogy and native fixed NH_4^+ was found for the soils studied. However, native fixed NH_4^+ was related to clay content (Fig. 7). Although significant, this relationship shows large variation. In fact, previous fertilization history under intensive cropping in addition to different ecological conditions from one region to another would explain the observed NH_4^+ fixation (Soudi et al., 1992).

Nitrogen mineralization potential (N0) was found to be related to total N (Nt), organic matter content (OM), clay content, and calcium carbonate equivalent for 38 soils in Morocco when taken together in multiple regression analysis (Ejbari, 1991). No ranged from 60 to 270 mg kg^{-1} of soil. When used separately, only total N and OM content were related to No. The best prediction could be obtained using the following equations:

$$N0\ (mg\ kg^{-1}) = 65.8 + 650.8\ Nt\ (\%) + 0.53\ clay\ (\%) \quad ;\ r^2 = 0.57\ (P < 0.001)$$

$$N0\ (mg\ kg^{-1}) = 77.7 + 30.4\ OM\ (\%) + 0.42\ clay\ (\%) \quad ;\ r^2 = 0.58\ (P < 0.001)$$

The possible effect of clay mineralogy on mineralization potential has not been investigated yet, but the availability of N to plant can be evaluated through several availability indices. The anaerobic incubation index (AII) was determined for many soils of Morocco (Soudi, 1988; Ejbari, 1991). This index was well correlated to N uptake by wheat in a pot experiment. Similar results were found by Felus (1995) for soils from the Rommani and Gharb regions of Morocco. Values of AII were correlated only with OM content of the soils. No relationship was found between AII and clay content or CEC. Extensive work is needed to investigate possible relationships between clay mineralogy and N availability since NH_4^+ previously fixed could be released and substantially contribute to N uptake by plants. The exact contribution of NH_4^+ is difficult to determine. The difficulties arise from the discrimination between soil N mineralization and fixed ammonium. Investigations with ^{15}N are needed for this purpose.

Conclusions

Quantitative relationships between clay mineralogy and soil fertility management are still difficult to establish for different reasons. First of all, reliable data on clay minerals quantification are needed, not only for crystalline layer silicates but also less crystalline iron oxides, amorphous silicates, and carbonates. Any progress in this area would help the understanding of soil behavior with respect to plant nutrients and water supply. In soils with similar mineralogy, percent clay would generally be enough to predict the behavior of K in the soil. For soils with different mineralogical composition the charge characteristics are important to consider.

For Vertic soils, 2:1 layer silicates could be of primary importance in understanding P behavior. The availability of P is increased with the presence of humic

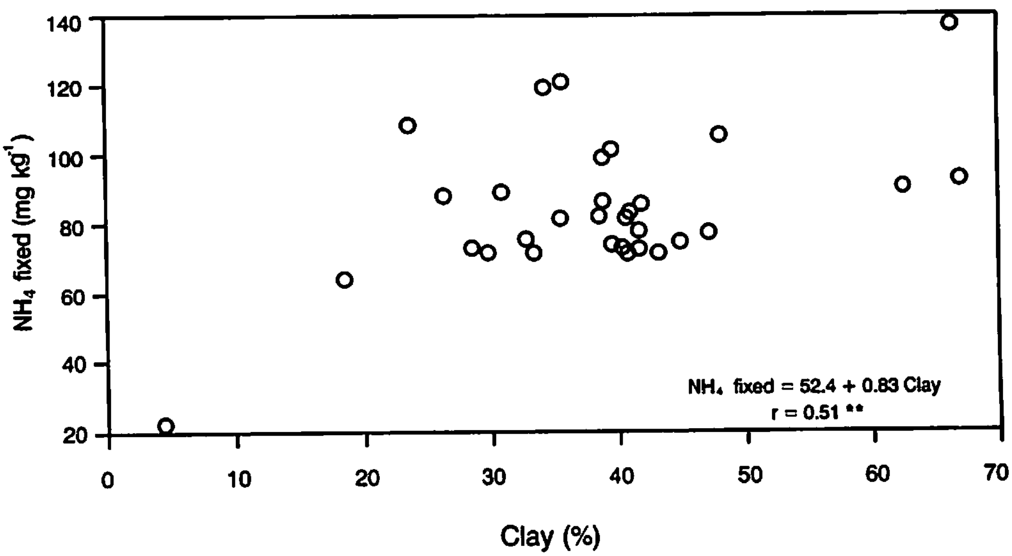

Fig. 7. Relationship between native fixed ammonium and clay content for 31 soil samples from Morocco.

substances which prevent the adsorption and precipitation of this element. The new approach based on direct observation of P-bearing particles using electron microscopy should be tested in Mediterranean soils. Except for NH_4^+ fixation, which was studied to some extent, N availability in relation to clay mineralogy is not clear yet. The use of ^{15}N in Characterization of soil clay mineralogy and the use of ^{15}N is necessary to investigate N availability-mineralogy relationships in different soil types under diverse ecological conditions.

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Evaluation of the Diagnosis and Recommendation Integrated System (DRIS) in Plant Analysis

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Abstract

Plant tissue composition is an integral value of all influences affecting growth. However, its fluctuation with plant parts and age makes its relationship with crop yield and quality rather confusing. Many advisory service laboratories use both soil and leaf analysis in making fertilizer recommendations. They utilize the *critical value* approach in *interpreting* leaf analysis. But this technique places severe constraints on the period during which leaf samples can be validly taken. The diagnosis and Recommendation Integrated System (DRIS) has the facility of handling leaf samples taken at any stage of growth. In contrast to the critical value approach, DRIS uses a survey which covers a large number of sites randomly distributed throughout the crop industry. At each site, leaf samples are taken for analysis and a set of norms, including leaf composition values and the corresponding crop yield, are recorded. The selected population is divided into low-yielding and high-yielding sub-populations on the basis of the crop yield level. Plant composition of the high-yielding sub-population is well balanced and is considered by DRIS as the desired composition. The nutritional diagnosis of leaf composition of a given crop, which belongs to the low-yielding sub-population, is made by estimating the deviation of this composition from the desired one using the DRIS chart or DRIS indices. The greater the deviation, the higher is the degree of imbalance among nutrients. Moving the actual plant composition towards the desired one, by adding nutrients with regard to their degree of limitation, is the way fertilizer recommendations are made by DRIS.

Introduction

Plant analysis is based on the principle that the concentration of a nutrient within the plant is an integral value of all of the factors that have interacted to affect it (Munson and Nelson, 1973). The factors affecting plant growth are numerous. Some are controlable by man, such as the genetic factor, i.e., plant cultivars, and farming practices such as seed-bed preparation, sowing date, fertilizer application, and pest management. Some others are partially controllable, i.e., chemical properties of the soil by fertilization, and the rainfall through irrigation. The remaining crop growth factors over which man has no control at all are solar radiation, temperature, and the CO_2 content in the atmosphere (Beaufils, 1973). Internal and environmental factors affect the metabolic processes and reactions which occur within the plant cells. The yield and quality of a crop are the resultants of the efficiency of realization of such processes.

Actually, all these factors affect crop nutrition either for availability of nutrients in the soil or by changing the ability of the roots in taking up nutrients. Thus, they affect the fertilizer recommendations. For instance, the high-yielding cultivars deplete soil elements much faster than the low-yielding ones do. Consequently, they require higher fertilizer rates. Another example, in irrigated lands nutrient uptake is maximized by the availability of soil moisture, which is not the case in dryland agriculture where moisture invariably limits crop response to nutrients. Hence, fertilizer recommendations should not be the same under both conditions.

Since soil is the life support for plants, any soil treatment would lead to a soil response to this treatment. The plant responds to the soil response to the treatment rather than to the treatment itself. In fact, the addition of equal amounts of fertilizers to soils with differing physical and chemical properties would lead to different nutrient concentrations in the soil solution. Thus, to different nutritional conditions. Plants growing on these soils would not respond similarly to such a treatment. The relationships between soil and environment in relation to crop yield is depicted by summer as: soil properties + soil treatment → soil response → plant response → crop yield and quality--with weather conditions and farming practices impacting at the soil and plant response stage.

Considering the relationship between soil treatment (fertilizer rates), soil response (soil tests) and plant response (plant analyses), any research work attempting to relate crop yield to fertilizer rates rather than to soil tests would not be appropriate. Given the complexity engendered by the multiple interactions among all the factors and their effect on plant growth, all the inter-relationships involved should be studied and calibrated. Since plant composition integrates the influences of all these factors, it gives the situation to be diagnosed.

In a narrow sense, plant analysis is the determination of the concentration of a nutrient in a plant sample. In a broader sense, it is a program including four different phases: *sampling, chemical analysis, interpretation of test values*, and *fertilizer recommendation* (Munson and Nelson, 1973). Unlike soil testing, plant analysis has been limited by a number of difficulties such as the variation of the nutrient concentration in the plant tissue with the plant part and age.

Interpretation of plant test values is usually based on pre-established norms for which soil fertility research is needed. Ulrich and Hills (1967) determined the "critical level" of elements for a number of crops--the critical level is the nutrient element concentration in a plant sample below which growth rate, yield or quality declines. Such a concentration can be used as an aid in fertilizing crops. The critical level technique has a number of limitations: it fails to handle the variation of plant nutrient concentration with age and with the plant part, and is based on field experiments where only few factors can be varied simultaneously and where such derived data have local applicability.

The Diagnosis and Recommendation Integrated System (DRIS) has been developed by Beaufils (1954, 1956, 1959, 1971, 1973) and successfully applied to rubber and maize. Sumner has used it on several other crops such as soybeans (Sumner, 1977a), wheat (Sumner, 1977b), sunflower (Grove and Sumner, 1982), and sugarcane (Beaufils and Sumner, 1976). Its potential relevance and use for cropping systems of the West Asia-North Africa (WANA) region are developed and presented.

Survey Technique for DRIS

Unlike the critical level approach, DRIS is based on a survey technique representative of the crop industry rather than on field experiments. In such a survey, one has to select throughout the crop zone a large number of sites randomly distributed. At each site, plant samples are taken and analyzed for a number of nutrients, and information on weather variables and on the cropping system such as the cultivar, land preparation, and fertilizer application, are recorded, together with the plant test values on a computer disk. Both sets of data constitute a data-bank. Such a bank should be completed with all reliable data available all over the world from production fields and experimental plots to cover as much farming situations as possible (Sumner, 1982).

The crop population is then divided into a number of sub-populations on the basis of yield levels (high, medium, and low-yielding sub-populations). Plant composition is expressed in as many forms as possible (% of dry matter, ratios, products, etc.). For each sub-population, the mean of each form of expression of plant composition is computed. To verify that the sub-populations are normally distributed, a X^2-test is performed. For all forms of expression, variance and coefficient of variance between yield sub-populations are calculated as well. The forms of expression that show the most significant variance ratios and the same mean values for the sub-populations are selected. An example of statistical data processing for N, P, and K in corn leaves, given by Sumner (1982), is presented in Table 1.

Table 1. Variance of a high- and low-yielding corn population.

Form of Expression	Low-Yielding Population (A)			High-Yielding Population (B)			Variance Ratio A/B
	Mean	CV	Variance	Mean	CV	Variance	
N (DH%)	2.86	20	0.326	3.06	18	0.303	1.075
P (DH%)	0.30	20	0.0036	0.32	22	0.0050	0.720
K (DH%)	2.32	27	0.392	2.12	23	0.238	1.647**
N/P	9.88	18	3.158	10.04	14	1.996	1.582**
N/K	1.39	28	0.150	1.49	21	0.101	1.485**
K/P	6.94	29	4.000	6.74	22	2.222	1.800**
P/K	0.13	26	0.0011	0.15	24	0.0013	0.846
P/N	0.10	18	0.00032	0.10	16	0.00026	1.231
K/N	0.81	24	0.0380	0.72	22	0.0259	1.467**
NP	0.85	33	0.0792	0.98	32	0.0961	0.824
NK	6.59	34	5.040	6.45	34	4.910	1.026
PK	0.71	37	0.0675	0.68	36	0.0611	1.105

DRIS Chart

The DRIS chart is used to make nutritional diagnosis of a given plant composition by comparing it with the desired one which corresponds to the mean values of a selected form of expression for the high-yielding sub-populations. According to Table 1, the forms of expressions that show the most significant variance ratios are N/P, N/K, and K/P, and their mean values for the high-yielding sub-population are 10.04, 1.49, and 6.74, respectively. These ratios are then related to one another in a DRIS chart, where they are presented in three axes. The point of intersection of these axes represents the mean values of each form of expression for the high-yielding sub-population. It is the desired plant composition that any sub-population should have to increase the chances to give high yield levels.

This intersection point should not be considered as a single inflexible point but rather as an interval encompassed by the inner of the two concentric circles. The diameter of this circle is set as 4/3 of the standard deviation of the high-yielding sub-population (Beaufils, 1971). A plant composition of any sub-population falling within the inner circle would be qualified as balanced and is denoted by a horizontal arrow (→). As we move away from this central zone along any axis there will be imbalance between the two elements. The region of imbalance can be divided into moderate imbalance which is encompassed by the outer circle and is denoted by an arrow making 45 degrees to the horizontal. Beyond the outer circle zone, which diameter is 8 SD/3, a region of marked imbalance between elements is denoted by a vertical arrow. The DRIS chart is presented in the cited publication of Beaufils and later by Sumner.

How to Make a Diagnosis Using the DRIS Chart

Suppose that the tissue composition of a corn leaf sample sent to an advisory service laboratory for N, P, and K analysis is as follows: 3.2%, 0.22%, and 1.20%, respectively. Then the ratios are: N/P = 14.54, N/K = 2.66, and K/P = 5.45. Using the DRIS chart the value of N/P lies beyond the outer circle, in the zone of P insufficiency (N| P| K). The N/K value lies outside the outer circle as well, in the zone of K insufficiency (N| P K|). The K/P value lies in the outer circle in the zone of moderate K *insufficiency* (N P/ K\). The final reading becomes N- P|/ K|\. This gives the following order of requirement of the crop for N, P, and K (K> P> N). This means that K is the most limiting factor, followed by P, while N is the least limiting factor.

DRIS indices

The arrow notation can be quantified by calculating the DRIS indices which measure the relative deviation of a given plant tissue composition from the desired one. The indices are given as follows:

$$N\ index = [\frac{f(N/P)+f(N/K)}{2}];\ P = -[\frac{f(N/P)+f(K/P)}{2}];\ K = +[\frac{f(K/P)-f(N/K)}{2}]$$

$$where\ f(N/P) = 100(\frac{N/P}{n/p} - 1)\frac{10}{CV}\ when\ N/P > n/p,$$

$$f(N/P) = 100(1 - \frac{n/p}{N/P})\frac{10}{CV}\ \ when\ N/P < n/p$$

N/P: The actual value of the ratio in the leaf under consideration; n/p = The mean value of the ratio for the population of high-yielding plants; CV = Coefficient of variation for the population of high-yielding plants. The other terms f(N/K) and f(K/P) are derived in a similar manner.

The DRIS indices have positive and negative values. They sum to zero. Like the DRIS chart, DRIS indices allow one to make nutritional diagnosis by looking at the order of requirement of nutrients in the plant tissue. Using the above example, the N, P, and K indices are calculated and are equal to 34.70, -10.63, and -24.07, respectively. These gives the order of requirement K > P > N, which is the same one given by the DRIS chart. This means that K is the most limiting factor followed by P, while N is the least limiting factor.

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Statistical Concerns for Soil Fertility Field Trials

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Abstract

Soil scientists are invariably involved in agronomic trials in the field, whether at experimental stations or on farms. Such field trials are conducted to assess aspects of conservation and management of soil resources for optimized production through improved crop husbandry, i.e., selection of cropping systems, tillage methods, adaptable/stable crop cultivars, seeding rates, row spacing and plant density, weeds, fertility and fertilizer response, pests and diseases, and land and water management. This paper discusses some statistical concerns in the context of fertility trials and suggests ways to deal with them. In essence, it alerts agronomists to the need for professional statistical advice in all phases of field trial design and data interpretation.

Introduction

Soil fertility is an integral part of agronomy. When it comes to applied field research, distinctions between the two disciplines are blurred. Applied soil fertility usually involves evaluating crop responses to nitrogen, phosphorus and potassium or other nutrients or soil amendments. Timing of fertilizer application and method of application are common activities. How sophisticated such studies are depends on the level of development of a country's agriculture. In developing countries, fertility related trials are, for the most part, simple; they involve one or two treatments in single-year experiments. More sophisticated trials might involve an integration of fertilizer with conservation tillage, several management treatments incorporated as multi-year rotation trials, or a consideration of the nutrient dynamics with time in relation to crop growth and development.

Irrespective of whether trials are conducted at agricultural experiment stations or in farmers' fields, the researcher has to be aware of the many factors which can affect the validity of the work. Therefore, in this paper we discuss the points which one must consider in selection of sites for experimentation, methods of sampling the soil parameters, and their quantification and distribution. Since soil properties vary in space, discussion has been made on the effect of the spatial correlation on the local mean value of the property. We discuss points to be considered in selection of the experimental treatments to achieve different objectives. Once the site--and field within a site--has been identified, factors determining the size and shape of the experimental plots and experimental designs are considered. Concerns are raised about advance planning of statistical analysis. Modelling fertilizer response at a given site and inter-site transferability in terms of observed native soil fertility and applied fertility, and associated problems, are dealt with.

General Considerations

Planning of Experiments

Selection of Sites

There are generally three kinds of trials in agricultural research: *comparative*, *evaluation* and *demonstration*. These are conducted on experimental stations and/or on farms. In the later case, experimental (i.e., spatial or plot-to-plot) variability is often found to be of larger magnitude compared with that on-station. The main requirement of a site to be selected for an experiment is that it should be representative of the environment for which the research results are actually intended. One therefore must ask questions such as: are the sites representative of the zone or the region in terms of soil type, rainfall distribution and other climatic conditions where results of the experiment would be generalized or transferred? Is the experimental material (plants, soil, etc.) representative of the responding units? If not, is it worth doing the experiment? For example, the long-term average rainfall at Jindiress , Breda, and Tel Hadya are 467/280 and 327 mm, respectively. The site at Tel Hadya then represents medium-dry sites in Syria and could not reliably reflect conditions prevailing in either the higher (Jindiress) or lower (Breda) rainfall areas. An exhaustive checklist of questions an experimenter is expected to resolve before carrying out the experiments are given in Jeffers (1978).

Field Characteristics

In reality, an experimental material may be reasonably homogeneous or may possess blocks/groups of homogeneous plots, but how does one ascertain the homogeneity of the experimental material, say in terms of inherent soil variables which influence the response. *Flatness of a surface* is not a sufficient measure of homogeneity. Soil variables may vary even if the surface is flat. Soil variation with depth in Block A of ICARDA's experimental station at Tel Hadya has been exhibited by Ryan et al. (1996). The problem which arises is how can such variability be estimated?

Spatial Variability

Soil scientists, agronomists and others have been engaged in studying soil types and other properties and their relationships with plants and environments as a whole. The studies often involve measuring inherent soil variables and establishing their relationship with crop response, and exploiting such a relationship by modifying soil variables. In evaluating such a relationship, measurement of inherent soil properties is of crucial interest. A practical exposure to dealing with soil heterogeneity data has been presented by Gomez and Gomez (1984).

Measurement of Soil Properties: To understand the behavior of soil properties, it is essential to evaluate soil measurements at various locations on the surface and with depth. Indeed, most soil samples are taken from the top 15 to 30 cm, especially for nutrient availability, but one must bear in mind the sub-surface variability with respect to chemical and physical properties, as well as depth (Ryan et al., 1996). The nature of the soil variables also varies; therefore, the scales to measure them may be different. Some properties are *binary* (e.g., representing the presence and absence of an attribute, i.e., sandy versus clay), multi-nomial (e.g., shape of structural aggregates which may be granular, blocky, prismatic, platy, etc.) or continuous (e.g., those taking values on a continuous scale, such as thickness of horizons (length), organic carbon content, shear strength, pH, CEC. But, one cannot measure everywhere on earth. One can, however, measure at best on small areas of the soil. The measurements can be made in the field or in the laboratory. Records of such measurements form a sample. *The variability in records may be due to sampling and/or associated with location.*

Methods of Sampling: Commonly used sampling procedures for soil properties (Sabbe and Marx, 1987) include: 1) *Simple Random Sampling*, given an area, spots are selected at random; 2) *Stratified Sampling*, the area under investigation in divided in sub-areas and spots are selected randomly within each sub-area; 3) *Systematic Sampling*, sampling on regular grid; 4) *Stratified Systematic Sampling*, and 5) *Triangular Sampling*.

We shall use the data on available P contents at Boueider in NE Syria, where soil samples were collected on a regular grid of 25 x 17 meters, and P content was determined. Contours of P values in two directions, east-west and north-south, were developed. Such pictorial presentation indicated the apparent spatial variability throughout the field, i.e., pockets or "islands" with high P values are dispersed within the variable matrix of the values for the field.

Statistical Description of Soil Properties

In practice, one observes variation in a soil property from place to place and in samples from the same bag filled at any one place. Various analytical procedures advocated in soil science would lead to reduced experimental error, if followed carefully. The population of observations of a soil property can therefore be described by procedures which assess the variability. Frequently used statistical techniques include: pictorial presentation such as *histogram* and *frequency curves* or *descriptive measures*; measures of location such as *mean*, *median* or *mode*; measures of dispersion such as *variance*, *standard deviation*, *range*; measures of shape of the distribution such as *skewness* by *coefficient of skewness*; and *peakedness* by *coefficient of kurtosis*. The distribution of soil property values can be described as a functional form called *probability distribution function*.

The descriptive measures of the population of soil properties can be expressed in terms of parameters of the probability distribution function. Therefore, the parameters can be interpreted accordingly. For example, in the case of P distribution at Boueider, we have n = 425 (total number of observations), Mean = 7.59 ppm , Variance = 3.80 ppm^2, Standard Deviation (SD) = 1.95 ppm, Skewness = 1.58, Kurtosis = 8.63 -3 = 5.63, and Coefficient of Variation (CV) = 18%. If we base our inference from a simple random sample of size n = 213, representing 50% of the total samples observed, we find: Mean = 7.44 ppm, Variance = 4.03 ppm^2, SD = 2.01 ppm, Skewness = 1.87, Kurtosis = 7.35, and CV = 27%. For a random sample of size n = 300, we found Mean = 7.59 ppm, Variance = 3.96 ppm^2 , SD = 1.99 ppm, Skewness = 1.55, Kurtosis = 5.06, and CV = 19%.

Fitting Commonly Used Theoretical Distributions: Often we come across finite populations with variable values measured on a continuous scale (e.g., P content). Among the continuous distributions, a distribution (or population) called *normal distribution* or normal population have found enormous application, and has been derived under a number of hypotheses such as "theory of errors" or Hagen's hypothesis, Maxwell's hypothesis, Herschel's hypothesis or " hitting the bull's eye", De Moivre's theorem or limiting binomial distribution, central limit theorem, maximum entropy for a given *mean* and *variance*, among others (Rao, 1973). The coefficients of *skewness* and *kurtosis* are zero for this distribution and is fully described by the values of *mean* and *variance* parameters only.

A number of goodness-of-fit test procedures are available for testing the normality of the distribution, such a Pearson's Chi-Square test based on observed and fitted frequencies, Kolmogorov's test based on sample distribution function, Shapiro and Wilks (1965) test based on the *order statistics*. A visual examination of values following normal distribution can be had from linearity of normal and half-normal plots. On the data sets, we fitted normal distribution with two parameters estimated, and the Chi-Square values obtained were: 1) 51.34 on 18 df for full sample (n = 425) with 21 groups; 2) 24.25 on 12 df for 50% sample (n = 213) with 15 groups; and 3) 48.85 on 14 df for sample of size n = 300 with 17 groups. This indicates that the data based on n = 213 or n = 425 do not indicate the *tenability* of normal distribution for soil P.

Spatial Variability and its Modelling

Soil properties vary continuously in space; soil units in close proximity are similar in properties compared with those far apart. This introduces a statistical dependence between the observations. One of the basic principles of field experimentation is randomization; this controls the bias and neutralizes--but does not remove--the effect of spatial dependence (Cressie, 1991). A number of spatial methods known as *nearest-neighbor* methods have been used in analyzing field trials to account for spatial dependence by treating residuals from neighboring plots as covariates (Wilkinson, 1983) and by accounting fertility trends in form of a separable auto-regressive-moving average model in one or two directions (Cullis and Gleeson 1991). In a spatial continuum, soil variable at a given site is a function of its location. But a more realistic approach is to consider it as a stochastic variable in space and use it to predict unobserved data.

Since a variable would be more similar to those in its neighborhood, it can be predicted in terms of observed values in the neighborhood or regional variables (Webster and Oliver, 1990; Cressie, 1991). It has been shown that in order to provide the same information about their mean value, a greater number of observations would be needed under positive correlation among regionalized variables than when the variables are independent. Geostatistical tools are used to model spatial variability. Soil properties measured over sample locations in two dimensions over the study area have been modelled using a *sample variogram* and then fitting some theoretical forms such as Spherical, Gaussian, Linear, Exponential, and Mixture Models to it. Once a certain form has been selected, it is then used to predict (or to krige) the response at any desired location (not necessarily in the sample) within the experimental region. We used a software GEOEAS (Englund and Sparks, 1991) for the required computation.

Selection of Experimental Treatments

Once the sites have been selected, the crop variety should be representative of the crop intended. The experimental fertilizer treatments should represent a realistic range of fertilizer levels for the crop variety, season of application and the region. The factor combinations should provide an efficient treatment design for estimation of main-effects and interactions among expected factors and/or the prediction equations, as the objective may be. Furthermore, the role of including a control and/or check variety or fertilizer application rates should be considered. In the following section, we present a few illustrations on related experimental and treatment designs:

Example 1. If the objective is to test the existence and estimation of main effects and interactions of N and P, the treatment design could be a full factorial which would allow estimation of all main effects and interaction. Further the effects and interactions can also be partitioned into various single degree of freedom polynomial contrasts in quantities of N and P. If several factors (generally more than three) are involved, one can use a fractional factorial design where it is possible to select a fraction of all the treatment combinations which provide information on main-effects and lower-order interactions, while sacrificing information on higher-order interactions. This leads to the saving of experimental resources. Several treatment designs and their methods of construction have been listed in the classic text of Cochran and Cox (1957).

Example 2. Having established the existence of effects of various factors and their interactions, one may be interested in estimating a relationship between response and the input factors and determine optimal application rates of these factors or in generating scenarios for a number of combinations of the factor levels not necessarily included in the experiment. Suppose we consider expressing a relationship between response (Y) and N rates and P rates using a mixed quadratic function:

$$\text{Yield} = a + b\,\text{N} + c\,\text{N}^2 + d\,\text{P} + e\,\text{P}^2 + f\,\text{N}\,\text{P}$$

where constants a, b, c, d, e and f are the coefficients/parameters of the relationship function, and would require estimation. Their estimates can be obtained, for example, by using the *method of least-squares.* It may be noted that the above relationship has only 6 parameters; therefore, 6 distinct combinations of N and P would be sufficient to provide their estimates (but without any estimate of their *precision* or *standard error*). Methods of construction of response surface designs and a list of such designs are given in Cochran and Cox (1957).

For example, we may consider the *central composite rotatable design* given in Cochran and Cox (1957) for fitting *second-order response surface* in two factors, say N and P, each at 5 levels in 13 combinations of N and P. Of the 13 combinations of N and P, there are only 9 combinations which are distinct, while the combination N : P = 0 : 0 (coded levels), called a *central point*, occurs four more times. The repetition of the *central point* five times gives 5-1=4 degrees of freedom to measure experimental error (this is also called "pure error"). The 9 distinct combinations would provide estimates of the regression parameters i.e. intercept a, slopes associated with linear (first order) terms b, d in N and P accounting for 2 df, and quadratic (second order) terms c, e, and f accounting for 3 df. The deviation of the observed response from the modelled response using above mixed-quadratic in NP will be based on 9-1-2-3=2 df and would measure the *lack of fit* of the assumed model.

Plot Shape and Size

An *experimental unit* (plot) is an identifiable portion of the *experimental material.* Experimental units constitute the experimental material when considered in totality. The *plot size* and *shape* must be suitable for application of the treatment, express the effect of the treatment and facilitate the recording of measurements. If there is any interference between neighboring plots, some plant material can be discarded from the plot-borders and edges in order to leave a real effect of treatment, as reflected by the central area of each plot. The question is how much of the plot should be sacrificed to achieve this? Very often, we need information which requires *destructive sampling*; thus the plot size should be able to accommodate plant sampling. In case no reliable information is available on the optimum plot size and shape, it would be worthwhile to conduct a *uniformity field trial* to determine them.

Experimental Designs

The major determinants of the experimental design are the nature of experimental material (expressed in terms of physical/geographical configuration, variability within individual blocks or overall) and the precision required on estimates of treatment effects/performance and/or comparisons, besides the nature of the treatments once selected (in terms of the operational constraints associated with their application to the experimental plots). The number of treatment replications depends on an estimate of the variability in the experimental material and the precision required with certain confidence in terms of probability.

Block Designs: If the experimental material contains groups of plots homogeneous in soil variables (while plots between groups may differ relatively) then such an experimental material can be used to form block designs where treatments (factorial combinations) are allotted randomly to the plots within blocks. If the blocks (groups of plots) are large enough to accommodate all the experimental treatments, the experimental design is then called a *randomized complete block design* (RCBD). If we use an RCBD as the experimental design for evaluating two factors N (3 levels) and P (4 levels) based on their full factorial combinations as treatment design and in 3 replications, then sources of variations would be blocks (2 df), N (2 df), P (3 df), N x P interaction (6 df), and the residual (22 df). However, with a large number of combinations for a treatment design, one may not find homogeneous blocks which can accommodate all treatments. In such a case, blocks would be incomplete with respect to treatments and thus some treatment comparisons (contrasts) would be the same as block comparisons (contrasts). This is called *confounding* of the treatment contrasts with blocks (Cochran and Cox, 1957). This very fact is then used to obtain experimental designs (i.e., the block contents in terms of factor combinations) in such a way that you can estimate desired effects (i.e., main effects and lower-order interactions) at the cost of confounding less important effects (i.e., higher-order interactions).

Sometimes the nature of the experimental treatment and material are such that the plot size required for application of a level of one factor is larger than those required for levels of the other factors. In such cases, an appropriate experimental design is adopted for the factor with larger plot size (called *main* or *whole plot* factor) and each whole plot is further sub-divided into smaller *sub-plots* to accommodate the other factor levels. Such experiments are called *split-plot* experiments in the experimental design opted for the main factor. The *levels of the sub-plot factor are randomized within each main-plot.* Further, where sampling over several dates is required, the design must facilitate the sampling.

Recording of observations: The recording of observations on the response variable under study (such as yields and N contents in grain and straw) must be done in appropriate units of measurements. Measurement can be made on any possible covariate. Covariates are the plot variables which affect the response but not the treatments. These are often those variables which are measured before treatment application. The observations can be recorded in fieldbooks and/or through some data-loggers, and stored in or transferred to a database management system or files on a safe system.

Planning for Statistical Analysis

At the planning stage itself, it is essential to have a clear understanding of the hypotheses to be tested, contrasts to be estimated, covariates, analysis of variance skeleton, the procedure for fitting the response surfaces, etc. If *spatial variability* is to be considered, then the due steps of computations should be available or attempts must begin to procure appropriate software before the data are available.

In soil fertility trials, the common aspects of the statistical analysis would be to test the existence of main effects and interaction, and estimate them. After an assessment of the interaction followed by a visual examination of factor level-response plots, we must identify the terms representing *linear, quadratic* or other non-linear forms, including the interactions with qualitative factors if any, for obtaining prediction equation. These equations are then used to obtain optimal application rates. Consider the two specific problems.

Modelling Fertilizer Crop Response Relationship and Optimum Application Rates. The crop response is a function of applied fertilizers as well as nutrients inherent in the soil and their interactions. However, it is easy to visualize that the applied fertilizer would reasonably be measured without errors, while the status of soil fertility inherent in the experimental plots would only be estimated through random samples within plots, and would also contain errors arising from the analytical methods used in the soil laboratory. Therefore, the variables representing soil fertilizers would contain errors of measurement. Therefore, a general regression model for fertilizer-crop response would have some regressors (based on applied fertilizers) measured free from errors and the others (based on soil variables and their interaction with fixed levels) with errors of measurements.

Based on the theory of "errors-in-variables" model, Singh et al. (1993) have attempted the estimation of a model to predict the response of N, P and K on a specific wheat genotype from a field experiment. However, optimal rates were not evaluated. Thus, there is a need to build prediction models for the WANA-region soils for yield responses in terms of applied fertilizers, soil nutrients and rainfall, and to incorporate the errors of measurement model for variables representing soil fertility; obtain an estimate of the optimal application rate and its statistical distribution; and provide guidelines for soil sampling and field plot designs for such purposes.

Inter-Site Transferability of Response Surfaces. Agro-technology transferability is based on effectiveness of response-input relationship, estimated from experimental sites, to other sites with similar conditions (Wood and Cady, 1981). Fertilizer-crop response equations are developed in experimental environments (experimental station, selected sites), but their use, such as optimal application rates, are actually meant for target environments such as farmers' fields. How to measure the success of transfer of such response surfaces is another question. A suitable inter-site transferability statistic, keeping in view the nature of fertilizer variables as discussed above, would be needed.

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6. Education and Economic Issues

Challenges in Soil Science Education in the West Asia and North Africa Region

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Abstract

All too frequently, applied soil fertility researchers and agronomists forget about the classroom and sources of knowledge for future researchers. This article takes a fresh look at soil science education in the current Middle East context; its strengths and weaknesses are highlighted along with indications of future directions.

Introduction

As educators in agricultural soil science, we form professionals who go on to earn their living based on the training they have received. This is, and should always be, the guiding principle of our endeavors. There are a number of implications to this apparently plain statement. The most important one is that it falls upon us to be flexible and to *adapt our teaching to the needs and realities of a changing world.*

Over the past decade, university education in general and agricultural education in particular have been under serious pressure. Miller (1995) recently analyzed the forces impinging upon higher education, and classified them into three categories, based on the 1994 Pew Higher Education Round-Table Initiative (Policy Perspectives, 1994). These are: 1) increased importance of "relevance" and "market forces" accorded by students and parents when selecting on area of study and a college, as these factors will largely determine the access to good jobs; 2) increased drive towards privatization, which places university funding at the mercy of market forces; and 3) rapid growth in new technology (electronic information, biotechnology), accompanied by a logarithmic decrease in costs. Not only do modern information technologies offer cheaper access to "education", they also impose on educators, and, by extension, on universities the need to *continuously update and upgrade their hardware, software and human resources.*

These pressures are not confined to the industrialized countries, and their effect is felt, perhaps even more strongly, in the developing world, particularly the Middle East, where they add on to a plethora of deeper social, economic and political changes. The impact of these forces on agricultural education has been generally *negative*, and has been reflected in budget cuts and dwindling student enrollment. Interest in careers in agriculture, a discipline that appears to be solely directed towards increased food production, is understandably low in industrialized countries where food surpluses rather than shortages are the usual sources of concern, and where the number of people directly involved in agriculture is minimal (March, 1994). In the developing countries of the West Asia and North Africa (WANA) region, economic and social changes have been accompanied by the availability of cheap food originating from Northern surpluses. This has led to a significant decline in the role and impact of agriculture, both as a profession and an economic sector (WHO, 1992), and to a subsequent narrowing down of the job opportunities window for agriculture graduates.

Universities and departments worldwide are having to initiate a soul-searching process in order to survive the new realities (Miller, 1995; Salvador et al., 1995; Smith III and Tsang, 1995; Coyne, 1993; Jayaraj, 1992). In the field of soil science, and in soil fertility in particular, we have to face this mounting pressure. If our graduates are not needed, then we ourselves will very soon become *redundant*. In a shrinking job market, we must ensure that our graduates are *competitive*. For that, we need to prepare students who are *creative, flexible* and *open to change* so as to adapt to the *changing needs of the market*. Our soil science graduates must have both *depth* and *breadth of knowledge* and acquire *cross-curricular* thinking, so that they can perceive the larger pattern and grasp the context of the issues.

A number of publications have recently addressed the issue of changes in the agriculture curriculum (March, 1994; Altieri and Francis, 1992; Jayaraj, 1992), usually by focusing on one or two specific modifications that will enhance the relevance of agricultural education. The authors do not, however, provide a framework that will allow an inventory of the possible options. Also lacking is a systematic approach that could be applied to the specific case of soil science education as well as to agricultural education at large. In order to identify such a methodology, one has to depart from the premise that *soil science education is a product that must be marketed.* The potential buyers are university students who will make the purchase because what they learn will maximize their future employment options and provide them with personal satisfaction. These two criteria cannot be dissociated. This endeavor is analogous to the pursuit of every marketing professional during the development of an appropriate marketing plan for a product. I have thus, by analogy, selected a marketing approach for improving the marketability and relevance of soil science education.

The Swot Analysis

The SWOT (Strength, Weaknesses, Opportunities, and Threats) framework of analysis is possibly the most commonly used tool in marketing plan development. The analysis is applied to the strategic business unit (SBU) which may be one product, a product line, a department or a whole institution. The list of strengths has implications for strategy formulation while the list of weaknesses is associated with investments to correct these weaknesses. Opportunities and threats describe outside factors facing the SBU, and are written so as to suggest possible actions (Kotler, 1980). Thus, "Strength" and "Weaknesses" are usually expressed on the micro scale (i.e., product-dependent) while "Opportunities" and "Threats" represent the macro-environment.

Marketing professionals also rely on "brainstorming" and "snowballing" approaches for determining the specific points of a SWOT analysis. In these techniques, ideas are thrown in by a focus group, regardless of their apparent relevance and importance, and later rearranged to provide a basis for action. Whenever a concerted interest in a specific thought is felt, the group may develop it further by "snowballing". In our academic field we have a similar, albeit more rigid and regulated, approach. A judicious literature survey can provide the "brainstorming" pool, and may be focused to enhance the "snowballing" effect. Hence, in this paper, I have gathered ideas from an unknowing peer group, and organized them into a SWOT framework. While few references focus on soil science education, a relevant list of issues can be readily extrapolated from the available analysis of agricultural education.

Strengths of Soil Science Education

In an idealized education system, soil science education is essential because it:

- Provides the technical ability to optimize food production systems, and hence is of public relevance and interest. This is especially important in drylands and tropical areas.
- Provides knowledge of chemistry and chemical transformations in the environment, which can be adapted into the environmental sciences.
- Is an integral part of resources cycling and ecosystem management.
- Provides understanding of industrial production systems (fertilizer industry).
- Interfaces between natural resources, social sciences and the environment, and thus can provide a broad-based knowledge of crops, animal, soil, water, social and economic sciences.
- Is an essential component of management and prevention of land degradation ("desertification"), an issue currently at the forefront of world environmental and socio-economic concerns.

Weaknesses of Soil Science Education

Authors who have analyzed current agricultural education have pointed at a number of weaknesses. I have selected among these those that bear relevance to soil science:

1) It has traditionally been taught as a technical subject, studied in isolation from economic pressures and from issues such as ethics, equity, policy-making and women (Ryan, 1982; Jayaraj, 1992; Chaudhry and Ryan, 1984; Miller, 1995; Salvador, 1995).

2) The approach has been mostly linear and compartmentalized, and has relied on simplistic criteria for an "apparent" cost-benefit analysis, while real life problems are highly complex-reductionist vs holistic (Salvador et al., 1995).

3) It has often ignored *local conditions* and *indigenous technologies*. This is most striking in WANA countries where textbooks are imported or translated from the US or Europe. The American University of Beirut (AUB) is a case in point, where

education and research was for a long time based on production systems and crops of little relevance to the Middle East (Ryan, 1982; Way-Gibbs, 1995).

4) There has been limited hands-on experience and practical training; little or no adoption of the "learning while doing" or experiential approach. Educational research (i.e., MSc thesis students) are all too often *theoretical, repetitive*, and with *no or little implications on the real situation* in the concerned country (Chaudhry and Ryan, 1984; Salvador et al., 1995).

5) Environmental and natural resource concerns are minimally addressed, in spite of the public concerns with new issues that overlap significantly with the field of soil science, such as environmental pollution. Specifically, the role of soil science in agricultural sustainability, agroecology and farming systems are not receiving the importance they deserve (Altieri and Francis, 1992; Miller, 1995; Peterson et al., 1993). At the American University of Beirut (AUB), for instance, a survey of the 86 MSc theses produced since 1959 indicated that 50% were in the field of soil fertility, with a majority focusing on phosphorus. Only 2.5% addressed issues of environmental quality, soil erosion, and cropping systems.

6) Teaching often lacks a *problem-solving, multiple-goal resolution approach.* Linkages between the various disciplines is rarely encouraged, and an oversimplified "yield response to inputs" has been the normal perspective (Altieri and Francis, 1992; Salvador et al., 1995). Improvement in teaching quality should however be accompanied by a sincere shift of emphasis by deans and departments from *scholarship in research* to *excellence in teaching.* This is still lacking at present, as university professors are evaluated primarily on their research output for promotion and tenure. The idea of adopting a Northern system for the evaluation of university professors is ludicrous in the WANA countries, where research output in international refereed journals constitutes 0.61% of the world's output. What is required, however, is a better educational format associated with adaptive research of local relevance (Reed, 1989; Davis and Beyrouty, 1995; Wayt-Gibbs, 1995).

Opportunities for Soil Science Education

The opportunities for the development of soil science education have been pointed out in the elaboration of the weaknesses, and may be summarized as follows:

1) Public concerns for new issues, especially the environment and natural resources. Soil science knowledge can be readily adapted to "stewardship of the land" and to "pollutant studies".

2) Current emphasis on farming systems, agro-ecosystems and integrated nutrient management. This will allow broad-based soil science graduates to capture the job market.

3) Interest in local industry development, such as bio-fertilizer production, which may yield job opportunities in the industrial sector.

4) Availability of low-cost electronic links will facilitate self-training of educators.

Threats for Soil Science Education

These may be divided between the general threats, i.e., those which apply to changes in all countries, and those specific to the WANA countries. The establishment and established academics may feel threatened by new methods, new names and new courses, while students may dislike the additional courses required for the formulation of a new curriculum (March, 1994). For instance, a new MSc program in Ecosystem Management at the Faculty of Agricultural and Food Sciences at AUB had to be fought for at every level of the administration. Students themselves are extremely positive to the idea, but many may be driven away by the high credits requirement (33+ thesis, compared to 21+ thesis for the regular specializations).

Specific problems of developing countries include: a) Donors' pressure for adoption of their agenda. Many of the WANA universities are subsidized, either by governments or by foreign-aid agencies, such as USAID. A shift in priorities will usually be a stillborn if it does not conform with the donor's priorities. b) Budget cuts are relatively more severe than in the North, and universities often lack the most basic educational tools such as slide projectors, photocopiers, journals and books. c) Pressure on the academic teacher originating from the social, political and economic environment of most WANA countries. These have been addressed by Sabour (1993), and include: i) academic freedom is severely curtailed; ii) standards of living of university teachers are very low, which causes job dissatisfaction, poor commitment, and the need to divert effort from teaching into a second job; iii) appointment of teachers is not always done on a merit basis; and iv) unstable political environment.

Conclusions

Teaching soil science in the WANA region appears to face problems similar to those of the industrialized nations, in addition to a myriad of site-specific difficulties. Consideration should be given to significant changes in the soil science educational curricula which will provide knowledge and improve employment opportunities. Based on the SWOT analysis, two levels of action may be identified for improvement in soil science education: what we teach and how we teach it. The "repacking and marketing" process must be operated without delay, as some of the windows of opportunities are already closing down. In the US, where a number universities have already operated the changes, many soil chemistry graduates currently work in environmental sciences. As the latest reports puts it, "opportunities in environmental consulting and regulatory agencies are available, but the expansion in these areas is slowing, if not halted" (Bloom and Robarge, 1995).

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Soil Fertility Education in a Teaching Institution for Dryland Agriculture

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Abstract

This paper deals with a teaching/research institution that focuses exclusively on dryland agriculture. It gives an overview of the soil fertility education program at the undergraduate and graduate level at the Barani College in Rawalpindi. Related fertility problems and fertilizer use issues are highlighted for that region of Pakistan.

Introduction

Pakistan is predominantly an agricultural country. Of the total cultivated area, 76% (15.5 million ha) is irrigated and 24% (4.9 million ha) is rainfed. Annual rainfall in the rainfed areas ranges from 125 mm $year^{-1}$ in the extreme southern plains to 500-875 mm in sub-mountainous areas and the northern plains. Rain falls as heavy downpours in summer from July to September, while about one-third falls in winter. Except in the mountainous areas, the summers are very hot with a maximum temperature of more than 40°C, and the winters are mild with a maximum temperature around 20°C and the minimum a few degrees above freezing (GOP, 1979). Based on annual precipitation, the rainfed areas are broadly classified into three distinct ecological zones (Malik and Hassan, 1992), i.e., these areas with average rainfall of 300 mm, 200-300 mm, and less than 200 mm.

Most of the rainfed soils of northern Punjab have developed *in situ* from Tertiary rocks, mainly consisting of shales and sandstones. Other important parent materials are loess and alluvium. The soils are alkaline, with pH ranging from 7.8 to 8.1, calcareous (8% free $CaCO_3$), and have organic matter contents less than 1% (Malik and Hassan, 1992; Khan et al., 1989). In the *barani* (rainfed) areas, in addition to flat land (including semi-desert), cultivated soils are found on rolling, steep, and very steep topography. Rolling lands are often derived from loess (Twyford et al., 1993). Cropping intensities are much lower on rainfed lands than on irrigated lands, and yields of major crops on *barani* farms are only half of those on irrigated fields. In addition, many other problems such as poor soil and water management and range management, lack of technical *know-how*, inadequate physical and social infrastructure, poverty, unemployment and economic uncertainty are more widespread in rainfed tracts (Supple et al., 1985).

Agricultural education in the country has been given much emphasis from the foundation of the state. The Punjab Agricultural College and Research Institute, Faisalabad (established in 1910) was upgraded in 1961 into two separate institutions:

1) University of Agriculture, and 2) Ayub Agricultural Research Institute. Later on, agricultural universities were set up in Sind and North West Frontier (NWFP) provinces. As these institutions are located in irrigated areas of the country, the main focus of agricultural education has been on irrigated agriculture--education on rainfed agriculture was not given due attention. To fill this vacuum, the Barani Agricultural College was established in 1980 at Rawalpindi to provide education on all aspects of rainfed agriculture in the *barani* areas of the Punjab. The main objectives of this college are to:

- produce adequately trained and motivated graduates in rainfed agriculture so that they become agents of change in a stagnated, stereotyped agriculture, which is characteristic of rainfed areas;
- boost agricultural produce through applied/fundamental research and crop planning;
- develop mechanisms and infrastructure for the dissemination of research results; and
- take effective measures for resource development through the creation of site-specific technology.

Barani College offers programs leading to BSc (Hons) and MSc (Hons) degrees in Agricultural Science. The BSc Agric. (Hons) is a four-year program after higher secondary education and is spread over eight semesters. After four semesters with a common curriculum, students specialize in an agricultural discipline of their choice. The MSc Agric. (Hons) program is of two years duration after the BSc Agric. (Hons) and is being offered in the areas of *soil science* and *agronomy*.

Soil Fertility Education at Barani College

Soil fertility education at Barani Agricultural College is based on the research findings applicable to rainfed agriculture at both national as well as international levels. The College is in close coordination with the following research institutions engaged in soil fertility research under rainfed conditions in the Punjab province.

- Land Resources Research Institute, National Agricultural Research Centre, Pakistan Agricultural Research Council, Islamabad.
- Soil Fertility Survey and Soil Testing Institute, Murree Road, Rawalpindi.
- Barani Agricultural Research Institute, Chakwal.
- Directorate of Soil Conservation, Murree Road, Rawalpindi.
- National Development Fertilizer Centre, Planning and Development Division, Government of Pakistan, Islamabad.

Soil fertility research is also carried out by the students of Soil Science during the MSc program and during the final year of the BSc program. The research by the students is supervised by qualified teachers at the College. Professors in the departments of Soil Science and Agronomy are also directly involved in this research. Two courses of soil fertility are offered, one at undergraduate and one at graduate level. All undergraduate students attend the soil fertility course in the Third semester. At MSc level, an advanced soil fertility course is offered to students majoring in soil science. Some details of these courses are warranted.

Soil Fertility and Plant Nutrition

This course (SS-401) is taught at undergraduate level and is of 4 credit-hours per week; three for theory and one for practical. The course covers: concepts of soil fertility; plant growth and factors affecting it; essential plant nutrients--their functions, forms in soil, deficiency and toxicity; transport of ions to roots and ion and water absorption by plants; soil and fertilizer N-cycle and its significance, N transformations in soil and factors affecting these, biological N-fixation, N fertilizers and their efficient use; soil and fertilizer phosphorus--factors affecting P availability to plants; soil and fertilizer potassium, calcium, magnesium, and sulfur; micronutrients and factors affecting their availability to plants and the status of micronutrients in Pakistani soils and the use of micronutrient fertilizers; organic wastes and their use for improving soil fertility; methods of soil fertility evaluation; and soil fertility problems of *barani* areas and their solution. Practical sessions include: determination of organic matter, N, available P, and exchangeable K in soil; assessment of NPK in fertilizers; identification of deficiency symptoms in the field; plant sampling and preparation; NPK determination in plants; and visits to fertilizer factories.

Besides available research materials, the following books are recommended to the students:

- Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers. 4th Ed. Macmillan Pub. Co. New York, USA.
- Mengel, K., and E.A. Kirkby. 1987. Principles of plant nutrition. 4th Ed. International Potash Inst., Bassel, Switzerland.
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Advanced Soil Fertility

This 3 credit-hours' course (SS-705) is taught at graduate level. It covers: fertilizer application and plant growth response; economic and scientific basis of fertilizer application; efficient fertilizer use technology for field, garden and vegetable crops; fertilizer use technology for *barani* areas; modern developments in N, P and K fertilizer research; foliar feeding of plant nutrients; biological aspects of nutrient availability--rhizobia and mycorrhizae symbiosis efficiency compared to chemical fertilizer use; and fertilizer guide for irrigated and rainfed areas. Practical sessions include: study of rhizobia and mycorrhizal symbiosis in relation to chemical fertilizer application; fertilizer guide based on soil test values; and visits to various research institutes to become familiar with research trends/achievements in soil fertility.

Besides soil fertility research publications, the following books are recommended for students' reading:

- McVickor, M.H., G.L. Bridger, and I.P. Nelson. 1983. Fertilizer Technology and Use. 3rd. Soil Sci. Soc. Am., Madison, Wisconsin, USA.
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Need for Soil Fertility Education

A large number of field trials and soil analysis data have revealed that our soils are universally deficient in N, about 90% lack adequate available P contents, while 40 to 50% have insufficient K (Bajwa, 1992). Widespread N and P deficiency in the rainfed areas may be due to low inherent organic matter in soils (<1%), soil erosion, little addition of organic manures, and inadequate use of NP fertilizers. High soil pH and calcareousness are other factors adversely affecting P availability in soils of rainfed areas. Response of rainfed wheat to NPK (average of 150 trials) is given in Table 1.

Table 1. Response of wheat to fertilizer nutrients under rainfed conditions.

Treatment	Yield	Increase Over Control
	----kg ha^{-1}----	------------ % ----------
No Fertilizer	1191	-
Nitrogen	2230	87
Nitrogen and Phosphate	3107	161
Nitrogen, Phosphate, and Potash	3167	166

Application: NPK at 100, 56, 30 kg ha^{-1}, respectively.
Source: Bajwa (1992).

According to a survey (Nisar et al., 1992), well drained rainfed soils of the northern Punjab contained less than 10 mg kg^{-1} of sulfate-sulfur. There could be a possibility of crop response to applied S with further depletion of this element. Studies regarding crop responses to S fertilization are needed to verify the soil test results. Field trials have also shown that peanut, an important crop of medium rainfall areas of the rainfed tract, gives positive response to Ca application.

Rashid and Qayyum (1990) conducted a survey to assess the micronutrient status of important districts of rainfed areas of the Punjab province. On the basis of analysis of 1000 soil samples, there was widespread deficiency of B and Zn in the rainfed soils of these districts. Iron deficiency also occurred in some districts. However, Cu and Mn levels were generally sufficient (Table 2).

Table 2. Micronutrient deficiencies in rainfed areas.

Micronutrient	Jhehlum	Chakwal	Rawalpindi	Attock
	---------------------% deficient samples ---------------------			
B	84	68	-	71
Zn	67	70	47	90
Fe	31	43	-	20
Cu	-	-	-	-
Mn	12	16	-	1

Source: Rashid and Qayyum (1990).

Micronutrient concentrations in peanut soils of Chakwal (76 samples) and Attock (24 samples) as presented in Table 3 indicate that about 60% of the samples were deficient in B and Zn, and 20% in Fe (Rashid, 1994). Peanut tissue analysis in the rainfed areas (Rashid, 1994) revealed that 50 to 54% of samples were deficient in B and 61-63% in Zn. Crop response studies to micronutrient application in rainfed areas indicated a 14.8% increase in wheat yield by application of B and 11.3% by Zn application (Khattak, 1994). However, more crop response studies are needed for micronutrients in the rainfed area.

At present, farmers try to manage soil fertility of their farms according to their own inherited or indigenous knowledge, availability of fertilizing sources and their ability to purchase organic manures and chemical fertilizers. Soil fertility is improved by the use of the following in rainfed areas: chemical fertilizers, farmyard manure, poultry manure, fallowing, and crop residues. Present soil fertility management practices do not seem efficient since the soil fertility status of rainfed areas remains low. It is not only N and P but also some secondary and micronutrients which may be deficient in these areas. Soil organic matter is also low (<1%). Maintaining adequate levels in the soil is especially important in rainfed areas to conserve soil moisture and to reduce soil erosion. Since farmyard manure, poultry manure, and crop residues are in limited supply, and soil fertility contribution by fallowing may not be significant, use of chemical fertilizers is the only feasible means of improving soil fertility and getting higher crop yields.

Table 3. Micronutrient concentrations in peanut-growing soils.

Micronutrient	Chakwal	Attock
	--------------- mg kg^{-1} ---------------	
B	0.12 - 0.96	0.02 - 5.65
Zn	0.12 - 4.18	0.28 - 1.64
Cu	0.46 - 3.62	0.28 - 1.58
Fe	0.62 - 21.96	0.18 - 53.40
Mn	0.14 - 7.86	0.00 - 141.60

Critical levels (mg kg^{-1}): B = 0-5, Zn = 0.9, Fe = 3, Mn = 0.5.

However, fertilizer use in the rainfed areas is quite low compared with irrigated areas. According to a survey (Twyford et al., 1993) on a cropped area basis, irrigated land received about 2 to 6 times as much N as *barani* lands. Phosphate levels in *barani* areas were about 45% of those in irrigated areas, and potash use was very small in both irrigated and *barani* lands (Table 4). There was a wide N:P ratio against a desired ratio of 1.5:1. Among fertilizer users, *barani* growers, on average, applied 39% of the N, and 49% of the P that irrigated growers used during 1986/87 (Table 5). Toyford et al. (1993) attributed the following reasons for non-use of fertilizers in rainfed agriculture: use of farmyard manure, 35%; lack of finance, 23%; unavailability of water, 17%; and unavailability of fertilizers, 12%. The above information regarding the present low soil fertility status of the rainfed areas, and inefficient soil fertility management practices of the farmers explains the importance and need of soil fertility education for the farming community of rainfed areas of Pakistan.

Table 4. Average nutrient application rates for irrigated and *barani* wheat areas.

	Season	N	P_2O_5	K_2O	$N:P_2O_5$
		----------	kg ha^{-1}	----------	
Irrigated	1985/86	73.7	26.1	0.7	2.82
	1986/87	82.1	26.2	3.1	3.13
Barani	1985/86	28.6	9.7	0.3	2.95
	1986/87	30.9	11.8	0.2	2.62

Source: Twyford et al. (1993).

Table 5. Average nutrient application rates on fertilized wheat.

	Season	N	P_2O_5
		---------- kg ha^{-1}	----------
Irrigated	1985/86	83.3	36.9
	1986/87	93.1	39.8
Barani	1985/86	45.9	23.0
	1986/87	36.3	19.7

Source: Twyford et al. (1993).

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Economic Considerations in Fertilizer Use and Related Public Policy

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Abstract

The enormous economic importance of fertilizers is seen in many forms at the farm and *national* levels. The complexity of the trade-offs and balances in fertilizer use decisions requires an integration of physical, biological and economic understanding. Examples are provided on the decisions for. 1) a single fertilizer on a single crop, 2) two fertilizers on one crop, 3) balances in crop rotation sequences over time, 4) balances across cropping zones, and 5) policy balances for efficiency, equity and environmental sustainability. Research teams ignoring the economic aspects of fertilizer choice relegate their work to academic interest only. Integration of economics with other studies on fertilizer use allows a research team to express their results in terms of greatest practical interest to farmers and policy-makers.

Introduction

Most will agree that soil fertility is of enormous economic importance to farmers and nations. It is also of great scientific interest because of the complex trade-offs and balances involved. Soil fertility, nutrient deficiency and toxicities are matters of *balance*: chemical, physical and economic *balances*. On the subject of policy, not only are we dealing with questions of efficiency, but, on a larger level, with national interests of equity and ecological sustainability.

In this paper, the simplest economic questions at the single field, single crop and single fertilizer level are discussed first. These are complicated by price and weather variation. And complications increase when the question includes the best balance of two fertilizers. When the question is put in terms which ordinary farmers face -- fertilizer use in the context of crop rotations in combination with other farm activities *such as* sheep production, and considering the cost and availability of hired harvest labor, etc. -- the only recourse is to economic calculation. Rough forms of such integrated calculations are done in farmers' minds all the time.

Taking these questions of balance to the level national policy naturally invokes further questions of balance, such as the choice between promoting domestic production or imports of fertilizers, and the choice of whether and where to promote fertilizer use with subsidies. Should the market alone decide, or are there questions of equity favoring assistance to some sectors of the farming population? What are the economic trade-offs? Important also are the questions regarding environmental sustainability of fertilized agriculture and the quality of life downstream. Antle and Wagnet (1995) have made the point:

> *"Economics provides research institutions with the tools they need to be accountable to society, to better set research priorities, and to design research programs that are consistent with public policy objectives".*

This short paper cannot treat any of these subjects in much detail. The simple aim is to reinforce the point that real team-work among physical, biological and economic disciplines is, and will continue to be, essential in sorting out the most important questions on fertilizer use. There is little doubt that these questions will arise with greater frequency and urgency in the future as the world's population pressure calls for ever greater production, and that few answers will serve once and for all.

Optimization for a Single Fertilizer and Crop

The economic analysis of fertilizer-crop response is not a new subject (Heady and Dillon, 1961). The most familiar question of balance is that of a farmer's decision on how much of a single fertilizer to apply to a crop. Where the farmer has an idea of the crop's likely response to the fertilizer, the key objective information for the decision is in place. Where the fertilizer has a cost and the farmer has an idea of the crop's market value per unit, there is now a basis for calculating an optimum fertilizer application. It will always be something less than the amount of fertilizer needed for maximizing crop yield.

The optimum balance will be that where the benefit of adding an extra kilogram of fertilizer just equals its cost. The picture is less clear in the case of rainfed farming where the farmer cannot know at sowing time how much rain will come during the season, whether it will be a good, average or poor year. Since the crop's response to fertilizer is conditioned on weather, a large element of *uncertainty* enters the picture.

Higher application rates are accompanied with the greatest variances in yield, ranging from higher attainable yields in good years, to depression of yields in dry years. Thus, choice of fertilizer rate is a *strategic question*, one which becomes richer where their are options for split applications, for example, at sowing and later at tillering, when more is known about the season (Whitaker, 1991).

Simultaneous Optimization of Two Fertilizers for One Crop

The economic question becomes more interesting when the decision is on optimizing the rates of two fertilizers, where the response to each fertilizer is conditioned on the level of the other. In principle, the question of economic balance is the same, finding the mix at which the marginal returns equal the marginal costs, but, this time, when there may be strong interactions and trade-offs among inputs. *The uncertainties of weather are always here to complicate the picture.* This is why it is so important to have representative fertilizer response information for typical crops on typical soils in a farming district, and to have this over time in order to assess the effects on yield response under different weather sequences.

The economic optimum may depend on risk attitude of the individual farmer, and other considerations we shall come to later, but basically boil down to the "expected response surface". This surface, which defines the expected trade-offs between fertilizer inputs and yields, when combined with price values of the inputs and those expected for the crop, provides the basis for a "best-guess" at the profit-maximizing combination of fertilizers. These will be guesses because the final weather sequence between fertilization and harvest dates is never known with certainty; final crop prices may also differ from farmer-expectations.

Balances in Crop Rotation Sequences Over Time

Now consider the practical situation of many farmers who must grow crops in rotational sequences to maintain soil fertility and, importantly, to avoid the worst problems with pests (weeds, insects and crop disease). Two examples of bio-economic analyses of whole-farm systems are given to illustrate the complexity of the trade-offs ordinary farmers face in decisions affecting soil fertility/productivity over time. In both examples, production costs and market prices were derived from farm and market surveys in each area.

The first one is in northeastern Syria, based on a rotation and grazing trial at Hemo station near Kamishly (Shomo et al., 1995). Five crop rotations (wheat-lentil, wheat-wheat, wheat-fallow, wheat-vetch and wheat-medic pasture), showed great differences in the net whole-farm incomes, and standard deviations of net incomes (after costs of all purchased inputs) over 8 years. These were results of a *linear programming analysis* that optimized livestock (sheep) numbers, feed purchases, labor hiring and crop sales under each rotation, and assumed a farm size of 16 ha (typical of the area) and typical family size.

Over most years of this trial, government regulations banned the wheat-fallow rotation in farmers' fields and required the adoption of continuous wheat on some land, with the objective of increasing domestic wheat production. Continuous wheat cultivation produced the poorest results in the trial, both biologically and economically. The lentil-wheat rotation produced the best economic results in terms of mean net incomes over the eight-year period. This was obtained, however, with the assumption that there are no limits on availability of cheap hired labor for lentil harvest. Inferior results were obtained for the medic-wheat rotation, in terms of lower mean income and higher variation in income. Vetch-wheat did little better.

Analysis of a contrasting case, where no hired labor is available, showed the income-maximizing allocation of a 16 ha farm with 40 sheep as: 4.6 ha of fallow-wheat; 1.2 ha of vetch-wheat; 4.9 ha of lentil-wheat; and 5.2 ha of medic-wheat (Shomo et al., 1995). This is very different from the first result that called for a lentil-wheat rotation on the entire 16 ha. In this trial, blanket fertilizer treatments were used in the wheat-phase across all rotations. *Performance differences in economic terms were* *due to effects of the rotations.* Availability or lack of crucial labor inputs affected optimal land allocations among crops.

Similar relationships among crop rotations were found in the preliminary analysis of another trial here at Tel Hadya -- the one discussed by Ryan et al.(1996) in this volume, and reported by Harris (1989) and Harris et al. (1992) -- in which four rates of N fertilization were applied to the wheat phase. This analysis also covers an eight-year span. Differences in incomes (mean and standard deviation) due to N level are also apparent.

In the cases of fallow-wheat, watermelon-wheat and medic-wheat, the highest mean net whole farm incomes were obtained with the highest N rate (90 kg ha^{-1}). In the cases of vetch-wheat and lentil-wheat, however, the medium N rate (60 kg ha^{-1}) gave the best results. The continuous wheat rotation was a aberration in that the zero-N rate gave better economic results than any of the positive rates.

In the case of each rotation, the highest N rates were associated with the highest variations in net incomes -- not all bad if deviations from the mean were positive, but this would be a contradiction in terms, there are negative deviations as well. This takes us back to the earlier discussion of response functions in different kinds of growing seasons. Analysis of this long-term trial is incomplete but provides an example in which optimal combinations of crop rotations with different N fertilizer rates in the wheat phase can occur on the same farm.

Balances Across Cropping Zones

At the level of the individual farmer, fertilizer prices are pretty well fixed -- by buying more or less, the farmer cannot influence the price, particularly as fertilizer purchase and use are "time-bounded" decisions which will not wait for months and months. At the national level, the world price has a similar constancy, though there is room for bargaining on large orders.

Since the optimum rate for a crop at a certain place is the rate at which marginal returns equal the unit price of the fertilizer, by horizontally aggregating fertilizer use across crops and zones at different price levels we come to a picture of national demand. An example of a bio-economic policy model, simultaneously taking into account fertilizer response functions from each main crop in each main production zone in Syria, is given by Saade (1991). The national demand curve for fertilizer is the sum of marginal return curves of all producers and all crops. The lower the fertilizer price, the greater the optimal use. Thus, subsidization of fertilizer will encourage greater use. In cases where farmers have little or no experience with fertilizers, subsidization has been justified as a way of speeding up their familiarization with it.

In areas where fertilizers have not been used, research and extension may be justified to learn and share information on crop response under the local growing conditions. In rainfed farming systems, as we have seen, the question of best rates may be confounded by weather and crop rotation. Knowing this, research should be designed accordingly and due caution observed in avoiding blanket recommendations. A fuller review of economic research on N fertilizer at ICARDA, illustrating numerous cases of conditional decisions is available from Nordblom (1997).

Policy for Efficiency, Equity and Environmental Sustainability

State-supported research can be considered as a kind of subsidy to local agriculture, and justified on the grounds of most quickly and surely sorting out the understanding of crop response and helping to bring input use into balance with production potentials. This will be most certain when researchers make an effort to learn from local farmers and from local farming conditions (soil and weather) the physical and economic context of production. Fertilizers may be made available to farmers locally on a timely basis and on credit -- they will do their own experimentation.

When the most-favored and least-favored farming areas in a country are ultimately balanced with equal access to inputs and markets, so each area fulfills its comparative advantage, the most important efficiency goals will be met. The reverse may be true where certain areas are politically favored and showered with subsidized inputs while others are neglected.

Research and input subsidies may be justified in the more marginal production zones by including consideration of *social and environmental benefits and costs.* Here we may think of rangeland fertilization as a topic worthy of national research interest. As shown by Osman (1996), significant responses in range plant growth in phosphorous-deficient areas can be found. Some changes may be needed in local rangeland control and management rules in order to provide the economic climate for private or communal investment in range fertilization. We are pursuing these questions with several national programs of the region in partnership with the International Food Policy Research Institute, Washington, DC.

A good example of *policy* and *sustainability* comes from our economic analyses of two long-run crop rotation trials: where farmers were required to cultivate continuous wheat crops, yields could not be sustained at the high levels possible when wheat is grown in rotation with food or forage legumes. Further discussion of fertilizer policy in the context of food and feed deficits expected by the year 2020 in West Asia an North Africa (WANA) is found in Nordblom and Shomo (1995).

In irrigated and high rainfall farming systems, as in the Netherlands, there are examples of environmental damage from overuse of fertilizers. This is the paradox where individual farmers, following their own best economic interest with high rates of fertilizer use, end up polluting the surface and ground-water used by their own or down-stream communities.

In the marginal rainfed farming areas, environmental degradation is frequently seen in the cultivation of crops on lands better suited to sustainable use as rangeland. Soil and native vegetation is lost, and cultivation is never fully successful. Unfortunately, this describes the situation over large areas of the region. Rangeland fertilization, with other rehabilitation measures, could increase the economic incentives for more sustainable land use (Osman and Bahhady, 1993).

Implications for Research

The important point of these examples is that *the production context matters a great deal.* Wheat and other crops are grown in crop rotations. And farmers growing them face markets for inputs and outputs which are different from place to place. The implications for national research are clear. *There is a need to understand responses to fertilizers in each production zone*, in the contexts of production found in each. As a window on the future, research may extend to examining balances for crops which are likely to gain importance through comparative advantage in free trade conditions, and under conditions of great population growth which are forecast for all countries of the WANA region.

Understanding and extending to farmers the local fertilizer responses (and micronutrient deficiency and toxicity information) under local soil and crop management conditions (and alternative future local management conditions they may chose) will go far toward the achievement of efficiency and equity goals. Information on local response and demand for fertilizers, and studies of environmental hazards and options, will inform policy-makers wishing to find the best national balances for present and future generations.

For some questions, the methods for doing such research are clear. In other cases, however, nobody has the final answer on how to approach the tougher problems. It is in the latter case that international and regional centers will have important roles in discovering, testing and sharing methods. Most likely, an integrated approach which brings together the social, economic, biological and physical aspects, has the best chance of answering the more complex problems facing dryland farming in the future. A continuing partnership among national agricultural research systems of the region, advanced institutions and ICARDA will be the foundation of success.

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B. SHORT COMMUNICATIONS

Nitrogen Uptake and Requirements of Wheat in Dryland Chickpea/Wheat Rotations in Central Anatolia

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Abstract

Wheat/chickpea rotation in Central Anatolia has become a widespread cropping system. Efficient use of N fertilizers was one of the main concerns of research in this system. A series of experiments was conducted under dryland conditions in order to identify the N amounts that should be applied to chickpea and wheat for optimum wheat yield under chickpea/wheat rotation during the years 1989-1994. The experimental design was a split-plot RCB. In the chickpea phase of the rotation, main plots were formed and 0, 30, and 60 kg N ha^{-1} applied. In the wheat phase, 0, 30, 60, 90 and 120 kg N ha^{-1} were given to the sub-plots. For optimum wheat yield, N applied to chickpea (N_c) and wheat (N_w) were 32.9 and 113.4 kg ha^{-1}, respectively. The N rates for profit maximization were also estimated. Nitrogen by wheat was influenced by N_w but not N_c and increased approximately twofold by 120 kg N_w ha^{-1} compared with the control plot (0 N) in two experimental years. Optimum N use in chickpea and wheat improved wheat yield and N uptake.

Introduction

Although fallow-cereal rotations have been the primary cropping pattern for centuries, it has changed remarkably in recent years. With the implementation of the project 'Utilization of Fallow Areas', fallow has been replaced by certain crops such as chickpea and lentil. Thus, fallow as a practice has been abandoned extensively in Central Anatolia (Durutan et al., 1990), and Turkey has become one of the largest lentil and chickpea producers and exporters on the world market (Uzunlu and Bayaner, 1991).

Shifting the cropping system from fallow/cereals to legume/cereals necessitated research on different aspects of new cropping systems. Efficient use of nitrogen fertilizers was among these concerns. Much research related to N use in legume/cereal rotation has been carried out in the plateau. Accordingly, optimum amounts of N for wheat changed from 80 to 120 kg N ha^{-1} depending on the variety of wheat and amount of rainfall (Avcı et al., 1993; Karaca et al., 1993; Aydın, 1987; Turan et al., 1991). Özbek et al. (1987) found that N fertilization increased N uptake by wheat up to 150 kg ha^{-1} under Çukurova conditions. Abdel Monem et al. (1978) indicated that wheat took up 26.5 and 55% of fertilizer N in different years of a study conducted under Syrian conditions. Using eight wheat varieties and two N rates, Moll et al. (1982) found that as N uptake and yields increased with high N application, and recovery of applied N decreased.

This study aimed to investigate both residual and direct effect of N on wheat grain yield in a chickpea/wheat rotation system. Optimum N rates that should be given are also estimated for both crops for optimum wheat production.

Materials and Methods

Experiments were conducted at the Haymana agricultural experiment station in typical Central Anatolian semi-arid conditions for six years (1989-1994). The trial field was split into two blocks, one for wheat (Gerek 79) and other for chickpea production, in order to obtain data from both crops in each year. Crops were rotated in these two blocks. The chickpea block was subdivided into three main plots, with 0, 30, 60 kg N ha^{-1} applied in each. In the following wheat year, these main plots were split into five sub-plots, and 0, 30, 60, 90 and 120 kg N ha^{-1} was applied. At wheat seeding time, 60 kg P_2O_5 and ⅓ of the N treatment was given with a double disk drill; the remaining N was broadcasted at spring time. In chickpea plots 40 kg P_2O_5 and the full rates of N treatments were applied at seeding time with seeder. No spring fertilizer was applied for chickpea. In the wheat year, one square meter of area was sampled for N analyses from each plot in the 1991/92 and 1992/93 seasons.

Results and Discussion

None of the N application treatments on chickpea plots was significantly effective on subsequent wheat grain yield in any of the trial years. However, N application in wheat plots significantly affected wheat grain yield in all six years. Only the N_c x N_w interaction was significant in 1989/90 and 1991/92 (Table 1). Combined ANOVA showed that N_c and N_w and the interaction N_c x N_w significantly affected grain yields of wheat. Among the season interactions, only the season x N was significant.

The carryover effect of N_c was remarkable when the yields obtained with the lower rates of N_w and 0 kg N_c ha^{-1} were compared. The 30 kg N_c ha^{-1} had a greater residual effect on yield than 60 kg N_c ha^{-1}, and increased yield between 12% and 122% depending on the year.

The best combination of N_c and N_w for highest wheat yield should be determined. In order to quantify this amount, a yield equation was developed: $Y = 14.29\ N_c + 13.68\ N_w - 0.1255\ N_c^2 - 0.0526\ N_w^2 - 0.0533\ N_c N_w + 1627$, $R^2 = 0.907$, where Y is the predicted grain yield of wheat (kg ha^{-1}) and N_w and N_c are in kg ha^{-1}. The equation accounts for approximately 91% of yield variation. From the above equation, by taking partial derivatives, optimum N_c and N_w were 32.9 and 113.4 kg ha^{-1}, respectively.

Figure 1 shows the economical relevant area and ridge lines as depicted by isoquant (150-yield) lines, which determine economic N usage limits. According to this figure, using more than 130 kg N_w ha^{-1} and 59 kg N_c ha^{-1} is not economic and, thus, cannot be recommended. Optimum N rates of 32.9 and 113.4 do not always indicate the economic N rate. Economic N rate is the function of per unit fertilizer buying and wheat selling price. Therefore, economic N rate for both crops is variable for every year and needs to be recalculated. If the prices per unit N_w and N_c are equal, economic N rate is given as follows: $N_c = 32.8 - 2.19r$ and $N_w = 113.5 - 8.43r$ where: r is the ratio of N price to wheat price. As it was seen from the equations, N_w was more affected by the change in N fertilizer and wheat price than N_c. The value of r was mostly around 2. Taking this value, the profit maximizing N rates were 28.4 kg ha^{-1} for N chickpea and 96.6 for N wheat.

Table 1. Average wheat grain yield response to N applied to chickpea and wheat

Chickpea	Wheat	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	Average
-- kg N ha^{-1} ---		------------------------ t ha^{-1} ------------------------						
0	0	1.71	1.18	1.77	1.44	2.04	1.20	1.56
0	30	2.08	1.78	2.40	1.76	2.49	1.40	1.98
0	60	2.3	2.25	3.10	2.17	2.75	1.46	2.34
0	90	2.41	2.34	3.43	2.24	2.32	1.48	2.37
0	120	2.44	2.52	4.23	2.05	2.70	1.45	2.57
30	0	2.08	1.61	3.17	1.61	2.57	1.29	2.05
30	30	2.18	2.01	3.23	1.98	2.90	1.49	2.30
30	60	2.26	2.59	3.80	2.04	2.73	1.41	2.47
30	90	2.31	2.66	3.90	2.06	2.56	1.36	2.47
30	120	2.30	2.64	4.47	2.35	2.56	1.44	2.63
60	0	1.66	1.69	2.87	1.70	2.25	1.26	1.90
60	30	2.07	2.52	3.67	2.21	2.65	1.38	2.40
60	60	2.21	2.54	4.20	2.34	2.65	1.50	2.57
60	90	2.42	2.34	3.60	1.97	2.65	1.34	2.39
60	120	2.46	2.45	4.57	2.41	2.57	1.35	2.63
N_c		NS	NS	NS	NS	NS	NS	*
N_w		**	**	**	**	**	**	**
$N_c \times N_w$		NS	*	NS	*	NS	NS	*
$CV_{0.05}(N_c)$			14.6	28.5	22.5	13.6	22.3	25.3
$CV_{0.05}(N_w)$			4.6	10.1	14.7	7.4	8.1	6.9

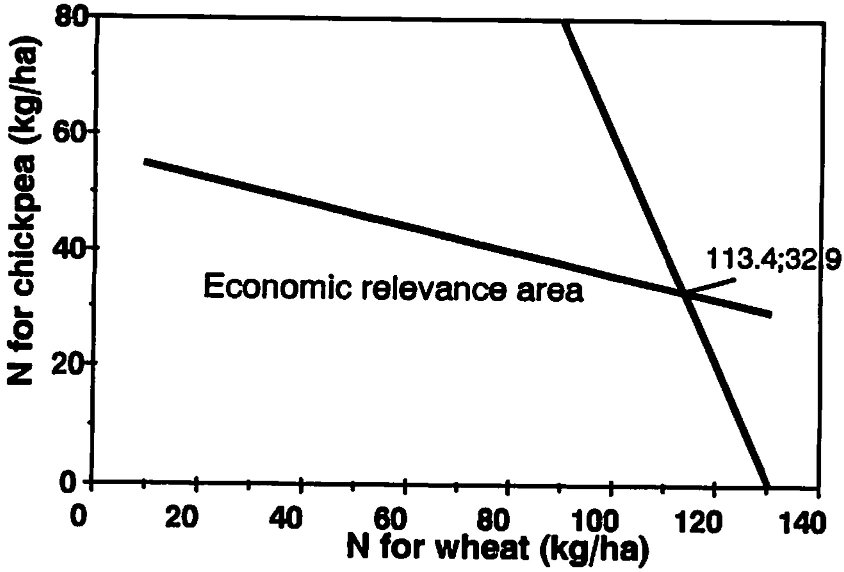

Fig. 1. Ridge lines of N (chickpea) and N (wheat) and economical relevant area (Stage II) for N fertilization.

Nitrogen Uptake by Wheat

Analysis of N uptake data showed that N_c did not affect the N uptake in either of experimental years, 1992 and 1993. Only N_w was effective on the N uptake (Table 2). The highest N uptake occurred with 120 kg N ha^{-1} applied and the lowest with no application of N. Nitrogen uptake increased as the amount of N applications increased. It was doubled with 120 kg N_w ha^{-1} compared with no N_w treatment.

Table 2. Summary of N uptake by wheat following chickpea in 1992 and 1993.

Chickpea			Wheat		
N	1991/92	1992/93	N	1991/92	1992/93
	--------------	--------------	kg ha^{-1} --------------	--------------	--------------
0	47.2	79.7	0	26.0	59.8
30	44.8	79.8	30	38.3	71.2
60	49.3	79.3	60	50.7	75.9
90			90	57.5	85.2
			120	63.0	106.0
$LSD_{(0.05)}$	15.0	19.0		7.4	16.2
$CV_{(0.05)}$	30.0	23.6		15.5	20.9

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Synthesis of Dryland Fertilizer Trials in Western Iran

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Abstract

This brief note points out the importance of nitrogen and phosphorus in the dryland calcareous soils of western Iran. Reference is made to crop responses in the field with these elements.

Introduction

Iran is a mountainous country of the Middle East. With an area of 164 million hectares, it is a vast region, the 16 largest country in the world. Generally speaking, Iran has a dry climate. It situated between 25 and 40°N latitude and 44 and 64°E longitude. Being located inside a dry belt of the globe, Iran has almost six million hectares of rainfed land. Soils are calcareous with pH around 8. The overall average annual precipitation throughout the country is about 200 mm.

Western Iran is composed to a large extent of mountainous lands which are predominately in semi-arid to dry sub-humid zones. Average yearly precipitation varies from 250 to 500 mm, most of which comes during winter and spring periods. It has cold winters and cool and dry summers. Vegetation consists of a thin cover of grasses and scattered shrubs. Organic matter (OM) and nitrogen (N) are low, while available phosphorus (P) is from 6 to 12 ppm (Olsen method). Its available potassium (K) is from 400 to 650 ppm (ammonium acetate method), there is no K fertilizer recommendation in the whole region. Although the amount of fertilizer applied per unit area is higher than world's average application, its performance in terms of crop yield (kg per kg ha^{-1}) is much lower than the rest of the world. Irregular fertilizer application with low organic matter causes soil compaction and some nutrient imbalances, and, in some cases, severe nutrient deficiencies.

Western Iran can be divided in to three different climatic zones. In Maragheh and Azarbaijan province, where the Dryland Agricultural Research Institute is situated, the average precipitation is 300 mm.

Fertilizer Trials

The results of fertilizer trials and P calibration showed that 60 kg N ha^{-1} and 30 kg P ha^{-1} were the best treatment for wheat production. The corresponding figures for barley were 50 and 30 kg ha^{-1}. For chickpea and lentil 20 kg N ha^{-1} is used together with the same rate of P as for other crops, i.e., 30 kg ha^{-1}, the best treatment. In Kurdestan, with an average 400 mm yearly precipitation, the results of fertilizer trials showed that 40 kg N and 30 kg P ha^{-1} were recommended for wheat and barley, while 20 kg and 40 kg ha^{-1} P for chickpea and lentil were the best treatments. In Kermanshah, with an average of 450 mm annual precipitation, the results of fertilizer trials and P calibration showed that 45 kg N and 30 kg P ha^{-1} was the best treatment for wheat. For barley production, less N is recommended (30 kg ha^{-1}), but the same P rate. The critical level for P in wheat and barley is 5 ppm. There is no recommendation for P application for wheat and barley when soil has more than 7 ppm available P.

While common urea, sulfur-coated urea and ammonium nitrate were applied and compared in all climatic regions, ammonium nitrate generally gave the best results. According to 6-year fertilizer trials, in Maragheh and Kurdestan, application of total N fertilizer in fall (planting time) had a better effect on wheat production than splitting it; in Kermanshah, splitting had a similar effect to fall application. In some preliminary experiments in the Dryland Agriculture Research Institute, separating applied fertilizers from the seeds had better results than mixing them. In the early years, applying fertilizers 4 to 6 cm below the seeds had a large effect on wheat yield.

Most fertilizer trials in Western Iran were concerned with N and P. However, based on some field observations and from soil analyses in the Dryland Agricultural Research Institute, it found that there may be some micronutrient deficiencies such as zinc. Therefore, with consultation with Soil and Water Research Institute and academic institutions, some experimental trials were designed and carried out. Since early results indicated that zinc application significantly increased wheat yield, it was decided to have more experiments on a wider scale. Waste materials (compost), which has some essential macro and micronutrients, were applied and tested.

Recommendations

1. In almost all of Iran, soils have low organic matter levels which may adversely affect soil compaction and water permeability and some nutrient deficiencies. Therefore, increasing soil organic matter by green manure and by proper rotations should be considered.
2. Fertilizer application should correspond with soil nutrient contents and plant uptake. Therefore laboratories should set up to identify nutrient constraints in each region.
3. Some micro-elements imbalances, i.e., zinc, or deficiencies, i.e., boron, may have considerable effects on crop production. Such deficiencies and/or toxicities should be identified and remedial action taken.

Practical Considerations in the Establishment and Management of Fertilizer Trials

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Abstract

This note emphasizes criteria for the establishment and layout of field trials. Proper site selection is required to avoid effects of uneven topography. Uniformity of the test site has to consider soil quality, rotation and management, as well as land preparation, particularly prior to the test season. The layout must include adequate border strips. Alleyways, required for combining planting and management operations, shall be cropped as far as possible to the end of the season. An idea to improve the precision in marking of the plot area for yield determination is described.

Introduction

Fertilizer trials are conducted mainly on research stations by national programs in the West Asia-North Africa (WANA) region. However, not enough care is given to the historical background of trial fields. Usually, there are sufficient amount of nutrients available in the soil that crop response to fertilizers are not significant. In fact, soil analyses are often done after the establishment of the trial. Therefore, it is difficult to justify the reason for the given field to be considered for fertility experiments. Therefore, fertility experiments are suggested to be conducted as on-farm trials in farmers' fields. In this way, calibration of soil tests can be done with respect to crop response to fertilizer under different agro-ecological conditions under given fertility levels of soils. Although this is an ideal situation to conduct fertilizer experiments as multi-year and multi-location on-farm trials to be able extrapolate the experimental results for different conditions, the majority of the national programs lack the facilities and manpower to carry such trials outside the research station.

Given these constraints, there has to be some sensible considerations in conducting fertility trials on research stations to be able to study crop response to fertilizer applications. Accurate establishment and management of fertilizer trials is a prerequisite for proper attributing effects of tested variants or treatments. Site selection affects the proper establishment through suitable/non-suitable surface topography, homogeneity of soil quality and uniform history and rotation of the plots. The layout has strong influence on the accuracy of results through the required elimination of border effects and precision of the evaluated plot area. Therefore, it is necessary to discuss these matters in detail.

Site Selection

Topography

Ideal fields have a flat, level surface. This reduces the risk of runoff, waterlogging, as well as non-uniform exposure to sunlight, wind or precipitation. An example of poor conditions could be a field next to a hill in an eastern/northeastern direction, where sunshine close to the hill starts more than one hour later in the morning, with no compensation in the evening. As a result, diseases related to leaf wetness, such as ascochyta blight of chickpea or late blight of potato may be favored in that part of the field.

Fertility gradients are also most pronounced in sloping areas, with lower parts more fertile than higher parts because of settlement of soluble nutrients in lower areas. If a level area is not available, a uniform area with a gentle slope should be preferred because such areas generally have predictable fertility gradients, which may be managed through the use of proper blocking (Gomez and Gomez, 1984).

Homogeneity

This includes soil uniformity with regard to depth and quality, but also the field history, such as uniform treatment of as many parameters as possible in the previous season(s). However, it is almost impossible to get an experimental area that is totally homogeneous. Tillage and seedbed preparation have a great influence on homogeneity. Soil tillage, if required, is best done under dry conditions. Working depth and speed should not be altered while dealing with the area for one particular experiment. Headlands, where tractors and machines are turning around and work in a non-uniform way should not be used for experimental plots. Different treatments usually increase soil heterogeneity. Therefore, areas planted with different crops, fertilized at different levels, or subjected to different managements should be avoided, if possible. Otherwise, such areas should be under uniformly managed cover crop for some years with no addition of relatively immobile plant nutrients for fertility related trials.

Field History and Rotation

On-station fertilizer trials should be separated from yield trials, because they may have a longer lasting residual effect, which, in turn, may require a different rotation in order to regain homogeneity. Trial locations in farms should be selected in a way to be representative or typical for the conditions for which conclusions will be drawn. In order to obtain responses to fertilizer application, e.g., phosphate trials, it is often important not to have had any fertilizer of that kind being applied during the previous few years or more on the covercrop areas.

Soil analysis is required before starting the trials. Apparently, in ICARDA's experience, this is often done after the beginning of the trial activities. In rotations where fields are prepared for fertilizer trials the cover crops may not be allowed to receive, e.g., P fertilizer. Cereals and summer crops should be given their N requirements according to the seasonal conditions. Practically N application should be done as topdressing during the season. The concept of using a non-experimental crop of wheat/legume to eliminate residual effects of fertility is incorporated into ICARDA's two-- and three-course rotations. The longer the time between the experimental season for the same plot, the larger the crop responses to applied fertilizers. This eventually will allow us to conduct detailed fertility experiments on research stations for multiple years with a good response to applied fertilizer and analyze the data properly.

Layout of Trials

Borders and alleyways are part of all trials. They are required as surroundings of the proper test plots. Borders are meant to compensate for "border effects", such as differences in moisture availability, nutrient availability, and to provide space for equipment to turn and to keep intruding effects, such as insects, dogs, sheep and visitors out of the real plot. Alleyways are areas between neighboring plots, mostly at beginnings and ends. Alleyways are usually not required between left and right side neighboring plots.

There may be two justifications for alleyways: 1) better separation of plots and avoidance of seed mixing, and 2) traffic track for operations during the season. Borders are usually cropped the same way as the trials are. Alleyways are often kept empty, like a fallow strip. This is simple at time of planting, but would result in two "border effects": one during the season, and one as residual effect a year or even two years later. The effect of non-planted borders has been given from a specific experiment conducted for this purpose by Gomez and Gomez (1984).

Particularly in areas with semi-arid conditions, such as the WANA region, small plots often show considerable border effects. There would be no border effect if the whole trial was planted without extra space at the left and right side, as well as beginning and end of each plot. Avoiding this extra space is usually easier at the left and right sides, in planting direction, but more difficult to achieve at the beginning and end of plots. Standard cone planters require 30-40 cm distance between plots, precision planters may require up to one meter. It is recommended to plant the alleyways in order to avoid border effects. The alleyways practically should be 25 cm wider than the tractor used for spraying, fertilizer top dressing, etc. The minimum alley width appears to be 125 cm.

Crops on alleyways will best prevent the occurrence of "border effects" if they are kept until maturity. This will require clear demarcation from the actual plot area. Alternatively, the alleyway crop is recommended to be mowed at the latest possible stage. However, the achievable accuracy in this operation is limited at best to ±10 cm. In the worst case this means shortening or lengthening of a given plot length of 20 cm each way. This problem will exist as long as both ends of one plot are prepared in separate operations, such as mowing or spraying an individual alley.

A system is presently developed to avoid this problem. It is based on applying herbicides on approximately 15 cm wide strips at both, beginning and end of particular plots simultaneously, shortly before heads develop. This system works well on wheat and barley, but is not yet tested on legumes. Legumes with their limited plant height, and branching growth habit pose some difficulties. The herbicide used is a mixture of paraquat and glyphosate. Paraquat enables monitoring of the effect within two to three days, while glyphosate ensures killing of the complete plant. At harvesting time the marker line will only be different in height, and will not bear heads. In the coming season the suitability and reliability of this system will be tested.

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Role of ICARDA in Soil Fertility Training in West Asia and North Africa

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Abstract

This note describes the role of the Soils Laboratory in training of participants from the various countries of the West Asia and North Africa (WANA) region in soil and plant analysis. Training materials were developed to support formal courses and individual study periods at the International Center for Agricultural Research in the Dry Areas (ICARDA). Several MS and PhD students from the region, in association with advanced academic institutions, conducted their research at ICARDA, and thus received their research training there. The laboratory has considerable potential to assist the region's various laboratories involved with personnel development and soil and plant analysis.

Introduction

Training and education are major components of ICARDA's mission to improve the agriculture and therefore the livelihood of the inhabitants of the WANA region. Underscoring the importance of this activity is that fact that a Unit is devoted to coordinating this endeavor across the various technical programs in collaboration with one technical officer in each area. The soil fertility section of the Farm Resource Management Program has already played a key role in all phases of training of participants from the national programs of the region. Its role can be put in perspective by some pertinent background information.

Laboratory Development and Training

The Soils Laboratory was set up in 1980, a few years after ICARDA's establishment. The present facility was established in 1987, when the new complex of laboratories began operation. The operation of the laboratory and related soil fertility-plant nutrition research was the responsibility of the resident soil fertility scientist. The initial task was to equip the laboratory and develop suitable analytical procedures, primarily for the analysis of nitrogen--inorganic and total-- and phosphorus. The main soil physical analysis was particle-size distribution.

Thus, the main analyses of the laboratory were ammonium (NH_4^+) and nitrate (NO_3^-) as well as Kjeldahl or total N, and available P using the Olsen 0.5 *M* $NaHCO_3$ procedure. The latter procedure was proven to be appropriate for the soil conditions of the region (Ryan and Matar, 1992). Measurements of pH and salinity are routinely made along with organic matter and calcium carbonate; more recently, available micronutrients are frequently measured, reflecting the current awareness of the potential importance of these elements for crop production.

A prerequisite to training participants from outside ICARDA is to have a cadre of trained technicians. Initially there were four technicians, recruited on the basis of formal training and laboratory experience; the number has now dwindled to two. An assistant at the "daily" level is employed for glassware cleaning, etc. The immediate supervisor of the laboratory is an experienced BS assistant (now has acquired the PhD). The "field" staff associated with the laboratory for soil sampling, preparation etc. (supervisor at BS level, two technicians, and one "daily") has also decreased over the past decade.

Educational Materials

Another condition for effective training is appropriate educational materials; while many procedures can be used directly from published sources, others have to be modified or adapted to the prevailing conditions. Thus, an initial report on standardization of the available P test was developed by Matar (1985) for distribution among the region's laboratories. Subsequently, Matar et al. (1987) developed a comparison between the hydrometer and pipette method for particle-size analysis. More recently, based on standard soil samples being sent to laboratories in the region, Ryan and Garabet (1994) showed the need for standardization of procedures commonly used in soil and plant analysis laboratories. Subsequently, in response to such variability in test procedures, Ryan et al. (1996) published a manual for use by soil and plant analysis technicians. This was a "cookbook" style volume which provided a minimum of background to provide rationale for the particular test, a step-by-step procedure, and interpretation of the data. Copies of this document will be distributed to all laboratories in the region, with a request for comments on its usefulness to laboratory operators which would be incorporated in a subsequent edition.

Formal and Informal Courses

Short-term training in the Soils Laboratory is basically of two kinds: formal courses of a few weeks' duration, and informal individual training from periods of one week to a few months. The number of such short-term courses, along with number of participants and their countries of region, is shown in Table 1. All courses were handled by internal staff, except the 1990 course on fertilizer recommendations which was run by staff of the International Fertilizer Development Center, Muscle Shoals, Alabama, USA.

Individual training has advantages of being more flexible in terms of logistics and subject matter. From the beginning of the laboratory to 1995, a total of 71 people received short-term individual training, usually singly or in groups of 2-3. Though the list is dominated by Syria (38), virtually all countries of North Africa and West Asia have been represented. Most modules for the 1-2 week duration have dealt with soil analysis, nitrogen analysis, moisture determination, plant analysis, and fertilizer trials. Participation in all courses formal and informal is recognized by an official certificate from ICARDA.

Table 1. Details of the Soil Laboratory short-term courses

1. Soil analysis, 1985: Syria (4).
2. Soil and plant analysis, 1986: Egypt (1), Jordan (2), Morocco (1), Syria (3), Tunisia (2).
3. Soil and plant analysis, 1987: Algeria (1), Egypt (2), Ethiopia (2), Jordan (1), Sudan (1), Syria (3), Tunisia (1).
4. Fertilizer use, 1988: Iran (1), Morocco (2), Kuwait (1), Syria (2), Tunisia (1), Turkey (1).
5. Soil and plant analysis, 1989: Algeria (2), Ethiopia (1), Yemen (1), Syria (3), Tunisia (1).
6. Fertilizer recommendation for the Mediterranean region, 1990: Algeria (1), Jordan (1), Libya (1), Syria (4), Tunisia (1).
7. Soil and plant analysis, 1991: Jordan (2), Syria (2).

Graduate Training

At the more formal level, the Soils Laboratory and its senior scientist have hosted graduate students, at the MSc and PhD level, in collaboration with degree-granting universities in Syria, Europe, and the USA. Six of the 11 MS students were from Syria, with others from Yemen, Iraq, and Jordan. The topics considered ranged from fertility management in rotational trials to supplemental irrigation.

The PhD students (10) were associated with diverse institutions: Reading University (water-use and N uptake), Colorado State University (labelled ^{15}N volatile loss), University of Cordoba (P dynamics in calcareous soils), Kuban University, Russia (soil physical properties in rotational trials), and La Trobe University, Melbourne (sowing depth, date, soil moisture). Whether at the MSc or PhD level, the research of the students concerned was an essential part of the research program at ICARDA, and in most cases represented a valuable contribution to our knowledge of Mediterranean farming conditions.

Conclusion

In conclusion, notwithstanding the restrictions in funding and the inevitable cutback in staff, the Soils Laboratory will continue to play a vital role in ICARDA's training program in addition to back-stopping the soil fertility research in FRMP and serving the analytical needs of the Center as a whole. With the new momentum for standardization of procedures, the Laboratory can play a vital role in helping the region's laboratories meet acceptable standards of analysis. Currently, the laboratory is re-joining the International Exchange Program at Wageningen University in Holland in an effort to indirectly validate the entire network of laboratories in the region, be they from ministries of agriculture, universities, or private sources. In recognition of the importance of reliable and acceptable standards of performance, FAO has kindly offered financial support to pursue this issue within the WANA region.

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C. WORKSHOP FINDINGS

Future Directions of Applied Soil Fertility Research in West Asia and North Africa

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Introduction

The latter part of the 20th century was one of great changes in farming practices throughout the world. For many, the era of low input traditional agriculture gave way to modern intensive systems of production. The native fertility of soils was supplemented by chemical fertilizers to sustain the high crop yields necessary to feed the world's burgeoning population. While today's farming in the West is unthinkable without fertilizers, the practice has been slower to catch in lesser developed areas of the world, such as the Middle East. Currently, that region is in a state of transition between the traditional and the modern. As in other areas of the world, adoption of high-input, high-technology practices has been associated with irrigated agriculture; the poorer rainfed sector was slower to change.

Fundamental to efforts to intensify crop production, be it irrigated or rainfed, is soil fertility. Significant efforts in soil fertility research in the region go back no more then three or four decades, as illustrated by Ryan (1990) in the context of Lebanon. Initial attempts involved pot trials in greenhouses, with various soil types and fertilizers, mainly nitrogen, phosphorus and potassium. Slowly, these experiments were translated into fields trials at experiment stations. What little research was done was conducted by universities and Ministries of Agriculture, with little or no collaboration between them. Only in recent times has the practice of on-farm trials caught on. Even then, trials were of limited duration, mainly examining responses to annual applications of N, P or K, and combinations thereof, in terms of specific crop response.

Rarely were fertilizer trials interpreted in terms of the native soil fertility. The Soil Test Calibration Network at the International Center for Agricultural Research in the Dry Areas (ICARDA) did much to promote the notion of testing soils at trial sites for P and, in some cases, N. The Network activity, in collaboration with the National Agricultural Research Systems (NARS), laid a firm basis for fertilizer recommendations. A brief mention of its highlights is in order.

Soil Test Calibration Network Achievements

The Network operated with scientists from the national programs to conduct standardized field trials in order to examine responses of dryland cereals and legumes to fertilizer N and P, and to relate such responses to the soil test level for each element. The Network:

- Identified the Olsen P test as the most suitable for the predominantly calcareous soils of the West Asia-North Africa (WANA) region.

- Established a critical level of about 5-6 ppm for that test.
- Indicated the transformation of applied P in soils and the value of residual P for crops.
- Showed that the nitrate test was sometimes a good indicator of the soil N status.
- Promoted simple but replicated, one-factor, on-farm trials.

Recognizing several deficiencies, the Network recommended that:

- Change occurs from on-station to on-farm trials, as many stations had above-normal levels of nutrients and were often unrepresentative of the area.
- Micronutrients be considered in soil testing and crop response studies.
- Spatial variability of soil properties be considered in the design and layout of trials.
- Factors related to soil test reliability, such as N mineralization and fertilizer efficiency, be studied.
- Efforts be made to promote public and private soil test laboratories

It was apparent that the Soil Test Calibration Network was a successful partnership between the NARS and ICARDA. The meetings and published proceedings in Aleppo, 1986 (Soltanpour, 1987), Ankara, 1987 (Matar et al., 1988), Amman, 1988 (Ryan and Matar, 1990), and Agadir, 1991 (Ryan and Matar, 1992) attest to the rapid and significant progress that was made. Not only did the number of participants expand, but so also did their diversity, the current meeting included universities and international agencies as well as the national programs. The concept of calibration inevitably had to expand to take a wide-angle view of fertility issues.

Soil Fertility Network

The concept of a soil fertility network is pivotal to ICARDA's training and educational role in the WANA region (Ryan et al., 1995). However, like all networks, supporting funds are required. The previous Soil Test Calibration Network was funded by the United Nations Development Programme (UNDP), with some assistance from the Institut Mondial du Phosphate (IMPHOS) for a 5-year period (1986-91). Since that time, the Network has been held together by a slender thread, waiting substantial donor support for its new phase of activity. The only significant achievement during the interim period was the preliminary survey of laboratory performance standards (Ryan and Garabet, 1994); that study raised serious concerns which need to be tackled. Currently, this workshop (November 1995) was designed to bridge the gap and infuse new life into the Network.

A proposal has been prepared for donor funding. Given the previous issues identified, the broad goals of the proposed Network are as follows:

- Establishment of research priorities and coordination of applied fertility research by national scientists.
- Promotion of a whole-farm systems approach to soil fertility research.
- Laboratory development and standardization of soil and plant analysis.

- Provision of data for a regional soil-climatic database.
- Promotion of the use of modelling and soil maps utilizing existing databases to predict crop response and improve fertilizer recommendations.
- Production and dissemination of a practical guide to dryland fertilization for the region's farmers.
- To serve as a catalyst for interaction with relevant international research agencies, and to foster cooperation in soil fertility issues between the public research and education sector and the private commercial sector.

Workshop Recommendations

During the meeting presentations and in the discussion groups, a number of suggestions for future research orientation were made, with varying degrees of specificity.

General Concepts

At the board conceptual or philosophical level it was suggested that:

- Soil fertility management should be seen in terms of the "long run": how productivity changes with time in rotational systems, and how this influences native fertility and fertilizer response.
- A more holistic concept of soil fertility be adopted, one that embraces physical, chemical and biological aspects, i.e., "soil quality" or "soil health".
- There is a need to emphasize the importance of nutrient cycling encouraging use of residues and soil conditions conducive to biological nitrogen fixation (BNF) and mycorrhizal activity.
- Researchers should identify "recommendation domains" for soil fertility management that involve soil classification as well as climatic factors. Rarely do agronomists or soil fertility scientists make any worthwhile use of soil maps, if they are available. Indeed, at the local level, soil type should be also identified according to indigenous perceptions.
- Closer collaboration is urged between the research sector and the fertilizer industry. Bulk blending could solve the problem of different fertilizer ratios for different regions.
- Consideration should be given to the micronutrient and heavy metal content of P fertilizers.
- More emphasis should be given to economic analysis of fertilizer trials, especially in rotations.
- The impact of fertilizers on crop quality should always be considered.

Specific Nutrients/Issues

Nitrogen

Despite the volumes devoted to N research, it is still the most contentious element as far as soils and crops are concerned. A number of general ideas emerged:

- N research in WANA should be conducted within the context of the total environment rather than being confined exclusively to the agricultural framework.
- Research in each WANA country should be collated by a designated scientist. Such shared data would be the basis for N models.
- At the practical level, recommendations to farmers should be improved, i.e., develop simple charts to provide farmers with a basis for N application, considering factors such as rainfall previous crop, current crop, expected yield. If N recommendations are available, they should be channeled through the Extension Services, if such exist. If not, general recommendations for a region could be made and the refined for a specific farm bearing in mind the relevant influences.
- At the more fundamental level, gaps still exist in our knowledge of the N cycle. The principles involved in dryland cycling need to be elucidated using ^{15}N, especially to identify environmental factors associated with mineralization, nitrification and immobilization. The contribution of legumes through BNF or residue decomposition needs clarification. Nitrogen-use efficiency of crop cultivars will need to be identified. In addition, statistically appropriate soil sampling procedures need to be developed to account for nutrient spatial variability. The issues of N volatilization loss as NH_3 from surface-applied urea and feces and urine need to be quantified.

Phosphorus

Despite a century of research on all phases of this essential but very complex element, there is still a lot we don't know (Matar et al., 1992). From the practical standpoint, the vast literature on the subject boils down to a few simple facts. The efficiency of P is very low, i.e., 5-10%, as a result of adverse soil reactions. When excess quantities of P fertilizer are consistently added, available P begins to accumulate. It is not all "fixed", but most of it will never reach the plant. The only way to improve P efficiency is by banding rather than broadcasting. If there is a light at the end of the tunnel of P research, it is difficult to see it. Few, if any practical suggestions spring to mind.

- Much has been said about the beneficial role of mycorrhizae to improve water relations and P uptake by crops. Perhaps, rotations which promote organic matter in soil also can promote mycorrhizal colonization of crop roots and improve P efficiency.
- The extent to which improvements in soil organic matter may reduce P fixation and increase efficiency is worthy of further investigation.
- At the practical level, the use of a grain drill to band apply P fertilizer would increase efficiency.
- The use of P in marginal lands is warranted in some situations.
- The reasons why clay soils have a lower critical P level is unclear.

Micronutrients

Having received little or no mention in the dryland soil fertility research in WANA, it is evident that a number of concerns do exist:

- Based on observations in Turkey, Iran, Iraq and Syria, boron toxicity is a factor in reducing crop yields, especially in drier areas and in heavy-textured soils. Its extent should be documented by soil surveys. Boron deficiency is more likely to be a problem in sandy soils and with irrigation. The B content of irrigation water should be monitored.
- Crop varieties designed for dry areas should be screened for B-toxicity tolerance (Yau et al., 1995).
- As a result of soil conditions which promote zinc deficiency (high pH and $CaCO_3$, low organic matter, exposed subsoils, reduced incidental Zn addition from fertilizers), numerous cases of deficiency have been identified (e.g., Materon and Ryan, 1995). The extent of this constraint in the WANA region should be documented. The problem can be easily solved with Zn fertilization.
- Iron deficiency is common under similar high pH conditions. The problem is more difficult to solve as the effect of Fe fertilization is either very costly (chelates) or short-lived, as with ferrous sulfate sprays (Ryan and Hariq, 1983).
- A 'universal' soil test for micro- and macro-nutrients is warranted.

Laboratory Management

It was clear from the survey of Ryan and Garabet (1994) and from the ensuing discussion that considerable variation exists with respect to performance standards in the regions' soil and plant analysis laboratories. It was urged that:

- Efforts be made (questionnaire, standard sample) to identify the specific causes of poor analytical results.
- Quality assurance could be maintained by involvement in the Wageningen Soil Exchange Program.
- A common manual being developed for distribution by ICARDA (Ryan et al., 1996) would greatly help to standardize procedures.

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D. GUEST REVIEW

Phosphorus Efficiency of Tropical and Semi-dryland Crops

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Abstract

As phosphorus is invariably deficient in agricultural soils and thus a limiting factor for crop production unless fertilizer P is used. As efficiency of both soil and fertilizer P is notoriously low, research emphasis in the past decade or has shifted towards developing crop varieties that are efficient at using this critical resource. This comprehensive review examines the genetic basis for crop efficiency for P use, the concepts of efficiency, and mechanisms involved in this process for a range of crops common to semi-arid areas. The role of mycorrhizae and techniques for screening for efficiency are highlighted.

Introduction

Fertilizer application has contributed to a major increase in crop production worldwide. The importance of plant species in this context was first recognized a few decades ago by the existence of fertilizer responsive and non-responsive genotypes. High-yielding, shorter-duration genotypes of small grain cereals, certain legumes, and oilseed crops gave best responses to phosphorus (P) fertilizer, in addition to other nutrients. This was attributed to better harvest index and partitioning of nutrients and photosynthates (Batten et al., 1984). Larger areas of the tropics and semi-arid tropics need P fertilizers to obtain a reasonable harvest because soil P availability is low. However, application of P fertilizer to sustain higher soil P fertility for a longer duration is not easy; it is even less practicable in developing countries that lack infrastructure, due to economic and logistic constraints such as high fertilizer production cost and transportation to distant agricultural areas. Phosphate fixation in soil causes losses and decreases availability to crops. Utilizing plant genetic resources to partially overcome such constraints is a possible and profitable alternative (INTSORMIL, 1993; Yeo and Flowers, 1994). Identifying P-efficient crops for introduction or selection and breeding crop genotypes with increased P efficiency is highly pertinent under such circumstances.

Research to enhance P efficiency of important crops of tropics and semi-arid tropics by the international agricultural research centers has focused on attaining maximum potential crop yields in these environments via efficient use of P fertilizer and the utilization of this scarce element in the soil. It is profitable for resource -poor farmers to obtain and use crop seed material endowed with greater P-efficiency genes, despite the extra cost. Genetic improvement of crops for P efficiency is also useful in high-input agricultural situations. Efficiency is equally pertinent when yield plateaux are encountered by farmers because of continuous fertilization, or to decrease deterioration of soils due to excessive applications of fertilizers, and chemicals in general. This review highlights the importance of improving the crop plant to achieve higher P efficiency. Excellent reviews are available on cultural practices and improved farming systems that result in efficient use of soil P resources and that applied as fertilizer are available (De, 1988).

Definitions of Phosphorus Efficiency

Definitions for P efficiency vary based on the measures of efficiency and the purpose (Clark and Duncan, 1990; Gourley et al., 1993). Low-P tolerance denotes that the crop genotype produces biomass/yield equally well while tolerating lower levels of P availability in soil in comparison with controls (non low-P tolerant) that need comparatively higher amount of P. The concept of 'critical P limits' in soil has been used to categorize crops as P-efficient or inefficient. It is defined as the soil P required to attain maximum physiological yield (biomass or seed), or 90 to 95% of it, in a given experimental environment. Crops, or their genotypes, with lower critical P limits will be efficient in terms of fertilizer P requirement. Critical tissue P limit refers to the minimum P concentration necessary for normal physiological functions of the plant tissue or organ (Bolland et al., 1995).

Phosphorus uptake efficiency (PUE or PE), is explained as P intake by the root system of a crop genotype in a given time period from a known level of soil P availability. It does not consider utilization or incorporation of P in different portions of the plant. Phosphorus utilization efficiency, *P efficiency ratio* (PER), refers to production of dry matter/yield per unit P in the tissue, and is the inverse of tissue P concentration (Gerloff, 1976). The term P efficiency has seldom been generalized to describe P uptake and/or utilization efficiency together or P tolerance. This is due to ambiguity, when specific measurements have not been possible (Gourley et al., 1993, 1994), or when they have been measured together. For example, higher P found in the final harvest of a crop genotype encompasses many of the P uptake and utilization efficiency factors (Batten, 1992). Agronomically, P efficiency is defined as the productivity (yield or biomass, or both) per unit of P fertilizer applied (Crasswell and Godwin, 1984). Measures of P uptake efficiency commonly used are rate of P uptake per unit root length, total P uptake per plant or plot, and those that indirectly confer P uptake efficiency such as root length, root extension ratio and root-hair intensity. *Utilization efficiency* has been measured by calculating the amount of dry matter or yield produced per unit P, i.e., P efficiency ratio.

Genetic Variation for Phosphorus Uptake and Utilization Efficiency

Genetic variation within a crop species, for various growth and yield factors, has been identified and utilized advantageously. Crop response to fertilizer P is among the major determinants of crop yield (Fageria,1992) in many soil types and agricultural zones. Efficient extraction of P from soil, and translocation and remobilization within the plant to obtain optimum yield and P efficiency by manipulating the plant factor, is important (INTSORMIL, 1993). Understanding the physiological basis of genetic variation available for P uptake efficiency and its utilization (Table 1), along with criteria for differentiating genotypes as P-efficient or P-inefficient, is a prerequisite for developing suitable screening procedures and trials that can provide P-efficient crop genotypes which are useful in low-input agriculture (Clark, 1983; Dambroth and El-Bassam, 1990).

Table 1. Components of genetic variation for phosphorus efficiency in crops.[1]

I. *Acquisition of P from soil:*

- Efficient root system.
  - High root density or absorbing surface, more root hairs.
  - Greater vertical and lateral roots spread, P-efficient root architecture.
  - High root-to-shoot ratio under P deficiency.
- Physiological efficiency of nutrient uptake per unit root length.
- Extension of root system by arbuscular mycorrhizae.
- Longevity of roots.
- Ability of roots to modify rhizosphere and enhance P availability to roots via exudation of organic acids and other biochemical substances.

II. *Movement of P across roots and delivery to the xylem:*

- Lateral transfer of P through endodermis and release to xylem.
- Control of redistribution of P to various plant parts.

III. *Distribution of P within plant:*

- Capacity for rapid storage of excess P for later use under P deficiency.
- Degree of re-translocation and re-utilization under P stress.
- Release of P from vacuoles.
- Rates of leaf senescence and regeneration; flower and fruit/seed production and abscision leading to flower or fruit drop.

IV. *Growth, metabolic activity and P utilization efficiency:*

- Capacity for normal tissue and organismal activity (CO_2 fixation and dry matter accumulation), even under lower tissue P concentrations, i.e., genotype tolerance to low-P.
- Higher dry matter production per unit P in the tissue, i.e., P use efficiency.

V. *Polyploidy and hybrid levels:*

- Gene copy number and quantitatively higher expression of genes, for secretion of proteins, relevant in P physiology and utilization efficiency, e.g., P*i* translocator, phosphatases, P transport proteins.

[1] Modified from Seetharama et al. (1987).

Genetic variation for P absorption traits are mostly root-governed. Type of root system and the extent of secondary and fine root production that determine the extent of soil P exploration, and age and physiological components of roots that affect rate of P intake, are major factors that determine availability of genetic variation for roots (O'Toole and Bland, 1987) and consequently P absorption efficiency. Root exudation in specific cultivars can augment higher P availability around root absorptive surfaces (Itoh and Barber, 1983). The biochemical quality and quantity of root exudation that varies with genotypes may cause genetic variation in P uptake. Genetic variation for arbuscular mycorrhizal colonization in roots that increases P absorption efficiency of roots, in turn, contributes to differences in PUE of crop genotypes (Baon et al., 1993; Smith et al., 1992). Genetic variation for efficient utilization of P depends on various crop physiological attributes that directly or indirectly affect the extent of P translocation and accumulation in the plant tissue. Genetic markers related to the amount of plant tissue, such as stem, leaves or seed, which are produced for a given amount of absorbed P, are important as they determine the extent of genetic variation for PUE within a crop species (El-Bassam et al., 1990).

Various selection parameters such as root length and/or root mass per plant, rate of P intake by unit root length, amount of P accumulated in shoots per unit root length or mass, amount and type of root tissue, or length of fine roots produced per unit P absorbed, have lead to identification of crop genotypes more efficient in P absorption. Total P accumulation and P efficiency ratio in shoots, seed or pods are the characters used to identify genetic variation for PUE (Gourley et al., 1993; Jones et al., 1992; Krishna, 1995). Most investigations have aimed at obtaining: a) genotypes having tolerance to low soil P levels, but producing optimum yields; these genotypes would resist P deficiency and its effects on yield reduction, b) genotypes possessing root systems endowed with greater P absorption from soil; such genotypes extract higher amounts of P from soil by efficient exploration, absorption and accumulation, and c) genotypes with greater biomass or yield production per unit P translocated; such genotypes yield greater amounts of biomass and seed through efficient P remobilization and utilization, i.e., higher PER within the plant structure. Efficiency traits are equally important at both high and low soil fertility (or P availability). Selection of genotypes that express P efficiency equally well at different soil P levels is possible but requires testing at each soil P level. Genetic variation for P uptake and utilization efficiency has been recorded for several crop species in the tropics and semi-arid tropics, i.e., staple cereal food commodities such as grain legumes, vegetables, forages and important cash crops (Table 2). They are mostly grown using fertilizer P, a high-cost input requiring efficient use. Incorporating P efficiency traits from these sources into agronomicaly elite cultivars of the respective plant species will be useful in efficient crop production.

Genetics of Phosphorus Absorption and Utilization Efficiency

Quantitative genetics of yield and yield attributes have been studied extensively for various agricultural crops and used to great advantage in breeding for increases in yield and biomass under different agro-climatic zones (Slafer, 1994). Genetic components of yield are many. Their heritability follows complex allelic interactions and inheritance

Table 2. Examples of crossing program and screening techniques for improvement of Phosphorus absorption and utilization efficiency in crops.

Crop	Breeding and Selection Technique	Reference(s)
Wheat	Pedigree methods, back-cross methods to transfer P efficiency traits, selection under low pH and low soil-P.	Mihlajev and Kastori (1983); Rosa (1988)
Maize	Diallel mating of selected inbreds of Low-P tolerant and intolerant lines; Screening, using nutrient-flow culture.	Da Silva et al. (1992)
Bean	Inbred back-cross line method, initial evaluation in nutrient solution, latter in field.	Schettini et al. (1987); Bliss (1981)
	Pedigree and back-cross methods, less-severe screening test in early stages to allow for desired gene recombination, using nutrient flow cultures.	Fawole et al. (1982b)
White Clover	Six high P-responding and five low P-responding lines, used in a diallel mating, without selfing, keeping reciprocals separate. Progeny screening for several P efficiency traits, including total P contents.	Caradus et al. (1992)
Tomato	Pedigree and backcross methods, with progeny (F_2) selection in low-P sand aluminum cultures.	Coltman et al. (1987)

patterns. Absorption, translocation and utilization of nutrients, such as P, is a major component that affects plant growth and yield traits. A clear understanding of the genetics of P absorption and use efficiency is essential to formulate proper crossing programs that enhance P uptake and use efficiency. Duncan and Baligar (1990) opined that relatively few genes might be contributing to P efficiency because high heritability estimates are usually reported for these traits and it is easy to isolate segregants from small populations of segregating generations. Individual crops may vary within such generalizations. Mode of inheritance and genetics of P-efficiency traits can be specific to each crop species.

Wheat

The genetic basis for PUE in wheat and that for tolerance to P deficiency may be different (Rosa, 1988). This seems plausible considering the different physiological mechanisms involved. Use efficiency relates to biomass and yield formation for a known amount of P in plant tissue. Low-P tolerance is concerned with minimum levels of P required for optimum physiological activity, biomass and yield formation. Mihlajev and Kastori (1983) suggested that the basis for genetic variability for PUE in wheat is due to additive gene action. A heterotic effect on PUE was noticed in 29% of the combinations. The tolerance to P deficiency in numerous wheat genotypes was related to the 1B/1R chromosomal translocation (Polle and Konzak, 1990). In an effort to study the heterosis in triticale (x *Triticosecale* wittm. ex A. Camus) in relation to ion transport traits, Jenson and Jonsson (1981) found that P influx and transport characters were inherited mainly from wheat rather than from rye.

Maize

A diallel analysis indicated that P accumulation in maize (*Zea mays* L.) leaves and grain were governed by additive gene action and that few genes might be contributing to P accumulation in grains (Gorsline et al., 1964). The genes responsible for P accumulation by maize leaves and grain were traced to loci located on chromosomes 1 or 9 and 2 or 4 from one parent, while chromosomes 1 or 8; 1 or 9, and 5 or 9 harbored the loci in the other parent (Barber and Thomas, 1972; Barber et al., 1967). Using genetic markers, Naismith et al., (1974) traced the loci for P accumulation on both short and long arms of chromosome 9 of maize. A recent study confirms that additive gene action provides for low P tolerance in maize and only a few loci control gene expression for low-P tolerance (Da Silva and Gabelman, 1992; Da Silva et al., 1992). Reiter (1989) has identified five RFLP marker loci that control tolerance to low P stress in maize.

Bean

Bean genotypes classified as efficient, moderately efficient, and inefficient for P utilization were crossed to derive six families. Total dry matter production under P deficiency was used as an efficiency indicator. Gene interactions such as epistasis, notably additive by additive and dominance by dominance gene effects, determined PUE. Broad sense heritability for plant dry weight indicated that the PUE for biomass production is a highly heritable trait. Narrow sense heritability for the same trait, in all six families tested, was also high, i.e., 0.68 and 1.13 for back-cross and F_2 segregants, respectively (Fawole et al., 1982a). Roots and their development affects total P absorption. Prior knowledge about genetic variation available for root characteristics and their heritability in a crop species would be valuable when embarking on breeding for enhanced P absorption efficiency. The same set of 6 families derived from the crosses used to study the inheritance of P efficiency was used to study the inheritance of root development traits (Fawole et al., 1982b). A high broad sense heritability occurred for root dry matter production efficiency under stressed P level. Dominance variance was more pronounced than additive variance in four of the six families assessed.

Root mass and length, anatomy, their spatial distribution and density, number of root hairs and their efficiency to absorb P are individual genetic traits in *Phaseolus vulgaris* whose inheritance will have strong influence on P absorption efficiency and its heritability and needs detailed investigation. Further evidence for quantitative inheritance of P efficiency traits in bean is provided by Schettinni et al. (1987), who assessed pure inbred lines for P efficiency. An isoline from accession Pi 206002, having high total P efficiency and ability for a large root mass trait when grown in P-deficient conditions, was identified. It was used as a donor in a back-cross program with agronomicaly elite cultivar, Sanilac, as the recurrent parent. The BC_2S_3 and BC_2S_4 populations, evaluated both in environmentally controlled growth conditions and in the field, showed transfer of P efficiency traits into Sanilac.

White Clover

Heritability values reported for P response traits in white clover are moderate but sufficient to select for P response (Caradus et al., 1992). Higher response dominates over low response P; inheritance could be explained by additive gene action. At least four individual loci or sets of genes could be involved in P response of white clover. Identification of germplasm with greater P efficiency and easily adaptable breeding methodology for transfer of those genes either within a species or through interspecific gene transfer, are very important. Success in transferring P efficiency to forage white clover (Caradus and Williams, 1981) bodes well for improving P efficiency using selection and crossing. Studies on genetics of P efficiency or its components have been attempted in a few other crops such as tomato (*Lycopersicum esculentum*), *Lolium perenne*, and rice (*Oriza sativa*).

Breeding and Field Evaluation of Crops for Phosphorus Efficiency

Few attempts have been made to improve crops for P efficiency traits via breeding. Such programs include identification of genetic variation, examining P response curves, confirmation of heritability, field assessment of bred genotypes, and physiological characterization. These steps should be suitable for most crops, with certain specificities for a particular crop. Genetic advance for P efficiency traits and consequent yield benefit obtained through breeding has been recorded (Gabelman and Gerloff, 1983). Selection and breeding for P efficiency trials contribute to total P efficiency and consequently optimum yield. Conversely, selection of wheat cultivars using yield parameters has lead to concurrent selection for P efficiency. Similar observations were made on sorghum (*Sorghum bicolor*) by Seetharama et al. (1987), wherein selection included P uptake and accumulation traits. This can be expected when P efficiency and yield components are very closely linked or contribute to cause the same effect.

Breeding shorter-statured wheat or the semi-dwarfs has led to an increase in P harvest index (Jones et al., 1989); selection of wheat genotypes meant for nutrient-deficient soils follow selection tests that can increase root efficiency for P uptake, i.e., root P efficiency ratio (RE), because wheat roots contribute significantly to P efficiency. Batten (1986) found considerable scope for improving P efficiency even within genotypes having a similar harvest index, indicating that utilization efficiency and remobilization of P can be specifically improved in wheat cultivars, in addition to the general yield attributes. In rice, 8 of the 314 selections made were useful in a breeding program meant to improve low-P tolerance (Polle and Konzak, 1990).

Breeding forage crops for P efficiency has been attempted (Caradus and Williams, 1981). Increased P absorption efficiency, augmented by greater P exploration of the roots of cereal and legume forage crops, enhances P contents of the produce. An indicator of utilization efficiency, PER, needs to be carefully used in selection and breeding of forages. Where it is envisaged to obtain higher P concentration in the animal feed, selection and breeding for low PER values and higher biomass accumulation are required. Selection and breeding of forage crops for higher P efficiency has relevance in increased adaptation of forage species to marginal and low fertility conditions (Rognli et al., 1994).

Evaluation of crop genotypes for P efficiency in the field is crucial, and only made with a few crops, for example, wheat (Batten and Khan, 1987; Batten et al., 1993; Jones et al., 1992), cowpea (Ntare et al., 1993), common bean (Yan et al., 1995), clover (Caradus et al., 1992), cassava (Pellet and El-Sharkavy, 1993). It enables one to rank the selected genotypes (cultivars) and crosses in terms of physiological characters, such as P removed from soil, P harvest index, yield per unit P fertilizer applied, for which they were selected initially in the greenhouse and field. An economic analysis using P-efficient genotypes, over a check variety not improved for P efficiency, may also be made at this stage. However, such studies are lacking.

Root System and Phosphorus Efficiency in Crops

Root Architecture

Exploitation efficiency of roots is defined as the ratio of soil volume occupied by depletion zones of roots (allowing for overlaps between competing roots) to the mass/volume of root tissue required to produce the root system (Fitter et al., 1991); this determines the amount of P that enters the plant system. Variation in the root architectural features, such as topology, branching angles, length, mass, radii, extent of fine roots and root hairs, in turn result in differences in the P exploitation efficiency of crop genotypes (Fitter and Stickland, 1991). Variation in root architecture is, to a certain extent, genetically controlled (Zobel, 1991), though plasticity for such traits is considerable due mainly to nutrient availability and soil factors. Computer simulations indicate that root systems having herringbone topology and predominant branching on the main axis give greater exploitation efficiency. Selection of crop genotypes having root architectures that allow for such efficiency will provide germplasm with greater P absorption efficiency (Fitter et al., 1991). In a given soil-P stress environment, the interactions between different types of roots (secondary and fine) and the different soil nutrient (P) stress, determines the extent of positive or negative root phenotypic plasticity displayed by a genotype (Zobel, 1993).

Root Morphogenetics

In corn, P uptake efficiency is closely linked with root length. Root hairs increased P absorption in some species. Root surface per gram of root tissue, rate of plant growth (root growth), contribute to P uptake efficiency in other species (Ito and Barber, 1983; Krishna, 1995). Efficiency in certain groundnut genotypes was predominantly governed by genes that produced higher root length and mass at different growth stages, for example, ICGS 9 (an ICRISAT, India, groundnut accession). Under P scarcity in soil, P influx into roots is immensely affected by root hairs; nearly 90% of root P uptake could be accounted for by root hairs (Fohse et al., 1991). In the same study, comparison of plant species suggested that differences in P influx could be attributed to extent of roots with smaller radius, and their perpendicular distribution away from the main axis. Such variation between genotypes of crop species is to be expected (Fohse et al., 1988). Prolific root hair formation can increase P exploitation efficiency of tomato plants. "Cottony root" (*crt*) hair trait that increases P absorption is such an example (Hochmuth et al., 1985).

It should be possible to obtain specific mutants that affect root morphogenetic traits such as epidermal layer, root thickness, root branching, extent of root hairs, and study the genetic basis of mineral nutrition in relation to root morphogenesis (Baskin et al., 1992). At present, information on these aspects pertain to a model plant, *Arabidopsis*, but more efforts with agricultural crops should be useful. Genetically controlled root formation follows monogenic recessive mode of inheritance in tomato (Hochmuth et al., 1985). Genetic differences in the rates of root senescence and regeneration affect the genotype profile for P uptake efficiency, but it is tedious and labor-intensive to measure this factor accurately in the field.

Root Phosphorus Kinetics

When P availability is sufficient, wheat varieties differ for P efficiency, more due to P uptake kinetics and less because of differences in root mass or length (Romer et al., 1988). Therefore, under P sufficiency, it would be relevant to consider the rate of P absorption by roots in addition to morphogenetic root development. Genetic variation for rate of P influx into roots occurs for many crops (Table 2). Groundnut germplasm with variation for physiological traits such as the rate of P uptake by roots, and root (P) efficiency ratio is known to exist. Certain genotypes depend on better P influx rate (kinetics) to achieve greater P absorption efficiency (ICGS 23, an ICRISAT, India, groundnut accession). Uptake differences in bean varieties were attributed to differential root phosphatase activity (Duff et al., 1994; Hellal, 1990). The soil P stress tolerance in wheat was attributed to root surface phosphatase activity (Rubio et al., 1990) that indirectly augment better root P kinetics. Investigations into the genetics and inheritance of such specific root traits responsible for P uptake efficiency would be valuable for breeding programs. Adaptations allowing a crop genotype to express genes for various morphogenetic and root P kinetics-related traits, either simultaneously or individually to increase P absorption efficiency, may occur. In fact, a crop genotype or agronomically elite line with a maximum number of root traits that contribute to higher P absorption and utilization efficiency would be ideal. It needs greater selection and breeding efforts to construct such genotypes.

Pho Mutants

Mutation in P nutritional characters of plants can be useful in understanding the genetic and physiological basis of P uptake and utilization efficiency. Mutations for P (*pho*) uptake have been identified (Poirer et al., 1991). In *Arabidopsis,* a model plant often used by plant geneticists and physiologists (Meyrowitz, 1987), the *pho* mutants were isolated using X-ray fluorescence spectroscopic (XRFS) analysis of the leaves. Both P-accumulator and P-deficient mutations have been identified (Delhaize and Randall, 1995; Delhaize et al., 1995). For example, a high-P accumulator *pho* mutant would possess greater efficiency in P translocation to shoot system but lower tissue P efficiency ratio (PER). While a P-deficient *pho* mutant may have a lesion for P absorption by roots, or P loading into xylem and translocation, or vein loading or unloading in the leaves or at seeds for proper assimilation and accumulation of P in these tissues.

The mutations may occur at all or any of these above points in P utilization efficiency. Poirer et al. (1991) identified a *pho* mutant wherein the *pho1* lesion reduced the activity of a protein involved in loading P into the xylem. Wu and Lefebvre (1990) have characterized a *pho* mutant of *Arabidopsis* deficient in P*i(inorganic)* absorption. The mutant roots need at least 100 µM P*i* for normal growth, while a wild type grows well at 10 µM P*i* in solution. The mutation was at cellular level since liquid cell cultures of the mutant plant carried the same deficiency. A single recessive gene was attributed to P*i* absorption deficiency. The *pho 2* accumulator mutant identified by Delhaize et al. (1993) resulted in 2- to 3-fold higher P level in leaves. This locus regulates P*i* concentration in leaves. Obtaining a quantitative increase of expression and copy number of P accumulator loci, by breeding and/or molecular techniques, could be highly valuable.

The molecular genetics and regulation of P*i* absorption and transport in plants is poorly understood (Delhaize and Randall, 1995); P*i* absorption and transport could involve a '*pho* regulon' (Goldstein et al., 1989). In certain plant species, the expression of 'P*i* affinity binding protein' follows an inducible mechanism. Working with cultured plant cells, Furihata et al. (1992) reported the occurrence of a constitutively regulated P*i* affinity system, at low P availability, and a high P*i* affinity system which is inducible based on the available P concentration in the medium. Extrapolation of results from cultured cells to P*i* uptake by roots in the field is not easy. Root tissue complexity, unloading of P*i* into xylem, and its transport to shoot system in a whole plant make it less feasible for such extrapolations without testing (Mettler and Leonard, 1979).

Photosynthesis, Canopy Growth and Phosphorus Efficiency

The rate of P absorption, translocation and accumulation in various plant parts, in interaction with the photosynthetic rate in the leaves, will determine the dry matter production and P utilization efficiency of a plant canopy. Phosphorus is important for carbon (dry matter) related metabolic activities in the plant. Phosphorus deficiency in soybean leaves reduced net CO_2 exchange rate via reduced stomatal conductance and an increase in mesophyll resistance (Jinchu and Isreal, 1992). Photosynthetic CO_2 and O_2 exchange, chlorophyll florescence and photosynthesis *in vivo* can be limited by reduction in orthophosphate supply to leaves (Sivak and Walker, 1986). Cytoplasmic Pi levels determine mesophyll photosynthetic rates (Morison and Batten, 1986). Lower P levels are known to affect calvin cycle enzymes (Jacob and Lawlor, 1992; Rao and Terry, 1989). They suggest that the photosynthetic rate is affected by low P*i* through significant changes in the activity of calvin cycle enzymes. The P*i* concentration in the leaves is also known to affect the photosynthetic rate by influencing the P*i*-translocator activity in the chloroplast (Heldt et al., 1977; Sivak and Rowel, 1988). The P*i*-translocator activity facilitates exchange of P*i*, triose phosphate and phosphoglycerate in the chloroplast/cytoplasm interphase.

The genetic variation for low P tolerance, might be related to few or all of the metabolic activities involved in P versus carbon fixation interaction in plants. Genotypes tolerant to low P would continue to fix CO_2 at normal rates, at comparative advantage over genotypes susceptible to low P (Lauer et al., 1989; Rao et al., 1987). Higher PUE in a genotype could be obtained by greater photosynthetic and dry matter accumulation rates at comparatively lower tissue P levels (Walker and Sivak, 1986). Therefore, interactions between mesophyll tissue resistance, CO_2 exchange rate, and tissue P level are the key factors determining PUE in the leaves and canopy of a plant (Freeden et al., 1989).

Tissue and plant analysis have shown that higher PUE correlates with increased leaf area and leaf area ratios, a decrease in starch concentration in the leaves, and increased proportion of dry matter accumulated per unit P or N (Israel and Rufty, 1988). Low P status in leaves did not consistently affect the starch accumulation process in tobacco (Crafts-Brandner et al., 1990). The P utilization in the shoot (canopy) of tobacco at a given P supply seemed to depend on the genotype. Re-mobilization of P, leaf senescence, and regeneration can significantly affect PUE. Mobilization of P from vegetative structures, such as leaf and stem to seed, affects measurement of P efficiency in these parts (Crafts-Brandner, 1992). However, P re-mobilization from leaves in soybean did not affect leaf senescence, which could be genotype-dependent. Under adequate P supply to soybean roots, re-mobilization of P, from leaves to seed, was not a major factor in yield formation (Crafts-Brandner, 1991). Stephenson and Wilson (1977) and Lawn (1989) found that more of recently absorbed P and photosynthate were traced in soybean seeds, than due to re-mobilization of stored P from leaves.

A similar mechanism was interpreted to occur in several field grown groundnut genotypes (Krishna, 1995, unpublished). Because of such a mechanism, it was suggested that breeding genotypes having a rapid P uptake rate during the pod filling/

fruiting stage is more important than relying on P re-mobilization (Krishna, 1995). In several other legumes and horticultural species, leaf senescence may be an important factor determining PUE and yield formation through re-mobilization of P and other nutrients. For example, in *Cajanus cajan*, significant leaf drop induces P re-mobilization as well as causes P loss from tissue, thus affecting tissue P status and utilization efficiency; this is known to be a genotype-dependent trait.

Selection of suitable genotypes with reduced leaf drop could be highly beneficial in certain crop species. Weineke (1990a) found that higher P efficiency could be attributed to higher intensity of P re-mobilization in one of the two sorghum genotypes. It compensated for the lower P absorption rate of roots. In spring wheats a change in stature due to breeding semi-dwarf genotypes did not affect the genes regulating the distribution and redistribution of P, which is deemed a very important trait to overcome any P shortfall during post-anthesis in that crop (Hocking, 1994). As P is important for flowering and seed formation in most field crops, panicle initiation is delayed due to P deficiency in many cereals.

Examination of P absorption and utilization efficiency of selected germplasm collections that represent wide variation for crop height, canopy size, crop duration, seed/fruit yield and general plant habit could lead to better understanding of the interesting and agriculturally applicable aspects of P efficiency in crops. In particular, the influence of seed P content and PER of seeds on other yield attributes such as seed size, number, weight and panicle/inflorescence size needs attention. Compensatory mechanisms related to P nutrition might affect expression and inheritance of seed yield attributes.

A clearer understanding of the regulation of P absorption rate by roots in relation to plant canopy size, duration and maturity stage of the genotype, total dry matter/yield potential is needed because these factors directly determine the total P efficiency of a crop species. Root-shoot communications and the signal compounds produced in response to P-stress, if any, and the consequent regulatory effects on aerial parts, canopy growth, photosynthesis and maintenance of PER in leaves is an aspect yet to be understood (Davies and Zhang, 1991).

Arbuscular Mycorrhizae and Phosphorus Efficiency in Crops

Mycorrhizal symbiosis improves P absorption and growth of many crop plants. Such symbiosis influences the variation and genetics of crop-P efficiency (Smith et al., 1992). Sufficient levels of arbuscular mycorrhizal (AM) colonization are needed to stimulate greater P absorption by plants. However, the extent of mycorrhizal colonization is controlled by host genetics (Berthau et al., 1980; Krishna et al., 1985). Genetic crossing tests between crop genotypes has indicated that the extent of AM colonization is a heritable trait. The heterotic effects for colonization by mycorrhizae and P absorption and growth increase since it allows for selection and improvement of the mycorrhizal component in roots through genetic crossing. Consequently, AM contribute to P absorption efficiency (Krishna and Lee, 1987; Lackie et al., 1988). Knowledge about optimum levels of AM colonization in crop roots that increases P absorption and utilization efficiency of the host is useful during a crossing program to increase/decrease AM colonization in roots. While host photosynthate is utilized for AM growth (Jakobsen and Rosendahl, 1990), ample photosynthetic potential of semi-arid and tropical crops should allow greater AM load in their roots.

Plant tolerance to low-P in soil can be significantly influenced by the mycorrhizal component in the roots because AM can extract P more efficiently at lower concentrations through better soil exploration and absorption. Obligate physiological dependence on AM for P uptake is not seen with any crop species or genotype. Only the critical soil P requirements of a crop genotype or species is vastly reduced by the AM in its roots. In non-AM state, the roots of the same crop species/genotype, lacking the inherent genetic make-up for efficient P absorption, need P at higher availability levels. Citrus (Menge et al., 1978) and cassava (Howeler et al., 1982) provide examples of this mechanism. Perhaps these species have evolved to dependence on AM for greater P absorption efficiency in preference to P efficiency genes in their roots. The critical soil P requirement of cassava (Howeler et al., 1982) decreased to 2-3 ppm Olsen's available P when roots are with AM, but to obtain similar efficiency in non-AM state, nearly 15 ppm P in soil is required. To achieve this level of soil P availability requires application of 150 kg P_2O_5 ha^{-1} as fertilizer. Identifying genetic variability for this phenomenon should be interesting and applicable in agriculture.

Genotype differences in PUK due to mycorrhizae occurs for many crops (Smith et al., 1992). The genetics of this phenomenon are not clearly understood. In pearl millet, genotypes with greater or no P uptake benefit due to AM has been observed (Krishna et al., 1985). Similar situations with other crops are possible. Selection and breeding for PUE needs to consider AM components along with other root traits, such as length, root hairs, P kinetics. In low-P input situations, utilizing mycorrhizal symbiosis would be highly beneficial. However, selection of crop genotypes, done continuously without scoring for AM, particularly at higher soil P levels that are commonly used during breeding for yield attributes, may result in the loss of the AM trait in roots, and its contribution to the P efficiency of genotypes.

Obviously, a series of gene interactions between the symbionts decides the net P uptake efficiency gain due to AM in excess of root P efficiency. Investigations on molecular mechanisms and specific plant and AM fungal genes responsible for higher P absorption efficiency and growth increase are being conducted (Gianinazzi, 1991). Understanding the classical genetics and inheritance of AM-related P efficiency in plants has applications in crop improvement and breeding programs. It has been successful and profitable with other plant-fungal combinations in agriculture. Identification and use of crop germplasm, resistant or susceptible to fungal disease, is a comparable situation. Development of resistance to infection (incidence rating) and disease intensity (effect on growth and yield) due to fungal pathogen compares with AM colonization and PUE (and/or growth) scoring, respectively, in a crop-AM symbiosis (Krishna and Sylvia, unpublished). Many reports support the possibility of increasing the AM component in roots, and its effect on P efficiency of the host genotype via selection and breeding (Manske et al., 1990; Smith et al., 1992).

Techniques Used in Phosphorus Efficiency Studies

Cell and Tissue Culture Screening

Cell culture or tissue/organs have been successfully used to test for P tolerance or efficiency traits (Sidwell and Krul, 1978; Furihata, 1992; Coltman, 1987; Bagley and Taylor, 1992). Such techniques are most helpful in rapid, preliminary screening of large numbers of accessions through cellular and molecular methods. They are useful as confirmatory tests for P-efficiency traits that function at cellular level, for example, assay of cell cultures for molecular markers related to P efficiency in various genotypes, advanced pedigree lines and crosses (Coltman, 1987; Da Silva et al., 1992; Knapp et al., 1990). Extrapolations from cell or tissue culture assessment for P efficiency need caution because P efficiency of a genotype is strongly influenced by the whole plant mechanisms and adaptation.

Greenhouse-based Nutrient Cultures

Pot cultures, nutrient flow cultures, hydroponics and aeroponics, or laboratory-based tube/pan cultures containing different rooting media can be adopted for preliminary screening of P tolerance or P efficiency traits. Pot cultures and nutrient flow cultures have been frequently used because P deficiency or sufficiency can be easily created (Gerloff, 1987) and are suited to accurately study differences in P absorption efficiency of roots. They are highly recommended for elucidating the critical P limits for P absorption, understanding the physiological and genetic mechanisms, and identifying mutants for P absorption-related characters. However, hydroponic and nutrient flow solution techniques are unsuitable to screen genotypes with characters related to P efficiency at root-soil interface because they may not accurately simulate P diffusion factors and physical properties found in soil that might affect root-related P efficiency traits. Inert substitutes can correct the situation to a certain extent.

Field Screening and Evaluation

Soil P availability and uniformity in fertility are important considerations when resorting to field evaluation of crop genotypes for P efficiency. It is cost-prohibitive to screen a large number of genotypes at different soil P availabilities and in each of the agro-climatic zones. Selecting a representative soil type, with appropriate P availability level in a given agro-climatic regime at which screening is intended, is an important step. Researchers have obtained low P availability by depletion of P without affecting the fertility status of other nutrients. Continuous cropping, withholding only P but providing normal applications of other nutrients, was resorted to achieve this. For example, in an Alfisol representative of Peninsular India, it took 9-12 cropping cycles with fast-growing herbaceous cereals and legumes to reduce Olsen's available P from an initial 12-13 ppm to 2-3 ppm. Sandy soils, intrinsically low in available P, which are representative of the Sahelian agricultural zone provide suitable screening areas for P efficiency or tolerance to low soil P levels. Similarly, field screening for P-stress tolerance and P efficiency in other major semi-arid and tropical soils of South America, Africa and Asia have been attempted (Fageria and Baligar, 1993; INTSORMIL, 1993).

Field grown plants are screened for P efficiency at various stages from seedling, vegetative, to seed/fruit yield, or at a suitable single stage that correlates to total P efficiency of the crop at maturity. Composite screening and evaluation tests suited to morphogenetic stage and physiological components of P efficiency can provide a better assessment of P efficiency of a genotype. Rapid tests, based on a single biochemical event at a point of time, may not reflect the net P efficiency during the crop growth period. They need to be used in conjunction with other tests that correlate to total plant-P efficiency. Patterns of P uptake and utilization efficiency at different stages of field-grown plants provide most accurate knowledge on fluctuations of P efficiency in a genotype, taking into consideration various physiological mechanisms and crop stages (Krishna, 1995). Such an analysis is most useful in authentically fixing the isolines and parent lines. Clark and Duncan (1991) stated that further detailed understanding about genetic variances and gene interactions (additive, dominance, epistatic) operative for P-efficiency loci, is needed to properly use the breeding methodology and techniques in the field. They suggested that conventional and population breeding methods and recurrent selection can be effective in breeding polygenic traits such as P efficiency.

Chemical analysis of P in the tissue, or biochemical methods that are indicative of P accumulation and metabolism in the plant have served to identify P-efficient genotypes. Some of them are less suitable for rapid analysis of large plant populations in a breeding program, meant to enhance P efficiency. X-ray florescence spectroscopy (XRFS) allows for rapid screening of several thousand genotypes for leaf P content. Standardized procedures to test field grown plants by XRFS makes analysis, identification and selection of genotypes more rapid. Near infra-red reflectance spectroscopy, upon calibration for use on field grown plants to estimate P, can be cost- and time-efficient for use in breeding and selection programs on P efficiency (Batten, 1992).

Implications for Crop Production, and Conclusions

Farming in approximately 36% of agricultural soils in the tropics and 16% in semi-arid tropics (Sanders and Garcia, 1993) is conducted under low fertility conditions, with P-deficiency as one of the predominant cropping constraints. Producing cultivars endowed with P-efficiency genes has relevance for such areas. Low-input technology that includes use of P-efficient genotypes would be relevant in 82% of the land area in the American tropics (Sanchez and Salinas, 1981). Such genotypes can help maintain optimum production levels of various crops at reduced use of soil P amendments in major cropping zones of West Asia and North Africa (Ryan and Matar, 1992) or Mediterranean zones (Matar et al., 1992) and in many countries of Sub-Saharan Africa where P fertilizer usage is extremely low. There is a need for appropriate crop breeding programs to screen and routinely include P-efficiency and related characters into cultivated varieties because P efficiency traits can benefit production in larger agricultural regions. When extrapolated, it has immense significance in macro-economic terms, particularly to maximize yields through efficient use of P fertilizer. It serves individual farmers equally well in conserving inputs and reducing costs.

Agronomic evaluation of selected crop cultivars for growth, total P accumulation and P efficiency have yielded interesting and applicable results. Quantification of benefits from P-efficient genotypes in terms of yield maximization and reduction of P fertilizer usage needs to be replicated and confirmed in many agricultural soils and regions. It helps to highlight the advantages of crop breeding for P efficiency and adaptation to low-P tolerance. Cultivars produced with greater P-efficiency traits are expected to be comparatively more stable in performance for that trait. With certain plant versus biotic factor interactions, a break down of resistance can occur because genetic recombination and/or mutation can make the pathogen or pest, severe and virulent, when new pathotypes arise. Such a situation is not known with P efficiency traits incorporated into the plant genotypes.

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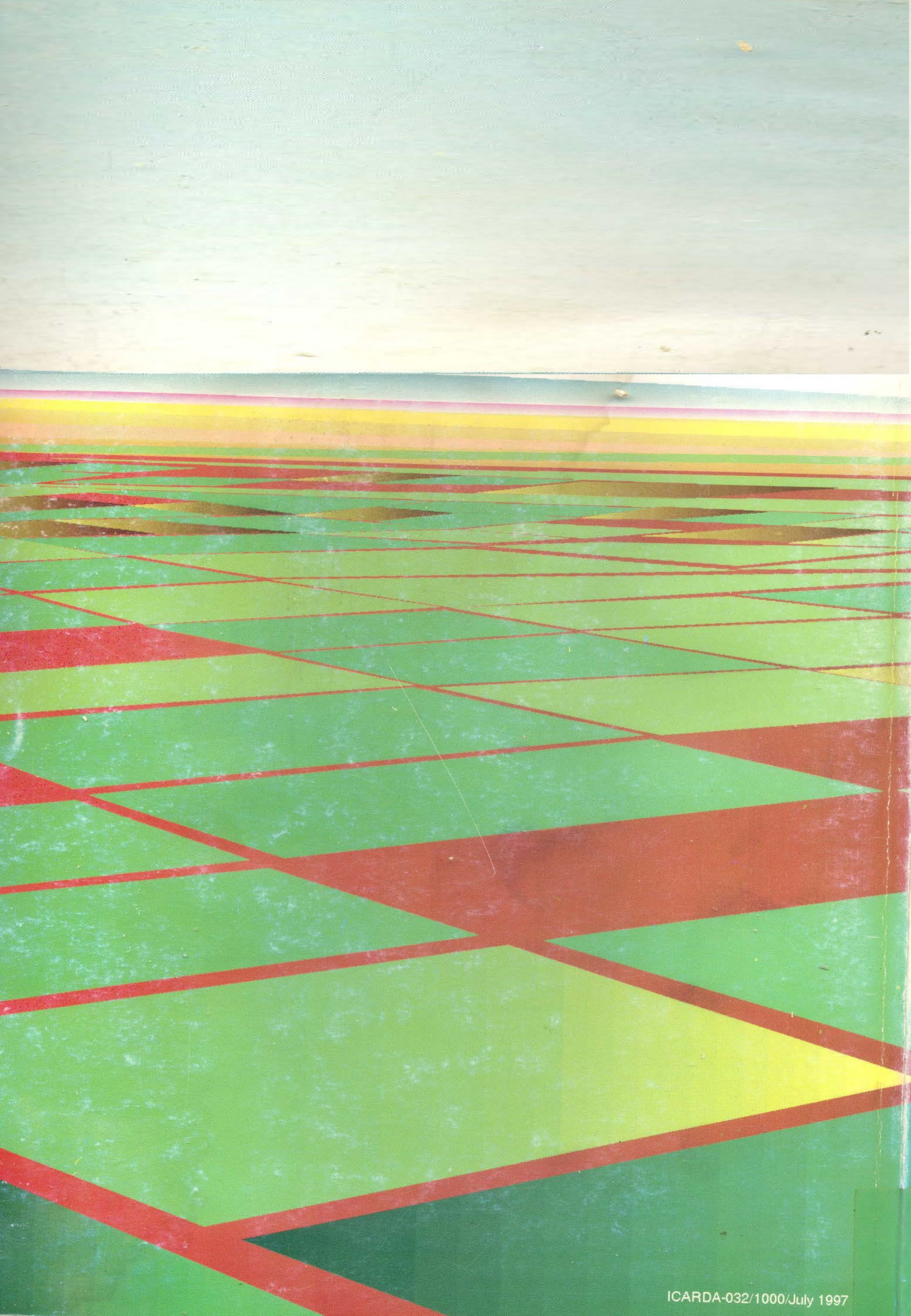

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