Fertilizer Use Efficiency under Rain-fed Agriculture in West Asia and North Africa

Proceedings of the Fourth Regional Workshop
5 -10 May 1991, Agadir, Morocco

John Ryan
Abdallah Matar

editors

International Center for Agricultural Research in the Dry Areas

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John Ryan
(MIAC, Settat, Morocco)

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Foreword

This volume is based on the presentations made by soil scientists from 11 countries in the West Asia/North Africa (WANA) region, at the fourth regional workshop on fertilizer use efficiency workshop held in Morocco. The workshop was the result of a decision taken by participants in the Network on Soil Test Calibration, set up in 1986 to conduct joint fertilizer experiments on prevalent field crops, establish reliable correlations between the results obtained and soil and plant tests, and improve the understanding of Mediterranean soils in relation to their nutrient availability and behavior.

The Soil Test Calibration Network represents an earnest attempt by scientists in the region to address one aspect of this experience: the efficient use of fertilizer for the benefit of farmers in WANA. The participants in this network come largely from WANA itself, and are therefore well equipped, through their experience and intimate knowledge of the region, to identify where the problems lie and what actions are most appropriate to resolve them.

The Network has been successful in drawing together the region's scientists involved in soil fertility research into a coherent and well-coordinated group. In addition to those from Jordan, Morocco, and Syria, scientists from Algeria, Iran, and Libya, just to name a few, have become active participants in the Network. Every year new participants are joining the Network. This intensifying interest from around the region indicates that the Network's goal of involving scientists from all the WANA countries proved to be of significant importance to the region.

We hope the increasing number of participating countries will be accompanied by a wider range of disciplines as well. After all, the most salient lesson in agriculture over the last 50 years is that farming does not take place in a cultural vacuum. Farmers are part of a larger society with traditions, beliefs, and histories which, though not always apparent, have a considerable influence upon their decisions. Likewise, the farmer's relationship with the workings of the regional, indeed global, economy, should not be underestimated. For these reasons, it is important that the Network become truly multidisciplinary, to include economists, agronomists, agro-climatologists, and others. Another important goal for the Network is to underscore the role of extension - the vital link between research results and the farmer's field - in both guiding the development of new technologies and ensuring that they are introduced effectively.

In pooling resources, Network participants should not hesitate to make use of the latest in computer technology to develop their recommendations. Increasingly, much time and effort is being saved by the use of such techniques as computer modelling.

While this network was intended for WANA, we must not underestimate the potential and real contribution of research institutions in Europe, North America and other regions. Likewise, countries outside WANA but with similar Mediterranean climates may also be able to provide positive inputs into the Network's activities. The University of Cordoba in Spain has provided excellent research opportunities, and is quite eager to maintain and strengthen its interaction with the Network. We hope these extra-regional links will continue to develop.

An important goal for the Network over the coming years should be the development of a regional soil fertility data base covering all the joint research conducted in WANA. Such a data base could significantly reduce research duplication, and put a wealth of useful data at the disposal of soil scientists in WANA.

The Soil Test Calibration Network in WANA was the result of a conviction that the region's scarce resources were being inefficiently used in two ways. Firstly, because large quantities of expensive fertilizer were being applied in a manner that was not optimal. Secondly, because research efforts of regional soil scientists were being conducted in isolation, they could not benefit fully from previous experience and ongoing work. To date, the Network has succeeded in addressing both of these problems, but much work remains to be done.

ICARDA is indebted to the United Nations Development Programme (UNDP) for supporting the Network by funding workshops and related training courses; to the Institut Mondial de Phosphate (IMPHOS), which provided partial funding for the field soil research program in several WANA countries; to the regional office of the International Development Research Center (IDRC) in Cairo for sharing in the workshop costs; and finally to the Mid-America International Agricultural Consortium (MIAC) in Morocco for its assistance.

Nasrat Fadda

Nasrat R. Fadda
Director General
ICARDA

Preface

Since its inception in 1986 at Aleppo, Syria, ICARDA's Soil Test Calibration Network has grown from strength to strength. With its roots firmly established in the soils of the West Asia-North Africa region, the Network has embraced scientists from most countries of that semiarid rainfed area. The fact that representatives of 12 countries, involving governmental, research, development, and educational institutions, should convene in Agadir just after the turmoil that sadly engulfed the Middle East, is testimony to the Network's resilience and augers well for its viability in the future.

A welcome development has been the active participation of universities and institutes of higher learning--the trainers of future soil scientists and agronomists of the region. The varying perspectives present at the meeting provided stimulating and fruitful discussions. While it was comforting to see again familiar faces from previous workshops, it was heartening to meet new ones; we missed those who were not able to attend.

A glance at the program shows how far we have come in so short a time. In addition to traditional papers on soil-fertilizer responses, other presentations dealt with fundamental aspects of N mineralization in soils, economic assessment of crop response data, new approaches to available soil-P testing, and the implications of mineralogy for both P and K in dryland zone soils.

Because the presentations were made by a multidisciplinary group of scientists, we agreed to organize the text into five sections, each dealing with a particular discipline. Most presentations are followed by lively discussions, which emphasized the importance of a multidisciplinary approach, particularly the integration of agronomy and agro-climatology with economy, in guiding the Network towards a brighter future. These discussions were based on the question-and-answer sheets that were returned to us by the contributors. A section on conclusions and recommendations of the workshop is included separately.

While some papers were edited only for style, others had to be substantially revised. The limitation of time and the mail problem did not permit us to clear the editorial changes in papers with all authors, as originally scheduled. However, while revising the papers, every possible effort was exerted not to change the meaning in the text or modify the author's style unless otherwise it was absolutely necessary.

It was apparent that the Network has attracted a dedicated group of scientists who are committed to solving soil and fertilizer use problems that we are confronted with. Though soil problems throughout the WANA region are many and daunting, we are confident that the momentum of the Soil Test Calibration Network will continue in the years ahead to grapple with this important task for the betterment of the farmers of the region--and ultimately its stability and well-being.

John Ryan
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SECTION I

Relationships between Mineralogy, Chemistry, and Soil Fertility

Mineralogy of Mediterranean Soils and its Implications in Phosphorus Behavior

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ABSTRACT

From a mineralogical standpoint, Mediterranean soils have some common features such as the predominance of 2:1 clay minerals in the clay fraction, relative low amounts of amorphous aluminosilicates and aluminum oxides, and presence of calcium carbonate. Moreover, of those minerals known to have a high P sorption capacity, only iron oxides occur in significant amounts. Accordingly, experiments in the last ten years have shown that short-term sorption at low P concentrations is well correlated with Fe oxide content for groups of Mediterranean soils ranging widely in properties. Probably because of its relatively low surface area and P adsorption capacity, $CaCO_3$ has little effect on adsorption at low P concentrations. At high P additions, $CaCo_3$, however, plays an important role in long-term loss of P availability, which is influenced by the nature and amount of other soil minerals. Soil test calibration experiments have shown that Olsen P critical levels differ--sometimes widely--from one group of soils to another. There is evidence that soil mineralogy influences critical levels. Future research will have to consider how simple mineralogical data can help improve prediction of critical levels.

INTRODUCTION

Many soil scientists use the term "Mediterranean soils" to designate the soils formed under the xeric moisture regime typical of Mediterranean regions. At present, this term does not convey any precise genetic or morphological meaning to pedologists. Soil mineralogists, however, know that soils formed under a Mediterranean environment have certain distinctive features, both in type and abundance of their minerals. This paper deals with how knowledge of this distinctive mineralogical assemblage helps understand and predict P behavior in Mediterranean soils and, in turn, provides a basis for an adequate P fertility management.

MINERALOGICAL FEATURES IN MEDITERRANEAN SOILS

Clay Minerals

Soils formed under a xeric moisture regime have undergone relatively little weathering and removal of the weathering products. Thus, mineralogy of the clay fraction of the Mediterranean soils is highly influenced by the parent material. This explains the abundance of clay mica, the most common clay mineral in sedimentary rocks. Clay mica also results from transformation of primary rock micas. Smectic is the second most common clay mineral; it is either inherited or formed in soils with a nonleaching regime, in which high concentrations of silica and divalent cations occur (e.g., Vertisols). Vermiculite and chlorite are much less abundant.

Hydroxyl-Al interlayered minerals are of rare occurrence, since leaching and acidification of the upper soil horizons are insufficient for their formation. Kaolinite is rarely dominant but almost universal in Mediterranean soils. This is not unexpected, as the composition of the soil solution in these soils falls within the stability field of this mineral (Bohn *et al.*, 1979); indeed, formation of kaolinite has been reported in some cases (Barshad, 1966). Halloysite is restricted to some soils of volcanic or acid igneous rocks (Torrent and Benayas, 1976).

The former statements are illustrated in a study by Peña (1990), who examined the phosphate sorption in 114 soils from the Mediterranean part of Spain. These soils were Entisols, Inceptisols, Alfisols, and Vertisols developed from widely different parent materials and climatic environments (mean annual temperature: 10-18°C; mean annual rainfall: 250-750 mm). The means (and ranges) of the clay mica, smectite, and kaolinite contents were 55 (6-97), 22 (0-87), and 20 (1-87)%, respectively. In about 20% of the samples, other clay minerals (illite-smectite, vermiculite, chlorite) were detected by x-ray diffraction. Poorly crystalline aluminosilicates (allophane, imogolite, and allophane-like constituents) are usually absent, except for soils developed on volcanic rocks in subhumid areas (Fernandez Caldas and Tejedor Salguero, 1975).

Iron and Aluminum Oxides

Iron oxides and oxyhydroxides (henceforward called "Fe oxides") usually make up from 1 to 10% of the clay fraction of Mediterranean soils. They occasionally occur in the sand and silt fractions where they aggregate other soil particles. Goethite (α-FeOOH) and hematite (α-Fe_2O_3) are by far the most common forms, followed by magnetite, ferrihydrite, lepidocrocite, and maghemite.

The total amount of Fe oxides is usually determined by reductive dissolution by citrate-bicarbonate-dithionite (CBD) (Mehra and Jackson, 1960). The poorly crystalline Fe oxides (ferrihydrite) are determined by treatment with acid NH_4-oxalate (Schwertmann, 1964). Thus, the CBD-extractable Fe (Fe_d) minus the oxalate-extractable Fe (Fe_o) measures the crystalline Fe oxides. Quantification of goethite and hematite is a difficult task, and can only be carried out using sophisticated X-ray diffraction and other methods. Hematite content can also be estimated from color since this mineral imparts an intense red coloration (Barron and Torrent, 1986).

Mediterranean soils have, with few exceptions, low contents of poorly crystalline Fe oxides, i.e., low Fe_o/Fe_d ratios (Singer, 1978; Torrent *et al.*, 1980; Ryan *et al.*, 1985a). This is because a xeric pedoclimate favors crystallization of poorly crystalline minerals formed immediately after Fe release from Fe-bearing primary minerals (Schwertmann, 1985). Specific surface area of Fe oxides of Mediterranean soils is of the order of 50-100 m^2/g oxide (Peña and Torrent, 1984; Boero and Schwertmann, 1989). Aluminum oxides have rarely been reported in Mediterranean soils, except for gibbsite in well-drained soils from granite.

Carbonates

Probably more than 75% of Mediterranean soils have some calcareous horizons, and about half have a calcareous surface horizon. Calcite ($CaCO_3$) is by far the most common soil carbonate, followed by dolomite ($CaMg(CO_3)_2$) and Mg-calcite. The $CaCO_3$ can be lithogenic or pedogenic, whereas dolomite is lithogenic. Pedogenic $CaCO_3$ occurs in different forms, i.e., nodules, calcans, neocalcans, and crystallaria (Dress and Wilding, 1987).

Total $CaCO_3$ equivalent is determined by routine soil analysis. However, total $CaCO_3$ does not necessarily reflect reactivity of this phase. To better estimate reactivity, determination of "active lime", i.e., $CaCO_3$ capable of reacting with neutral NH_4-oxalate, has been suggested (Drouineau, 1942). Values of active lime are usually very close to the sum of clay-plus fine silt-sized $CaCO_3$. Unfortunately, this suggests that active $CaCO_3$ includes particles of both high specific surface area (fine clay) and low specific surface area (coarse clay plus silt). To circumvent this, methods which measure specific surface area (SSA) of $CaCO_3$ by difference in surface areas of intact and decalcified soil samples have been proposed. Talibudeen and Arambarri (1964) measured $CaCO_3$ SSA by isotopic exchange with ^{45}Ca, while Borrero *et al.* (1988) used N_2 adsorption for the same purpose.

Little work has been done to characterize $CaCO_3$ SSA in Mediterranean soils. Borrero *et al.* (1988) studied a group of 36 soils from Spain, which ranged widely in $CaCO_3$ and clay contents and found, by N_2 adsorption, that the average surface area (SA) of $CaCO_3$ was 4.8 m^2/g soil material. More recently, del Campillo *et al.* (1991) found $CaCO_3$ SSA values of 1-27 m^2/g (^{45}Ca method) and 1-112 m^2/g $CaCO_3$ (N_2 method). The $CaCO_3$ SSA ranged between 1 and 4.8 (mean = 2.3) m^2/g soil material (^{45}Ca method) and between 0.5 and 15 (mean = 6.0) m^2/g soil material (N_2 method). The carbonate SSA in Mediterranean soils is therefore relatively low, amounting to few m^2/g soil.

Relationships Between Phosphate Sorption and Mineralogy

Sorption of P by soils has been intensively studied in the last 25 years. Very often, sorption has been described by the quantity/intensity (Q/I) plots (Bache, 1977), also called sorption curves or "adsorption isotherms". These curves depict the amount of sorbed P at certain specified conditions (equilibration time and temperature, supporting electrolyte, soil solution ratio, etc.) against equilibrium P concentration. Theoretically, once a sorption curve has been constructed, the amount of P that has to be added to reach a certain concentration in the soil solution is known. This knowledge can be combined with the P concentration needed for adequate plant growth, i.e., the "external P requirement" (Fox, 1981), to estimate fertilizer needs. This approach has proven to be useful (Menon and Fox, 1983), although fertilizer rates recommended, even for relatively low external P requirements, appear to be too high (Azzaoui *et al.*, 1989b).

Obtaining a sorption curve requires more time and effort than carrying out a common soil P test (e.g., Olsen's test). For this reason, many researchers have investigated relationships between P sorption and mineralogical properties. If statistically satisfactory, these relationships could actually be used to predict fertilizer needs from some soil data since they are much more easily determined than sorption curves.

Evidence accumulated in the last 15 years suggests that in Mediterranean soils, like those from other regions, Fe oxides have a dominant influence on P sorption (Singer, 1978; Peña and Torrent, 1984; Ryan *et al.*, 1985a; Torrent, 1987; Solis and Torrent, 1989a; Peña and Torrent, 1990). This is not surprising since experiments with synthetic Fe oxides have shown that surfaces of these minerals have a high affinity for P and possess a high P-sorption capacity (1-3 μmol P/m^2). Moreover, as noted earlier, soil Fe oxides have relatively high SSA. Both factors compensate for the generally low proportion in which Fe oxides occur in most Mediterranean soils. Fig. 1 shows the relationship between P sorption and Fe_d for 19 soils from different areas within the WANA (West Asia-North Africa) region (Afif, Matar, and Torrent, unpublished).

Different multiple regression equations relating P sorption to several soil properties for several groups of Mediterranean soils were developed (**Table 1**). Those referring to calcareous soil groups show that the coefficient for active $CaCO_3$ is one order of magnitude lower than the one corresponding to Fe_d. This suggests that $CaCO_3$ does not have much influence on P sorption. Reasons for this are: (1) the $CaCO_3$ SSA is relatively low in most soils, as discussed before; (2) at P concentrations within the 0.1-1 mg/L range (i.e., near or slightly above the external P requirement) $CaCO_3$ is able to adsorb only 0.1-0.3 μmol P/m^2 (Griffin and Jurinak, 1973; Borrero *et al.*, 1988), representing one order of magnitude less than for Fe oxides. The subordinate role of $CaCO_3$ to Fe oxides has also been reported for a group of calcareous soils in England (Holford *et al.*, 1990), where analysis of the sorption curves indicates that $CaCO_3$ and Fe oxides provide low and high affinity P-sorbing surfaces, respectively.

The limited influence of $CaCO_3$ on P sorption apparently challenges the long-maintained contention that this component has a marked negative effect on applied fertilizer P availability. However, at P concentrations much higher than those at which sorption curves are usually characterized, i.e., those which can occur around fertilizer granules, Ca-phosphate precipitation readily occurs, with a concomitant decrease in solution P.

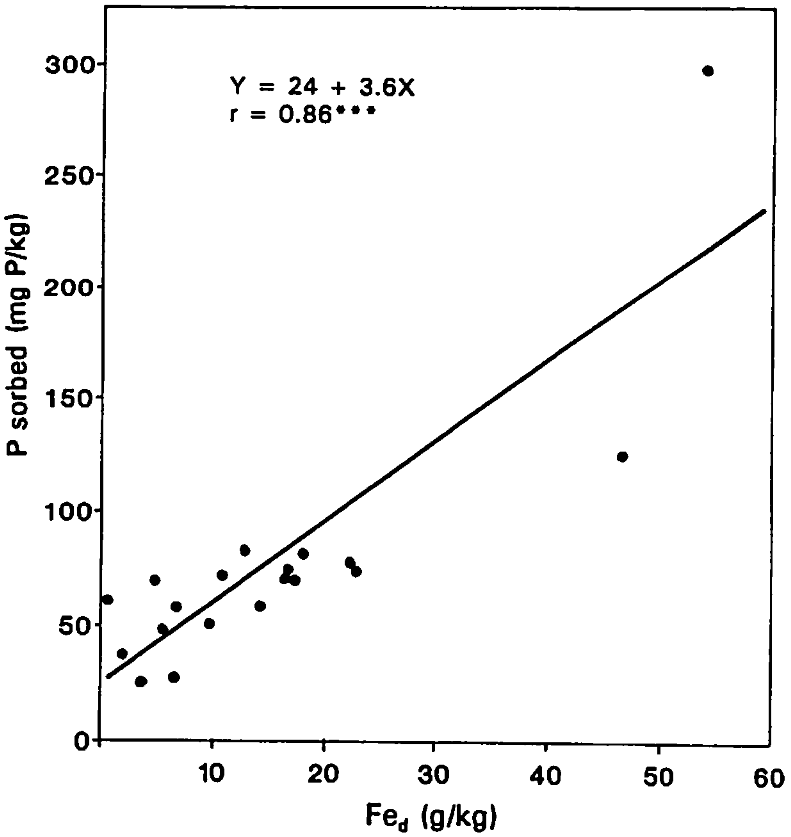

Fig. 1. Relationship between P sorbed at 0.2 mg P/L equilibrium concentration and CBD-extractable Fe (Fe$_d$) for 19 soils from the WANA region (Afif, Matar, and Torrent, unpublished).

For different soil groups, stepwise regression equations include clay content or cation exchange capacity as significant explanatory variables. In some cases, P sorption is better correlated with clay content or cation exchange capacity than with Fe$_d$. Since Fe$_d$ and clay content are usually correlated, statistical analyses do not tell us much about the relative contribution of clay minerals and Fe oxides to P sorption. Pure clay minerals are, indeed, able to sorb P (White, 1981), although their sorption capacity depends on SSA and relative extent of edge and planar faces, among other factors. In his P sorption study of 114 Mediterranean soils, Peña (1990) did not find any significant increase in the variance accounted for when clay mica, smectite, and kaolinite, rather than clay contents, were taken as variables. In practice, clay content seems to have good predictive value for groups of soils of relatively similar origin and which do not differ much in clay fraction mineralogy or the Fe$_d$/clay ratio (Peña and Torrent, 1984).

Mediterranean soils have, as indicated before, low amounts of poorly crystalline Fe and Al oxides and aluminosilicates, all of which have high P-sorbing capacity.

Table 1. Some regression equations relating P sorption and soil properties in Mediterranean soils.

Soil type	Sample no.	Supporting electrolyte	Equilibrium P * (mg/L)	Equation[1]	r^2
Alfisols, mainly noncalcareous, in a chronosequence[2]	26	0.1 *M* KCl	0.3	$Y = 6 + 3.5\ Fe_d + 0.22\ clay$	0.81
Calcareous soils of different origins[3]	36	0.1 *M* KCl	0.62	$Y = 22 + 2.8\ Fe_d + 0.13\ clay + + 0.37\ active\ CaCO_3$	0.63
Noncalcareous soils of different origins[4]	71	0.01 *M* $CaCl_2$	0.2	$Y = 10 + 2.1\ Fe_d + 0.18\ clay$	0.71
Calcareous soils of different origins[4]	43	0.01 *M* $CaCl_2$	0.2	$Y = 48 + 1.9\ Fe_d$	0.53
Calcareous Vertisols and Inceptisols[5]	24	0.01 *M* $CaCl_2$	1.0	$Y = 23 + 8.5\ Fe_d + 0.17\ clay + + 0.22\ active\ CaCO_3$	0.71

[1] Y = Sorption in mg P/kg soil; Fe_d, Clay, and $CaCO_3$ are expressed in mg/g soil.
[2] Peña and Torrent (1984).
[3] Borrero *et al.* (1988).
[4] Peña (1990); [5] Solis and Torrent (1989b).
* = Concentration at which sorption is reported.

Consequently, P sorption in these soils is rarely related to oxalate-extractable Fe and Al (Fe_o and Al_o), which are considered to measure that "active" Fe and Al; this contrasts with soils of humid temperate areas. In what seems to be an exception, Ryan *et al.* (1985a) reported that P sorption was related to Fe_o for a group of 20 soils from Lebanon.

Phosphate Transformations--Availability vs Mineralogy

When soluble P is added to soil, the rapid initial sorption is followed by a slow reaction that continues for months or indeed years. The slow sorption is attributed to processes such as interparticle diffusion, diffusion into adsorption sites in surface pores of minerals, or changes in the type of P bonding with adsorbing surfaces. In sorption studies with low ($< 100\ \mu M$) P concentrations and low soil:solution ratios, sorption after an initial period of several days has usually been very slow (Torrent, 1987; Solis and Torrent, 1989a; Peña, 1990). In most cases, slow sorption accounts for only a small percentage of total sorbed P after several weeks or months. For 20 noncalcareous soil clays, Torrent (1987) found that slow sorption was related to Fe_d. Solis and Torrent (1989a) found both Fe_d and active $CaCO_3$ accounted for 43% of the variance in slow sorption rate for a group of 24 calcareous Vertisols and Inceptisols from Southern Spain. Peña (1990) also found the slow rate to be positively correlated with Fe_d; however, it was negatively correlated with active $CaCO_3$ for the 114 Mediterranean soils that he studied. Thus, Fe oxides seem to influence slow sorption more than other soil components.

Under field conditions, plants take up P from the soil solution in a simulated desorption process which does not usually coincide with laboratory-generated sorption curves, despite similarities in conditions under which these are determined with respect to the field. Generally, part of the P needed to increase *in vitro* equilibrium P concentration in the soil solution from concentration C_1 to C_2 will not have been taken up by the plant when, under cropping, the equilibrium P concentration in the soil solution has dropped from C_2 to C_1. This loss of availability is not usually related to the magnitude and time course of the rapid and slow sorption (Barrow, 1980). In other words, the magnitude and kinetics of sorption do not specifically indicate how much sorbed P will be plant-available during a specified period and under certain growing conditions. In practice, the available P/sorbed P ratio is estimated by procedures such as isotopically exchangeable P, resin-extractable P, or P extracted by a routine soil test (e.g., Olsen P).

Little information exists on the relationship between the available P/applied P ratio and the properties of Mediterranean soils. Ryan *et al.* (1985b) found, for six calcareous soils from Lebanon, that the P extracted by $NaHCO_3$ was inversely related to Fe_d content but unrelated to total or active $CaCO_3$. However, for 23 calcareous soils from several semiarid areas, Sharpley *et al.* (1989) found that the decrease in available P, estimated by resin-extraction with increased incubation time from 30 to 180 days, was related to total $CaCO_3$ content. For 24 calcareous Vertisols and Inceptisols from southern Spain, Solis and Torrent (1989b) found that recovery by resin of added P decreased with increasing Fe_d content. In a 6-month incubation study with 16 soils from the WANA region (Afif, Matar, and Torrent, unpublished), the percentage of applied P recovered by $NaHCO_3$ was related to the total $CaCO_3$/cation exchange capacity (CEC) ratio.

However contradictory these results may be, they can probably be explained by the different types of soil minerals that affect P dynamics in Mediterranean soils. On the surfaces of silicate clays and Fe oxides, P is adsorbed but not precipitated unless P concentration is high (m*M*-*M* range); this can occur, for instance, around dissolving fertilizer granules. By contrast, $CaCO_3$ surfaces not only adsorb P but also provide suitable conditions for nucleation and further precipitation of Ca phosphates, even below the m*M* range (Freeman and Rowell, 1981).

Adsorbed P, even for high affinity surfaces such as those of Fe oxides, appears to be more accessible to chemical extraction or isotopic exchange and, consequently, to plants than precipitated P. In goethite-rich, carbonate-free soil materials, Torrent (unpublished) found that six months after P addition isotopically exchangeable P amounted to 31-53% of the added P. In active $CaCO_3$-rich vertisols and Inceptisols, Castro and Torrent (unpublished) found that, after six months' incubation, only 10-25% of added P remained isotopically exchangeable.

Consistent with these facts, we can hypothesize that availability of applied P in Mediterranean soils depends on the nature and relative extent of "purely adsorbing" (mainly those of silicate clays and Fe oxides) and "precipitation-inducing" surfaces (mainly those of $CaCO_3$). Thus, in soils in which the first type of surface predominates, one should expect more P availability than in the case in which the second type predominates. In addition, in the first case, availability would be related to variables such as clay content (or CEC), Fe_d or Fe_o contents. In the second case, total $CaCO_3$, active $CaCO_3$ or other $CaCO_3$-related parameters should be the best explanatory variables.

The nature of the P-reactive surfaces cautions against extrapolating the results of laboratory incubation tests to field conditions. Laboratory experiments are usually carried out at relatively low levels of added P and by homogeneous mixing of the P source (usually monocalcium phosphate) with soil; in the field, high concentrations of phosphate can be expected near the fertilizer granules, powder or droplets. In these cases, supersaturation with respect to Ca phosphates is much higher, rapid precipitation taking place if the "precipitation surfaces" have a significant extent.

Critical Phosphate Levels and Mineralogy

As recently discussed by Khasawneh (1990), soil test calibration is an important aspect of soil testing and needs a substantial volume of field and laboratory research. Soil tests are usually based on chemical extractants of which 0.5 *M* $NaHCO_3$ (Olsen *et al.*, 1954) is the most widely used in Mediterranean countries. An ideal extractant for P should extract all or a proportional part of the plant-available form of P *from soils of variable properties* (Kamprath and Watson, 1980). In practice, the ability of $NaHCO_3$, or other extractants to recover the plant-available P will differ from soil to soil, probably depending on intrinsic soil properties such as mineralogical assemblage, suite, structure, or organic matter content.

Soil test calibration data in rain-fed agriculture are affected, among other factors, by moisture regime and placement of fertilizer (Khasawneh, 1990). Critical Olsen P levels are likely to significantly depend on soil and environmental and management factors. Calibration studies in the WANA region show that these values vary from 5.2 (Gharbi *et al.*, 1990) to 13 mg/kg (Saad *et al.*, 1990). In greenhouse work Azzaoui *et al.* (1989a) identified a critical level of 10.2 mg/kg. However, work on calcareous Vertisols of semiarid tropical India gave values of 2.5 mg/kg (ICRISAT, 1985). In calcareous Vertisols of southern Spain, lack of response to applied P is observed for values of 6-7 mg/kg or more--a critical range that is most frequently reported in the region.

Discounting environmental and management factors, the extent to which mineralogy affects critical available P levels in Mediterranean soils is unclear. However, it can be expected that the extent and nature of P-reacting mineral surfaces has some influence. This contention is supported by Solis and Torrent (1989c) for 15 calcareous soils from Spain. The critical levels for wheat grown in pots were significantly correlated with active $CaCO_3$/(clay + 20 Fe_d) ratio (Fig. 2). This ratio is obviously a rough measure of the relative importance of adsorbing and precipitating mineral surfaces; a factor of 20 is given to Fe_d to compensate for the higher adsorbing capacity of Fe oxides with respect to silicate clays, as suggested by the regression coefficients of the equations of Table 1. Recent pot experiments for wheat cropped in 19 calcareous WANA soils (Afif, Matar, and Torrent, unpublished) produce a similar conclusion; there the critical level was = 9.0 + 0.055 active $CaCO_3$/(clay + 20 Fe_d) with r = 0.48*. Whether this type of relationships holds under field conditions remains to be seen. If this were so, Mediterranean soils could be divided, according to their mineralogy, into two or three broad categories, each with a typical range of critical levels.

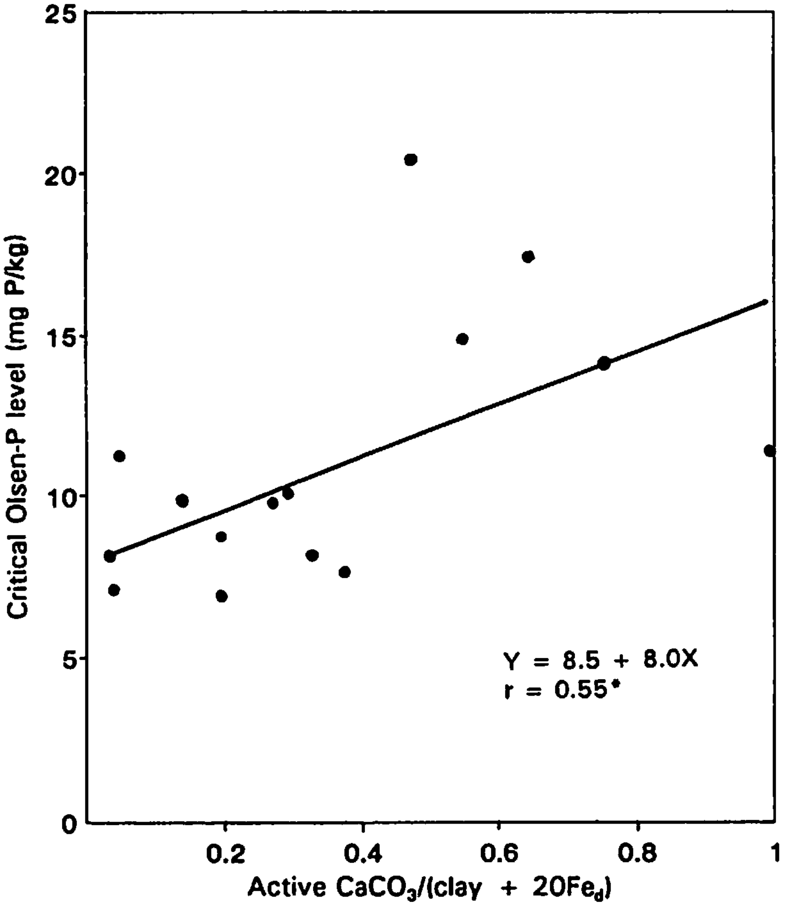

Fig. 2. Relationship between critical Olsen-P level and the active $CaCO_3$/(clay + 20 Fe_d) ratio for wheat pot-grown in 15 calcareous soils from Spain (Solis and Torrent, 1989b; 1989c).

CONCLUSIONS

The main conclusion of this report is that the mineralogy of Mediterranean soils has a marked influence on the applied P behavior. Sorption and loss of availability of applied P are related to simple analytical data which basically describe the mineralogical suite, i.e., active $CaCO_3$, CBD-extractable Fe or clay content. Critical Olsen P levels also seem to be related to some of these properties.

However encouraging these results may be, an enormous task lies ahead. Future research is needed to: (1) better characterize the mineralogy and P reactions in Mediterranean soils; (2) field test the general validity of hypotheses resulting from laboratory and greenhouse experiments on availability and critical levels, and (3) develop simple analytical methods yielding data capable of being routinely used for practical predictive purposes.

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DISCUSSION

A. Matar

What are the practical implications you might suggest for Fe oxides in calcareous soils in relation to P availability and in developing better fertilizer phosphate recommendations?

J. Torrent

One possible approach would be to use regression equations to predict the P to be added to reach a specified equilibrium P concentration (e.g., 0.1 us pm/l). One should, however, "subtract" the native soil P when making recommendations. If native P = resin P, we already see that native P ≃ 2-3 x Olsen-P.

S. Khattari

In practice, we consider extractable P as a basis for P recommendation, then we complement the amount of required P by fertilizers assuming that it will also be available, but we practically do not consider how much will be sorbed during the plant life. So, do you suggest to study both extractable and sorbed P before recommendation?

J. Torrent

The sorbtion study gives another dimension to improve recommendation, keeping in mind that sorbtin and minralogy are not the only factors considered, provided that more factors are involved under natural conditions.

P. Orphanos

What would be a practical test to assess the effect of $CaCO_3$ surface area in precipitating phosphate?

J. Torrent

"Active $CaCO_3$" is as good a measure of this as other measurements, e.g. the fraction of $CaCO_3$ in the clay, but is still a very poor one!

H. Bellouch

In calcareous soils there is a problem of availability of iron and phosphate. The question is how to make these elements available for the plant?

J. Torrent

The problem of the nonavailability of iron can be handled by several methods among which adding some fertilizers, such as iron phosphate which are less expensive than chelates, is only one.

T.M. Abu-Sharar

Given that removal of P from the soil solution is a ligana exchange in Fe/Al-OH but a precipitation reaction in $CaCO_3$ dominated soils, don't you think it would be better to establish two different functional relations between any availability index and plant response to P fertilizers accordingly?

J. Torrent

Thermodynamics is not the appropriate approach to establish such a functional relation. May be kinetic models would provide feasible tools to help solve the problem.

J. Ryan

Could you reconcile the large adsorption shown by soils in laboratory experiments and rapid buildups of residual P in the field, i.e., over one to two years?

J. Torrent

Conditions are completely different. Complete saturation in laboratory occurs rapidly and not in field. Laboratory data are artifacts. Using pellets might more realistically reflect what happens in nature.

M. Badraoui

1) Most Mediterranean soils have high pH. How do you explain adsorption by iron oxides in these conditions especially that iron oxides are negatively charged?
2) Fe_d does not come only from iron oxides, how about Fe which make the linkage between organic matter and clays?
3) How about the importance of smectites and illites?

J. Torrent

1) Even at high pH positive charges exist also and can adsorb P specifically. Ligana exchange proceeds even with net negative charge.
2) Fe_d is still a good explainer of P adsorption. Organic Fe contents are very low in most Mediterranean soils.
3) Only Al at the edge of alluminosilicate clays can adsorb P specifically. That limits the adsorbing surface.

Chemistry and Mineralogy of Potassium in Moroccan Soils: Implications for Fixation and Release

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ABSTRACT

The dynamics of potassium in the soil and its availability to plants are strongly influenced by the mineralogical composition of the soil's clay fraction. Both a detailed identification and quantitative estimation of the relative proportions of the clay minerals present in the soil are necessary to establish relationships between K fixation (and release) and soil mineralogy. Representative soils from different agricultural regions of Morocco were sampled and characterized physicochemically and mineralogically. Potassium fixation was measured in wet and dry conditions, and K release was evaluated for some soils in pot experiments.

A highly significant correlation was found between smectite content (with beidellitic character) in the clay fraction and K fixation in the soils from Chaouia and Gharb regions. Potassium fixation is most explained by the tetrahedral charge of the clays. For illitic soils, K fixation is partially related to the degree of opening of illites, which is a result of intensive cropping. Potassium release depends on total soil cation exchange capacity and on the abundance of smectite and opened illites in the clay fraction. It was found that illitic soils that were high in K-fixing capacity also readily released recently-fixed K. For beidellitic soils, however, the rate of release of recently-fixed K was low. Data on soil mineralogy and the relationships between K fixation and release capacities should be taken into consideration when setting experiments or making K fertilizer recommendations.

INTRODUCTION

Since the work of Thomann (1952) it has been recognized that Moroccan soils are rich in potassium. Either insignificant or no increases in potassium were found as a result of K fertilization in pots (Michel *et al.*, 1967) and in long-term field experiments installed by the National Institute of Agronomic Research (INRA) in different regions of Morocco (Agbani, 1978; Agbani *et al.*, 1983). Such studies also showed that the agricultural K balance (K added - K uptake) was always negative regardless of the cropping system (Papy *et al.*, 1979). It was therefore concluded that all Moroccan soils are rich in K, despite the fact that the soils of INRA experiment stations are not representative of the soils of their respective regions with respect to K fertility (Ait Houssa, 1979). In addition, severe Zinc (Zn), Copper (Cu), and Sulfer (S) deficiencies were found in the soils of these experiment stations (Agbani *et al.*, 1983), and K may not have always been the limiting nutrient.

In recent years, agricultural production in both irrigated and rainfed regions of Morocco has been much intensified. Highly significant responses to K fertilizer were obtained in soils of the Doukkala region cropped with sugar beet under irrigation (Dadi, 1988; EL Harchioui, 1989; Achchag, 1989; El Mehdi, 1990). Using the interpretation scheme of exchangeable K proposed by Ait Houssa (1989), Bouchaara (1989) concluded that 64% of the soils of Doukkala have low to very low levels of exchangeable K. In other regions of Morocco, 10 to 50% of the soils are low in exchangeable K. In a one-year field experiment in Tadla region, sugar beet did not respond to K additions (Hamdani, 1990).

At present, it is still difficult to correctly interpret soil-K tests because of insufficient field experiment trials. Because of diversity of soil types, climatic conditions, and cropping systems in Morocco, increasing K addition would not be enough to solve this problem. The number of K response experiments needed to characterize response to K over the whole country would be very high. A more reasonable approach is to use the understanding of K behavior in soils in predicting response to K under any particular condition.

The dynamics of K is largely influenced by the mineralogical composition of the soil. The quantity of K which is immediately available for the plant roots is that of the soil solution. A dynamic equilibrium is established at any time between the soil K solution, adsorbed K, and that of the reserve in clay interlayers (Quemener, 1986). This equilibrium is under the control of the soil's mineralogy, especially the phyllosilicate minerals of the clay fraction ($< 2\mu m$). In many situations, K fixation and K release are responsible for the lack of response to K fertilizers (Loué, 1977; Mengel, 1985). These two phenomena are controlled by the amount of clay ($< 2\mu m$); even more important are the nature of these clays and the relative quantities of each mineral phase present. The release of K predominates in most soils containing weatherable minerals such as mica (illite) and K feldspars (Sparks, 1986), whereas K fixation is very important in soils where smectites and vermiculites are the major mineral phases present (Bajwa, 1983; Badraoui, 1988).

This paper summarizes the results and implications of a basic research program on the chemistry and mineralogy of K in Moroccan soils. It demonstrates how the mineralogy of the soils can be used to explain the fixation and release of K and thus its availability to the plant.

MATERIALS AND METHODS

Soils

Both Ap (0-20 cm) and subsoil (30-60 cm) samples, depending on soil profile development, were taken from representative soils of different agricultural regions of Morocco. The major soil types sampled were Chromoxererts, Calcixerolls, Xerochrepts, and Palexeralfs.

Clay Mineral Identification and Characterization

The preparation of soil clays for qualitative mineralogical analysis was performed according to Jackson (1979). Tetrahedrally- and octahedrally-charged dioctahedral smectites were distinguished by determining the decrease in CEC after heating Li-saturated clays (Green-Kelly, 1953). Also, beidellitic and montmorillonitic clays were separated by swelling of K-saturated clays (Schultz, 1969). These procedures are described by Badraoui *et al.* (1987).

The alkylammonium-clay complex method was used to estimate the total and tetrahedral interlayer charges of smectites (Lagaly and Weiss, 1969; Badraoui *et al.*, 1987). The percent smectite in the clay samples was determined using the mass balance method (Hodgson and Dudeney, 1984). Total chemical analyses of the clay samples were obtained by atomic absorption analyses after lithium metaborate ($LiBO_2$) fusion (Bankston *et al.*, 1979).

The relative quantity of illites in the soils was estimated from the total K content taking into account their degree of opening, i.e., % illite = (% K_2O/ X) x 100, with X = 4% for opened illite (Mimouni, 1990) and 7% for collapsed illite (Robert *et al.*, 1988).

The "crystallinity index," which is 001 peak breadth, measured in nm or degrees 2θ, at half peak height (Kubler, 1964) was used to characterize the degree of illite opening in the clay fraction. Crystallinity index is significantly larger for clay samples containing opened illite or irregularly interstratified I/S clays which are produced by weathering of mica in the soil.

Cation-Exchange Capacity Measurement

Both total and tetrahedral cation-exchange capacities (CEC) were measured. The former was measured by displacing Na^+ from Na-saturated clay (or soil) by 1 mol ammonium acetate/L at pH 7. The second CEC was measured after saturation of the clays (or soil) by LiCl and heating at 300°C in order to neutralize the octahedral charge (Badraoui, 1988).

Potassium Fixation

The Van der Marel (1954) method, which uses Mg^{2+} as extracting cation, was followed. The amount of K added was equivalent to 830 mg/kg of soil. Potassium fixation was measured under both wet (no heating to dryness) and dry (drying at 70°C for 24 hours) conditions.

Potassium Release

The DeMent *et al.* (1959) method, as detailed by Binet (1979), was used to determine the soil's K-release capacity to intensive cropping by Italian ryegrass. The amount of K released is considered as the difference between K uptake and the change in exchangeable K between the beginning and the end of the experiment.

RESULTS AND DISCUSSION

Clay Mineralogy

The mineralogical composition of the clay fractions of Vertisols (Chromoxererts of Chaouia, Sais, Doukkala, and Zaer regions and Pelloxererts of Gharb region) is dominated by smectite (> 60%). Both high-charge beidellite and montmorillonite are present in these clays. In the Chaouia region, the smectitic phase is exclusively a high-charge and iron-rich beidellite (Badraoui and Bloom, 1990), whereas the smectitic phase of the other Vertisols is a mixture of beidellite and montmorillonite.

A typical structural formula of beidellite in the Chaouia "Tirs" soils (Chromoxerert) when saturated with N is:

$$Na_{0.54}\,K_{0.07}(Si_{3.59}Al_{0.41})(Al_{1.28}Fe_{0.38}Mg_{0.42})O_{10}OH_2$$

The total charge is 0.61, and the tetrahedral charge is 0.41 charges per half unit cell. Sixty seven percent of the charge is located in the tetrahedral sheet. It was found that 10 to 12% of the exchange sites (11.5% for the formula above) contain nonexchangeable K in the Chromoxererts of the Chaouia region. This suggests that the smectitic phase of the Chaouia Chromoxererts contains some irreversibly-collapsed layers and that these smectites are, in fact, irregularly interstratified illite/smectite with more than 80% expanding layers. Similar results were reported by Tessier and Pédro (1987) and Vali and Koster (1986).

The decrease of CEC and the reswelling after Li-saturation and heating of the clay samples confirmed the high charge and the high Al substitution for Si in the tetrahedral sheets of these smectites (Badraoui and Bloom, 1990). Small amounts of kaolinite, chlorite, and palygorskite are associated with the smectitic clays of the High Chaouia region, whereas small quantities of illite and kaolinite are associated with smectite in the smectitic phases of the Gharb, Sais, Doukkala, and Zaer regions. Xerochrepts and Calcixerolls (Biad, Dehs, and Hamri soil series) of Chaouia, Gharb, Sais, Tadla, Haouz, and Souss-Massa regions contain mixed mineralogies with smectite, illite, kaolinite, chlorite, quartz, palygorskite, and interstratified illite/smectite or illite/vermiculite. Smectite and illite made up more than 60% of the clay mineral phases present in Gharb and some Calcixerolls of Tadla regions. Haouz and Souss-Massa soils are mostly illitic. The degree of opening of illite is variable depending on the soil horizon and previous crop management. Illite in Ap horizons (surface horizon) is generally more opened than in the subsoil.

Samples extracted from Alfisols (Palexeralfs) of Chaouia and Sais regions contain substantial amounts of vermiculite, illite, kaolinite, and quartz. No smectite is present in these old red soils.

In summary, 2:1 layer silicates, especially smectite and illite, are the major clays present in the soils sampled. Smectite (beidellite and montmorillonite) make up the largest proportion of the clays in the Vertisols, and thus determine their behavior with respect to water and K. Illites are the major mineral component of Mollisols, Inceptisols, and Alfisols.

Fixation and Mineralogy Relationships

In order to establish quantitative relationships between clay mineralogy and soil K behavior, it is necessary to quantify the amount of each mineral phase present in the soils. At present, it is still very difficult to make reliable quantification of clay minerals in mixtures based on X-ray diffraction intensities alone. In addition to the weight fraction of a mineral phase present in the clay mixture, the size, the crystallinity, and the chemical composition of the minerals greatly influence the intensity of X-ray diffraction peaks. In order to avoid the use of the intensity we used the method of Hodgson and Dudeney (1984), which is based on the X-ray diffraction for the identification of the minerals present, and the total chemical composition of the clay mixture. Applied to Vertisols and Vertic Mollisols of Chaouia and Gharb regions, this method was found to produce reasonable results (Bouabid, 1987; Badraoui, 1988).

A highly significant linear correlation ($P < 0.001$) was found between percent smectite and the amount of K fixed (Fig. 1) under both wet and dry conditions. However, in the clay fractions containing less than 40% smectite the fixation did not vary with percent smectite in the Mollisols from the Gharb region. For Chaouia clays, K fixation was principally controlled by the smectitic phase. Chaouia clays fixed more K than Gharb clays. This is explained by the fact that Chaouia smectite is beidellite, whereas Gharb smectite is a mixture of montmorillonite and beidillite.

For illitic soils, the degree of opening of illite may be more important than smectite content. In general, the soils containing opened illite fixed more K than those where illite was still collapsed. For example, in Souss-Massa soils (Agadir region) K fixation was highly correlated ($P < 0.01$) with percent illite in the soils regardless of the degree of opening of the illite (Fig. 2). Although the correlation was statistically significant, the scattering of the points was very high. When the percent of opened illites was considered, the correlation was greatly improved (Fig. 3). As the amount of opened illite increased in the clay fraction of Souss-Massa soils, the quantities of K fixed increased. Opened illites are in fact, irregularly interstratified illite/smectite or illite/vermiculite which are very difficult to characterize by X-ray diffraction. These minerals contain partially-opened interlayers which are active in fixing K.

In Tadla and Haouz regions, no significant correlations were found between percent illite or percent opened illite and K fixation. Because the soils of Tadla and

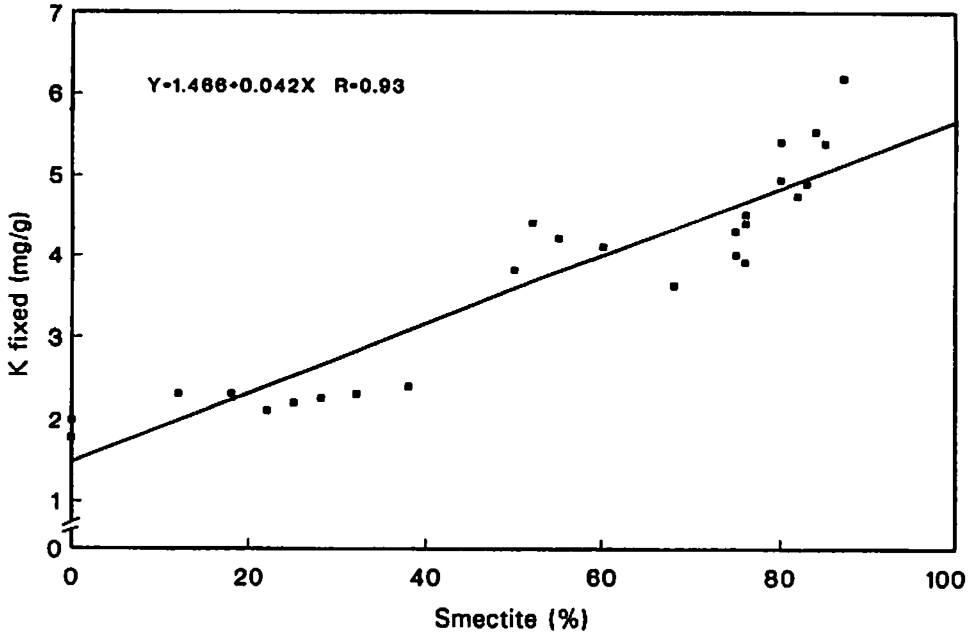

Fig. 1. Relationship between % smectite and K fixation in wet conditions by Chaouia and Gharb soils. The amount of K added = 19.92 mg/g clay.

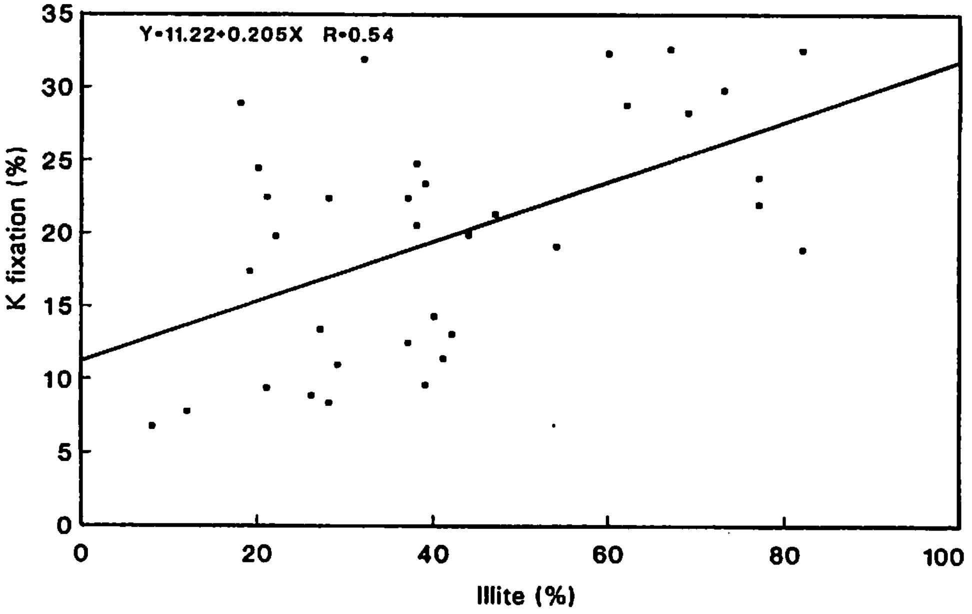

Fig. 2. Relationship between % illite and K fixation in wet conditions by Souss-Massa soils. The amount of K added = 830 mg/kg soil.

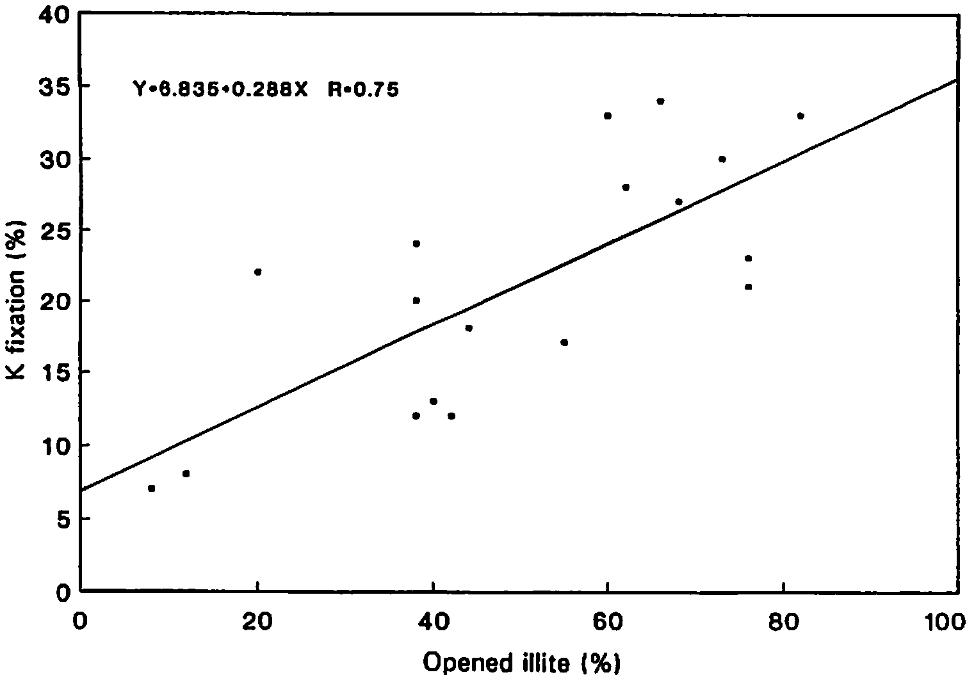

Fig. 3. **Relationships between % opened illite and K fixation in wet conditions by Souss-Massa soils. The amount of K added = 830 mg/kg soil.**

Haouz regions have mixed mineralogy, it is difficult to assess the relative importance of opened illite and smectite. Both of these minerals contribute to K fixation.

Fixation and Charge Characteristics

In order to take into account the total charge of the clay mixture and not only the interlayer charge of the smectitic phase, K fixation was related to the total CEC of the clay fractions extracted from the different soils studied. Under both wet and dry conditions, K fixation was very highly correlated ($P < 0.0001$) with total CEC for Chaouia, Gharb, and Sais clay fractions (Fig. 4, Bouabid *et al.*, 1991). A positive interaction existed between K fixation and the quantity of K added. More K was fixed per unit CEC as the added K increased (results not shown). The fact that the intercepts were close to zero fixation at zero total CEC suggests that total CEC would explain most of the fixation.

The amount of K fixed was also correlated with the tetrahedral CEC (Fig. 5) in both wet and dry conditions. The slopes of the regression lines were very close to those found for total CEC (Fig. 4). No significant correlation was found between K fixation and octahedral CEC (total CEC — tetrahedral CEC). Although octahedral

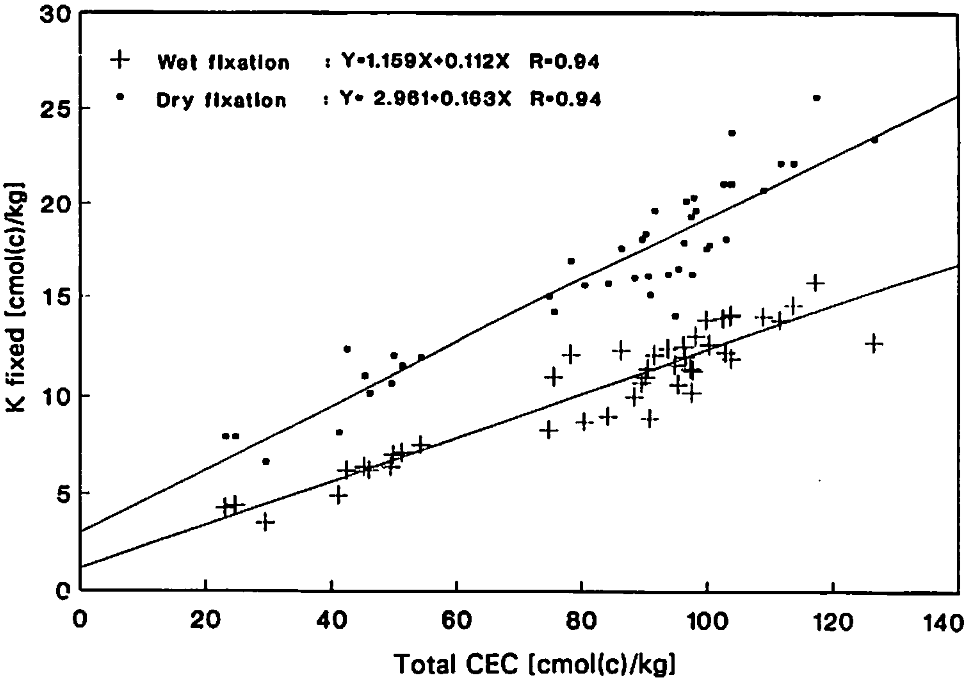

Fig. 4. Relationships between total CEC and K fixation in both wet and dry conditions by Chaouia, Gharb, and Sais clay fractions. The amount of K added was equivalent to 50 mol(c)/kg (Bouabid *et al.*, 1991).

CEC by itself was not correlated with K fixation, it did contribute to total CEC and thus to K fixation. This fact was demonstrated by the high intercept at zero tetrahedral CEC (Fig. 5). Similar results were obtained using not only the clay fractions extracted from the soils but also the whole soil samples of Chaouia, Gharb, Tadla, Haouz (Mimouni, 1990), and Souss-Massa (Annouaoui, 1991) regions.

From a practical viewpoint, our results show that a simple measure of both total and tetrahedral CECs of the soils gives a good prediction of the K-fixation capacity for the soils studied. The CEC, which reflects the total electric charge of the soils, is probably the most important soil factor influencing K behavior.

Potassium Release

When soil solution and exchangeable K are reduced by plant uptake to a minimum level, specific for each soil, nonexchangeable or previously-fixed K is released from interlayer sites. Intensive greenhouse cropping using Italian ryegrass, as a test plant, is of particular interest in assessing K release (Binet *et al.*, 1984).

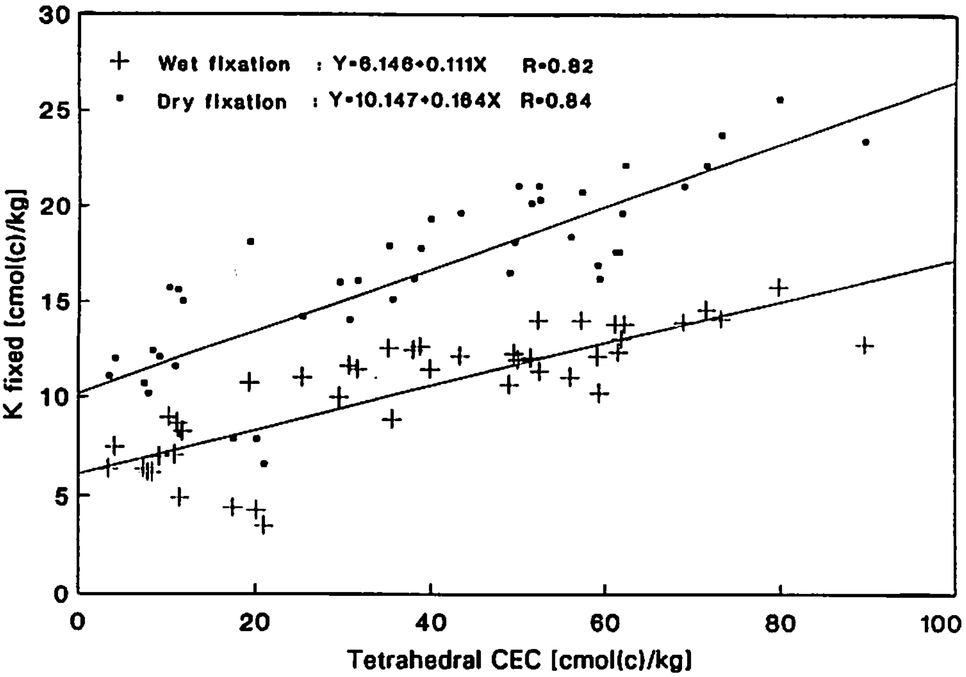

Fig. 5. **Relationships between tetrahedral CEC and K fixation in both wet and dry conditions by Chaouia, Gharb, and Sais clay fractions. The amount of K added was equivalent to 50 mol (c)/kg.**

The capacities of the studied soils to release nonexchangeable K ranged from 46 to 226 mg/kg for Tadla region, 67 to 215 mg/kg for Haouz region, 5 to 155 mg/kg for Gharb region, 1 to 83 mg/kg for Chaouia region, and 4 to 178 mg/kg for Doukkala region. Illitic soils of four of these five regions released more K than smectitic soils. In Chaouia, however, the least amount of K released was by the old illitic Alfisol. Iron coatings may have inhibited mobilization of interlayer K (Badraoui *et al.*, 1991).

Also, Vertisols of the Chaouia region released small amounts of K. In fact, these soils are very low in solution, exchangeable, and total K compared to most other soils of Morocco. The rate of release of nonexchangeable K, which, in this case, is mostly made up of native and previously-fixed K by beidillite, is very low (Badraoui *et al*, 1991). Highly K-fixing soils can also be highly K-releasing soils when they contain illites. This is the case of the alluvial soils of the Gharb region. In Doukkala region, a highly significant ($P < 0.001$) correlation ($r = 0.77$) was found between K released and K fixed (Bouchaara, 1989). In the same region, the amount of K released was positively correlated with clay content and total CEC. In Tadla, Chaouia, and Gharb regions, no relationships were found between K release and CEC (Mimouni, 1990; Tazi, 1988). In these regions, K release was higly correlated with percent clay.

CONCLUSIONS

Data on the mineralogy and chemisty of K fixation and release capacities help in understanding K behavior in the soil. They can be used to interpret the results of field experiments, and should also be taken into consideration when setting up experiments or making K fertilizer recommendations.

Smectitic soils fixed much more K than did the mixed-mineralogy soils. In Souss-Massa region, soils containing opened illite fixed more K than those where illite was still collapsed. In soils containing both opened illite and smectite, it was difficult to assess the relative importance of these minerals. Both total and tetrahedral CECs are important in explaining K fixation by the soils studied. Native- and previously-fixed K can be easily released from illitic soils except for the old Chaouia Alfisols where iron coatings may have inhibited the diffusion of interlayer K. Chaouia Vertic soils, which fixed the highest amount of K and contained the largest quantities of beidillite, had the least capacity to release K for growing ryegrass under intensive cropping.

Field experiments should be set in soils with contrasting mineralogies using the highly K-demanding plant of the cropping succession in a given region. Preliminary results in Doukkala region using sugar beet under irrigation showed response to K fertilizer in all soil types, despite the high release capacities of these soils. These results were explained by the high quantities of K removed by sugar beet crops.

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Soil Phosphorus Adsorption and Evaluation of Soil-Phosphorus Buffering Capacity Indices

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ABSTRACT

The soil-P test calibration approach requires a large amount of empirical data in order to perform the calibration. Also, calibration curves must be developed for the different soils, a task which is expensive and time-consuming. It would be very helpful if a soil-P parameter can be used concurrently with the soil-P test to account for differences among soils.

The objectives of this study were to (i) investigate the P adsorption properties of some Moroccan soils, (ii) compare different soil-P buffering capacity indices with respect to crop P requirement prediction in combination with different soil-P tests, and (iii) determine if routine soil analyses can be used in predicting the soil-P buffering capacity.

A P-adsorption study was conducted on 21 soils sampled from four agricultural regions. Wheat (*Triticum aestivum* L.) was grown, up to heading, in a greenhouse on 11 soils including those used in the P-adsorption study. The P rates were 7.7, 15.4, 30.8, and 61.6 mg/ha soil, applied as monocalcium phosphate.

Phosphorus adsorption was correlated with soil clay content, CEC/Clay ratio, lime content, and organic iron. The correlation with organic matter was considered to be indirect since there was a strong correlation between organic iron and organic matter. Dry-matter production and P uptake were highly correlated with the $NaHCO_3$-P soil level, while the Joret-Hebert P test was not appropriate on the Gharb soils. The Truog soil-P tests were not effective. The $NaHCO_3$-P soil test was also correlated with wheat P requirement.

INTRODUCTION

The methods currently used to predict crop response to P fertilizer make use of extractable soil-P levels. The soil-P test level is compared with crop response to P fertilizer in field experiments. Fertilizer recommendations are then made on the basis of field calibration experiments. Even though this approach has served as a useful tool in developing fertilizer recommendations, it has some shortcomings: (1) a large amount of empirical data is required in order to perform such calibration, and (2) calibration curves should be developed for the different soils, a task which is expensive and time-consuming.

Nye (1963) assumed that for a soil and plant nutrient such as P, three things should be known: (1) the intensity level of the nutrient needed for satisfactory growth, independent of soil, (2) the present intensity level of the soil, and (3) the relation between the quantity of nutrient in the soil and its intensity. This characterizes the dynamic relationship between labile solid phase P and the soil solution phase from which plants withdraw their nutrient supply (Beckett and White, 1964). Phosphorus concentration in soil solution is a useful parameter to assess plant P uptake over a relatively short period. However, over an entire season, prediction accuracy is greatly improved by assessing the P buffering capacity of a soil (Mattingly, 1965; Khasawneh and Copeland, 1973).

Ozanne and Shaw (1967) using 0.3 mg P/L (or ppm) in soil solution as the intensity level needed for satisfactory growth of wheat found that P required was highly correlated to P sorbed. Ozanne and Shaw (1968) showed that when--in addition to sorbed P--the soil-P buffering capacity was included, prediction of the P fertilizer required by a crop was improved. Also, prediction of the P required using the Olsen-P test (Olsen *et al.*, 1954) was improved when the soil-P buffering capacity was included in the regression. Low levels of Olsen-P were adequate for near maximum yield in soils of low soil-P buffering capacity, and high Olsen-P levels were required in soils with higher soil-P buffering capacity. Therefore, this relationship suggests that in order to make fertilizer recommendations more accurate, the intensity, quantity, and soil-P buffering capacity should be considered. The determination of soil-P buffering capacity of major soils in a geographic area and its use in combination with soil test would improve the prediction of the crop fertilizer requirement. This is only feasible if the P buffering capacity of a soil is not altered by fertilizer application.

Olsen and Watanabe (1963) used the initial linear slope of a quantity/intensity curve up to a solution concentration of 0.3 mg P/L, in order to measure the soil-P buffering capacity. Barrow (1967) measured the slope at which there is no adsorption or desorption of P from the soil. Beckett and White (1964) used the slope at the natural equilibrium P potential of the soil. The maximum slope of the sorption isotherm was used by Holford and Mattingly (1976), as the concentration tends to zero. Bache and William (1971) assumed that the isotherm slope at 10^{-4} M was the best representation of the sorption properties of soils. Bowman and Olsen (1985) used a desorption isotherm by an anion exchange resin besides the adsorption isotherm. In addition to the different parameters used in determining the soil-P buffering capacity, equilibration time of P added to soil may vary from 17 hours (Ozanne and Shaw, 1967) to 60 days (Barrow, 1967). Since no general agreement exists in this area, studies were conducted to determine the applicability of these parameters to Moroccan soils.

The objectives of this study were to: i) characterize the P adsorption properties of some Morocco soils, ii) determine if the soil P-buffering capacity can be predicted from routine soil analysis, and iii) judge if P buffering capacity can be used as a guide in making P fertilizer recommendations.

MATERIALS AND METHODS

Twenty one soil samples were taken from four agricultural regions in Morocco: Chaouia, Gharb, Tadla, and Zaer. The range of selected chemical and physical properties of the soils is provided in **Table 1.**

Table 1. Range in properties of soils for buffering capacity assessment, Morocco.

							Iron		
	Clay	Silt	$CaCO_3$	CEC[1]	pH	OM	Cryst-alline	Amorphous	Organic
	--------- (%)	--------		(1)		(g/kg)	------------ (mg/kg)	-----------	
Minimum	2	6	0	5	6.3	1	0.37	1.07	0.07
Maximum	75	55	16	60	8.6	35	16.69	6.31	3.32

[1] = cmol(+)/kg.
OM = organic matter.

Soil-P adsorption isotherms were determined using the procedure outlined by Holford and Mattingly (1975). Two replications (5-g soil samples) were equilibrated with a 0.01*M* $CaCl_2$ solution containing the following amounts of P as monocalcium phosphate (MCP): 0.78, 3.10, 4.65, 6.20, 9.30, 12.40, 18.60, 24.80, 31.00, and 37.20 µg P/ml. The soil:solution ratio was 1:20. Toluene was added to inhibit microbial activity. After a 24-hour shaking period at 750 rpm, the suspensions were filtered and P concentration was determined. The difference between added P and that in the filtrate was considered as P adsorbed.

The sorption data were described using the linear form of the Langmuir adsorption isotherm:

$$C/X = C/X_m + 1/KX_m, \text{ where:} \qquad (1)$$

X = adsorbed P (mg P/kg)
C = equilibrium P concentration (mg P/L)
X_m = maximum P adsorption (mg P/kg)
K = adsorption/desorption equilibrium constant.

This allowed the description of the adsorption data and computation of the soil-P adsorption parameters, X_m and K.

The following buffer indices were determined from these isotherms:

i. Maximum buffering capacity (MBC) = maximum slope of the Langmuir isotherm, $(dx/dc)_{c \to 0}$, calculated from KX_m (Holford and Mattingly, 1976).
ii. Buffering index (BI) = maximum slope of the Langmuir isotherm over an equilibrium concentration range of 0-5 mg P/L.

iii. Standardized buffering capacity (SBC) = slope of the tangent to the Langmuir isotherm at an equilibrium P concentration of 0.3 μg P/ml (Ozanne and Shaw, 1968).

iv. Sorption test (ST) = amount of P sorbed at an equilibrium concentration of 0.3 μg P/ml (Ozanne and Shaw,1967).

v. A buffering index (IBC) proposed by Salmon (1973) was also determined: rates of 0 and 20 mg P/kg soil as MCP were applied in duplicates. The soil samples were incubated for a 24-hour period after moisture was adjusted to field capacity. Phosphorus was extracted with 0.01*M* $CaCl_2$, by shaking for 1 hour, using a soil:solution ratio of 1:20, and was determined calorimetrically. The buffering index was calculated as:

$IBC = Q/(I_t - I_c)$, where: (2)

Q = difference between added P and P determined in the filtrate
I_t = final P concentration in the treated sample
I_c = final P concentration in the check.

Three methods were used to extract different forms of soil iron. *Method 1*: the dithionite-citrate bicarbonate method (Mehra and Jackson, 1960) which extracts crystalline forms (finely divided hematite and goethite), amorphous Fe, and organic-complexed Fe. *Method 2*: the ammonium oxalate method (Schwertmann, 1973) which was used to extract the amorphous Fe and the organic-complexed Fe. *Method 3*: the sodium pyrophosphate method (Wang and Wood, 1973) which extracts the organic-complexed Fe. Thus three forms of iron were identified: i) organic-complexed Fe (Method 3), ii) crystalline Fe (Method 1 - Method 2), and iii) amorphous Fe (Method 2 - Method 3).

The greenhouse data presented in the previous chapter were used in the present study. In that experiment, five P rates (0, 7.7, 15.4, 30.8, and 61.6 mg P/kg) were applied to wheat grown in 3-kg soil in pots. A complete randomized block design with three replications was used. The total aerial parts were harvested at the heading stage, dried at 70°C for 48 hours, and weighed. The crop P fertilizer requirement was considered to be the P rate necessary for the production of 90% of maximum yield from the crop response. The Systat statistical package (Wilkinson, 1986) was used to perform statistical analyses.

RESULTS AND DISCUSSION

Soil-P Adsorption

In order to determine the maximum soil-P adsorption (X_m), the Langmuir adsorption isotherm was fit to the adsorption data. The correlation coefficients presented in Table 2 are highly significant, indicating that the Langmuir equation adequately describes the adsorption data. The maximum P adsorption capacity ranged from 68 to 521 mg/kg (Table 3). These results are in agreement with those reported by Ouchtoubane (1980).

Table 2. **Langmuir adsorption isotherm equations, Morocco.**

Soil no.	Equation	"r"
1	$C/X = 0.00269*C + 0.00690$	0.99**
2	$C/X = 0.00279*C + 0.01100$	0.99**
3	$C/X = 0.00247*C + 0.00535$	0.98**
4	$C/X = 0.00215*C + 0.00533$	0.97**
5	$C/X = 0.00219*C + 0.00633$	0.97**
6	$C/X = 0.00207*C + 0.00963$	0.98**
7	$C/X = 0.00225*C + 0.00770$	0.98**
8	$C/X = 0.00234*C + 0.00717$	0.98**
9	$C/X = 0.00286*C + 0.01093$	0.98**
10	$C/X = 0.00192*C + 0.00525$	0.98**
11	$C/X = 0.01475*C + 0.05751$	0.95**
12	$C/X = 0.01986*C + 0.00385$	0.99**
13	$C/X = 0.00215*C + 0.00533$	0.99**
14	$C/X = 0.00218*C + 0.00725$	0.97**
15	$C/X = 0.00415*C + 0.02640$	0.81**
16	$C/X = 0.00206*C + 0.00547$	0.98**
17	$C/X = 0.00230*C + 0.00750$	0.98**
18	$C/X = 0.00228*C + 0.00750$	0.99**
19	$C/X = 0.00223*C + 0.00256$	0.99**
20	$C/X = 0.00406*C + 0.01483$	0.96**
21	$C/X = 0.00571*C + 0.09407$	0.97**

* $P < 0.05$.
** $P < 0.01$.

Table 3. **The maximum P adsorption and equilibrium constant determined from the Langmuir equations for all soils, Morocco.**

	Maximum P adsorption (X_m) (mg/kg)	Equilibrium constant (k) (L/mg)
Minimun	68	0.06
Maximum	521	0.87

Soil-P adsorption isotherms are difficult to use in routine soil testing. Therefore, it would be desirable to predict soil-P adsorption from routine analyses. Clay content, CEC/clay ratio, lime, organic matter and organic-complexed iron were correlated with X_m (Table 4). The other forms of iron, crystalline, and amorphous, were not correlated with X_m. The high correlation between soil clay content and X_m conforms with the results of Ellis and Truog (1955), Sen Gupta and Cornfield (1963), and Syers *et al.* (1971).

Table 4. Correlation coefficients of the maximum soil-P adsorption capacity and equilibrium constants with soil properties, Morocco.

Parameter	Maximum P adsorption (mg/kg)	Equilibrium constant (L/mg)
Clay	0.73**	0.59*
CEC/Clay ratio	-0.82**	-0.19 NS
Lime	0.53*	-0.01 NS
Organic matter	0.48*	-0.24 NS
Crystalline Fe	0.26 NS	-0.40 NS
Amorphous Fe	0.12 NS	0.06 NS
Organic Fe	-0.53*	0.11 NS

* $P < 0.05$. ** $P < 0.01$. NS = nonsignificant.

Rajan and Fox (1975) reported that there are two types of adsorption sites. Phosphorus adsorption in the first type leads to a release of silicate and sulfate and a rise in pH, indicating that P was replacing adsorbed silicate, sulfate, and hydroxyl groups. In the second type of sites, at higher P concentrations, there was a sharp increase in the release of silicate only, suggesting that silicate clay minerals were being disorganized and structural silicate displaced, thus allowing more P to be adsorbed. Kurtz (1953) reported that P can be adsorbed on clay minerals through exchangeable calcium and magnesium, which are the major exchangeable cations in our soils.

It is interesting to note that even though CEC was not correlated with X_m, the CEC/clay ratio was highly negatively correlated with X_m. This means that as the CEC of the clay minerals increases, soil-P adsorption decreases. Tisdale *et al.* (1985) reported that P is retained to a greater extent by 1:1 than 2:1 clays. Positive correlations between X_m and lime content were also reported by Ouchtoubane (1980) and Zakaria (1983) for other Moroccan soils.

The mechanism of P adsorption by $CaCO_3$ is still not well understood. Studying P adsorption by $CaCO_3$, Cole *et al.* (1953) and Holford and Mattingly (1976) showed that, at low concentrations, P is adsorbed as a monolayer on $CaCO_3$. However, at high P concentrations there is precipitation of octacalcium phosphate or monocalcium phosphate. Kuo and Lotse (1972) have suggested that P on calcite may replace bicarbonate and hydroxyl ions.

Soil organic-matter content had a positive effect on soil-P adsorption (Table 4). Although this effect is not well understood, similar results have been reported (Holford and Mattingly, 1975; Holford, 1977; Zakaria, 1983). Appelt *et al.* (1975) suggested that P can be adsorbed by ligand exchange of P for hydroxyl groups. Others reported a negative effect of organic matter on P adsorption as a result of competition between P and organic ions on the adsorption sites.

Phosphorus adsorption in calcareous soils was frequently related to lime content. In acid soils, iron oxides were used to explain P adsorption. Holford and Mattingly (1975) reported that even in calcareous soils iron oxides may affect P adsorption. Our results show that organic-complexed iron is negatively correlated with X_m.

Soil-P Buffering Capacity Indices

The adsorption isotherm data were used to compute different soil-P buffering indices (Table 5). The maximum buffering capacity (MBC) data are similar to those reported by Zakaria (1983). Holford (1980) reported soils with MBC values ranging from 58 to 2456 ml/g. He defined three classes of MBC and the present values fit into the class with low MBC. The correlation matrix of the soil-P buffering indices (Table 6) shows that the correlation coefficients are all statistically significant. This suggests that any of the indices can be used if the purpose is to compare diffrent soils with respect to P adsorption.

Table 5. Different soil-P buffering capacity indices determined from adsorption isotherms, Morocco.

	MBC	BI	SBC	ST	IBC
	(L/mg)				(mg/kg)
Minimum	11	36	10	3	25
Maximum	390	473	245	67	3242

MBC = maximum buffering capacity.
BI = buffering index.
SBC = standard buffering index.
ST = sorption test; Salmon (IBC) = Salmon buffering index.

Table 6. Correlation matrix of different soil-P buffering capacity indices, Morocco.

Parameter	MBC	BI	SBC	ST
BI	0.97**			
SBC	0.98**	0.94**		
ST	0.99**	0.95**	0.99**	
IBC	0.80**	0.80**	0.74**	0.78**

MBC = maximum buffering capacity.
BI = buffering index.
SBC = standard buffering index.
ST = sorption test; Salmon (IBC) = Salmon buffering index.
** $P < 0.01$.

Buffering Capacity Indices vs. Soil Properties

The correlation coefficients between soil-P buffering indices and soil properties are presented in Table 7. The soil clay content was highly correlated with all the soil-P

Table 7. Correlation between different soil-P buffering capacity indices and clay content and CEC/clay, Morocco.

	MBC	BI	SBC	ST	IBC
Clay	0.70**	0.66*	0.76**	0.73**	0.67*
CEC/Clay	-0.53*	-0.45*	-0.62**	-0.58**	-0.43+

MBC = maximum buffering capacity.
BI = buffering index.
SBC = standard buffering index.
ST = sorption test; Salmon (IBC) = Salmon buffering index.
* $P < 0.05$.
** $P < 0.01$.

buffering indices. These results suggest that clay content affects the ability of a soil to replenish the soil solution with P. Previous results showed that maximum P adsorption capacity was also correlated with clay content. Therefore, as clay content increases the P storing capacity of a soil increases. The stored P thus increases the ability of a soil to replenish the soil solution as plants withdraw P from soils.

The CEC/clay ratio was negatively correlated with all the soil-P buffering capacity indices. These results indicate that as the cation exchange capacity of the clay minerals decreases, the soil-P retention ability increases, rendering applied P less available. As a consequence, the ability of the soil to replenish the soil solution decreases. Regression equations using other soil properties together with clay content did not improve the coefficient of determination. This indicates that clay content alone can be used as a distinguishing parameter of soils with respect to their P buffering capacity.

Buffering Capacity vs. Fertilizer Requirement

Table 8 presents Olsen-P for the 11 soils used in the greenhouse experiment, the maximum dry-matter yield, and the P fertilizer rate required for that maximum yield, determined as the 90% maximum yield.

Table 9 presents the percentage of crop P requirement explained by the Olsen-P test alone and after the introduction of different soil-P buffering capacity indices in the regression. The Olsen-P test explained 56% of the variance in crop's P fertilizer requirement, the latter being nonsignificant. The objective here is to determine if the use of the soil-P buffering capacity can improve the prediction of a crop's P fertilizer requirement. The results indicate that the IBC index gave the highest coefficient of determination.

The additional variance accounted for by the soil-P buffering capacity indices varied from 4.6 to 16.2% for the Olsen-P test. The statistical analysis showed that the contribution of the Salmon index was significant.

Table 8. P fertilizer requirement for wheat in the greenhouse at 90% of maximum dry-matter yield, Morocco.

Soil no.	Olsen-P (mg/kg)	90% of maximum yield (g/pot)	Fertilizer P requirement (mg/kg)
1	17	22.9	1.1
2	12	21.3	5.6
3	13	22.8	10.3
4	6	11.2	26.1
5	6	14.4	14.2
6	12	14.5	1.0
7	9	12.8	12.8
8	8	13.4	15.0
9	6	13.9	27.7
10	9	15.4	5.8
11	6	8.6	9.2

Table 9. Contribution of different soil-P buffering capacity indices to crop P fertilizer requirement prediction.

Variable	R^2	DR^2
Olsen-P	55.7**	-
Olsen-P + MBC	60.6**	4.9 NS
Olsen-P + BI	65.0**	9.3 NS
Olsen-P + SBC	60.3**	4.6 NS
Olsen-P + ST	60.3**	4.6 NS
Olsen-P + IBC	71.9**	16.2*

DR^2 = improvement in R^2 due to P buffering capacity.
* $P < 0.05$.
** $P < 0.01$.

Besides the IBC index, all the other buffering indices were derived from the soil-P adsorption isotherms. The adsorption data were based on a soil:solution ratio of 1:20 and a 24-hour shaking period, while the IBC index was based on field capacity moisture and a 24-hour incubation period. The soil:solution ratio used for the Salmon index is closer to conditions prevailing when fertilizer P granules are in contact with the soil constituents under cropping conditions. Salmon (1973) reported that the index he proposed was useful in predicting the optimum P fertilizer requirement for tobacco and corn. However, the other soil-P buffering capacity indices were not tested under field conditions. The results suggest that based on soil-P tests the Salmon index can be useful in formulating improved P fertilizer recommendations. The major advantage of the Salmon index is that it is as easy to determine as a routine analysis and does not require special equipment to be performed.

CONCLUSIONS

The results reported here confirmed that the Langmuir adsorption isotherm describes the P adsorption data. These results are similar to those reported by other researchers. The maximum P adsorption capacity (Xm) derived from the adsorption isotherms was correlated with clay, CEC/clay ratio, organic matter, and lime content.

The comparison of different soil-P buffering capacity indices used in this study showed that any of them can be used if the objective is to compare the P buffering capacity of different soils. All were highly correlated. For routine analyses, the soil-P buffering capacity can be predicted from its clay content.

With respect to crop P nutrition, the relationships between the soil-P test levels, determined by the Olsen-P and the Joret-Hebert P tests, and dry matter or crop P uptake were not affected by the soil-P buffering capacity. This could be attributed to the fact that the soils used did not present a wide range in P buffering capacity.

The prediction of crop P requirement under greenhouse conditions, was significantly improved by the concurrent use of soil-P tests and the soil-P buffering capacity index (IBC) proposed by Salmon (1973). This index is as easy to determine as a routine soil analysis and does not require special equipment. Clay content can be used to predict the Salmon buffering index.

As the present work was conducted under greenhouse conditions, the results need to be tested under field conditions before they can be routinely used for fertilizer recommendations.

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SECTION II

Factors Affecting Response to Fertilization

Implications of Spatial Variability for Soil Testing and Fertilizer Use

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ABSTRACT

On any landscape the distribution of soil types is variable. Variability, either at the macro or micro level, is an inherent property of soils. Even within relatively uniform soils, fertility, i.e., available nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and micro-nutrients, can vary considerably. This presentation deals with spatial variability of nutrients at a regional, local, and micro level in Morocco's dryland zone.

The regional survey involved sampling four fields previously cropped to cereals from each soil type depicted on a map of the Chaouia area; in each case, 20 sub-samples which were taken to a depth of 0-30 cm were composited. Generally, most soils were deficient in N (nitrate), and about half of the samples were deficient in Olsen-P, while extractable K was adequate in virtually all samples. Of the DTPA-micronutrients, Zn was the only one with a significant number of samples being short of. A more intensive sampling of major soil types - Petrocalcic Palexeroll, Calcixeroll, and Chromoxerert - revealed similar variability.

A local-type survey involved sampling according to plot or field section at five INRA stations, i.e., Ain N'Zagh, Sidi El Aydi, Jemat Riah, Khemis Zemamra, and Jemaa Shaim. All were relatively high in nitrate, particularly Sidi El Aydi, while P was high in some stations, especially in Jemat Riah. Large differences existed between plots, probably because of fertilizer and cropping histories.

An intensive survey of a 200 x 200-m area on a Petrocalcic Palexeroll, involving seven fields or parts of fields at one site and one apparently uniform field at another adjacent site, showed some relationship with previous cropping in the case of N, a poor relationship for P, and none for K. Variability for micronutrients was an inherent characteristic of the soil itself. The three distinct surveys provide implications for fertilizer use, cropping decisions and resource utilization, and soil sampling, respectively.

INTRODUCTION

From the earliest days of soil science, variability of soil types--and hence soil properties--on any landscape or region was readily recognized. While soil maps depict such variable distribution of soil types in scientific terms, farmers have already recognized differences in land quality even over short distances and between fields on their own farms. Identifying broad regional differences in soil fertility can help provide a rational policy for fertilizer use and agricultural development. Fertility surveys can be rapidly conducted, and lead to a profile of nutrients needs of a region. In view of the recent intensification of fertilizer use in Morocco and the need to increase output, this approach was adapted for part of the dryland semi-arid zone.

Less readily appreciated is fertility variation at small scales, i.e., between plots at agricultural experiment stations and within individual fields. Stations are used for a variety of purposes at any one year and from year to year, and receive varying management and fertilizer treatment to influence fertility levels. Such differences between plots would have obvious implications for researchers, especially for plot selection, and for station managers in terms of resource allocation, and for technology transfer of practical findings from station research. However, notwithstanding inter-plot variability, few researchers seem to be aware of fertility differences, or realize that fertility levels vary over time depending on the nutrient. To date, while only rudimentary generalized maps exist for the experiment stations in the semiarid zone of Morocco, no attempt has been made to characterize within-station fertility.

The recent drive to promote soil testing has highlighted variability within fields as a factor to be considered in soil sampling. The significance of spatial variability for sampling design and intensity has been discussed recently (Sabbe and Marx, 1987). Many factors such as small fragmented fields and varying management are likely to cause even more variability than normally encountered elsewhere.

The purpose of this presentation was to create an awareness of soil nutrient variability at the macro and micro level and to develop practical implications for researchers, farmers, and administrators.

REGIONAL SOIL VARIABILITY

As soil is the product of several factors--parent material, climate, relief, vegetation, and the time it has been exposed to weathering--it is inevitable that any land area which varies in any of these factors would have different soil types. Their distribution would be related to the extent of variation in some soil-farming factors. Soil maps are designed to depict soil variability on any landscape.

While Morocco has a large portion of its agricultural land surface mapped to some degree, the dryland semiarid zone has been somewhat neglected in that respect. Of the approximately 4 million ha of arable land, only two areas are surveyed : 1) Chaouia (Stitou, 1985) with 410,000 ha at a scale of 1:100,000, and 2) Safi (Oumri *et al.*, 1984) with 240,000 ha at a scale of 1:50,000. While potentially much practical use can be made from such maps, we are not aware of any attempt at applying the knowledge contained in such maps, except perhaps for siting field trials or using named soil groupings for greenhouse experiments. Indeed, the initial soil test calibration work at the Aridoculture Center in Settat concentrated on three "benchmark" or representative soils in the Settat area : Chromoxerert, Calcixeroll, and Petrocalcic Palexeroll (Abdel Monem *et al.*, 1990a). As soil analysis can determine ranges of deficiency, adequacy, or toxicity of major or minor elements, fertility or nutrient surveys can reflect the fertilizer needs of a region for crops. Soil test data can be arranged according to region, major crops, or soil type (Cope and Rouse, 1973) and help prioritize and complement fertility research. Though the fertility survey of the Chaouia region was described in detail by Abdel Monem *et al.* (1990b), the main features are presented here to illustrate the concept of variability.

Procedure

The basis for this survey was the soil map by Stitou (1985) of the Chaouia region which used the French classification system. Despite the diversity of soils in the region and complex distribution in some areas, a sampling strategy was devised to reliably reflect the fertility status of each of the major mapped soil types. As the region is devoted mainly to dryland wheat, and the potential implications of the study are mainly related to wheat fertilization, only fields currently cropped to wheat were included in the survey. Four fields from each of the principal mapped soil types or units cropped to wheat were selected on as random as possible basis. A composite sample from each consisted of 10 random subsamples taken in a zigzag pattern to a depth of 0 to 20 cm. As the soil was dry at time of sampling (Oct 1988), the samples were sieved through a 2-mm sieve in the field.

The sampling strategy was modified to accommodate two additional objectives. In view of the importance of P mining in the Khouribga area where the soils were unmapped, samples were taken at 1 to 10 km to the west of Berrechid, and 2 to 12 km adjacent to the road to the east of Oued Zem. Because of the importance of some soil types in soil test calibration studies (Abdel Monem *et al.*, 1990a), a more intensive survey approach was adapted. The soil types were Unit 15 (shallow Rendoll or Petrocalcic Palexeroll), Unit 18 (moderately deep Calcixeroll), and Unit 10 (deep Vertisol). In this case, composite samples were taken from a total of 25 wheat fields on each of these three major soil types.

Soil samples were subsequently analyzed in the laboratory for pH (1:2.5, soil solution) on an electronic meter; organic matter by the standard Walkley-Black procedure; $CaCO_3$ by the calcimeter, NO_3-N by colorimetry using chromothropic acid; P by the standard Olsen $NaHCO_3$ procedure followed by measurement with molybdenum blue; K by *IN* NH_4OaC and determined by atomic absorption, and micronutrient cations according to the chelate extraction procedure of Lindsay and Norvell (1978).

These data were interpreted in terms of critical values, i.e., measurements below which a deficiency would be likely to occur, and a crop response likely to increase if that particular element were added as a fertilizer. For NO_3, the threshold range was considered as 7 to 10 ppm, 5-7 ppm for $NaHCO_3$-P (Ryan and Matar, 1990) and 150 ppm for K (Halvorson *et al.*, 1987), and 5.0, 0.8, 0.2, and 1.0, for Fe, Zn, Cu, and Mn, respectively (Lindsay and Norvell, 1978).

Results

The total number of wheat fields sampled from 25 soil types provided overall values of soil nutrients (Table 1). Virtually all samples were calcareous. As a consequence, most pH values were about 8.1. The mean NO_3-N value of 6.2 ppm suggested that at least a significant fraction of the fields were deficient since this value was less than the critical value of 7 to 10 ppm. Indeed, this was reflected in the wide range in values, i.e., 3.0 to 19.3 ppm. The mean P values of 14.1 ppm suggested that most samples were adequate in P in view of the critical P values of 5 to 7 ppm.

Overall K levels also suggested adequacy. An obvious exception was one mapping unit (No. 5), which was sandy in texture with very little clay. This shallow soil is of limited distribution in the area. While mean Fe, Zn, and Cu values appeared adequate, some were obviously less than the critical level for these elements. For all nutrients, the wide range and variability, as reflected by SD and CV values, suggested a closer look at the data.

Mean values for each of the 25 soils indicated that most samples were deficient in NO_3, while only a few soils were low in P or K. There was no apparent relationship between organic matter (OM) and any of these elements. Though OM varied widely, it tended to be higher on the shallower soils, i.e., Unit 15 (Rendoll). Presentation of the micronutrient data revealed further disparities. It was apparent that virtually all soils were well supplied with both Mn and Cu. However, few soils were above the critical levels for Zn and to a lesser extent for Fe. These trends were quantified for the two categories of micronutrients and showed that 56,8, and 12% of the samples were deficient in N, P, and K, respectively. The corresponding figures for Zn, Fe, Cu, and Mn were 84, 28, 4, and 0%, respectively.

The second type of survey was more intensive rather than extensive, since 25 rather than four fields were sampled from only three major or "benchmark" soils. Though the most common soils in the environs of Settat, wide differences with respect to fertility were observed among. These data, particularly for major nutrients, illustrated important differences due to soil type. While mean NO_3 values for the

Table 1. Mean soil analyses of wheat fields from 25 soil types in Chaouia, Morocco, 1988/89.

Parameter	pH	$CaCO_3$	OM	NO_3-N	P	K	Fe	Zn	Cu	Mn
		------ (%)	-------	------------	-------	----- (ppm)	-------	-------	-------	------
Mean	8.1	4.7	3.2	6.7	14.1	220	5.5	0.9	0.5	23.3
Minimum	6.4	0	1.1	3.0	3.6	15	2.0	0.4	0.1	5.0
Maximum	8.6	21.3	6.2	19.3	37.4	1450	24.0	4.3	1.4	4.7
Standard deviation	0.4	5.3	1.2	2.6	9.8	167	3.0	0.7	0.2	1.1
Coefficient of variation	4.9	113.1	38.5	38.0	69.7	75.5	54.1	76.2	49.2	6.8

[1] OM = organic matter.

three soils were less than the critical values; NO_3 in the Vertisol (Unit 10) was considerably less than the other shallower soils. This soil is intensively cultivated and no fallowing is normally practiced. However, yields on this soil are normally much higher than on the Rendoll (Unit 15), where fallowing is common.

Phosphorus, on the other land, exhibited a different pattern. All mean values were less than the critical value, with the samples from the Sidi El Aydi-Berrechid plain area (Unit 18, Calcixeroll), being well supplied with "available" or $NaHCO_3$-P. Potassium, too, was well above the supposed critical level for two of the soils and marginally so for Unit 18. Thus, of these elements, NO_3 is the only one that one would need to be concerned about. Mean micronutrient values not only varied between soils by any element, but the general level for adequacy varied for any element. For instance, Cu and Mn were well above their respective critical values. However, they followed the same relative order between soils. The two elements which may pose possible plant nutrition problems were Fe, where mean values were just above the accepted critical level, and Zn, which was marginal for two soils (Units 10, 15) and considerably lower for Unit 18.

VARIABILITY AT EXPERIMENT STATIONS

Experimentation is the cornerstone of agricultural development. Field stations have been the testing ground for new ideas and practices. The history of agriculture in the past century has revolved around the agricultural experiment station. Their relevance is no less important today, particularly in developing countries where on-farm options are more difficult to obtain.

In Morocco, the national research organization or the Institut National de la Recherche Agronomique (INRA) has a network of stations which are either commodity- or discipline-oriented depending on the location. In the low-rainfall, resource-poor dryland zone (250-450 mm/yr) such stations are all the more crucial in catalyzing innovations and rural change. Theoretically, experiment stations should represent broad agroecological zones, especially in terms of rainfall, temperature, and soil type. While some characteristics at stations do not change with time, some soil properties do change, especially with respect to nutrient availability.

For example, with continued fertilization available P accumulates in the soil (Halvorson and Black, 1985), thus reducing or eliminating the need for P fertilizer. As stations are used in small segments or parcels by a variety of researchers and for different purposes, a differential pattern of fertility levels is inevitable. For example, Ryan *et al.* (1980) found large differences between individual research plots; while P declined with depth, land areas devoted to more intensively-fertilized irrigated crops had higher residual levels of P than the corresponding rainfed area. In view of the possible consequence for fertilizer use and the type of experimentation, Ryan *et al.* (1990) assessed the fertility status of five stations in dryland area of Morocco. The highlights of their survey are presented here to illustrate nutrient variability.

Procedure

The stations surveyed were in two broadly differing climatic zones. In the more favorable Chaouia area (over 380 mm/yr), three locations were considered: 1) the Ain N'Zagh station at the Aridoculture Center with most shallow and highly variable soils, 2) Sidi El Aydi (SEA) with relatively deep soil (Vertic Calcixerolls and Vertisols) which were intensively used since 1972, and 3) the newly-acquired Jemat Riah, 20 km to the east of SEA with a relatively deep Vertic soil. The two stations in the drier southern zone (280 mm/yr) are similar in soil type, primarily Vertisols, and relatively close to one another. Based on rudimentary soil maps or sketches and on existing plot plans, each plot was intensively sampled (10 cores per plot to form a complete sample) and analyzed for available nutrients.

Results

While broad differences existed among stations (Table 2) the main concern here is variability within such relatively small land units. Within any one station, organic matter levels varied two- to threefold. However, the distribution of NO_3-N, Olsen-P, and extractable K showed even wider variation. For instance NO_3-N values ranged from 3 to 52 ppm at Khemis Zemamra, while P ranged from 7 to 68 ppm at the same station. Though K values were much larger than either NO_3-N or P, the range was similar to that of organic matter. While variability in micronutrients was low in some stations, it was high in others, with no consistent pattern for any element.

What emerged from this study was the conclusion that any plot at these stations can vary greatly from adjacent plots in terms of organic matter and nutrient availability. While organic matter is more likely to reflect natural soil variation since changes in soil levels because of cultivation and crop management are slow, the wide variation in NO_3-N and P can only be attributed to fertilization. While the plots also varied with depth, differences were minimal at about 0.5 m. Thus, nutrient accumulation mainly affected the surface horizons. In some cases K showed an irregular pattern with depth because of soil genetic factors.

The most obvious implications of this survey pertain to N and P fertilizer use. Where such levels are above the critical values in any plot, these elements could be omitted thus saving on fertilizer costs. Also where levels are higher than critical values, experiments which seek to evaluate response or compare application methods should be avoided. Both man-made and natural soil variability should be considered in the design of field trials. Similarly, awareness of field variability can help explain apparently random deficiencies or growth irregularities in the field. Likewise, where field trials are being established, individual plots should be sampled.

LOCALIZED FIELD VARIABILITY

Soil differences occur naturally as a result of genetic processes and its position on the

Table 2. Variability of soil properties at five agricultural experiment stations in Morocco's rainfed zone, 1988/89.

		Element[1]						
Station	Variance	OM	NO_3-N	P	K	Fe	Zn	Mn
Ain N'Zagh	CV.	26	51	42	21	14	15	33
	Max.	5.6	15	35	285	4.2	1.3	12.3
	Min.	2.3	3	8	160	6.1	0.9	4.3
Sidi El Aydi	CV.	13	56	27	163	40	65	51
	Max.	3.2	50	35	500	8.4	2.0	29
	Min.	1.9	7	11	275	1.0	0.1	0.9
Jemaa Shaim	CV.	29	65	24	86	34	8.7	32
	Max.	2.8	25	24	330	16.7	3.9	9.9
	Min.	1.1	4	9	210	31	0.2	2.5
Khemis Zemamra	CV.	22	12	67	35	113	13	58
	Max.	2.6	52	68	284	63.6	0.8	19.9
	Min.	1.2	3	7	45	2.8	0.6	2.5
Jemat Riah	CV.	22	12	67	34	30	18	15
	Max.	2.2	17	88	185	11.7	0.9	101.6
	Min.	1.1	5	17	130	3.0	0.5	58.0

CV = Coefficient of Variability; Max. = maximum; Min. = minimum.

[1] Values in ppm for Max. and Min., except organic matter (OM), which is based on %.

landscape. In addition to inherent soil differences, variation in fertility can occur because of deposition of annual droppings, uneven vegetative stands resulting from selective grazing, uneven hand-broadcasting of fertilizer, small fields, rotations, and erosion, etc. In Morocco, the situation is even often compound because of the absence of permanent field boundaries. Soil sampling of any field or group of fields assumes a degree of uniformity and a practical number of sub-samples to reflect that sampling unit's fertility. The purpose of this study was to highlight the variation that can exist over small seemingly uniform areas and to examine the hypothesis that they may be linked with cultural practices.

Procedure

The on-farm site was about 5 km from Settat in the Chaouia region. The area is usually devoted to cereals--barley and wheat--in rotation with legumes or corn and weedy fallow. The mean annual rainfall is 386 mm while the soil is a Petrocalcic

Palexeroll. Two adjacent 4-ha sites were chosen; one comprised seven fields or parts thereof while the other was from one field. Each site consisted of a 200 x 200 m grid with samples taken to a depth of 0-30 cm every 20 m in October 1989 prior to the growing season. Samples were subsequently analyzed in the laboratory for nitrate, $NaHCO_3$-P, extractable K, organic matter, and DTPA-extractable Fe, Mn, Zn, and Cu (Lindsay and Norvell, 1978).

Results

An overall picture of the variability in organic matter and plant nutrients is given in Table 3. While the variation in organic matter was relatively low - being a function of soil type and environment - all nutrients showed wide variation, especially NO_3 and available P. While this variation was not spatially depicted, the range was so wide as to reflect the heterogeneity of the site. Contrary to the belief that the one-field site would be more uniform than the multi-field site, the one field site in fact tended to be even more variable. For both sites, the micronutrients, except Mn, tended to be less variable than the macronutrients whose distribution was probably influenced by N and P fertilizer application. In fact, an examination of NO_3 distribution indicated

Table 3. Descriptive statistics for soil variables at two sites[1], Chaouia region, Morocco.

Variable	Minimum		Maximum		Mean		Range		SD		CV	
	A	B	A	B	A	B	A	B	A	B	A	B
	(ppm)											
O.M.	4.2	4.3	6.2	6.5	5.1	5.2	2.0	2.2	0.3	0.3	5.8	6.6
NO_3	2.8	121	43	73	12.6	12.5	40	71	6.5	9.9	52	46
P	3.0	5.4	48	70	9.0	14.6	45	65	5.4	8.4	60	58
K	155	90	950	500	280	218	967	498	86.4	73	31	34
Fe	2.2	2.3	7	7	4.1	4.3	4.8	4.7	1.1	1.0	27	22
Mn	3.0	3.8	20	8.7	10.6	2.6	16.8	8.3	3.6	22.3	34	86
Cu	0.1	1.4	1.8	7.4	1.0	3.1	1.7	6	0.3	1.1	28	34
Zn	0.1	0.2	1.9	3.1	0.5	0.8	1.8	2.9	0.2	0.4	43	51

[1] Site A = 7 fields, Site B = one field.

a relationship with field boundaries; in fields where an N-fixing legume was grown the previous year, values for residual soil NO_3 were higher than for fields without a legume.

CONCLUSIONS AND IMPLICATIONS

Despite the range in scale of the areas surveyed, all underlined the concept of variation of spatially distributed nutrients. The principal conclusions and ensuing implications are presented for each.

The regional survey pinpointed the almost universality of N deficiency, and thus, the need for stressing N fertilization. On the contrary, P deficiency was less frequent, and that of K rare. Fertilizer recommendations and formulation should consider these needs. However, it was clear that soil type greatly influenced mean nutrient levels.

The experiment station survey indicated that:

1. The variation between plots or samples for individual stations can be attributed to man or nature, depending on the element.
2. The highest levels of NO_3 at Sidi El Aydi were probably because of continuous use of N fertilizers leading to N accumulation. However, with cropping and reduced fertilization, this "surplus" soil N could be depleted in a few seasons.
3. The high levels of P at all stations were probably because of fertilization. Unlike NO_3, this level could not be reduced within a few seasons' cropping.
4. The variation in K is probably related to differences in mineralogy of the individual soils.
5. Potassium deficiency is unlikely to occur for dryland wheat in the limited-rainfall area.
6. If any micronutrient deficiency would occur, it would probably be that of Fe or Zn. Of the crops grown in the semiarid rainfall area, wheat and barley are least likely to have problems with either element.
7. The high levels of Mn at the Jemat Riah station (formerly Monin Lucien) may be related to inherent geology or intensive P fertilization.
8. The variation in micronutrients is probably related to natural soil variation, since these elements are not normally added as fertilizers.

This variability has implications for all categories of people involved with station work. Research should select trial sites for plots based on fertility levels. Where such levels are high, fertilizer use should be restricted or eliminated, thus reducing operation costs.

While recognizing fertility variation within any field, the sampling scheme for soil analysis should : a) consider fields or areas of fields where legumes were grown, and b) provide sufficiently large number of sub-samples to reliably reflect the mean fertility status of the field. Devising appropriate sampling schemes will depend on a more detailed consideration of the spatially variable data.

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Direct and Residual Effects of Applied Phosphorus on Water-Use Efficiency, Yields, and Nutrient Uptake of Lentil

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ABSTRACT

The purpose of the work was to study, under contrasting soils and rainfall conditions, the relative contribution of residual P (accumulated from previous P applications) and direct P (drilled with lentil seed at sowing) in meeting the P requirement, crop growth rate, plant N accumulation, yield, and water-use efficiency (WUE) of lentil. The experiment was conducted at three sites: Breda (278 mm), Tel Hadya (345 mm), and Jindiress (452 mm) for two consecutive seasons (1987/88 and 1988/1989), using different fields every season.

Each field was divided into five plots with two replicates. Phosphorus was applied at 0, 50, 100, 150, and 200 kg P_2O_5/ha, with Tel Hadya and Jindiress planted to wheat and Breda left fallow (residual P). The main plots were divided into three subplots and lentil was grown the second year, with direct P application at rates of 0, 50, and 100 kg P_2O_5/ha. The experimental design was split-plot, with residual P as the main plots and direct P as the subplots. Three treatments were selected to study the water use by lentil: P_0 (control), P_{R100}(100 kg P_2O_5/ha, residual), and P_{D100}(100 kg P_2O_5/ha direct to lentil), using a neutron probe to record with time the change in soil moisture to a depth of 150 cm. Biological yields were determined at five to six growth stages. Nitrogen and P contents were analyzed and total uptake determined at all stages. At harvest, grain and straw yields were determined and analyzed for N and P.

At Breda, both residual and direct P contributed significantly in increasing the rate of lentil growth and grain and straw yields over the two seasons. At Tel Hadya, residual P significantly increased biological yield. However, direct P alone did not have any significant effect on yield in either season. Likewise, at Jindiress, residual P significantly increased yield. Water-use efficiency in the first rainy season ranged between 15 and 23 kg/ha/mm for total yields at different sites, with no significant effect of direct or residual P. However, in the second dry season, direct and residual P increased WUE, though not significantly (WUE ranged between 10.9 and 20.4 kg/ha/mm). In both seasons, residual P had a very significant effect on total N and P uptakes, growth, and yield at harvest, at all three sites. Directly applied P alone had a significant effect only at Breda. Significant (1%) linear relationships were observed between water use (WU) and total dry matter (TDM) during crop growth up to harvest, and between WU and N or P uptake.

INTRODUCTION

Lentil is an important crop in the rainfed farming systems in the dry areas of West Asia and North Africa (WANA), where its grain is a valuable source of good-quality protein in the human diet. Lentil is grown in rotation after cereals on highly calcareous soils that are naturally low in native P. In Syria, and elsewhere in the region, significant responses of lentil to P application have been reported (Loizides 1970, Matar *et al.* 1987, 1990). In 1986/87, an investigation of the response of food and forage legumes to P fertilization was initiated under controlled conditions at Tel Hadya station. The legumes (faba bean, chickpea, pea, vetch, and lentil) were equally responsive to both applied and residual P (FRMP Annual Report, 1988). Biologically, residual and applied P are likely to have a different "timing" of availability, and we would expect the relative importance of the two sources to depend not only on the characteristics of legume root development, but also on the soil type and on the particular seasonal temperature and rainfall distribution.

In the present work, and because of the importance of lentil in the rainfed cropping systems of the Near East, the interactions between P fertilization and water use in lentil yields and nutrient uptake were investigated under different soil and environmental conditions.

MATERIALS AND METHODS

The study was carried out in 1987/88 and 1988/89 at three ICARDA stations: Breda (278 mm), Tel Hadya (345 mm), and Jindiress (452 mm). General information on soil properties of the sites are provided in Table 1. Meteorological conditions for the two seasons are sketched in Fig. 1.

The experiment was a split-plot design with two replications. The main plots were the P applied (at five levels equivalent to 0, 50, 100, 150, and 200 kg P_2O_5/ha) in the season preceding the experiment (1986/87)--called the residual P (PR). The subplots were the P applied during the season, drilled with the lentil seeds at 0, 50, and 100 kg P_2O_5/ha (directly applied P or PD).

The above-ground total biological yield, and N and P uptakes were determined at five to six growth stages depending upon site and season. At harvest, grain and straw yields were recorded. Soil moisture was measured gravimetrically every 10 days in the 0-15 cm soil layer, and with a neutron probe at 15-cm intervals in the profile to 150 cm. Ground-plant samples were digested (H_2SO_4 solution + 1% Se) and N was determined in the digest by steam distillation, receiving the NH_3 in H_3BO_3, and then back-titrating with 0.01 N H_2SO_4 to pH 5. The P in the digest was determined by the ammonium-vanadate method.

RESULTS AND DISCUSSIONS

The effect of P application on biological yield of lentil will be discussed for all treatments. However, discussion on the interaction between water use and growth, yields, and nutrient uptake by lentil will focus on three treatments in which the water content of the soil profile was measured: plots that received 100 kg P_2O_5/ha in the preceding season (PR 100); plots that received 100 kg P_2O_5/ha in the current season (PD 100), but none in the preceding season; and the control (P0).

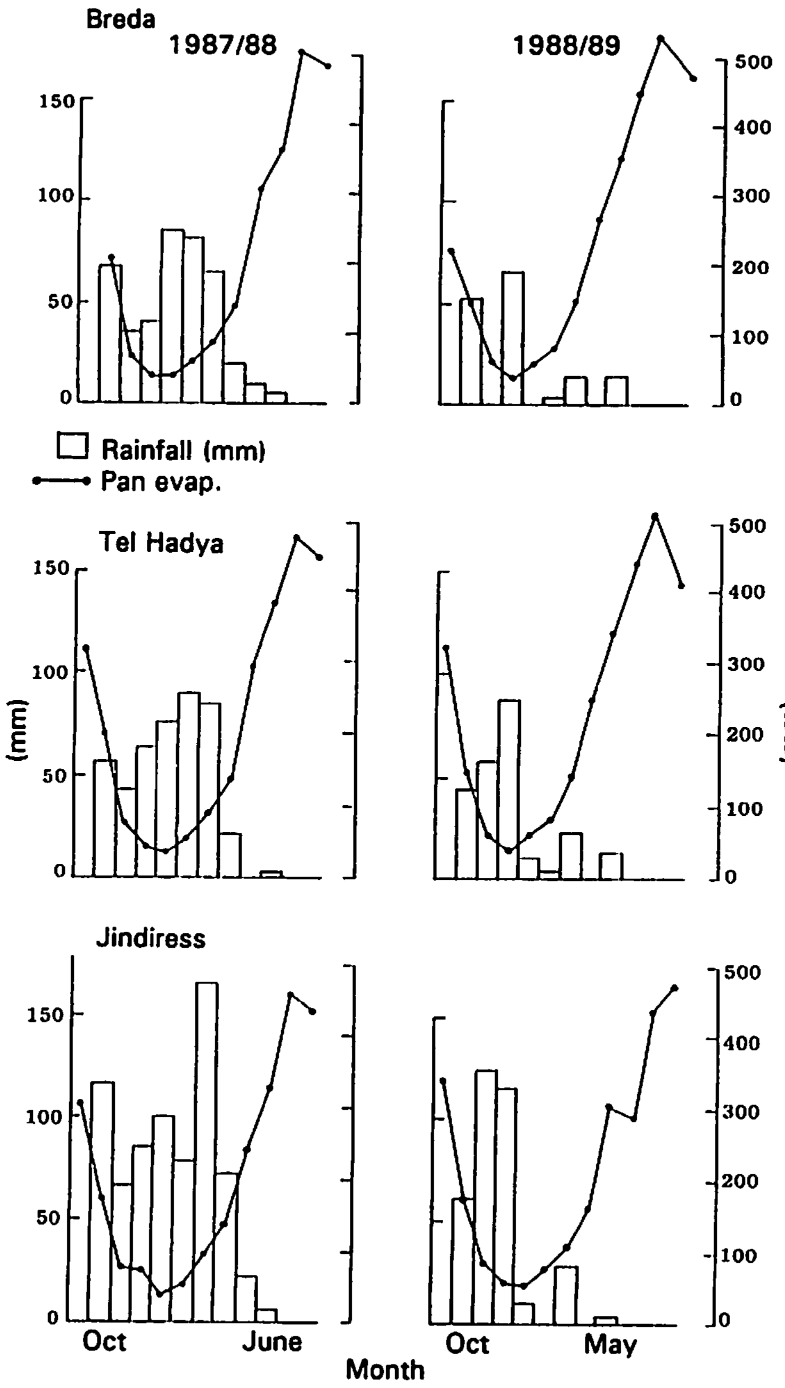

Fig. 1. Monthly variation in precipitation and pan evaporation at the ICARDA three experimental stations, 1987/88 and 1988/89.

Table 1. Some chemical and physical analyses of the soil at three experimental sites, Syria, 1987-89.

Site	Depth (cm)	pH	E.c. (ms/m)	Total-N (ppm)	$CaCO_3$	Active lime	OM	Texture
					(%)			
Breda	0 - 20	8.3	0.29	650	30.0	9.4	1.17	clay loam
	20 - 40	8.4	0.34	310	31.1	14.5	0.74	clay loam
	40 - 60	8.5	0.26	240	37.1	22.2	0.58	silty clay
	60 - 90	8.5	1.56	170	56.5	19.0	0.35	silty clay
	90 - 120	8.3	5.00	100	50.0	12.4	0.25	clay loam
	0 - 20	8.1	0.18	460	27.9	8.8	0.80	clay
Tel Hadya	20 - 40	8.1	0.18	430	29.1	10.6	0.69	clay
	0 - 60	8.1	0.22	310	28.9	10.6	0.62	clay
	60 - 90	8.1	0.32	240	28.1	10.6	0.55	clay
	90 - 120	8.1	0.32	160	28.6	10.1	0.51	clay
	120 - 150	8.1	0.30	210	28.6	9.6	0.48	clay
Jindiress	0 - 20	7.9	0.18	670	19.5	10.5	1.10	clay
	20 - 40	7.9	0.15	610	20.4	11.1	1.00	clay
	40 - 60	7.9	0.14	440	21.2	11.3	0.83	clay
	60 - 90	7.8	0.17	530	21.6	11.1	0.74	clay
	90 - 120	7.8	0.17	380	22.4	11.3	0.60	clay
	120 - 150	7.8	0.18	280	23.9	11.8	0.50	clay

EFFECT OF PHOSPHATE APPLICATION ON LENTIL GROWTH AND YIELD

The effects of newly applied P and residual P on lentil growth were monitored at various growth stages, from emergence to maturity. In both seasons, new P (drilled with the seed) had a positive and significant effect on total above-ground dry-matter production, plant P%, and total P uptake (TPU) at Breda, but at Tel Hadya and Jindiress only few responses were observed (Table 2). However, it was remarkable that responses to residual P, from fertilizer applied for the crop preceding lentil (wheat at Tel Hadya and Jindiress, and fallow at Breda) and mixed with the plow layer by pre-seeding cultivation, proved to be more important and efficient at Tel Hadya and Jindiress as well as at Breda (Table 2). The P% of lentil plant material was significantly higher in the presence of residual P at all three sites and in both seasons. Furthermore, whenever a P response occurred, residual P was equal and sometimes superior to newly applied P in increasing dry-matter accumulation or TPU. However, both applied and residual P contributed to growth and P uptake of lentil, especially at the dry site, Breda.

Table 2. Significance levels of the responses of plant components to residual or newly applied P fertilizer (kg/ha) at three experimental sites, Syria, 1987-89.

Component	New P				Residual P			
	Growth stage				Growth stage			
	S1	S2	S3	S4	S1	S2	S3	S4
				1987/88				
Breda								
Total dry matter	xx	xx	xx	xx	NS	xx	x	x
Plant P%	xx	xx	xx	xx	xx	xx	xx	xx
Total P uptake	xx	xx	xx	xx	xx	xx	xx	xx
Tel Hadya								
Total dry matter	NS	x	NS	NS	NS	x	NS	x
Plant P%	x	NS	NS	NS	NS	x	xx	NS
Total P uptake	NS	NS	NS	x	NS	x	x	x
Jindiress								
Total dry matter	NS	x	NS	-	NS	NS	NS	-
Plant P%	x	NS	x	NS	xx	xx	xx	xx
Total P uptake	NS	x	xx	-	xx	NS	x	-
				1988/89				
Breda								
Total dry matter	xx	xx	xx	xx	xx	xx	xx	xx
Plant P%	xx	NS	NS	NS	xx	xx	NS	NS
Total P uptake	xx	xx	x	xx	xx	xx	xx	xx
Tel Hadya								
Total dry matter	NS	NS	NS	NS	NS	x	xx	x
Plant P%	NS	NS	NS	NS	xx	NS	xx	xx
Total P uptake	NS	NS	NS	NS	xx	xx	xx	xx
Jindiress								
Total dry matter	NS	NS	NS	NS	NS	NS	NS	NS
Plant %	NS	NS	x	NS	NS	xx	x	x
Total P uptake	NS	NS	NS	NS	NS	NS	NS	x

S1 = early; S2 = advanced early; S3 = full flowering; S4 = early podding.
NS = nonsignificant; x = 5% ; xx = 1%.

Total dry matter (grain + straw) at harvest was responsive to P, especially to residual P, and where soil Olsen-P was low (<4 ppm). This was observed in the 1988/89 season when all three sites had soil available P values of less than 3.9 ppm, and in 1987/88 at both Breda and Tel Hadya; at Jindiress, with Olsen-P equivalent to 4.8 ppm, no response to P application was observed (Tables 3 and 4). Previous work had shown that a critical level of about 5 to 6 ppm of Olsen-P could lead to maximum production of lentil (Matar *et al.*, 1987).

The response to a new application of P was highly significant (1%) in both seasons at Breda only. At harvest, no effect of new P was evident at Tel Hadya or Jindiress. One could conclude that applying P with the seed is important at Breda because its immediate availability provides a boost to young seedlings. This leads to a better coverage of the soil surface and a reduced water loss by evaporation, which is especially important at Breda because it is the driest site.

Table 3. Effects of residual and newly applied P on total dry matter of lentil at three experimental sites, Syria, 1987/88.

Newly applied P (kg/ha)	Residual P (kg P_2O_5/ha)					
	0	50	100	150	220	Mean
Breda						
0	6092	6740	6811	7300	7557	6900
50	7414	7410	7552	7846	7588	7569
100	7625	7726	7610	7294	7524	7556
Mean	7044	7292	7334	7480	7556	
Significance	New P (**); Residual P (*); Interaction (*)					
Tel Hadya[1]						
0	5188	6752	5988	7710	6661	6460
50	6057	6813	6323	7635	7193	6804
100	6032	7498	6424	7154	7974	7016
Mean	5759	7021	6245	7500	7276	
Significance	New P (NS); Residual P (**); Interaction (NS)					
Jindiress						
0	7694	7890	7855	7777	8204	7884
50	7888	7827	8044	8181	8060	8000
100	7739	8214	7543	7884	8022	7880
Mean	7773	7977	7814	7947	8095	
Significance	New P (NS); Residual P (NS); Interaction (NS)					

[1] Tel Hadya field was moderately infected with Orobanche.

* Significant at the 5% level.

** Significant at the 1% level.

NS = nonsignificant.

Table 4. Effects of residual and applied P on total dry matter of lentil at harvest, at three experimental sites, Syria, 1988/89.

Newly applied P (kg/ha)	Residual P (kg P_2O_5/ha) 0	50	100	150	220	Mean
Breda						
0	1321	1497	1441	1845	2077	1636
50	1683	1818	1697	1977	2059	1847
100	1577	1762	1626	2032	1928	1785
Mean	1527	1692	1588	1951	2021	
Significance	New P (**); Residual P (**); Interaction (NS)					
Tel Hadya						
0	1664	1881	1920	2048	2001	1902
50	1588	1973	2105	1887	2274	1965
100	1609	1893	1698	2176	1961	1868
Mean	1620	1916	1907	2037	2079	
Significance	New P (NS); Residual P (**); Interaction (NS)					
Jindiress						
0	3248	3649	4198	3979	3991	3813
50	3617	3521	4114	3743	4038	3806
100	3640	3251	4242	3668	3531	3667
Mean	3501	3474	4185	3797	3853	
Significance	New P (NS); Residual P (*); Interaction (NS)					

* Significant at the 5% level.
** Significant at the 1% level.
NS = nonsignificant.

The effects of P application on lentil grain production were indirect. Table 5 shows that grain yields were quite high (2.2 - 2.5 t/ha) at all three sites, under the high rainfall of 1987/88 (414 mm at Breda rising to 715 mm at Jindiress). But, increasing the P rate, either in the current or preceding season, tended to reduce grain yield. The reason for this is not known yet. In 1988/89, rainfall was scarce (194, 249, and 352 mm at Breda, Tel Hadya, and Jindiress, respectively), and mean grain yields were 538, 653, and 1254 kg/ha, respectively. The response of grain yield to residual P was positive and significant at all three sites (Table 6), but no significant effect of newly applied P was observed, except at Breda.

Again, these results demonstrate that response to P fertilization is relatively more important in dry years. In wet years, root development is more extensive and the pool of available P in the soil is effectively larger, which reduces the need for P fertilizer in all but the most P-deficient soils.

Table 5. Effects of residual and applied P on grain yield of lentil at three experimental sites, Syria, 1987/88.

Newly applied P (kg/ha)	Residual P (kg P_2O_5/ha)					
	0	50	100	150	220	Mean
Breda						
0	2278	2415	2314	2376	2314	2339
50	2621	2451	2432	2322	2108	2387
100	2334	2369	2296	2181	2049	2246
Mean	2411	2412	2348	2293	2157	
Significance	New P (*); Residual P (**); Interaction (NS)					
Tel Hadya						
0	2081	2489	2114	2290	2310	2257
50	2383	2354	2321	2495	2048	2320
100	2218	2562	2167	2308	2537	2358
Mean	2227	2413	2201	2364	2354	
Significance	New P (NS); Residual P (NS); Interaction (NS)					
Jindiress						
0	2961	2765	2696	2675	2607	2741
50	2804	2283	2488	2646	2337	2511
100	2807	2794	2531	2300	2524	2591
Mean	2857	2614	2572	2540	2489	
Significance	New P (*); Residual P (*); Interaction (NS)					

* Significant at the 5% level.
** Significant at the 1% level.
NS = nonsignificant.

PHOSPHORUS APPLICATION AND WATER USE BY LENTIL

Water use by lentil was similar at all three sites in 1987/88, with average values of 329, 344, and 374 mm at Breda, Tel Hadya, and Jindiress, respectively; water-use efficiency (WUE) was apparently unaffected by newly applied or residual P (Table 7). In 1988/89, WUE was slightly but significantly (5%) increased by direct or residual P at Breda, and by residual P only at Jindiress (Table 7). No significant effects were observed at Tel Hadya. In general, improvements in WUE from P application were less apparent for lentil than were previously reported for barley (Cooper *et al.*, 1987).

Table 6. Effects of residual and applied P on grain yield of lentil at three experimental sites, Syria, 1988/89.

Newly applied P (kg/ha)	Residual P (kg P_2O_5/ha) 0	50	100	150	220	Mean
Breda						
0	417	474	407	587	652	507
50	547*	599*	494	581	625	569
100	477	553*	480	625	559	539
Mean	480	542	450	598	612	
Significance	New P (**); Residual P (**); Interaction (*)					
Tel Hadya						
0	582	646	655	737	680	660
50	547	696	690	638	772	668
100	560	624	596	739	631	630
Mean	563	655	647	705	694	
Significance	New P (NS); Residual P (*); Interaction (NS)					
Jindiress						
0	1039	1144	1220	1377*	1384*	1233
50	1213	1188	1293	1371	1415	1296
100	1191	1044	1350	1238	1346	1234
Mean	1148	1126	1287	1328	1382	
Significance	New P (NS); Residual P (**); Interaction (NS)					

* Significant at the 5% level.
** Significant at the 1% level.
NS = nonsignificant.

WATER USE, TOTAL DRY MATTER, N AND P UPTAKE OF LENTIL

A linear relationship was found, as expected, between water use by lentil and total biological yield, taken across all growth periods in both seasons and across all three sites, with R^2 values of 0.84 and 0.87 for P-fertilized and nonfertilized treatments, respectively (Table 8). Also, similar linear relationships occurred between lentil water use and total N and P uptakes. This may be attributed, in the case of P, both to the direct effects of greater P mobility and availability under wetter soil conditions and to the indirect effect of the biomass-water use relationship. For N, the effect of moisture on root proliferation and depth may have been a significant factor. From regressions cited in Table 8, a general estimate of total N and P uptakes by lentil can be calculated from the volume of water used, and vice versa.

Table 7. Phosphate application for yields and water-use efficiency of lentil sown at three experimental stations for two consecutive seasons (1987/88 and 1988/89).

Parameter	Breda						Tel Hadya [1]						Jindiress					
Season rainfall	1987/88 (414 mm)			1988/89 (194 mm)			1987/88 (449 mm)			1988/89 (249 mm)			1987/88 (715 mm)			1988/89 (352 mm)		
Available P (ppm)	3.1	8.3	3.4	2.8	10.5	2.2	3.0	5.9	2.8	3.2	6.3	3.2	4.7	7.3	3.5	3.4	9.2	3.9
P treatment	PO	PR	PD	PO	PR	PD	PO	PR	PD	PO	PR	PD	PO	PR	PD	PO	PR	PD
Water use (mm)	309	317	331	114	111	107	345	367	320	153	151	156	368	372	383	218	206	21
Water-use efficiency (kg TDM/ha/mm)	19.7	21.5	23.0	11.6	13.0•	14.8•	15.0	16.3	18.8	10.9	12.8	10.3	20.9	21.1	20.2	14.9	20.4•	17.1
kg grain/ha/mm	7.4	7.3	7.1	3.7	3.7	4.5	6.0	5.8	6.9	3.8	4.4	3.6	8.1	7.3	7.3	4.8	5.9	5.6

PR = residual P with 100 kg P_2O_5/ha applied to preceding crop.

PD = new application of 100 kg P_2O_5 applied with the seed drill.

[1] Possible loss of water by deep precolation, shallow site (< 1 m deep).

• Significant at the 5% level.

Table 8. Relationships between lentil parameters taken across various growth stages, sites, seasons (1987/88 and 1988/89), with or without direct P application.

Dependent variable	Regression equation	R^2
TDM (P0)	= 20.28 WU - 1256.8	0.87**
TDM (P+)	= 21.60 WU - 1152.5	0.84**
TPU (P0)	= 0.042 WU - 2.31	0.81**
TPU (P+)	= 0.051 WU - 2.63	0.77**
TNU (P0)	= 0.429 WU - 20.23	0.88**
TNU (P+)	= 0.464 WU - 17.21	0.83**

TDM = total dry matter; TPU = total P uptake; TNU = total N uptake;
WU = water use; P+ = with P; P0 = without P.
** Significant at the 1% level.

CONCLUSIONS

It may be concluded from the present work that:

1. Residual and directly applied P are likely to have a different timing of availability, and the relative importance of the two sources depends on the soil type, particular seasonal temperature, and rainfall distribution.
2. Phosphorus drilled with lentil seed was, in general, found to be much less effective than residual P on growth, biological and grain yields, and total N and P uptakes of lentil. Direct P was significant only in the dry sites and/or dry seasons where rapid plant establishment after sowing could lead to good soil coverage, reducing evaporation and improving water use efficiency by lentil.

Finally, for practical purposes and for best P-use efficiency, it is advisable to apply most of the lentil P requirement to the preceding cereal crop. However, a small portion of P could be drilled with the lentil seed to stimulate rapid establishment and good soil coverage.

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DISCUSSION

S. Khattari

From your conclusions, it seems that P placement is a very important factor. We expect that root's activity will also be affected; this will reflect on water-use efficiency and eventually on yield. Will you elaborate on this and how it affected your findings?

A. Matar

P placement had an effect on root distribution at Breda (studied in the 1988/89 season). P application had improved WUE as well as yield, especially straw yield. But P applied to lentil as the previous crop (P residual), which was mixed by cultivation before sowing lentil, was more easily available than directly drilled P with the lentil seeds.

J. Ryan

1) The difference in response to P for barley and lentil is not clear!

2) The absolute response to P in a dry year is low in yield terms. Is this economical?

A. Matar

1) It may be related to root systems of each crop.

Most of the barley roots are close to the soil surface and benefit from P drilled with the seeds at few centimeters from the surface. However, the lentil root could be deeper and could most likely benefit more from P mixed with the plowed layer than from P drilled.

P. Orphanos

Patterns of uptake may also be different.

2) Lentil production is marginal in that area. Probably the best is to fertilize the cereal, and the residual P would benefit the lentil crop. This is the most economical method.

A. Haddad

The lentil grain is one of the richest legume in Fe. Is there any relationship between Fe concentration in the plant and P uptake?

A. Matar

I am not aware of the subject. However, studies on the relationship between P uptake and trace elements of legumes are being conducted at ICARDA. Many examples have been quoted in the literature regarding P x Fe interaction.

I. Papastylianou

By applying additional P to the preceding cereal: a) is there any risk of Zn deficiency? b) can the farmer afford to have inputs and guarantee return two years later?

A. Matar

The additional quantity of phosphate needed to apply to lentil is rather small. I think that there is no risk of Zn-induced deficiency. This method is the most economical.

A. Boukhal

You mentioned that P availability depends on soil moisture. Based on this, what can we say about the critical P level in dryland and in irrigated areas?

A. Matar

Since P should move by diffusion in the soil solution to the root's interface, P availability will increase with soil moisture availability in the soils. Based on this we can say that more soil P is available in the wet or irrigated area than in the dry one, and as a consequence, the critical P level in the dry land will be higher than in the irrigated land. But since the requirement is much higher in the irrigated area, and as Dr Moughli mentioned in his presentation, the critical level of P that optimizes production is expected to be higher in the irrigated area.

A. Abdelmalek

This experiment shows that when developing fertilizer recommendations, residual P is as important as the P applied. Should we consider the crop alone or the whole rotation when providing services to farmers, in order to help increase yield of the crops in the rotation not decrease it?

A. Matar

I think that in developing P fertilizer recommendation we should consider P requirement of the whole rotation.

Soil Water and Inorganic Nitrogen Accumulation at Sowing Time of Wheat in a Two-year Rotation as Influenced by Previous Crops under Central Anatolian Conditions

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ABSTRACT

Established in 1982, the experiment was previously cropped to winter- and spring-sown lentil (*Lens culinaris* L), winter vetch (*Vicia* spp.), chickpea (*Cicer arietinum* L.), cumin (*Cuminum cyminum*), sunflower (*Helianthus anuus* L.), and cereal, and was then left fallow. After these crops were harvested winter wheat was sown in the following season as a test crop. During 1985-87 and prior to wheat seeding, soil water and inorganic nitrogen levels were recorded in a soil profile at 120 cm depth. At harvest, wheat grain yields were determined. The amounts of soil water left in the profile by winter legumes (Hungarian vetch and winter lentil) were the closest to that of fallow, which ranked highest. All the preceding crops, except safflower (*Carthamus tinctorius* L.) and cereal, gave approximately similar or higher inorganic N values than the fallow plots. As a consequence of soil water and N accumulation, wheat yields after legumes and cumin were somewhat higher than, or equal to, yields after fallow. These results have considerable implications for subsequent fertilizer application policy and its use efficiency by winter wheat.

INTRODUCTION

Central Anatolia is the most important wheat-producing region of Turkey, with 37% of the country's total wheat production (7.5 million tons) produced in the area (State Inst. Stat., 1988). Wheat cultivation has been practiced for centuries in rotation with fallow, but with the initiation of a project aiming to reduce the fallow area by replacing it with a crop, a 40% reduction has occurred. As a consequence, cropping intensity has increased, with incorporation of winter or spring crops in rotation with cereals.

These crops may affect subsequent cereals in several ways. Each crop has its own requirements for water and nutrients, so its contribution to the following crop is expected to be different. The most limiting factors for good production in the area are inadequate water and nitrogen. Therefore, development of an effective fertilizer program requires better understanding of the relative effects of previous crops on these limiting factors.

Low precipitation in the dry areas causes low yield, and only small amounts of N are left by the crop. Carryover N affects crop yield in different ways. High levels of N fertilization of cereals in the drier regions cause overstimulation of vegetative growth. Available soil moisture is used by the excessive vegetative growth at the expense of grain yield. Therefore, N fertilization of cereals should be balanced with available water. Olson *et al.* (1976) reported both beneficial and adverse effects of residual soil N on wheat yield. In a fallow area of 400-580 mm rainfall, yield depression from added N occurred when residual soil N exceeded 135 kg/ha, and the potential response curve was below that level.

The main objective of our work was to measure soil moisture and soil NO_3- and NH_4-N contents (to 120 cm depth) at seeding of wheat following different previous crops, and to consider their impact on wheat grain yield.

MATERIALS AND METHODS

Soils in the Central Plateau are mainly characterized by brown and reddish-brown great soil groups, which are poor in P, N, and organic matter, but rich in K and $CaCO_3$. Soil depth ranges from shallow to medium, with mostly heavy texture. Annual precipitation in the region ranges from 250 to 400 mm which falls mainly in winter and spring (Table 1). Both low temperature during winter and low precipitation during summer limit crop growth and development. As a result, the cropping system is dominated by cereal-based rotations.

Table 1. Monthly average precipitation (mm) for the growing periods at the Haymana experimental site, Ankara, Turkey.

	Month*									
Year	10	11	12	1	2	3	4	5	6	Total
1984/85	0.8	20.8	9.9	41.6	55.6	20.6	28.5	35.6	21.9	235
1985/86	64.8	38.0	33.3	49.3	29.0	14.7	11.6	52.4	46.0	339
1986/87	10.6	20.5	42.4	62.5	29.6	28.8	33.8	28.8	62.0	319
1987/88	24.4	33.6	71.9	23.0	26.6	69.0	56.4	35.1	42.2	382

* Jan = 1; Dec = 12.

In Haymana, a two-year rotation experiment was established (1982) in two adjacent fields to obtain data every year. Winter wheat (Cakmak-79) was planted in 10 x 15 m plots every other year following spring crops such as sunflower (SU), safflower (SA), cumin (CU), chickpea (CH), and lentil (SL); and winter crops such as barley (*Hordeum vulgare* L.) or wheat (*Triticum aestivum* L.) (WH), winter lentil (WL), and Hungarian vetch (HV, *Vicia pannonica*), and fallow (FA). Winter crops were sown in October and spring crops in March. In 1985, barley was planted instead of wheat as a previous crop and in the following years wheat was used as the previous crop. Hungarian vetch was harvested for green fodder at the beginning of flowering, and dry-matter yield was measured.

The experimental design was a randomized complete block with four replications. Prior to planting wheat, soil water and mineral N (ammonium and nitrate) were recorded each year in a 120-cm soil profile. Soil mineral N was determined by the MgO-Devarda alloy steam distillation method (Bremner, 1965).

RESULTS AND DISCUSSION

Soil Moisture

Average effects of previous crops on soil moisture accumulation during the 1985-87 growing seasons are shown in **Fig. 1.** These were statistically significant in 1986 and 1987, but not so in 1985. Fallow had the highest water accumulation, while safflower resulted in the lowest water content. However, vetch, cumin, and winter and spring lentil were closest to the fallow. Because winter crops (vetch and winter lentil) left the field earlier than did summer crops (sunflower and safflower) they had higher water accumulation, with the exception of wheat and chickpea. Wheat is a winter crop, but it consumes more water than do shallow-rooted legumes. Chickpea matures late and its contribution of water is low.

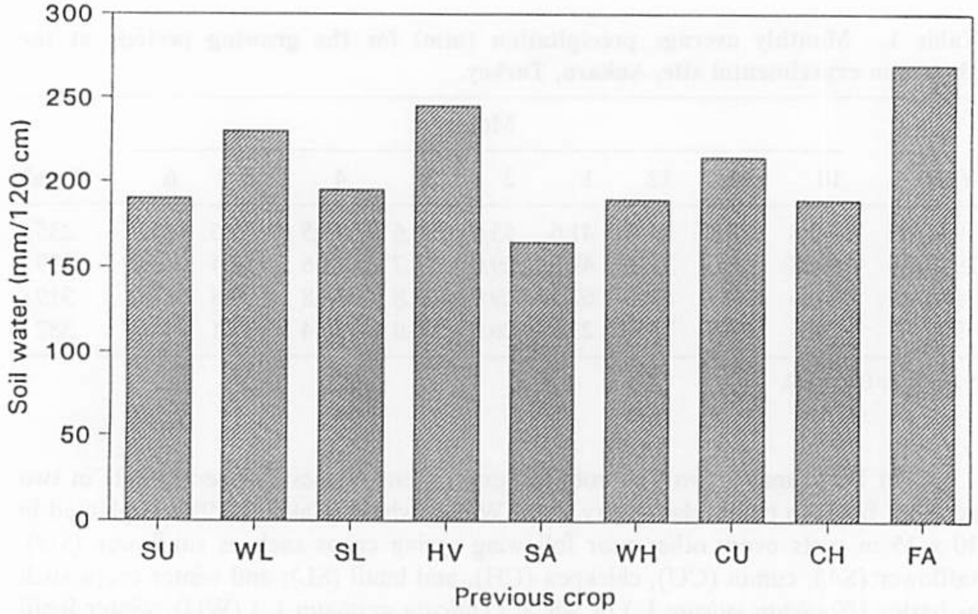

Fig. 1. Soil moisture accumulation to a 120-cm depth as affected by previous crops, Haymana, 1985-87.

Previous crops also affected soil moisture distribution in the 120-cm profile (Fig. 2). Generally, all treatments showed a rapid soil moisture decline from 0 to 30 cm compared with 30 to 120 cm. Fallow was superior to the other treatments, and vetch and winter lentil were closest to it with respect to water content of each layer.

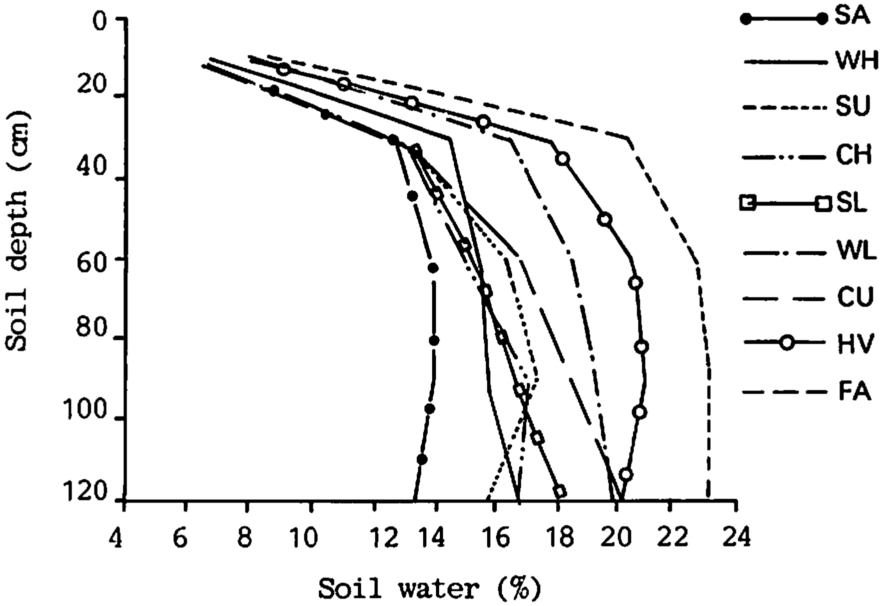

Fig. 2. Soil moisture distribution in the soil profile as affected by previous crops, Haymana, 1985-87.

Inorganic N

Accumulation of soil inorganic N (ammonium and nitrate) in the 120-cm soil profile was significantly affected by previous crops in all three years (Fig. 3). Vetch had the highest accumulation while barley or wheat had the lowest values. All crops, except safflower and wheat, contributed more mineral N to the soil N pool than did fallow at the seeding time of the test crop, wheat. This might have resulted from more N uptake by safflower and wheat.

It is worth noting that the ammonium contents were several times greater than the nitrate contents for each crop effect, suggesting that neither ammonium or nitrate determination alone is sufficient to adequately formulate N requirements of wheat under such conditions. Also, nitrate contents in plots after fallow were greater than those after any crop. This may be explained by more water accumulation in fallow resulting in more nitrification than in plots following a crop.

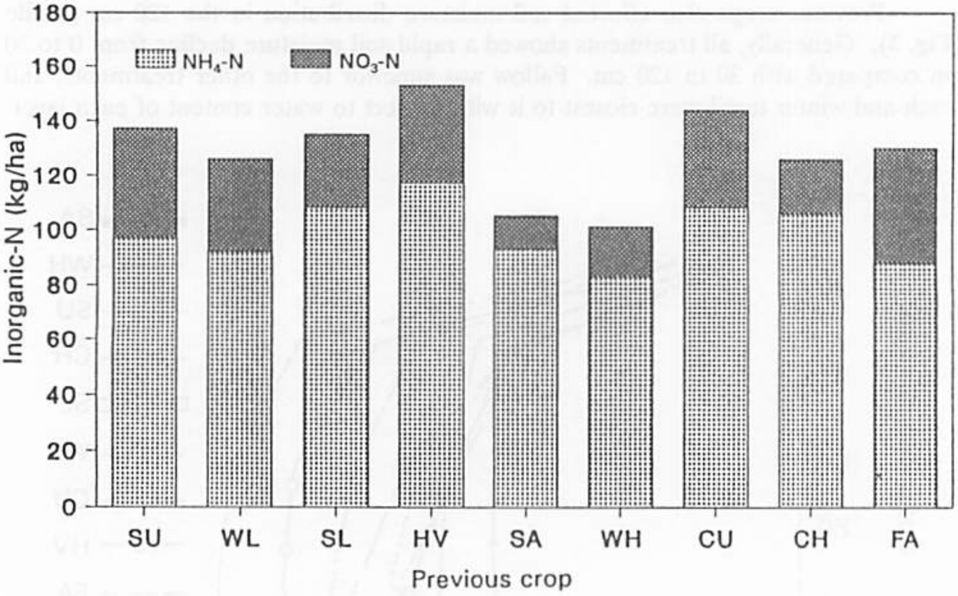

Fig. 3. Soil mineral N accumulation to a 120-cm depth as affected by previous crops, Haymana, 1985-87.

Distribution of total inorganic N was also different for each crop (Fig. 4). In the 0-30 cm layer, fallow and vetch showed highest N accumulation, thus indicating that this layer appears to be an active N mineralization zone. Higher moisture and temperatures in that layer seem to have favored N mineralization under fallow and vetch. The 30-60 cm layer generally seems to be a layer of mineral N accumulation under previous crops. Generally, after that depth mineral N declined, which may be a result of shallow moisture penetration during the rainy season.

Wheat Yield

The effects of previous crops on wheat yields were significantly different for each year of 1985-1987 (**Table 2**). Wheat yields following cumin, vetch, chickpea, and winter and spring lentil were higher than those following fallow, sunflower, safflower, and cereal. Wheat as a first crop resulted in lowest wheat yield the following season. The results show the importance of legumes in rotation with wheat as a good alternative to fallow. As already shown in **Figs. 1** and **3**, these rotations resulted in more water and mineral N accumulation than the others.

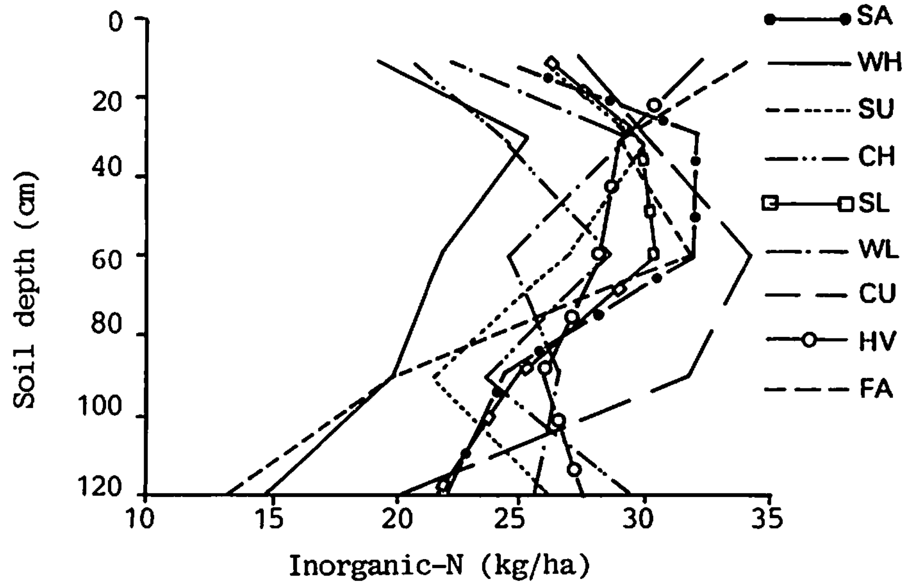

Fig. 4. Inorganic N distribution in the 120-cm soil profile as affected by previous crops, Haymana, 1985-87.

Table 2. Wheat grain yield response (t/ha) to the previous crops, 1986-88, Haymana, Ankara, Turkey.

Crop	1986	1987	1988	Average
Sunflower	3.09	2.80	3.56	3.15
Winter lentil	4.47	3.45	2.90	3.61
Spring lentil	3.73	3.46	3.59	3.59
Hungarian vetch	4.64	3.48	3.04	3.72
Safflower	2.34	2.31	3.28	2.64
Wheat	2.67	2.22	2.48	2.46
Cumin	3.60	3.45	3.53	3.53
Chickpea	3.96	3.44	3.56	3.65
Fallow	3.95	2.99	3.55	3.50
F	0.01	0.01	0.05	
CV (%)	5.28	7.45	11.96	

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DISCUSSION

S. Khattari

You stated "Therefore, N fertilization of cereals should be balanced with available water." Can you quantify the N fertilizer with available water from your findings to fulfil your objectives?

A. Avcin

This study aimed to show the important effects of previous crops on soil water and mineral nitrogen accumulation and not to quantify the N fertilizer-available water balance. In order to do that, further long-term research is required.

B. Soudi

1) I am very interested in scatter diagram showing different levels of NH_4-N and NO_3-N after different previous crops. Under what climatic regime were these measures made? 2) Do these levels significantly differ? If yes, then this complicates the motion of critical level of N-NO_3.

A. Avcin

1) In the experimental area, winters are cold and snowy limiting crop development, and summers are dry and hot. I measured soil mineral N in fall prior to wheat seeding. At the time of sampling, temperature tends to decline, and precipitation is too low. 2) There were significant differences among treatments with respect to mineral nitrogen.

Response of Wheat to Different Rates and Methods of Phosphorus Application in Rain-fed Areas of Pakistan

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ABSTRACT

Two experiments were conducted on different soil series having low and medium soil P test values, to study the effect of different P rates and application methods on yield and yield components of wheat (*Triticum aestivum* L., variety Pak 81) during the *rabi* seasons of 1984/85 and 1985/86. The P rates were 0, 10, 20, 30, and 40 kg P/ha with a basal dose of 60 kg N/ha to all treatment plots. Application methods were band placement (5 cm to the side and 5 cm below the seed) and broadcast with incorporation into the soil before planting.

All P rates increased grain and straw yield, N and P content, and uptake by grain and straw significantly over control treatments. Band placement of P up to 30 kg P/ha had a significant positive effect on yield and other characters compared with broadcast application at the same rate. No significant difference between the methods of application was observed when the P rates were further increased up to 40 kg P/ha.

INTRODUCTION

There has been increasing emphasis on research and development of rain-fed areas of Pakistan. One of the main limiting factors to good yield is the lack of information on optimum and efficient use of fertilizers. Concerted efforts have been made to improve efficiency by using different fertilizer minerals, as well as application rates, methods, and time of application (Tandon, 1987). The phenomenon of P fixation in soil is widespread, and has been found to be influenced by the amount and nature of clay minerals (Bajwa, 1982), pH (Bell and Black, 1970), and soil carbonates (Holford and Mattingly, 1975). Very low recovery (10-30%) of added P fertilizer on calcareous soils of Pakistan has been reported (Gilani *et al.*, 1983).

There are several P application methods, broadcast with incorporation being the most common one. However, under conditions of low P availability, banded P is usually more effective (Gingrich, 1964). The effectiveness of band application may be three to four times that of broadcast on such soils (Peterson *et al.*, 1981). Broadcast application of fertilizer results in fixation of its major portion; on the other hand, applying it in the restricted root zone in a band enhances the rate of supply of P to the roots (Barber and Kovar, 1985). Even in soils with medium-to-high levels of available P, banding of fertilizer provides early P availability to the roots, thereby increasing grain and dry-matter production (Alessi and Power, 1980).

Keeping in view the importance of the problem, the present study was designed to test the relative effectiveness of the two P fertilizer application methods at different P levels on two soil series having low and medium soil P test values.

MATERIALS AND METHODS

The experiments were conducted on the Buneer and Mingora soil series of Swat Valley during 1984/85 and 1985/86, respectively. The experimental unit was 5 x 10 m. The soils under study were well-drained, weak-structured, noncalcareous, deep, and permeable. The climate was humid to subhumid having 700-800 mm mean annual precipitation and mean annual temperature that ranged from 14°C in winter to 38°C in summer. The physicochemical analyses of both the sites are given in Table 1. Various P rates used in the study were 0, 10, 20, 30, and 40 kg P/ha. Basal application of nitrogen was made at the rate of 60 kg N/ha to all treated plots, broadcast and incorporated into the soil before planting. Only P was applied by two different methods: M1 = band placement, 5 cm to the side and 5 cm below the seed, and M2 = broadcast and incorporated into the soil. Pak 81 was used as the wheat test variety at both sites. The experiments were organized in a split-plot design with application methods as the main plots and P rates as the subplots. Treatments were replicated four times. The crop was harvested at maturity. The N content in grain and straw was determined by the modified Kjeldahl method, and P in $H_2SO_4/Se/H_2O_2$ plant tissue digest was determined using the acid ammonium molybdate color procedure.

Table 1. Physicochemical analysis of the Buneer and Mingora experimental sites, Swat valley, Pakistan, 1984-86.

Soil property	Soil series	
	Buneer (1984/85)	Mingora (1985/86)
pH (Sat paste)	7.2	7.5
EC x 10^3	0.76	1.8
Textural class	Sandy clay loam	Silt loam
CEC (meq/100 g soil)	13.70	28.0
Organic matter (%)	1.06	2.13
$CaCO_3$ equivalent (%)	1.56	1.70
Total N (%)	0.072	0.095
NO_3 -N (ppm)	24.0	47.0
NH_4-N (ppm)	13.0	25.0
$NaHCO_3$ extractable P (ppm)	3.0	8.0
Ammonium acetate-extractable K (ppm)	185.0	212.0

RESULTS AND DISCUSSION

All fertilizer rates and application methods significantly increased grain yield over control treatments. Band placement of P up to a rate of 30 kg/ha had a significant positive response compared with broadcast application at the same rate on both the sites. When the P rate was increased further, up to 40 kg/ha, no significant difference between the methods (Table 2) was observed. Highest grain yields of 2.7 and 3.5 tons were obtained when P was applied at 30 kg/ha on Buneer soil series (1984/85) and 20 kg/ha on Mingora soil series (1985/86) as a band. Banding P at 10 kg/ha had a significant effect on straw yield, but when high rates of P (20, 30, and 40 kg/ha) were used as band placement, a significant increase in straw yield was observed compared with broadcast at the same rate during 1984/85.

Table 2. Wheat grain and straw yield (kg/ha) with different application rates and methods, Swat valley, Pakistan, 1984-86.

P (kg/ha)	Grain				Straw			
	1984/85		1985/86		1984/85		1985/86	
	M1	M2	M1	M2	M1	M2	M1	M2
0	1.2 n	1.1 n	2.0 j	2.1 j	1.5 i	1.6 i	3.4 e	3.5
10	1.6 i	1.3 m	2.1 d	2.4 i	3.0 g	2.7 h	4.1 b	3.8 d
20	2.1 j	1.8 k	3.5 a	2.8 e	3.2 f	3.1 fg	4.2 ab	4.2 ab
30	2.7 f	2.6 g	3.2 b	3.1 cd	3.9 cd	3.9 cd	4.3 a	3.9 cd
40	2.5 hi	2.6 hg	3.2 b	3.2 bc	3.9 c	3.8 cd	4.3 cd	3.9 cd

Means followed by the same letter do not differ significantly at the 0.05 level.
M1 = Banding; M2 = Broadcast.

On the other hand, all fertilizer rates when band-applied did increase straw yield significantly compared with the same broadcast rate on Mingora soil series during 1985/86. Comparing the different P rates, no significant difference in straw yield was observed between 30 and 40 kg P/ha (1984/85) and 20, 30, and 40 kg P/ha (1985/86). Similarly, band placement of P at lower rates up to 20 kg/ha significantly increased the N content of grains and straw at both locations, but when the rate of P application was increased further up to 40 kg/ha, no significant difference was observed between the methods of application (Table 3). All the P rates, applied either as band or broadcast, significantly increased N content of both grains and straw compared with the control treatment.

The data for grain and straw P content showed that all the fertilizer treatments significantly increased the P values on both sites over the control. Comparing the different P application methods, band placement at all rates had a significant positive

Table 3. Grain and straw nitrogen concentration (%) as influenced by different P rates and application methods, Swat valley, Pakistan, 1984-86.

P (kg/ha)	Grain				Straw			
	1984/85		1985/86		1984/85		1985/86	
	M1	M2	M1	M2	M1	M2	M1	M2
0	1.0 g	1.0 g	1.1 g	1.1 g	0.3 g	0.3 g	0.4 g	0.4 g
10	2.2 de	1.2 g	2.5 c	1.4 f	0.3 g	0.3 g	0.7 de	0.3 g
20	2.6 bc	2.1 e	2.9 ab	2.1 e	0.7 cde	0.5 f	0.9 ab	0.9 a
30	2.5 c	2.4 cd	3.08 a	3.8 ab	0.8 cd	0.8 cde	1.0 a	1.0 a
40	2.5 c	2.5 c	2.9 ab	3.0 a	0.8 bc	0.8 c	1.0 a	1.0 a

Means followed by the same letter do not differ significantly at the 0.05 level.
MI = Banding; M2 = Broadcast.

effect on P content of both grain and straw in 1984/85, but the effect was evident only at lower rates up to 20 kg P/ha during 1985/86. It was observed at both sites that there was no significant difference between 30 and 40 kg P/ha, whether applied as band or broadcast, on P content of either grain or straw.

Phosphorus uptake by grain and straw increased with increasing levels of P applied up to 30 kg/ha; uptake decreased as the P rate increased (Figs 1 and 2). A marked difference was observed in total P uptake between different methods of P application, being more pronounced in band placement than in broadcast at all P levels.

The effectiveness of band placement over broadcast is explained on the basis that P fixation by broadcasting rendered a greater portion of the applied P unavailable (Barber and Kovar, 1985). Even though the soil was relatively high in plant-available P (1985/86), the superiority of band placement over broadcast can be attributed to the

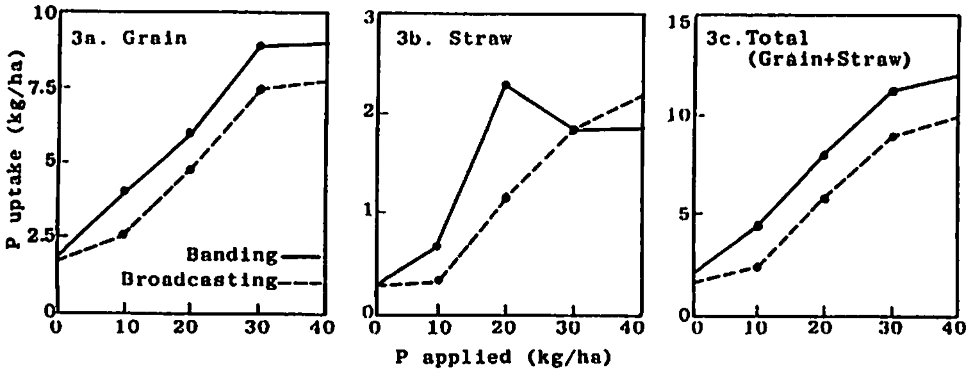

Fig. 1. Phosphorus uptake by wheat as influenced by different P rates and application methods, 1984/85.

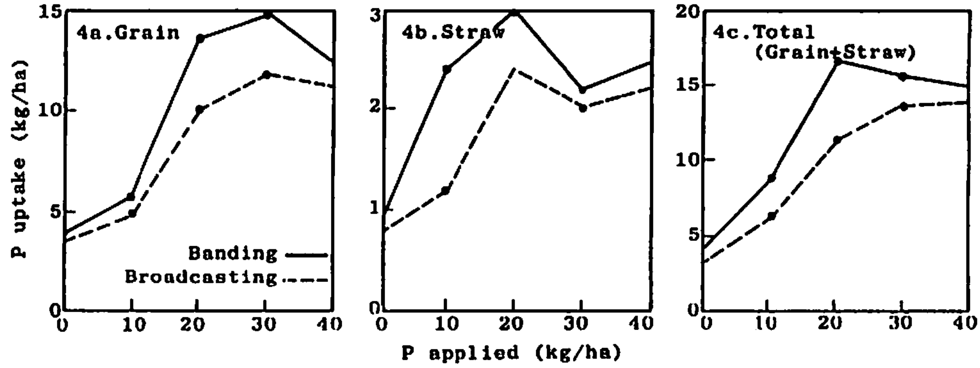

Fig. 2. Phosphorus uptake by wheat as influenced by different P rates and application methods, 1984/85.

very high P-fixing capacity of soil. In fact significant loss of plant-available P via "slow reaction" can occur in many soils (Westermann and Leggette, 1988; Gingrich, 1964).

The study suggests that band placement of P is better than broadcast application at lower rates up to 30 kg P/ha on soils having low and medium plant-available P. No significant difference was observed in grain and straw yields, N and P uptake when P was applied as band or broadcast at rates higher than 30 kg/ha.

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Response of Wheat and Barley to Different $NaHCO_3$-Extractable Soil-Phosphorus Levels under Varying Soil Moisture

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ABSTRACT

Soils from three regions of rainfed cereals were used in a greenhouse study: Ramtha, Mushahar, and Maro. All three were fine-textured Chromoxererts. For each soil, three levels of $NaHCO_3$-extractable P (5, 7.5, and 10 ppm) were established, and available soil water determined. Three levels of moisture: 60, 80, and 100% of the available soil water, were used in each soil of the different P levels. Pots containing 12 kg oven-dried soils, passed through a 2-mm sieve, were planted, on January 1989, with the local varieties of wheat (Sham 1) and barley (Deir-Alla 106) in four replications. Soil moisture levels were maintained throughout the study period (Jan-May) by weighing the pots every other day. Depleted moisture was replenished with water. At harvest, the plant portion above the soil surface was cliped. Roots were washed, collected, and weighed. Responses of yield components to P and soil moisture were assessed. Grain P content for both crops was measured. The results indicated that $NaHCO_3$ exptractable-P, soil type, available moisture level, and their interactions were interrelated and affected the different parameters measured in the study.

INTRODUCTION

Responses of cereal crops to similar phosphate fertilizer rates in the rainfed areas of Jordan are inconsistent and vary between locations. Soil type, moisture regime, indigenous soil P level are among many factors that affect the interaction of applied P with the soil, and therefore its availability to plants. Khattari and Tell (1988) studied the effect of applied P levels on four wheat varieties in different locations of Jordan and concluded that location had a significant effect on yield response to P fertilization. Similar results were obtained on barley when different P fertilizer placement methods were studied. It was found that both wheat and barley respond to much higher P rates (up to 75 kg P/ha) than those recommended in different regions of the country (Khattari and Tell, 1989a; 1989b).

However, the location effect reflects the integral interaction of many factors, including soil physical and chemical properties, soil extractable P, and available soil moisture, on P availability and yield response. Therefore, in order to improve the P fertilizer efficiency and crop response, a soil P calibration test is needed for the different areas. The objective of this study was to determine the effect of different $NaHCO_3$-extractable soil P levels under a range of available soil moisture on wheat and barley.

MATERIALS AND METHODS

A greenhouse experiment was conducted in 1989 with three soils from the main rainfed cereal areas : Ramtha (fine, mixed, thermic, typic Xerochrept; Mushakkar (v. fine, smectitic, thermic, typic Chromoxerert), and Maro, (fine, smectitic, typic Chromoxerert). Bulk soil samples were air-dried and passed through a 2-mm sieve for analysis. Initial concentrations of $NaHCO_3$- extractable soil P were determined. Three levels of extractable P (5,7.5, and 10 ppm) in each soil were established by enrichment with known amounts of K2H PO_4 added as solution and mixed with the soil before potting. Available soil moisture was determined as the difference between the field capacity (l/3 bar) and permanent wilting point or WP (15 bars). Three levels of available soil moisture, 60%, 80%, and 100% of field capacity (FC) were calculated and used as sub-treatments for each extractable P level.

Pots containing 12 kg of P-treated oven-dry soil were planted with wheat (Sham 1), and barley (Deir Alla 106). The experimental design was a randomized complete block arranged as a split-plot with three replications. After plant emergence and thinning (10/pot), moisture levels were maintained by replenishing depleted moisture after weighing the pots every other day until maturity. At harvest, plant portions above the soil surface were clipped. Different biological yield components were determined. Roots were washed, collected and both fresh and oven-dry weighed. Grain P of wheat and barley was determined. The results were statistically analyzed.

RESULTS AND DISCUSSION

The effect of soil type, available moisture, extractable P, and their interactions on the total yield, yield components, root weight (growth) of both wheat and barley are presented (Table 1). Soil type had a significant effect (0.01) on all parameters of both wheat and barley. Soil moisture levels significantly affected all parameters except roots growth. The range of moisture levels in the study was apparently adequate for root growth. The interaction of soil x moisture was not significant, neither for fresh root weight nor grain P. Soil extractable P had a highly significant effect on all parameters. The effect of extractable P x soil interaction was generally more significant on barley than on wheat, reflecting relatively better response of barley to extractable levels P when both crops were grown under similar conditions. The soil moisture x extractable P interaction had a weak to non-significant effect on both crops. The low solubility and mobility of P in calcareous soils are probably the main reason for neutralizing this interaction effect. The collective interaction of soil x moisture x extractable P significantly affected total yield of both crops, but only the straw yield of barley.

Table 1. ANOVA summary for effects of soil type (S), soil moisture level (M), and $NaHCO_3$-extractable P (P) on wheat (W) and barley (B), Jordan, 1989.

Variable	df	Total yield		Grain yield		Straw yield		Dry root		Fresh root		Grain P	
		W	B	W	B	W	B	W	B	W	B	W	B
S	2	***	***	***	***	***	***	***	***	***	***	NS	***
M	2	***	***	**	**	***	***	NS	NS	NS	NS	***	***
S x M	4	***	***	**	**	***	***	**	**	*	NS	NS	NS
P	2	***	***	***	***	***	***	**	***	***	***	***	***
S x P	4	NS	***	NS	***	NS	***	*	**	NS	**	***	***
M x P	4	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
S x M x P	8	**	**	NS	NS	NS	***	NS	**	NS	NS	NS	*
C.V. %		8.1	8.9	20.7	16.5	6.6	8.0	48.6	27.5	45.6	44.6	4.8	19.7

*, **, *** = Significant at the 0.1, 0.05, and 0.01 probability levels, respectively. NS = nonsignificant.

Wheat Response

The highest mean value of total yield under the different soils and moisture levels, regardless of extractable P levels, was at field capacity, i.e., 36.35 g/pot, which was significantly higher than the mean value of total yield at lower soil moisture. However, highest total yield was obtained from Ramtha, Maro, and Mushakkar soil at 80% or higher of available soil moisture (Table 2). Grain yield followed the same pattern, where it had increased with increasing soil moisture. Highest mean value was also obtained at soil moisture level higher than 80% FC. The mean straw yield was 29.60 g/pot at FC, which was significantly higher than the yield obtained at lower moisture levels.

Soil type affected the straw yield; Ramtha soil produced the highest amount, even at lower moisture levels, than the other soils. Previous results showed that Ramtha soil was more responsive to both moisture and available P, while Mushakkar soil was least responsive. Grain P content was similar in all soils, especially at soil moisture content higher than 80% of available soil water.

Root weight, reflecting root activity in the different soils, may be the most important factor that affects yield component. Fresh root weight in Ramtha and Maro soils was significantly higher (about twofold) than in the Mushakkar soil at all moisture levels. Dry root weight followed the same pattern, again being twofold higher in Ramtha and Maro than in Mushakkar.

The increasing levels of $NaHCO_3$-extractable P in the different soils caused significant increase in total yield. At 7.5 ppm, total yield was 40.0 and 37.7 g/pot in Ramtha and Maro soils, respectively. In Mushakkar soil, there was no significant difference in total yield at the extractable P range of 5 to 10 ppm (Table 3).

Table 2. Soil type and available soil water in relation to wheat components, Jordan, 1989.

Soil	Available soil water (%)					
	100		80		60	
	TDM	Grain	TDM	Grain	TDM	Grain
Ramtha	40.3 a	8.9 a	37.8 ab	7.7 ab	34.2 cd	6.5 bc
Mushakkar	32.4 d	5.2 cd	27.7 e	3.0 e	28.5 e	3.8 de
Maro	38.1 ab	7.9 ab	36.6 bc	7.5 ab	36.2 bc	7.0 b
Mean	36.9 a	7.3 a	33.7 b	6.1 a	32.9 b	5.8 b
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %
Ramtha	11.6 a	0.3 a	10.6 a	0.32 ab	6.8 b	0.27 c
Mushakkar	5.6 b	0.3 ab	6.5 b	0.33 ab	6.7 b	0.34 ab
Maro	12.9 a	0.3 a	12.9 a	0.30 bc	13.4 a	0.26 c
Mean	10.0 a	0.3 a	10.2 a	0.32 b	9.0 a	0.29 c

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

Table 3. Soil type and $NaHCO_3$-extractable soil P in relation to wheat components, Jordan, 1989.

Soil	$NaHCO_3$-extractable P (ppm)					
	5		7.5		10	
	TDM	Grain	TDM	Grain	TDM	Grain
Ramtha	35.2 b	6.8 bc	40.0 a	8.8 a	37.0 b	7.5 bc
Mushakkar	28.4 c	3.8 d	29.7 c	4.6 d	29.4 c	3.6 d
Maro	35.5 b	6.6 c	37.7 ab	7.9 ab	37.7 ab	7.9 ab
Mean	33.0 b	5.7 b	35.8 a	7.1 a	34.7 a	6.3 b
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %
Ramtha	8.1 bcd	0.32 bcd	10.5 b	0.29 def	10.4 b	0.35 b
Mushakkar	6.0 d	0.25 ef	5.7 d	0.34 bc	7.0 cd	0.41 a
Maro	9.3 bc	0.25 f	14.8 a	0.30 cde	15.3 a	0.36 ab
Mean	7.8 b	0.27 c	10.2 a	0.31 b	10.9 a	0.37 a

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

However, the highest mean value of total yield over the three soils was obtained at 7.5 ppm extractable P. Grain yield was affected in the same pattern. Significantly high grain yield was obtained at 7.5 ppm P in Ramtha and Maro. No grain yield response was obtained in Mushakkar soil at 5 to 10 ppm P, even though highest grain yield was obtained at 7.5 ppm. However, the mean value of grain yield at 7.5 ppm P was significantly higher than the values obtained at the other P levels.

Straw yield varied with extractable P levels in the different soils. Highly significant yield was obtained at 7.5 ppm P from Ramtha and Maro soils. Straw yield from Mushakkar soil was significantly less at similar extractable P levels in the other soils. Generally, there was no significant difference in straw yield at any level of extractable P higher than 7.5 ppm.

Fresh root weight was significantly affected by extractable P levels in the different soils. Root weight ranged from 8.1 to 10.5, 5.6 to 7.0, and 9.3 to 15.3 g/pot in Ramtha, Mushakkar, and Maro soils, respectively. Highest mean weight was obtained at or higher than 7.5 ppm P. Dry roots weight followed the same pattern under the effect of both soil and extractable P levels. Fresh and dry root weight in Ramtha and Maro were twofold higher than in Mushakkar soil. In all parameters, the most substantial and significant increase occurred at 7.5 ppm P or higher.

The effect of extractable P, available soil moisture, and their interactions, regardless of soil type, on the various parameters are shown in **Table 4**. The total yield increased significantly (35.86 g/pot) at 7.5 ppm P. Generally, the highest yield was obtained at or more than 80% FC with 7.5 ppm P or higher. Grain yield was not

Table 4. Available soil water and $NaCHO_3$-extractable soil P in relation to wheat components, Jordan, 1989.

	$NaHCO_3$-extractable P (ppm)							
Available water (%)	5		7.5		10		Mean	
	TDM	Grain	TDM	Grain	TDM	Grain		
100	35.0 bc	6.1 bc	37.8 a	7.8 a	36.1 ab	7.1 ab	36.3 a	7.0 a
80	32.3 cd	5.6 c	35.3 ab	7.1 ab	33.5 bcd	5.8 c	33.7 b	6.1 a
60	31.8 d	5.5 c	34. bcd	6.4 bc	34.5 bc	6.4 bc	33.6 b	6.1 a
Mean	33.0 b	5.7 b	35.8 a	7.1 a	34.7 a	6.8 b		
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %	Mean	
100	9.5 abc	0.32 bc	9.5 ab	0.33 bc	11.0 a	0.40 a	10.4 a	0.35 a
80	7.2 bc	0.26 d	11.3 a	0.31 bc	11.4 a	0.39 a	10.0 a	0.32 b
60	6.8 c	0.24 d	9.9 abc	0.29 cd	10.2 ab	0.34 b	9.0 a	0.29 c
Mean	7.8 b	0.27 c	10.2 a	0.31 b	10.9 a	0.37 a		

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

affected by moisture, although the highest mean value was obtained at 80% FC or more. The effect of extractable P was more pronounced at high moisture levels. Straw yield followed the same pattern as grain yield. The highest mean value of straw yield (29.2 g/pot) was obtained at the same moisture and extractable soil P. Grain P was highest at the highest levels of available water and extractable P.

Root fresh and dry weight were similarly affected by both available moisture and extractable P. Results showed no significant difference in root weight at different soil moisture levels. This indicates that 60% of FC is sufficient for adequate root growth. However, both fresh and dry root weight was significantly increased at 7.5 ppm extractable P.

Barley Response

Total grain and straw yields were similarly affected by the available soil water (Table 5) and extractable soil P (Table 6). Yield and its components increased significantly at or above 80% of FC. At any moisture level, the yields were highest in Maro, Ramtha, and finally Mushakkar soil, where a very low grain yield was obtained. Grain yield obtained from Ramtha and Maro was twofold greater. Grain P content was inconsistent under similar moisture levels in the different soils. Generally, highest values were at 80% FC or more.

Fresh and dry roots weight were also affected similarly by the soil moisture and extractable P. Highest root weight was obtained from Maro, Ramtha, then

Table 5. Soil type and available soil water in relation to barley components, Jordan, 1989.

Soil	Available soil water (%)					
	5		7.5		10	
	TDM	Grain	TDM	Grain	TDM	Grain
Ramtha	43.7 a	10.4 b	38.7 b	9.4 de	39.7b	8.8 e
Mushakkar	38.4 b	6.9 f	30.4 c	5.8 g	29.8 c	5.3 g
Maro	43.7 a	11.6 ab	43.4 a	10.3 bc	46.4 a	12.5 a
Mean	41.9 a	9.6 a	35.8 b	8.6 b	38.6 b	8.8 b
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %
Ramtha	11.7 d	0.36 a	16.6 bc	0.33 abc	13.1 cd	0.26 d
Mushakkar	7.4 e	0.35 ab	7.2 a	0.37 a	6.3 cd	0.33 abc
Maro	17.1 b	0.29 bcd	16.8 bc	0.28 cd	21.5 a	0.24 d
Mean	12.1 a	0.34 a	13.5 a	0.32 a	13.5 a	0.27 b

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

Table 6. Effect of soil type and $NaHCO_3$ interaction on different barley components, Jordan, 1989.

Soil	$NaHCO_3$-extractable soil P (ppm)					
	5		7.5		10	
	TDM	Grain	TDM	Grain	TDM	Grain
Ramtha	41.7 bc	9.7 b	39.2 c	8.9 b	42.1 bc	9.9 b
Mushakkar	28.8 e	4.3 d	35.1 d	5.8 g	34.8 d	7.0 c
Maro	40.5 bc	9.8 b	42.7 b	10.3 b	50.3 a	14.8 a
Mean	37.0 c	7.9 b	39.0 b	8.6 b	42.4 a	10.6 a
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %
Ramtha	12.2 c	0.27 cde	14.2 bc	0.35 b	15.0 bc	0.33 bc
Mushakkar	5.2 e	0.27 de	7.1 de	0.35 b	8.7 d	0.44 a
Maro	16.7 b	0.22 a	14.8 bc	0.31 bcd	23.9 a	0.27 cde
Mean	12.1 a	0.34 a	13.5 a	0.32 a	13.5 a	0.27 b

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

Mushakkar soil. Fresh rootweight in Maro and Ramtha soil was at least twice as high as in Mushakkar soil, while the dry root weight was 3-4 times greater. Unexpectedly, root weight under the low moisture level was highest in Ramtha (at 80% FC) and Maro (at 60% FC).

Extractable P and soil type affected the total, grain, and straw yield (Table 6). Under similar extractable P, the soil type reflected significant variation. Highest yield and yield components were obtained from Maro, Ramtha, than Mushakkar soil, particularly at 7.5 and 10 ppm P. Mean values of total, grain, and straw yield were highest at 10 ppm P, and significantly different from those at lower P levels. Grain P was not clearly affected by soil type, but rather was affected by extractable P. Highest values were obtained at 7.5 ppm or higher. Fresh and dry root weight were affected by soil type and extractable P in the same pattern. Fresh root weight in Maro and Ramtha, were two- to threefold of that in Mushakkar, while dry root weight was even higher. Generally, highest root weights were at 10 ppm P in all soils.

The effect of available moisture and extractable P were not pronounced for total yield and its components. However, the soil moisture effect was similar with no substantial difference. Highest total yield, grain, and straw were obtained at 80% FC or higher with 10 ppm P (Table 7). Roots fresh and dry weight were not affected by either soil moisture or extractable P. No significant differences in root weight occurred at the different moisture levels or extractable P. Highest grain yield was obtained at 7.5 ppm P or higher, but moisture level did not affect grain p significantly, although the highest value seemed to be associated with the high moisture level.

Table 7. Available soil water and $NaCHO_3$-extractable soil-P in relation to barley components, Jordan, 1989.

	$NaHCO_3$-extractable P (ppm)							
Available water (%)	5		7.5		10		Mean	
	TDM	Grain	TDM	Grain	TDM	Grain		
100	39.8 bcd	6.1 cd	41.2 bc	9.3 bc	44.7 a	11.0 a	41.9 a	9.6 a
80	34.9 c	7.5 d	38.1 cde	8.2 cd	40.4 bc	10.3 ab	37.8 b	8.6 b
60	36.2 c	7.8 d	37.6 de	8.3 cd	42.0 ab	10.4 ab	38.6 b	8.8 b
Mean	37.0 c	7.9 b	39.0 b	8.6 b	10.6 a	10.6 a		
	Fresh roots	Grain P %	Fresh roots	Grain P %	Fresh roots	Grain P %	Mean	
100	10.5 d	0.28 bc	10.9 ab	0.37 a	14.8 abc	0.35 a	12.1 a	0.35 a
80	11.9 cd	0.26 cd	12.7 cd	0.35 a	16.6 a	0.35 a	13.5 a	0.32 b
60	11.7 cd	0.21 d	13.0 bcd	0.28 bc	16.3 ab	0.33 ab	13.6 a	0.29 c
Mean	11.4 b	0.25 b	12.0 b	0.33 a	12.0 b	0.35 a	15.9 a	

Similar letters in rows or columns denote nonsignificance (5%), Duncan's Multiple Range Test.
Values in g/pot except for grain P.
TDM = total dry-matter yield.

From the previous results, there was close similarity in the response of wheat and barley to extractable P levels in the different soils. Soils also varied in their effect under similar P levels. Mushakkar soil was the least responsive to P. Highest grain yield was obtained at 7.5 ppm P or higher, but the moisture level did not affect grain P significantly, although the highest value seemed to be associated with the high moisture level. Likewise, there was a close similarity in the response of wheat and barley to extractable P levels in the different soils. Soils also varied in their effect under similar P levels. Mushakkar soil was the least responsive to P. Highest values with all parameters were obtained at 7.5 ppm P in all soils.

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Distribution of Total Phosphorus in the Soil Profile in Relation to Fertilization Practices

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ABSTRACT

Total phosphorus distribution throughout the soil profile has been reported in the literature in numerous ways. Phosphorus fertilizer application, crop uptake, as well as soil processes related to soil genesis have been addressed in this regard. In this study, different types of soil total P distribution patterns have been found in the soils of Meknes region (Morocco). These profile distributions seem to be closely related to the degree of intensive cropping and to the level of fertilizer use. For these reasons, such P distribution profiles should be kept in mind when designing management programs and making P fertilizer recommendations.

INTRODUCTION

It has been established that phosphorus applied annually as fertilizer is not totally removed during the crop life cycle; only an average of about 10% is commonly observed (Barrow, 1980). Based on the results obtained by Matar (1990), barley (*Hordeum vulgare* L.) grown in low-rainfall areas, and wheat grown in higher-rainfall areas removed 6 and 10%, respectively, of P applied. Therefore, a major part of the fertilizer P remains in the soil (residual P). In fact, P fertilizers applied are rapidly transformed in the soil (hydration, solubilization, fixation, and precipitation) in various ways according to soil type and characteristics. The products of such reactions evolve with time and result in compounds which are less and less available. Thus, by trying to ensure enough P for crops on a regular basis, fertilized soils are becoming richer in total P. Since P movement in the soil is limited, its distribution throughout the profile in relation to a particular fertilized crop is of interest. It is this question that the study aims to provide an answer for. To this effect, total P distribution was estimated by adding the different forms of extracted P based on an inorganic fractionization scheme for different soil in the Meknes region (Loudyi, 1939).

MATERIALS AND METHODS

Soils were selected from different locations of the Meknes plateau based on a soils map. These were:

1. Vertisol (III.2), developed on cultivated marl with average fertilizer application (6-12 kg P/ha in some years).
2. Mollisol (V.2), on soft limestone, cultivated but not well managed (rarely fertilized, stubble removed).
3. Mollisol (V1.1), on hard limestone, cultivated, with average fertilizer application (6-12 kg P/ha in some years).
4. Mollisol (V1.2), on hard limestone, not cultivated, with little grazing.
5. Alfisol (IX.1), modal with some calcite, developed on hard limestone, cultivated, heavily and regularly fertilized with 18 kg P/ha.
6. Leached Alfisol (IX.3), on light brown sand, not cultivated, heavily grazed.
7. Leached Alfisol (IX.4), on light brown sand, cultivated, poorly managed, rarely fertilized, with stubble gathered.
8. Int. intergrade, with characterized soils ranging from calcimagnesic to sesquioxides and isohumic on hard limestone, cultivated and fertilized.

The number of samples for each soil varied between three and four depending on the horizons studied. Physical and chemical analyses shown in **Table 1** were obtained following the method developed by Williams *et al.* (1969) with some modifications to obtain the different inorganic P fractions considered for mineral P estimation; organic P was determined by the ignition method.

RESULTS AND DISCUSSION

The total P content extracted (Pt), i.e., mineral plus organic, showed large variation between the different soils (Table 2). The limits ranged between values of around 1500 mg/kg for the Vertisol (III.2) and close to 400 mg/kg for the leached Alfisol or fersiallitic soil (IX.3) developed on sand. A significant effect of the soils' original materials contents on soil with such variations was underlined by Loudyi (1989).

However, despite the original P content of the parent rocks, Pt content varied within each soil with depth. The Pt quality regressed proportionally according to soil types, from the top stratum to the subjacent stratum, but the profile base content was either equal, superior, or inferior to the top stratum. As for the intermediate stratum (where two samples are taken), Pt content either increased or decreased with depth.

Different types of P profiles appear throughout the data collected from various references. The Pt content increases or decreases at different levels for different soil types (Ahmad and Jones, 1979; Syers and Walker, 1969; Alaoui, 1972). Relatively regular distributions showing either decreases according to depth, or patterns being somewhat higher or lower in the middle of the profile were observed by Dahnke *et al.* (1964) and Sharpley and Smith (1983). Similarly, a regular decrease in Pt with

Table 1. Relevant soil properties, Meknes, Morocco.

Soil[1]	Horizon	Clay	$CaCO_3$	pH	C	C/N	Olsen-P	CEC
		-------- (%) -------			(%)		(ppm)	(meq/100 g)
V.2	0-30	24	13	7.9	0.8	10.1	6	34
	30-110	18	48	8.3	0.4	9.9	-	28
	+110	6	90	8.4	0.4	9.5	-	22
III.2	0-25	55	3	7.9	1.2	11.5	13	43
	25-80	50	2	8.1	0.8	10.8	-	41
	+80	49	3	8.2	0.6	8.7	-	41
Int.	0-20	35	10	8.1	0.7	10.8	15	36
	20-40	39	19	8.2	0.6	11.1	-	36
	+40	40	28	8.2	0.2	9.5	-	38
VI.1	0-20	51	1	7.2	1.4	11.5	9	38
	20-80	52	1	7.2	1.4	11.8	-	38
	80-100	13	29	8.2	0.3	11.1	-	26
	+100	10	65	8.4	0.2	9.7	-	24
VI.2	0-25	51	1	7.3	0.8	10.1	6	36
	25-60	43	2	7.8	0.7	12.5	-	35
	60-80	30	50	8.2	0.2	11.3	-	30
	+80	15	80	8.3	0.2	9.5	-	35
IX.1	0-20	53	1	7.3	1.4	13.6	45	39
	20-40	54	1	7.5	1.0	9.7	-	38
	+40	26	35	8.2	0.8	7.8	-	32
IX.3	0-18	8	1	7.2	0.5	8.0	5	12
	18-40	14	0	7.2	0.3	9.9	-	14
	40-70	20	1	7.1	0.3	11.0	-	22
	+70	38	1	7.0	0.4	9.5	-	27
IX.4	0-28	6	1	7.1	0.7	9.7	3	11
	28-55	6	1	7.1	0.3	10.8	-	12
	55-90	30	7	7.2	0.1	8.5	-	26
	+90	32	1	7.3	0.1	-	-	27

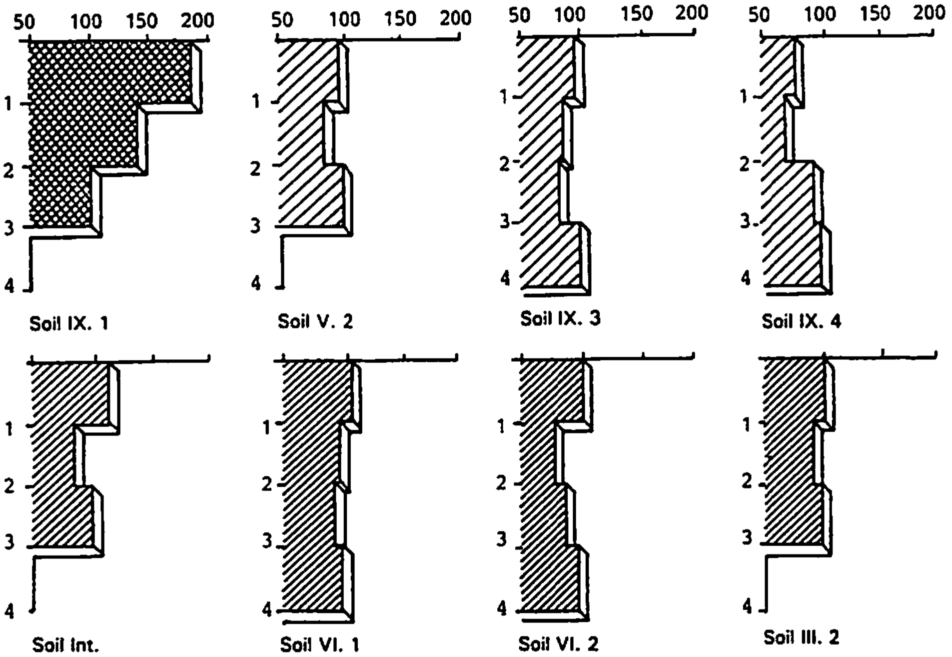
[1] Mapping units based on soils map of the Meknes plateau.

depth was observed by Awan and Richer (1964) for four Jordanian soils. Some Pt profiles similar to those observed in the Meknes plateau were found in soils studied by the above-mentioned researchers, as well as in other soil types of the San Joaquim Valley (California) studied by Meixmer and Singer (1985).

Table 2. **Total soil phosphorus content (mg/kg).**

	Soil unit							
Horizon	V.2	III.2	Int.	IV.1	V1.2	IX.1	IX.3	IX.4
1	823	1593	996	818	704	1447	485	715
2	730	1428	733	737	597	1093	434	630
3	868	1540	861	703	598	785	416	859
4	-	-	-	753	671	-	508	926

Different reasons were cited to explain the Pt distribution, among which are P fertilizer application, crop P uptake, processes related to soil genesis, mineralization of organic P, and immobilization of mineral P. The high P content in the noncultivated, nonfertilized top stratum could be explained by biological increases and considered as the result of a normal soil evolution (Smeck, 1973). The Pt evolution with depth (Fig. 1) permitted us, at the same time, to distinguish three principal types of P distribution in the soils studied.



Soil IX. 1 | Soil V. 2 | Soil IX. 3 | Soil IX. 4

Soil Int. | Soil VI. 1 | Soil VI. 2 | Soil III. 2

Fig. 1. Distribution of total phosphorus (Pt) with depth, expressed as a percentage of Pt content with depth, Meknes, Morocco.

The first distribution type showed lowest Pt content at the deepest soil level. In that case, P accumulated on the surface and decreased more or less regularly to the profile base. Soil IX.1, which was cultivated and heavily and regularly fertilized, showed this distribution. The second type showed highest Pt content at the profile base. Consequently, P distribution was irregular, and, as in all the cases within the surface layer, was higher than in the subsurface stratum. Soil V.2, IX.3, and IX.4 showed this distribution pattern. The third distribution type had most Pt in the top stratum, while the middle layers were lowest in Pt. It was noted that for the last two P distribution types the poorest stratum was located at variable depth in the profile, which was probably related to root activity. This can occur just beneath the top stratum and has been observed at the deeper level, close to the parent rock.

For all the soils studied, the Pt content for the second horizon was less than for the top stratum (Table 2). In some cases, enrichment in the cultivated surface was obviously the result of significant amounts of P fertilizer applied. In some other soils where fertilizer use is nonexistent or low, the Pt content in the intermediate strata was more or less very poor and inferior to those of the original parent materials. This could be explained either by removal by crops, or by grazing on noncultivated soils.

The lateral and vertical movement of P in the soils shown by some researchers (Nys, 1975; Hashimoto and Leir, 1973; Smeck and Runge, 1971) may have been the cause for the distribution observed in fersialitic sandy (IX.3) and leached (IX.4) soils. However, some unpublished data showed that these soils have a Pt distribution similar to the first type when they are heavily and regularly fertilized. The erosion impact on the soils studied and the regional scale can be considered insignificant. It appears that the manner of soils management, specifically relative to their fertilization, determines the type of total P distribution with depth.

The schematics of the three P distribution types (Fig. 2) can be depicted as follows:

Type E. Profile: "Enriched," characterized by a high P level in the top stratum, because of constant P fertilizer application which widely exceeds crop removal and other annual soil losses. The Pt content decreases somewhat regularly from the surface to the parent rock. Such a profile is quite common in the Meknes region and is characteristic of soils belonging to modern farms, in contrast to the traditional agricultural environments characterized by insufficient and irregular fertilizer application.

Type D. Profile: "Degraded," typical of low P-content soils at all strata. In this case crop removal and other P losses are not balanced by fertilization which is often limited to N application. In some extreme situations (raking, straw removal, and overgrazing), yields decrease in an alarming manner, in which case, the effect of biological uptake weakens and the organic-matter level diminishes.

Type A. Profile: "Impoverished," typical of poor soils at the level of intermediate horizons, the content at the surface being equal or higher than in the deepest stratum. This type of P distribution is found in noncultivated soils which are not grazed, or lightly grazed, as well as in soils that received small amounts of fertilizers.

These three types of profile demonstrate the total P distribution through all the soil layers. They do not necessarily imply any level of enrichment or depletion for the

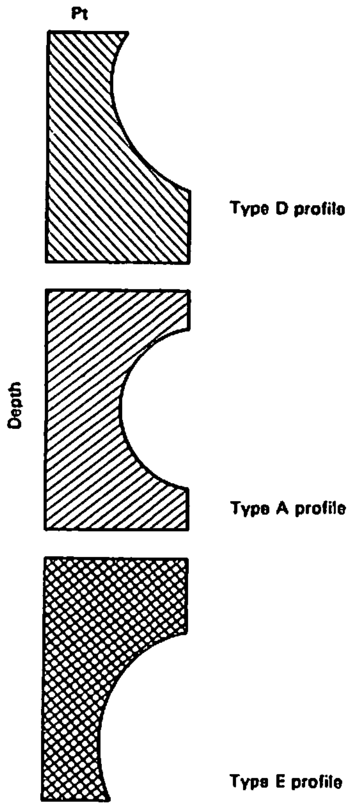


Fig. 2. Types of total phosphorus profiles (Pt), Meknes, Morocco.

soils involved, but only describe an actual state for the given soil type, resulting from a balance between P application and losses due to the abundance in the parent rock. Considering mainly the P availability, it would be adequate to focus on the following points for each soil type:

Type S Profile: "Sufficient," a theoretical profile which could be demonstrated by a pattern similar to *Type A* profile or *Type E* profile. The soils would already have just enough Pt, or would be enriched in order for the P availability level to be sufficient.

The profile configuration would not be the same for all the soil series, and would be determined by Pt content in the original material, by the soil type and its properties and also by the conditions affecting P dynamics and plant availability.

CONCLUSIONS

While P studies are numerous, they often only involve the surface soil layer or stratum. Less abundant are studies which aim at deeper strata; these consider primarily soil genesis rather than fertility aspects (Meixmer and Singer, 1985; Smeck, 1973; Syers and Walker, 1969; Dahnke *et al.* 1964; Hsu and Jackson, 1960). Root distribution and differences observed in available P contents throughout the soil profile could explain the contradictory results sometimes obtained during experimentation or field observations.

Soil exploitation and its fertilization necessarily involve an effect on P distribution through the soil profile. The P profile defined above could indicate the intensification of the agricultural level, and the diagnosis of the soil fertility. As soon as it is established it will be a useful guide in providing better definition and orientation of content fertilizer recommendations.

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DISCUSSION

A. Gharbi

Have you studied the distribution of available P in the soil profile? Is there any relationship between total P and Olsen-P?

L. Bousselham

I have studied it and found that available P was high in the upper horizon for type "E" of distribution. In other soils, Olsen-P distribution showed variations with depth especially in sandy soils.

T. Al-Ashhab

Why did you use total P given that this parameter could not have a correlation with plant response?

L. Bousselham

Total P distribution in the profile could be used as a guide in appreciating the degree of depletion or accumulation in a given soil. It should be established from time to time to provide information that could be used in managing fertilization.

F. Mosseddaq

You distinguished different types of P profiles and related those to fertilization practice. How can we relate those P profiles to P fertilizer recommendations? Does it mean that for type "E," the enriched one, we will not have to apply P?

L. Bousselham

These profiles may be of importance in the management of fertilization. Type "A" or type "D" profiles may receive more fertilizers than type "E". Also, we have to consider a type "S" profile.

*Wheat Response to Nitrogen and Phosphorus Fertilization under Various Environmental Conditions of Northern Syria**

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ABSTRACT

A series of researcher-managed wheat fertilizer trials were conducted in farmers' fields across northern Syria over four seasons (1986-1990), with a total of 70 successfully harvested trials. Four levels of N (0, 40, 80, and 120 kg N/ha) and P (0, 20, 40, and 80 kg P_2O_5/ha) were used with two replications. Mean yields were little affected by soil available P and mineral-N contents, mainly because of the dominant effect of rainfall. Over the four-year data set, the general yield-rainfall trend was well described by a quadratic equation. Response to rainfall at higher fertilizer rates was larger. Mean grain and straw yields showed highly significant response to N fertilizer, but response to P was nonsignificant. Interactions between N and P were negligible. Fertilizer N was very effective and interacted strongly with rainfall and initial soil fertility. Quadratic equations with applied N and seasonal rainfall were most appropriate for determining fertilizer needs. The Spatial Weather Generator was used in combination with the quadratic production function to indicate expected distribution of yield, increased by fertilizer application.

INTRODUCTION

Wheat is the most important staple food crop grown in West Asia and North Africa. In Syria, wheat is grown in a wide range of land extending from the wettest to the driest areas. In dry areas, where barley predominates, wheat is grown for subsistence, even at the edge of the steppe (Thomson *et al.*, 1985). In wetter areas (over 325 mm mean annual rainfall), wheat is the dominant crop and is grown in rotation with food legumes and summer crops.

In general, less fertilizer is used on poorer soils. Nitrogen use is also significantly related to the previous crop. For example, more N is applied to wheat following summer crops, regardless of soil type. Bailey (1982) reported that farmers in two Hama villages believed that irrigated summer crops deplete soil nutrients, so that a subsequent wheat crop required more fertilizer. However, contradictory results

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* Study conducted jointly with the Soils Directorate/Ministry of Agriculture, Damascus, Syria.

were obtained from on-farm trials in the same area. The effects of both P and N use on wheat grain yield following summer crops were nonsignificant, whereas the effect of N on grain yield was significant where the previous crop had been chickpea, which is contrary to farmers' opinions (Pala *et al.*, 1987).

Since fertilizer is not a new input in wetter areas of the region, research on this subject should be oriented towards technology optimization rather than generation. Nutrient levels in soils at sowing are also very important criteria for optimum and economic fertilizer use. Under dryland conditions on farmers' fields in Turkey, approximately 55 kg available P_2O_5/ha was found to be the critical level in the top soil, beyond which no economic response to P fertilization could be expected from wheat (Yurtsever, 1986). For rainfed wheat in northwest Syria, Matar *et al.* (1986) reported that a critical level of available P of about 33 kg P_2O_5/ha gave about 90% of the maximum total dry-matter production.

The objectives of the present work were to: i) assess the biological and economic responses of wheat to N and P fertilizers through multiple-season, multiple-location trials in farmers' fields, in wetter areas (over 325 mm) of northwest Syria. ii) study the relationship between the available soil N and P at sowing time and crop response, and determine critical soil N and P test values. iii) establish guidelines for developing fertilizer recommendations for wheat in common crop rotations, based on soil N and P tests and rainfall.

MATERIALS AND METHODS

A series of researcher-managed wheat fertilizer trials were conducted on farmers' fields across northwest Syria over four seasons, 1986-1990, with a total of 70 successfully harvested trials. Trial sites were distributed in Aleppo, Idleb, and Hama provinces above the 300-mm isohyet.

Sites were selected each year to represent the main soil types used by farmers for wheat, the range of natural fertility found in those soils, and the three predominant crop rotations: wheat following lentil (L-W), chickpea (Ch-W), and summer crops (SC-W), mostly watermelon. Each trial (10 x 5m plots) comprised two replicates of a randomized complete block with four P rates (0, 20, 40, and 80 kg P_2O_5/ha) as triple superphosphate, and four N (0, 40, 80, and 120 kg N/ha) as ammonium nitrate.

Wheat (Cham 1, a durum cultivar) seed was treated with fungicide (Vitavax) and sown at a rate of 150 kg/ha, following the farmers' practice of hand-broadcasting seed and fertilizer over ridged land, with subsequent covering by splitting the ridges with a one-set ducksfoot-tyned cultivator (row spacing 45 cm). Mean sowing date was 17 November ± 6.1 days. The P fertilizer and half of the N were applied at sowing, the remaining N being topdressed at the tillering stage. Weeds were controlled with a tank-mix application of brominal (0.5 kg bromoxynil/ha) and illoxan (1 kg diclofop-methyl/ha), applied once when the crop was at the 3-4 leaf stage, usually during February. Harvest was done during the last week of May and the first week of June, depending on the season.

Soils were sampled in 20-cm increments down to 100-cm depth at planting time for the determination of mineral N. Available P (Olsen) was measured at the 0-20 and 20-40 cm depths only. Soil profiles were described at each location. The main soil subgroups were either Typic Chromoxerert (deep, moderately well-drained, fine-textured), or Typic Xerochrept (deep, more or less freely drained, brownish soil characteristic of Mediterranean climates. Both have deep wide cracks in summer if no irrigation is applied.

Rainfall was recorded on a daily basis at each site, starting a month before planting until harvest. Grain yields were determined by using a Hege plot harvester to cut the central three rows in each plot at maturity. At the same time two 1-m long rows were cut at the ground level, to determine harvest index. Finally, total dry-matter and straw yields were calculated from the Hege grain yields using the harvest index. These samples were subsequently analyzed for N and P contents.

RESULTS AND DISCUSSION

Crop Response to Site Conditions

Crop response to fertilizer is closely related to environmental conditions such as soils and weather. So it is appropriate to briefly describe the conditions at the experimental sites and their effect on crop growth. Soil available P and mineral-N contents at planting time were well distributed between low and high values: about 50% of the sites had available P less than 5 ppm and mineral N less than 10 ppm, values taken to be critical nutrient levels. Available P values did not differ according to previous crop, but mineral-N values tended to be higher at W-SC sites.

Seasonal (October-May) rainfall totals varied widely between sites over the four years, with a mean of 363.4 mm (± 151.5) and a range of 153.0-907.4 mm. Over the four-year data set, the general yield-rainfall trend was better described by a quadratic equation. Fitted equations show that the maximum biological yield was obtained at 500-600 mm rainfall in each rotation. Summer crops (watermelon) provide better growth conditions for the subsequent wheat crop in lower rainfall situations, but the advantage is lost as the rainfall increases. A comparison of equations fitted to the two extremes, the zero-fertilizer check and the $N_{120}P_{80}$ treatment, shows the general trend of the yield-rainfall relationship to be unaffected by fertilizer, but response to rainfall at the highest fertilizer rate was larger (Fig. 1).

Mean yields were little affected by soil available P and mineral-N contents, mainly because of the dominant effect of the rainfall. This can be understood better from the equations (over the 70 sites) given below:

$$Y = 135.96\ NA - 2.36\ PA + 851\ (R^2 = 17.4\%) \quad (1)$$

$$Y = 82.29\ NA - 43.59\ PA + 20.18\ Q - 0.016\ Q^2 - 3289\ (R^2 = 67.0\%) \quad (2)$$

where Y is the grain yield (kg/ha), NA and PA are the soil available-N and P (ppm), respectively, and Q is the seasonal rainfall. All coefficients in the equations are

Fitted equations:			R^2 (%)
W-L:	N_0P_0 ;	$Y = 28.44Q - 0.021Q^2 - 2753$	61.3
	$N_{120}P_{80}$;	$Y = 49.68Q - 0.029Q^2 - 6069$	84.4
W-Ch:	N_0P_0 ;	$Y = 50.24Q - 0.042Q^2 - 6350$	45.4
	$N_{120}P_{80}$;	$Y = 75.02Q - 0.059Q^2 - 1057$	67.2
W-SC:	N_0P_0 ;	$Y = 29.79Q - 0.025Q^2 - 890$	36.8
	$N_{120}P_{80}$;	$Y = 48.20Q - 0.036Q^2 - 3213$	69.1

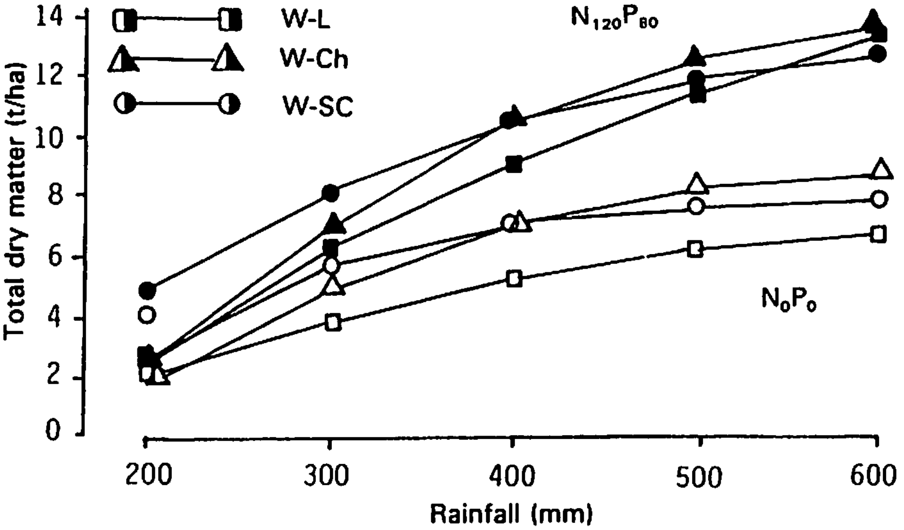


Fig. 1. Relationships of total dry-matter yield to rainfall under zero and high fertilizer regimes in wheat-lentil (W-L), wheat-chickpea (W-Ch), and wheat-summer crop (W-SC) rotations, separately.

significant at 1%, except that of PA in Equation 2. The inclusion of rainfall in the regression increased R^2 by about four fold. Therefore, site yield differences would be difficult to explain in terms of initial soil fertility levels.

Major differences were found between sites, irrespective of rainfall, mainly as a result of rotation. Wheat preceded by a summer crop had a significantly higher mean yield than wheat in the W-L and W-Ch rotations. These results are in agreement with other studies showing that summer crops such as melon do not utilize all the stored water in the profile, and the subsequent wheat crop is able to utilize it (ICARDA, 1984; Cooper *et al.*, 1987; Pala *et al.* 1987). As already seen in the regression of total dry matter on rainfall, summer crops gave advantage to subsequent wheat crop under lower rainfall conditions (Fig. 1).

Crop Response to Fertilizer

Mean grain and straw yields across the 70 sites showed highly significant responses only to N fertilizer (Table 1). Although response to P was nonsignificant, there was

Table 1. Mean fertilizer effects over 70 sites on wheat grain and straw yield (kg/ha) and 1000-grain weight (g), 1986-1990.

		P_2O_5 (kg/ha)				
Parameter	N	0	20	40	80	Mean**
Grain	0	1852	1959	1999	2031	1960
	40	2254	2291	2323	2443	2328
	80	2390	2413	2458	2481	2436
	120	2436	2426	2479	2459	2459
			NS			
	Mean	2233	2272	2315	2362	2296
Straw	0	3493	3752	3770	3790	3701
	40	4469	4510	4566	4781	4581
	80	4902	4932	5133	5188	5039
	120	5327	5339	5422	5573	5415
			NS			
	Mean	4548	4633	4723	4833	4684
1000-grain weight	0	32.5	32.3	32.7	32.9	32.6
	40	31.5	31.5	31.6	31.5	31.5
	80	30.9	30.6	30.5	30.6	30.7
	120	30.0	30.1	29.8	30.0	30.0
			NS			
	Mean	31.2	31.1	31.2	31.2	31.2

N x P interaction is not significant.
** $P < 0.01$.

still a trend of yield increase from P application. The maximum fertilizer rate ($N_{120}P_{80}$) gave mean increase of 35% in grain over the control treatment.

The frequency of significant responses to fertilizer in relation to site factors is shown in Table 2. The importance of N increased with increasing rainfall. It was lower in W-SC than in W-L or W-Ch rotation, and was higher when initial soil mineral N at 0-60 cm depth was below 10 ppm. However, crop responses to P showed little relationship with any site factors. Nitrogen application (120 kg N/ha) increased wheat grain yield by 34, 22, and 19% over the zero control in the W-L, W-Ch, and W-SC rotations, respectively; and by 3, 24, and 32% in rainfall ranges of < 250 mm, 250-400 mm, and > 400 mm, respectively.

Interactions between N and P fertilizers were negligible. Analysis has therefore been focused on the main N and P effects on wheat production under different conditions of rainfall, soil fertility status, and preceding crop. However, relationships between yield and these factors need to be quantified through best-fit equations, to give a better understanding of crop fertilizer response and to provide useful recommendations to decision-makers, and eventually to farmers.

Table 2. Percentage distribution summary of significant N and P responses as affected by main site factors, 1986-90.

			Grain		Straw	
Factor		Number of sites	N	P	N	P
All sites		70	54	21	87	16
Rainfall (mm),	<250	20	25	5	65	15
	251-400	25	60	28	92	12
	>401	25	72	28	96	20
Rotation	L/W	21	52	14	71	5
	Ch/W	21	48	10	76	5
	SC/W	28	43	14	68	18
Available P	< 5 (Pa)	32	63	22	84	22
	> 5 (PA)	38	47	21	89	11
Mineral N	< 10 (Na)	39	59	23	89	21
	> 10 (NA)	31	45	19	80	10

Ch = chickpea ; SC = summer crops ; W = wheat ; L = lentil.
Upper and lower case print for PA and NA (available soil P and N) indicate high and low values, i.e., NA = >10 ppm; Na = <10 ppm; PA = >5 ppm; Pa = <5 ppm.

Table 3 shows adjusted R^2 values for different data sets according to two fitted equations. Equation 3, with terms for N and P and rainfall in both linear and quadratic forms, provides quite a high R^2 values for each data set or subset. However, the coefficients for linear and quadratic P terms were not statistically significant. This agrees with the findings of Matar and Samman (1969) and the observation that the available P status of farmers' fields in the wheat-based system has greatly increased over the last 20 years as a result of frequent application of P fertilizer (Jones *et al.*, 1987). It is therefore concluded that equation 4, which takes only N and rainfall into consideration, is most appropriate in determining fertilizer recommendations (Table 4).

Wheat response to applied N was also affected by soil nutrient content at planting and by previous crop, as shown in Fig. 2 for total dry-matter yield increase over the control at three standard rainfall values. All crop responses to fertilizer increased with increasing rainfall, although wheat following summer crops outyielded wheat following lentil and/or chickpea under low- rainfall conditions (data were not collected). Yield increases over the control were very similar in each rotation at low rainfall. Sites with lower mineral-N content gave larger responses to applied N with increasing rainfall. The present study shows nitrate-N to be a reliable guide to N fertilization of wheat. The optimal level of soil NO_3-N maximizing wheat yields is function of the target yields and the preceding crops (Matar *et al.*, 1990).

Table 3. Empirical equations and their respective R^2 values for different data sets, 1986-90.

Data set	No of sites	Adjusted R^2 E-3	Adjusted R^2 E-4
Grain		(%)	(%)
All sites	70	64.6	64.5
L-W	21	83.4	83.3
Ch-W	21	64.0	64.2
SC-W	28	60.9	60.7
PaNa	24	57.9	57.5
PaNA	10	78.4	78.3
PANa	15	55.7	55.9
PANA	21	75.4	75.5
Total dry matter			
All sites	70	65.4	65.2
W-L	21	80.5	80.4
W-Ch	21	61.2	61.4
W-SC	28	65.2	64.7
PaNa	24	62.9	62.4
PaNA	10	80.3	79.9
PANa	15	57.4	57.5
PANA	21	74.9	75.0

E-3: $Y = aN + bP + cNP + dN^2 + eP^2 + fQ + gQ^2 + hQN + iQP + \text{constant}$.

E-4: $Y = aN + bN^2 + cQ + dQN + eQ^2 + \text{constant}$.

N and P represent rates of fertilizer N and P_2O_5 (kg/ha) applied, Q is total seasonal rainfall (mm), and a, b, c, ... i, are derived coefficients, different for each version of the equations.

Upper and lower case print for PA and NA (available soil P and N) indicate high and low values, i.e., NA = >10 ppm; Na = <10 ppm; PA = >5 ppm; Pa = <5 ppm.

In conclusion, P fertilizer has now only a small effect on wheat production, because of heavy applications by farmers over the last 20 years. Use of P fertilizer could now be reduced to just a maintenance level to maintain optimum soil available P status. Long-term studies are currently being conducted at ICARDA to determine the optimum P maintenance requirements under different soil and climatic conditions.

In contrast, N fertilizer is very effective, but it interacts strongly with rainfall and initial soil fertility. It follows that any economic N application should be based on probable rainfall during the growing season. One objective of the work is to improve fertilizer-use efficiency by defining recommended rates in terms of seasonal conditions and soil nutrient status. Since most N is topdressed at the tillering stage,

Table 4. Coefficients of equation E-4 for different data sets, 1986-90.

Data Set	N	Q	NQ	N^2	Q^2	Const.	Adj R^2 (%)
Grain							
All sites	1.7442	20.2413	0.0239	-0.0538	-0.0167	-2814	64.5
L	1.4615	10.8249	0.0326	-0.0737	-0.0043	-1625	83.3
Ch	1.6503	27.8983	0.0219	-0.0525	0.0232	-4592	64.2
SC	1.6642	18.0242	0.0199	-0.0399	-0.0151	-1940	60.7
PaNa	1.7702	14.7644	0.0276	-0.0551	-0.0120	-1803	57.5
PaNA	3.2225	24.7710	0.0230	-0.0524	-0.0250	-3197	78.3
PANa	-0.4522	20.1341	0.0319	-0.0655	-0.0166	-3122	55.9
PANA	1.2081	26.4535	0.0189	-0.0449	-0.0215	-3859	75.5
Total dry matter							
All sites	9.9122	48.3069	0.0659	-0.1325	-0.0417	-5428	65.2
L	8.9008	33.9333	0.0949	-0.1938	-0.0227	-4108	80.4
Ch	12.3210	61.8129	0.0511	-0.1179	-0.0524	-8579	61.4
SC	7.0068	45.8766	0.0600	-0.0976	-0.0418	-3777	64.7
PaNa	5.5403	38.0197	0.0863	-0.1348	-0.0336	-3590	62.4
PaNA	7.5954	67.3028	0.0717	-0.1397	-0.0724	-7429	79.9
PANa	12.2231	44.5036	0.0700	-0.1652	-0.0370	-5731	57.5
PANA	10.0598	60.9126	0.0522	-0.1039	-0.0518	-7236	75.0

Upper and lower case print for PA and NA (available soil P and N) indicate high and low values, i.e., NA = >10 ppm; Na = <10 ppm; PA = >5 ppm; Pa = <5 ppm.

in late winter or early spring, there is scope to do this. At topdressing time, soil water storage is at its maximum for the season, and one can judge better how much N to apply. Analysis of long-term climatic records can be used to predict probabilities of receiving different amounts of rainfall thereafter, and "best-bet" N topdressing requirements can be determined.

Spatial Yield Generation

Spatial Weather Generators (SWG) are useful tools for estimating the frequencies of climatic events which are of significance for crop production (Goebel, 1990). In combination with crop models of various types, from simple regression models to complex simulation models, SWG can provide information on the expected yield distribution and on the effects of management alternatives such as fertilizer use in the present study. The SWG were used in this study in combination with the production functions given in Table 5.

Isohyets of the area under study (Fig. 3), generated by the SWG, of long-term average of October-May rainfall totals in northwest Syria in relation to the major

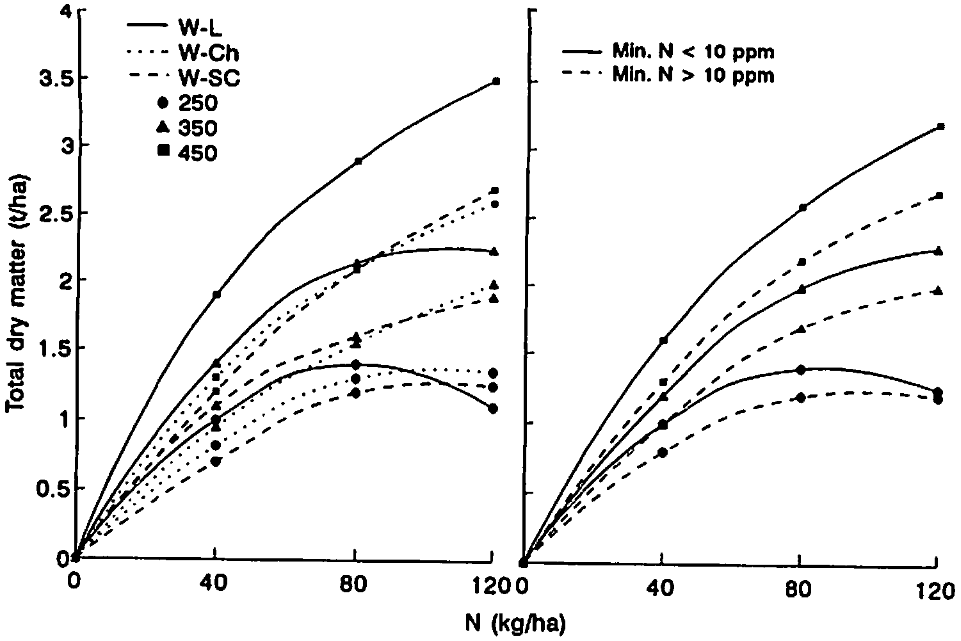


Fig. 2. Effect of previous crop and initial soil nutrient content on total dry-matter response to applied N fertilizer at three rainfall levels relative to the zero fertilizer control (drawn from E-4 in Table 4).

Table 5. Coefficients for terms in grain production function for different data sets with none and maximum fertilization levels, 1987-1990.

Data set	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	R^2	Const.	Adj. R^2(%)
					No fertilization						
All sites	11.31	1.54	19.61	4.59	19.89	12.85	28.75	-26.55	0.0099	-1043	59.6
L-W	22.72	2.87	30.56	25.63	30.79	6.83	25.60	64.56	-0.0188	-3286	70.5
Ch-W	2.34	-0.39	15.52	-5.77	27.51	20.36	22.16	-81.37	-0.0050	-910	70.2
SC-W	11.02	19.35	30.17	11.97	30.11	25.07	60.85	-36.12	-0.0261	-2400	65.4
					Maximum fertilization ($N_{120}P_{80}$)						
All sites	18.61	3.10	23.02	12.17	22.66	21.04	28.79	-18.57	-0.0121	-1776	75.7
L-W	22.64	0.37	22.28	19.97	27.52	7.71	4.64	53.84	-0.0062	-2696	90.6
Ch-W	6.96	-13.66	20.30	-3.51	32.88	37.94	26.14	-21.40	-0.0097	-947	86.6
SC-W	14.66	21.67	29.12	16.82	27.29	29.77	54.33	-22.34	-0.0244	-2511	74.5

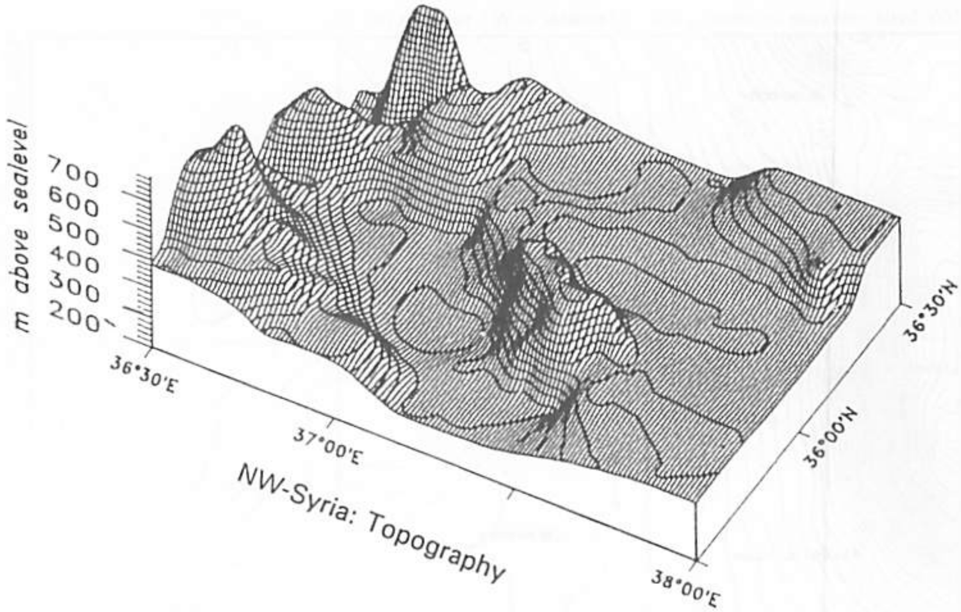


Fig. 3. Major topographic features of the study area in northwestern Syria.

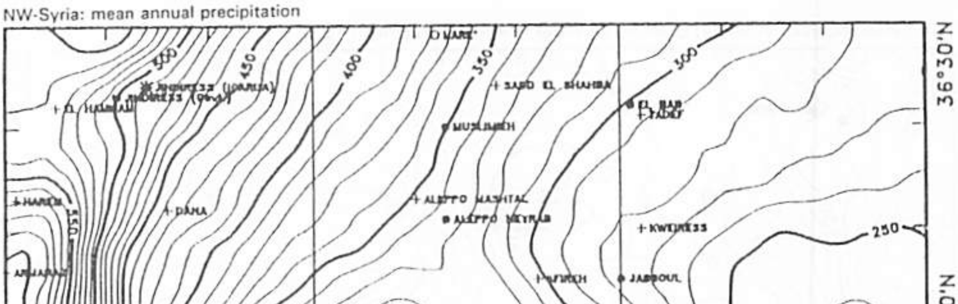
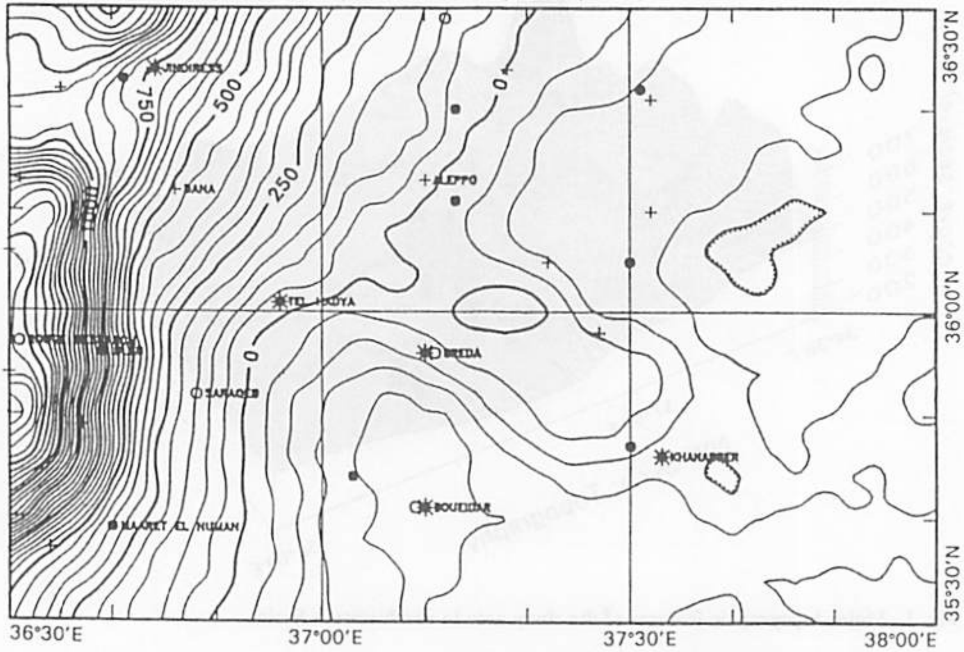


Fig. 4. Mean annual rainfall (mm) and locations of the meteorological stations whose data were used in this study (* daily precipitation, air temperature, and solar radiation, ● daily precipitation and air temperature, ○ daily precipitation, + monthly precipitation only). Following the last three seasons with below-average precipitation, the values on parts of the map may seem 10 to 15 mm higher.

NW-Syria: increase in wheat grain by fertilizer in W-L rotation (n = 21)



NW-Syria: increase in wheat grain by fertilizer in W-Ch rotation (n = 21)

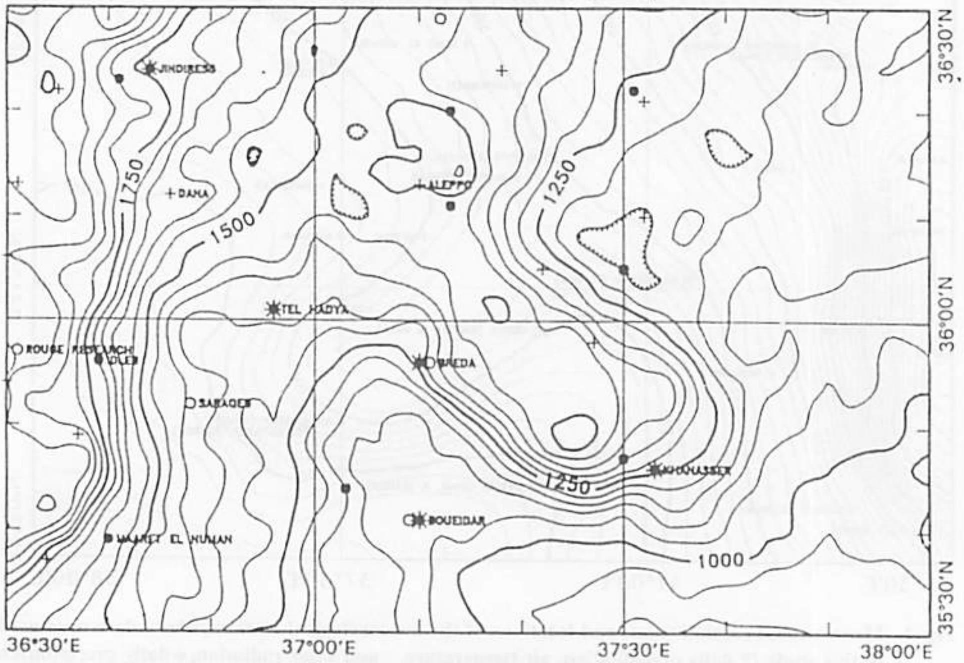
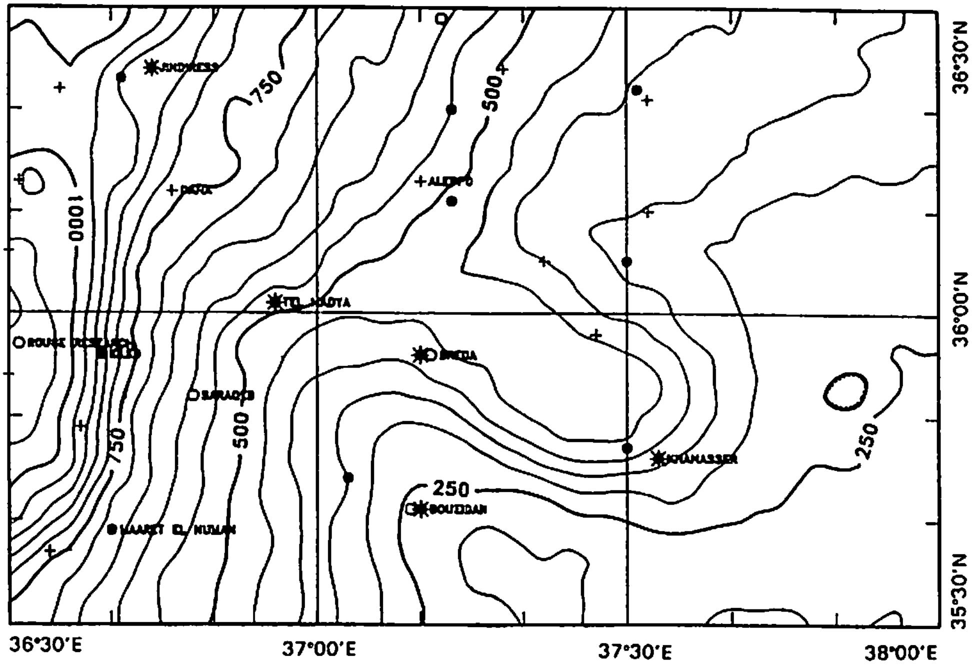


Fig. 5. Calculated wheat grain-yield increases generated by SWG from fertilization (120 kg N + 80 kg P_2O_5/ha) in wheat-lentil (W-L) and wheat chickpea (W-Ch) rotations.

NW-Syria: increase in wheat grain by fertilizer in W-SC rotation (n = 28)



NW-Syria: increase in wheat grain by fertilizer across 70 sites

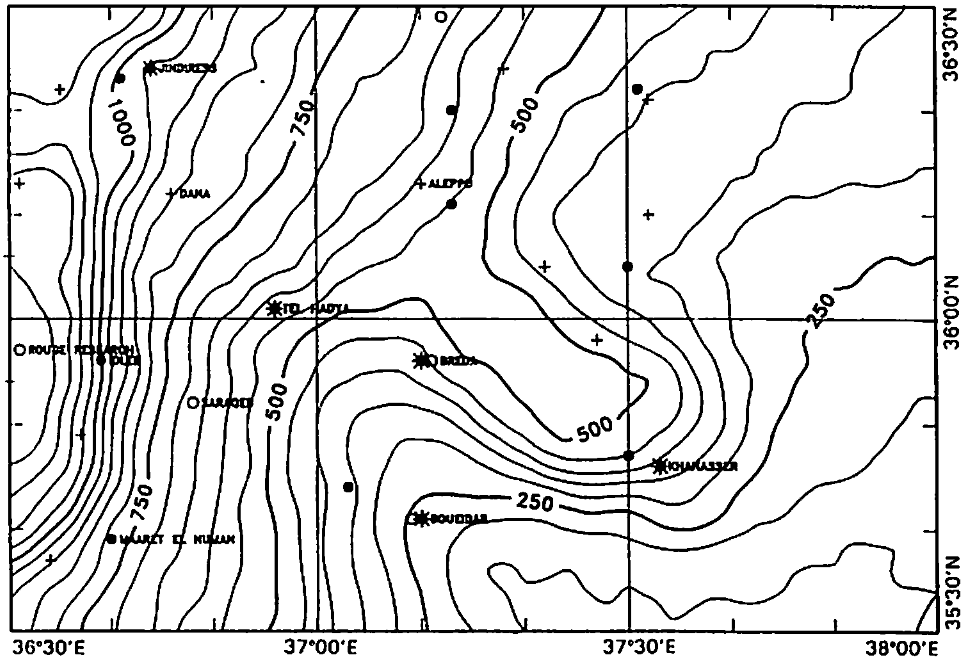


Fig. 6. Calculated wheat grain yield increases generated by SWG from fertilization (120 kg N + 80 kg P_2O_5/ha) in wheat-summer crop (W-SC) rotation and across all rotations in 70 sites.

topographic features are shown in Fig. 4. These isohyet values were translated into maps of fertilizer response isolines using the production functions derived from monthly rainfall subtotals as separate linear terms, as given in Table 5 for three rotations and across sites under none and maximum fertilization levels. Fertilizer responses of wheat in Ch-W, L-W, and SC-W rotations in all sites are shown in Figs. 5 and 6. These, as expected, show that increases in wheat grain yields are higher in the wetter areas than in the drier areas. However, the validity of the results in the drier areas is questionable, due to the lack of experimental results. Once validated as in the higher rainfall areas (>300 mm seasonal rainfall) it would be a good tool to offer decision-makers for their consideration to prioritize fertilizer allocation.

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DISCUSSION

J. Ryan

I'm impressed with your yield response--rainfall patterns as depicted in your charts. We used that here in Morocco. The question is a logistic one–how do you select sites? Sample soils for analysis? Layout trials? What arrangements with farmers?

A. Matar

We send out teams in summer to select sites for analysis, especially for P, representing the dominant soil and various climatic zones. We select more than we need. Then we set out trials and use our own machinery. We ask village leader or farmer to take rainfall data and pay a small fee, i.e., 150 SYP/mo.

F. Mosseddag

In humid areas in Morocco (>450 mm) we found that 120 kg N/ha was the optimum N rate for wheat, and your results seems to confirm this within that range of rainfall. However, with more productive varieties we can go beyond 120 kg N/ha, up to 160 for instance. Don't you think that the optimum rate should be modulated depending on the variety?

A. Matar

The optimum N requirement for various varieties should be checked by field researchers. Based on this, the N recommendation should be adjusted according to the optimum rate for each variety.

A. Abdelmalek

1) Do you think that 4-5 years are adequate to develop simulation models?

2) Would you please elaborate on the need for permanent sites for long-term studies throughout the WANA region?

A. Matar

1) Four-to-five years of experimentation, distributed on a wide range of soil and environmental conditions, should be adjusted to generate a preliminary simulation medel that can be improved by time with more research.

2) I think that long-term benchmark sites should be selected in the WANA region to monitor and study the long-term effects of fertilization on soil productivity.

A Current Perspective on Dryland Cereal Fertilization in Morocco

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ABSTRACT

Prior to 1988, research in Morocco had established the importance of nitrogen and, to a lesser extent, phosphorus for bread wheat (*Triticum aestivum* L.) on three soils in the environs of Settat (Chromoxerert, Calcixeroll, and Petrocalcic Palexeroll), and emphasized the importance of residual N from previous legumes. Subsequently, N response (0, 40, 80, 120 kg/ha) for a wheat (Nesma) susceptible to Hessian fly (*Mayetiola destructor* Say) and a genetically resistant one (Saada) was evaluated at six sites throughout the entire dryland zone (250-450 mm/yr).

One P trial with triticale (*Tritico-secale*) was conducted at a Settat location. The following year, a similar range of N trials involved barley (*Hordeum vulgare* L.) and triticale, while one involved P fertilizer with bread wheat, durum wheat (*T. turgidum* var. *durum* L.), barley and triticale at a low-P site. Responses to N were consistent for cereals and decreased with decreasing rainfall, with a maximum rate in the higher rainfall area of 90 kg/ha decreasing to 30 kg/ha in drier areas. Response to P varied with the year and was generally consistent and significant. Other fertility studies have dealt with residual N after medics (*Medicago* spp.) and P-zinc interactions for corn (*Zea mays* L.).

Soil test calibration has progressed to the point where N recommendations are based on soil test levels in conjunction with soil, crop, and climatic factors. Economic analyses have underlined these conclusions. The challenge now is to promote farmer's use of soil analysis as a basis for fertilizer application, and to encourage a network of service laboratories to satisfy those needs.

INTRODUCTION

Since the inception of the Dryland Applied Agricultural Research Project, which established the Aridoculture Center in Settat in 1982, the role of fertilizers was given prominence in the effort to enhance cereal output in Morocco's marginal rainfall zone (250-450 mm/yr) through improved management practices promoted by adaptive research (Ryan *et al.*, 1989b). While the efforts up to 1985 were frustrated by a prolonged and disastrous drought, subsequent experimentation at research stations and in farmers' fields laid the foundation for the current expanded program. In addition, researchers in soil fertility in Morocco played a pivotal role in the establishment of the Regional Soil Test Calibration Network of ICARDA; their contributions were documented in the Network's meetings in Aleppo (1986), Ankara (1987), and Amman (1988). The latter meeting provided a comprehensive overview of what had been achieved in the initial phase of the soil test calibration work in Settat.

Field research with fall-planted spring wheat (Nesma) amply demonstrated the ubiquity of N response (Abdel Monem *et al.*, 1990e); this was influenced by soil type, being higher on Vertisols than on shallow soils and also in years of more favorable rainfall, but less where a legume was previously grown. Other work (Abdel Monem *et al.*, 1990f) showed that N and P both accumulate in soils with time, but no difference can be expected between banded and broadcast P in terms of efficiency where soil test levels are above critical values (Abdel Monem *et al.*, 1990h). Numerous trials in countries of the West Asia-North Africa region have indicated the Olsen-P critical value to be between 5 and 7 ppm (Ryan and Matar, 1990; Ryan and Abdel Monem, 1989). Moroccan field trials with P generally corroborated this observation.

Since the Amman meeting (Ryan and Matar, 1990), the cereal fertilization program has expanded in several directions, primarily in terms of the increased range of wheat cultivars and other cereals - barley, triticale, and durum wheat - and of local sites in the diverse areas of the semiarid zone. Broadcasting was generally adopted in these trials, rather than drilling, since it is the farmer's common practice. Increased emphasis was placed on economic analysis. This presentation gives an overview of the various aspects of the expanded field research program. In view of unrepresentative fertility levels at agricultural research stations (Ryan *et al.*, 1990), experimentation was exclusively confined to farmers' fields and involved small-scale farmers who are the majority in Morocco (Shroyer *et al.*, 1990). The individual trials described here are categorized under the main nutrient elements or category of concern.

NITROGEN-CEREALS

Fertilization and Hessian Fly Resistance

Hessian fly is a major cereal pest in Morocco and other semiarid areas of the North Africa-West Asia region. Research has focused on mitigating its effects, largely by introduction of resistant or tolerant varieties. The study of Abdel Monem *et al.* (1990c) combines demonstration of the benefits of N fertilization with genetic resistance to Hessian fly. One such bread wheat variety, Saada (SD 8036), was compared with an established bread wheat (Nesma) and a durum wheat (Cocorit) in a research-demonstration trial using fertilizers (100 kg N and 36 kg P/ha) and chemical control of weeds, fungi, and Hessian fly. The trial site, on a Calcixeroll, was near a main highway for maximum visibility. The impact of Hessian fly was apparent in the early growth stages. However, this was not reflected in final yield data. Without N, Saada was similar to Nesma and Cocorit in grain yield, but higher in straw yield. Grain yield response to added N was lower with Saada, although the straw yield response was high. Grain protein for Saada tended to be lower than for the other varieties. As such parameters tend to be environment-specific, and the severity of Hessian fly damage varies with season, a comprehensive program of testing Saada at multiple locations appeared to be warranted.

Cereal Deficiency: Survey Approach

While the initial soil fertility trials were concentrated in the environs of Settat, future efforts depended on the extent to which the deficiencies observed here were representative of the entire 4 million ha of cultivated land in the dryland zone. A rapid way of making this assessment was deemed to be a visual survey of N-deficiency symptoms in cereal fields throughout the zone (Ryan *et al.*, 1992). While several local trials have shown the importance of N and, to a lesser extent P, extension of the findings generated is beset by many constraints. This survey of wheat and barley areas, based on a rainfall gradient of 500 to 200 mm/yr, involved visual assessment of 2152 cereal fields at tillering to stem elongation stages (Feekes 5-6). Plant material samples were taken for N and related to standard criteria.

From 77 to 91% of the fields appeared deficient to some degree; with decreasing rainfall, the proportion of adequately fertilized fields decreased, while those with severe N deficiency increased. Plant tissue N concentrations were poorly related to visual observations. In view of potential economic benefits for both the farmer and the national economy, major efforts should be made to promote N fertilizer use. Visual assessment of N deficiency can play a role in crop evaluation in developing countries that lack more sophisticated resources, and where there is an urgent need to promote output through fertilizer programs.

Cultivar-Environment Interactions

As a result of its Hessian fly resistance, Saada was incorporated into a trial involving N (0, 40, 80, 120 kg/ha) at six locations with relatively favorable rainfall (above 375 mm/yr at Oulad Said, Khouribga, and Berechid, and 280 mm/yr at a drier more precarious location at Jemaa Shaim, and even more arid areas inland, Chemaia and Ben Guerir). The standard cultivar Nesma was included in addition to a chemical treatment (carbofuran) to control Hessian fly. The data (Ryan *et al.*, 1991d) showed that N response was related to rainfall, being highest at the Oulad Said site (Vertisol) and nonexistent at the dry Chemaia and Ben Guerir sites. Despite favorable rainfall, N response was negligible at the Khouribga site, probably because of mineralization. For most sites, maximum yield was achieved with 40 kg N/ha. The ravages of Hessian fly were pronounced in the drier Jemaa Shaim site, but did not occur at Chemaia with a similarly dry climate. Chemical treatment mitigated these effects. While this treatment is feasible at researcher level, it is unlikely to have any impact at the farm level because of exorbitant costs and hazards associated with its use.

Application Time

Another aspect which has not been considered with N use in Morocco's semiarid zone is the time of application. Where fertilizer is applied, it is done so mainly at planting. If the subsequent crop is lost to or decimated by drought, the economic argument for N use in the fall is doubtful. However, spring application of N by top-dressing allows the consideration of crop stand and stored soil moisture. This is particularly relevant to Morocco where financial reserves for fertilizer purchases are scarce and where labor is readily available for top-dressing in spring, if necessary. The objective of the Ryan *et al.* (1989a) experiment was to study the effects of time and rate of N application on straw and grain yields of Saada wheat.

While spring-applied N and split application were more effective in terms of dry-matter (DM) yield, the difference was not significant. Grain yield was likewise not significantly affected by N application time, although fall-applied N tended to give higher grain yield. Generally, maximum yield occurred with 40 kg N/ha. Absence of any clear-cut agronomic advantage from spring- or split-applied N is consistent with data obtained elsewhere for dryland winter wheat. Although there appears to be no agronomic advantage of deviating from the traditional practice of fertilizer application at or prior to planting, applying some fertilizer in spring is less risky than the full dressing in the fall; if the season has favorable rains, additional fertilizer can be used to economic advantage, but if drought limits crop growth, the farmer can reduce or eliminate any further fertilizer application. Even if fertilizer is applied with no current year crop response, it would stay in the ground and benefit the next crop with favorable growing conditions.

Barley

Although barley, which is well adapted to the semiarid conditions of the Mediterranean zone, occupies about 50% of the dryland cereal cropped area, it is poorly fertilized at best. While traditional low-yielding cultivars and disease susceptibility are contributing factors, lack of adequate fertilizer input is a serious impediment to increased output. While many trials with N and barley at experimental stations showed no response in terms of yield, it was clear that there was a need for evaluation in farmers' fields with due consideration of soil N levels. Thus, Ryan *et al.* (1991a) attempted to remove some of the ambiguity with barley fertilization.

In this field trial of improved barley varieties (Arig 8, Asni, Tessaout, ACSAD-60, and ACSAD-176) grown on a shallow soil (Petrocalcic Palexeroll) in the Settat area of Chaouia, N was broadcast at 0, 40, 80 and 120 kg/ha as ammonium nitrate at planting. The 370 mm rainfall during the season coincided with the 50-yr average for the area. Marked responses were evident even at tillering. All varieties responded to increasing N to 120 kg/ha, where yields were 200 to 250% higher than the controls. At any N level, the six-row variety, Arig 8, was better than the others, while the earliest cultivar, Tessaout, tended to yield less than the others. These differences were generally reflected in grain yield. The study clearly showed the potential of N to increase barley output in dryland Morocco.

Triticale

Because of high potential yields, disease resistance, satisfactory nutritional components, and adaptability to a wide range of marginal or stressed environments, triticale, a novel cereal with considerable commercial potential, is seen as an alternative, or at least as a complementary cereal crop, particularly in low-rainfall areas of the world. In the past decade, it has been the subject of breeding and agronomic research in the rain-fed North Africa-West Asia zone.

Initial recent trials in Morocco showed that triticale was well adapted to a wide range of harsh environments and generally outyielded other cereals under such conditions. This study from the dryland area of Morocco (Ryan *et al.*, 1991e) involved a range of N and P rates in separate trials with three triticale varieties grown in a drought-prone shallow Petrocalcic Palexeroll. The mean effects of N and P were significant; for N, maximum responses were between 100 and 150 kg/ha, while the maximum P rate was 30 kg/ha. Varieties differed in grain and DM yields, without N and P, and in their response to these elements. At 100 kg N/ha, the order was Juanillo > Drira Outcross > Beagle. With P fertilization, Drira Outcross consistently outyielded Juanillo, with both being superior to Beagle. Where soils are deficient in N and P, economic responses to both elements are likely. Thus adequate fertilization can markedly increase both grain and straw yields of triticale in Morocco's dryland zone.

Triticale-Environment

Given the responses of triticale to N, the next logical step was to examine its performance under a range of rainfall and temperature environments. As triticale is reputed for drought tolerance, it was compared with barley at five locations in 1989/90, which, in order of decreasing rainfall, were Khouribga (396 mm), Settat (370 mm), Skhour Rehamna (260 mm), and Chemaia and Sidi Bou Othman in the drier South (Ryan *et al.*, 1991f). Nitrogen was applied up to 150 kg/ha.

The experiment underlined the hazards of dryland farming. As a result of drought (no rain for 10 weeks after emergence), two sites (Chemaia and Sidi Bou Othman) were destroyed and were not harvested. However, observations showed that triticale persisted longer than barley. Under such drought, there was no N response; in fact, levels of N beyond 30 kg/ha depressed crop growth. Nevertheless, good yields were obtained at the other three sites.

At all three sites, triticale outyielded barley in terms of straw and grain. Mean yields were directly related to rainfall; the Settat and Khouribga sites yielded about twice that of Skour Rehamna. Maximum responses to applied N were only 30 kg/ha at Skour Rehamna, but up to 90 kg/ha at the other two sites. This trial again stressed the potential of triticale for adaptation in Morocco's semiarid areas.

Fertilization-Cereal Disease

While the prime concern with fertilizers is yield increase--total biomass and straw and crop quality to a lesser extent--peripheral concerns relate to indirect effects on disease control. Tan spot, caused by *Pyrenophora tritici-repentis* (Died) Drechs, is a major disease of cereals, especially durum wheat, in Morocco. Chemical control is not a feasible approach for most farmers. Development of resistant varieties is the most attractive solution. Furthermore, there have been reports (Jones *et al.*, 1991) that N fertilizers, especially ammonium forms, reduce the incidence of tan spot. This on-farm trial on a Petrocalcic Palexeroll examined N response (0, 40, 80, and 120 kg/ha) of one resistant and two susceptible durum wheat lines. All lines responded to N depending on the rate. While disease counts were high for the susceptible lines, the resistant one was moderately infected also. The response of these lines to N was inconsistent; however, one susceptible line showed less infection with added N. Mechanisms involved in the differential response are not clear, if in fact they are real. The field significance of N fertilization in relation to tan spot amelioration is not yet clear. More definitive conclusions must await the outcome of more comprehensive studies that involve a large number of years and sites.

RESIDUAL IMPACT OF MEDICS

Of the many issues related to N fertilization of cereals, the impact of a crop that fixes N on the subsequent cereal was of concern. While carryover of N is well documented for annual legumes such as peas (*Pisum sativa* L.), chickpeas (*Cicer arietinum* L.), or faba beans (*Vicia faba* L.), this effect for medics was not assessed (Abdel Monem *et al.*, 1990e). Medics (*Medicago* spp.), self-regenerating annual legumes, are important forages which potentially can reduce the area devoted to weedy fallow in a more economical manner. Derkaoui *et al.* (1991) assessed the residual impact of two medic cultivars (Snail and Serana) at different seeding rates. However, while medic increased yields and % N in the cereal grain, the effect was not significant, and neither was the increase in residual soil nitrate. Whether the medic crop was cut for forage or left for seed had some apparent effect on soil nitrate. Soil nutrient variability at this site (Abdel Monem *et al.*, 1989) and high mineralization potential may have contributed to confounding these results. Clearly, further research is called for.

CORN-PHOSPHORUS x ZINC

The role of P and zinc and their interactions in field crops, especially corn (*Zea mays* L.), has been the subject of numerous investigations. While both elements alone promote increased growth, additional P frequently induces Zn deficiency. While the causal mechanisms are not always clear, the effect of P on Zn appears to vary with cultivars. Corn is grown extensively in Morocco's dryland zone, where soils are mainly calcareous and conducive to both P and Zn deficiency. As deficiency in corn has been noted in the field, this greenhouse study (Ryan *et al.*, 1991c) considered P (0, 50, 150 mg/kg) response of six corn cultivars (local and improved) grown on a deficient Mollisol and a Vertisol.

For both soils, applied P increased dry-matter yields and plant P concentration, but decreased plant Zn concentration. Zinc increased dry-matter yield for both soils as well as plant Zn concentration. There were significant differences among cultivars for dry matter and P concentration for both soils, as well as with Zn concentrations for the Vertisol, where values were considerably lower than for the Mollisol. Zinc deficiency symptoms also were more extensive with the Vertisol. Dilution due to increased growth from added P was the apparent reason for the Zn deficiency in the Mollisol, which was common to all cultivars, while Zn values for the Vertisol increased or were inconsistent. The data presented here create an awareness of the importance of P and Zn for cropped corn in Morocco.

PHOSPHORUS-CEREALS

The past two years have seen less attention given to P than to N, since several trials showed no response to P (Abdel Monem and Ryan, 1990a; Abdel Monem *et al.*, 1990e). Indeed, a soil sample survey of cereal fields in Chaouia (Abdel Monem *et al.*, 1990g), suggested that less than half of the area was considered deficient. Nonetheless, meaningful trials with P could be conducted with prior analysis of the proposed site for available P. The impact of continuous fertilization at agricultural experiment stations reduces or eliminates crop responses to applied P because of P accumulation in the soil (Ryan *et al.*, 1990).

Therefore, not surprisingly, subsequent P trials did show good field responses to applied P. In 1988/89, the trial site at Settat (Petrocalcic Palexeroll, 4.0 ppm P) showed consistent responses of triticale cultivars (Juanillo, Beagle, and Drira Outcross) to P (0, 15, 30, and 60 kg P/ha) (Ryan *et al.*, 1991e). Although there were no differences among cultivars, mean yields were increased by about 25% with 30 kg P/ha. However, at the same site, Saada wheat did not respond significantly in terms of final biomass or grain yield (Abdel Monem and Ryan, 1990a), though visual differences were apparent in the early growth stages.

The following year, P evoked a similar yield increase for triticale at another site; this time the soil type was a Vertisol (Mergoum *et al.*, 1990). That same year at the Petrocalcic Palexeroll site, P applied at 0, 10, 20, and 40 kg P/ha to four cereals (bread wheat, durum wheat, barley, and triticale) increased grain and total biomass yields with each increment of P (Ryan *et al.*, 1991b). Relative responses were highest for barley. Interestingly, added P was reflected in increased soil P values which changed little over the growing season.

ECONOMIC ASPECTS

Soil, Rotation, Seasonal Factors

Despite the extensive number of field trials conducted from 1985 to 1988, few results were subjected to economic scrutiny. As this was one of the "new" directions of the expanded research effort, the multi-site multi-year trials of Ryan *et al.* (1991d) were examined economically (Abdel Monem *et al.*, 1990d) in terms of returns of N fertilizer on bread wheat as affected by soil type, previous crop, and seasonal or rainfall variation.

The experiment was conducted at farmers' fields under rain-fed conditions in the Settat area of central Morocco during 1986/87 and 1987/88. One shallow, one medium, and one deep soil type were chosen for the study. The previous crops at the shallow soil were barley, fallow, or legumes, while those at the medium and deep soils were wheat, corn, or legumes. The fertilizer treatments were 0, 30, 60, and 90 kg N/ha as ammonium nitrate for the shallow soil, and 0, 40, 80 and 120 kg N/ha for the two deeper soils. Rainfall at the trial sites varied from a low of 200 mm in 1986/87 to an above-normal 471 mm in 1987/88.

On the shallow soil in 1986/87, maximum net revenue was obtained at 30, 60, and 90 kg N/ha for the crop following legume, fallow, and barley, respectively. In the last year, net revenue increased with up to 90 kg N/ha for the crop following legume and fallow. On the deep soil in 1986/87, net revenue was maximized with 120, 40, and 0 kg N/ha for the crop after wheat, corn, and legume, respectively. In the wet year, net revenue increased as the N rate was increased for each of the three rotations. Benefit/cost ratios for N application were generally highest after cereal on both shallow and deep soil types, and higher in 1987/88. Favorable benefit/cost ratios were obtained with N application after fallow in the wet year but not in the dry year. In general, N application after a legume gave poor benefit/cost ratios.

Hessian Fly Control--Economic Implications

As spectacular as yield increases may be from N or disease prevention, to be acceptable at the farm level these practices must have economic appeal. Here, using input and product (grain and straw) prices, Abdel Monem and Ryan (1990b) established a revenue profile for Saada and Nesma with and without chemical control of Hessian fly, in response to N fertilization at five locations with diverse rainfall and soil conditions. However, in economic terms divergence between varieties was large. Average benefit/cost (B/C) values for Saada (4.8) were higher than for Nesma (2.6); with chemical treatment, the B/C of Nesma decreased to 1.8. As N increased, B/C values decreased with diminishing yield increases. Different B/C values for Nesma and Saada among locations reflected the degrees of fly severity and N response. The study clearly showed the economic benefits of N fertilization and of using a Hessian fly-resistant wheat variety.

OUTLOOK

The past decade of soil fertility research in Morocco's marginal rainfall zone has clearly shown the need for and the benefits of fertilization for increasing cereal yields. While a number of challenges to research still exist, a sufficient data base has been established to refine the more global recommendations of the past which did not consider variation in rainfall, crop yield potential, soil type, or preceding crop. No similar basis existed for P, nor was there an awareness of the fact that soil P levels build up with repeated application.

Future efforts need to be concentrated on transferring these results to farmers to make them aware of the need for proper fertilization based on sound technical and economic guidelines. It is a challenge that is more difficult to realize than articulate, given the socioeconomic milieu of the region. Future research should involve an integration of soil fertility in all aspects involving cereals and other field crops and in the scientific disciplines related to these. Similarly, all technologies or developments should be economically assessed.

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SECTION III

Soil Test Calibration under Dryland Conditions

a. Phosphorus
b. Nitrogen

Soil Test Calibration with Phosphorus for Wheat under Dryland Conditions in Western Iran

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ABSTRACT

Twenty-two wheat trials (var. Safid) were conducted during 1989/1990 at farmers' fields in western Iran (Bakhtaran). Five levels of P (0, 20, 40, 80, and 120 kg/ha) were applied with three replications. Nitrogen at 45 kg N/ha was broadcast and applied uniformly for all treatments. Before planting, total N and $NaHCO_3$-extractable P were determined in the 0-20 and 20-40 cm soil layers. The annual rainfall in Bakhtaran is about 420 mm and common rotation is chickpea-wheat. Four available soil P levels (poor = less than 4 ppm; medium = 4-7 ppm; high = 7-10 ppm; and very high = above 10 ppm) were studied in that rotation system.

Since most farmers use large amounts of fertilizer every year, it was difficult to find a soil with P analysis of less than 5 ppm. According to the results obtained, grain did not respond significantly to P fertilizer except at two sites. In other experiments (N x P factorial), only in two years out of nine was a significant response to P observed. The critical level of available P for 80% of maximum yield was found to be about 5 ppm. Using the Cate-Nelson graphical method, the critical level of available P showed the same value.

INTRODUCTION

The experiment was carried out to study the effect of P on winter wheat in Bakhtaran province in western Iran. In this province about 300,000 ha of cereal and 1000 ha of chickpea (*Cicer arietinum*) are grown under rain-fed conditions every year. Crop rotation in some parts of this area is wheat-chickpea and in other parts, wheat-fallow. In these areas, farmers broadcast seed and fertilizer and thereafter plow the soil by disc or shallow moldboard plow.

Based on 20 years' climatological data, annual precipitation in the region is about 420 mm, occurring mainly during winter and early spring. In 1989/1990, precipitation was 346.5 mm, most of which occurred in winter. There was no rainfall at the heading stage in early May and thereafter.

The experimental sites were situated at altitudes ranging from 1100 to 1600 meters above sea level. The region is plateau and alluvial plains. Soil temperature and moisture regime in the northern part of Bakhtaran is mesic-xeric and in the south, termic-xeric. Soil family in the experimental sites was fine, mixed, mesic Calcixerollic Xerochrept and fine, mixed, termic, Calcixerollic Xerochrept.

MATERIALS AND METHODS

A multilocation field experiment was conducted to determine the effects of P fertilizer application on the yield of dryland winter wheat. The experiment was carried out at 33 sites throughout the region during the 1989/1990 growing season. However, results of only 22 sites were obtainable for analysis. At each site the experiment was conducted as a randomized complete block with three replications and five P treatments (0, 8, 10, 32, and 48 kg/ha).

Nitrogen fertilizer was applied uniformly (at a rate of 45 kg/ha) for all treatments. Wheat seed (var. Safid), which had previously been treated with P.C.N.B., was sown at a rate of 150 kg/ha. Fertilizer and seed were broadcast following which the soil was plowed by disc. Soil samples were collected before seeding from 0-20 cm depth and analyzed for pH, EC, N, P, K, total neutralizing value (TNV), and texture (Table 1). Grain yield obtained from each site was analyzed to determine any

Table 1. Physical and chemical properties of soil (0-20 cm) from 22 experiments, Bakhtaran, Iran, 1989/1990.

Texture	EC	pH	TNV	N	P	K
				(%)	---- (ppm) ----	
Silty-clayey-loam	0.87	7.4	29.5	0.1	8	460
"	0.76	7.3	30.5	0.12	8	600
"	0.73	7.3	28	0.1	5	380
"	0.70	7.4	26	0.11	6.5	440
"	0.62	7.5	2.5	0.13	16	456
Clayey-loam	0.60	7.4	32	0.17	10	350
"	0.41	7.6	23.5	0.09	5.5	290
"	0.62	7.5	22	0.10	11	420
Silty-clayey-loam	0.62	7.4	17	0.08	8	340
Clay	0.45	7.4	18.5	0.08	9	330
Silty-clay	0.47	7.6	20.5	0.08	3	380
"	0.51	7.4	5	0.12	9	500
"	0.57	7.6	8	0.19	6.5	400
"	0.64	7.4	28	0.12	6	440
Silty-clayey-loam	0.56	7.5	28.5	0.07	4	380
"	0.70	7.4	27.5	0.09	7.5	380
"	0.97	7.4	9	0.12	10	510
"	0.47	7.4	8.5	0.1	6	470
"	0.36	7.6	26	0.09	3	400
Silty-clay	1.2	7.6	34.5	0.1	3	260
Silty-clayey-loam	0.47	7.5	33.5	0.08	3	290
"	0.4	7.6	33.5	0.14	6	420

P = $NaHCO_3$ (Olsen); K: in NH_4OaC TNV = Total neutralizing value EC = Electrical conductivity.

significant response to P fertilizer application. Weeds were controlled by 2,4-D in early spring. The constants of c_1 and c for b_1 and x (Mitscherlich-Bray equation) were calculated in each experiment (Table 2).

RESULTS AND DISCUSSION

The analysis of variance indicated that, except at two sites, the effect of P fertilizer application on grain yield was nonsignificant. Added P increased grain yield at most

Table 2. Soil test values and response of wheat to P application in 22 experiments, Bakhtaran, Iran, 1989/1990.

	Applied P_2O_5 (kg/ha)							
	X_0	X_{40}	X_{80}	X_{120}		Mitscherlich constant		
	Yield obtained (kg/ha)					C_1	C values	
Expt.	Y_0	Y_1	Y_2	Y_3	P_2O_5 (kg/ha)	for b_1	for x_{40}	for x_{80}
1	2120	2404	2500	2680	40	0.0169	0.0077	0.0062
2	1990	2194	2344	1970	47.6	0.0172	0.0093	-
3	1990	2200	2400	2540	32.1	0.0207	0.0052	0.0074
4	1950	2136	2200	2380	41.7	0.0178	0.0062	0.0047
5	1684	1484	1480	1206	102.6	-	-	-
6	2620	2634	2720	2824	55	0.0207	0.0008	0.0037
7	1514	1650	1750	1840	35.3	0.0212	0.0059	0.0070
8	2120	2450	2394	2380	70.5	0.0136	-	-
9	1196	1220	1304	1440	51.3	0.0150	0.0011	0.0032
10	1610	1700	1740	1624	57.7	0.0195	0.0128	-
11	1584	1700	1896	1966	16.5	0.0431	0.0039	0.0092
12	2072	2266	1756	1730	53.6	-	-	
13	2470	2840	2960	3160	32.7	0.0202	0.0083	0.0067
14	1804	2000	2140	2270	35.5	0.0193	0.0059	0.0069
15	2654	2814	2900	2990	22	0.0431	0.0070	0.0072
16	2896	3000	3326	3530	41.2	0.0181	0.0019	0.0062
17	2634	2665	2914	2930	35.7	0.0278	0.0013	0.0158
18	1240	1364	1400	1586	20.8	0.0317	0.0049	0.0034
19	1484	1864	1920	1994	16.5	0.0359	0.0148	0.0104
20	1736	1840	1986	2100	16.5	0.0461	0.0037	0.0063
21	1106	1196	1200	1234	38.5	0.0256	0.0131	0.0072
22	2966	2866	2584	2540	59.5	-	-	-
	Average					0.0249	0.0066	

sites, but at some sites increasing P decreased grain yield, especially when P available in the soil was about 11 ppm or more.

In other experiments (N x P factorial), only in two years out of nine was there a significant P response. The critical P level was determined using the Cate-Nelson graphical method and the Mitscherlich-Bray equation. The Cate-Nelson method involved plotting the relative yield (0-100%) of wheat against the level of soil P (Fig. 1). Relative yield for each location is total dry matter obtained in the treatments without fertilizer as a ratio of maximum obtained when fertilizer is added. According to the Cate-Nelson method, the critical level of Olsen-P in the top 20 cm of soil was about 5 ppm. At relative yield of 80% (in the absence of applied P fertilizer), the Mitscherlich-Bray equation indicated that the critical level of available P in the soil was about 5 ppm.

Not only in this study under rain-fed conditions but also in other studies on wheat and maize under irrigated conditions, no significant response to P fertilizer was shown when available P in the soil was up to 7 ppm.

Since most farmers use large quantities of P fertilizer every year, P will remain in the soil leading to increased P availability.

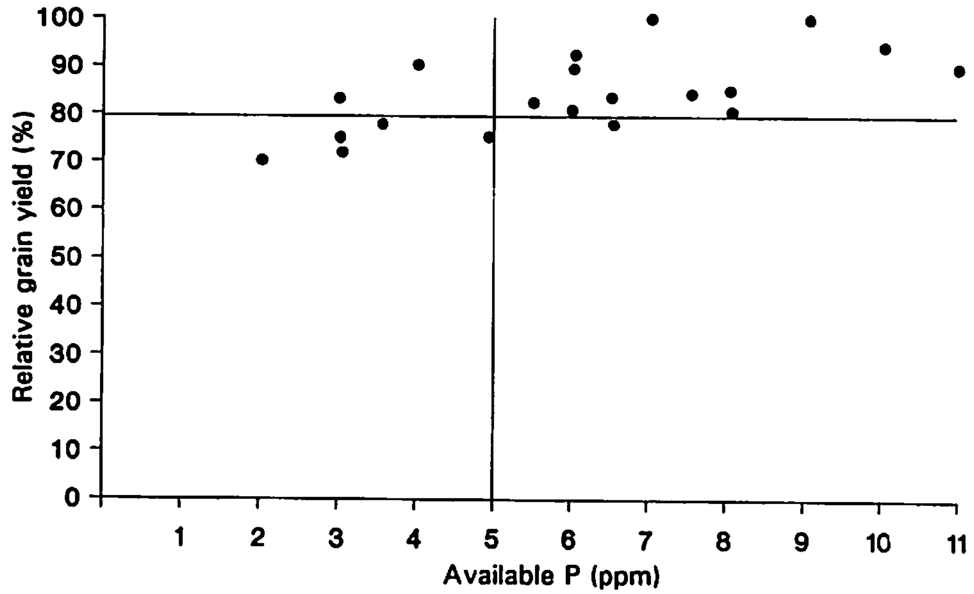

Fig. 1. Scatter diagram of relative percent of wheat grain yield at harvest as related to available soil-P at sowing in farmers' fields in Iran, 1989/90.

DISCUSSION

J. Ryan

Why did you get a decrease in yield at high levels of applied P? Perhaps it was because of depressed levels of Zn as a result of an interaction!

K. Sayyadyan

The reason for this is not known yet. However increasing the available P (by adding P fertilizer) resulted in that some elements could not be absorbed by wheat, which lead to a decrease in the wheat yield.

A. Matar

How far is soil fertility research developed in Iran and how many scientists are working on fertilization research?

K. Sayyadyan

Soil fertility divisions in Iran have been operating for over 25 years. However, at Bakhtaran, only three experts are working on soil fertility under rainfed agriculture. I do not know about other regions in Iran.

Soil Test Calibration with Phosphorus for Three Different Wheat Varieties Cropped under Turkish Rain-fed Conditions

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ABSTRACT

This paper reports two years' data from our soil test calibration study for three high-yielding wheat varieties in the Central Anatolia region of Turkey. Twenty-six on-farm wheat experiments were conducted during the 1987/88 and 1988/89 growing seasons at 10 farmers' fields. These consisted of five P levels (0, 12, 24, 36, and 48 kg P/ha) with four replications. The specific objective was to determine if there were any differences in response of different wheat varieties with the same yield potentialities to P fertilization, and to correlate response data with soil $NaHCO_3$-P levels. Using the Mitscherlich-Bray equation the constants c_1 for the soil test value b_1 and c for fertilizer rates x were calculated. The c_1 values for Haymana, Gerek, and Bolal varieties were 0.014, 0.016, and 0.015, and c values were 0.0062, 0.0076, and 0.0077, respectively. Based on these constants, two calibrations and P fertilizer application rates for the varieties Haymana, Gerek, and Bolal are suggested.

INTRODUCTION

Agronomists have always been interested in relating plant growth to levels of a given nutrient in the soil. In general, growth is a function of rate of energy fixation acting through a given period. In relating a level of a soil nutrient to growth, as is done in soil test correlation studies, two assumptions are made: (i) that the nutrient acts essentially as an independent variable, i.e., that a reduction in the quantity of the nutrient reduces the energy fixation rate independently of the other nutrient levels, and (ii) that some measured quantity of a soil nutrient level will, or can, express or define the rate factor for that particular nutrient.

To understand the influence of a given level of a soil nutrient on growth rate, Bray (1954) and Melsted (1963) proposed the classification of nutrients according to their behavior in the soil. Usually only two broad classifications are needed: (i) those nutrients that are relatively immobile, and (ii) those that are mobile in the soil. A relatively immobile nutrient is one that is adsorbed by the soil colloid, such as exchangeable cations, and therefore moves or diffuses very slowly in the soil and is resistant to leaching. A mobile nutrient is one that moves freely in the soil, is not attracted to or held on the colloid surfaces, and moves both in and with the soil solution. As a result, a mobile nutrient can be completely exhausted from the soil volume by the plant root system. Therefore, nitrogen, as a mobile nutrient, follows the "Law of the Limiting Nutrient" in contrast to immobile nutrients such as phosphorus and potassium, which follow the Mitscherlich-Bray "Percentage Sufficiency Concept." For this reason, varying soil levels of an immobile nutrient are usually best correlated with growth by using the Mitscherlich-Bray equation.

The amount of P fertilizer required to correct a soil deficiency is determined essentially by four variables: (i) the level of available soil P; (ii) the upper limit of desired yield attainment; (iii) fertilizer application method, and (iv) plant species, and even varieties to be grown. Thus, the objective of this study was to relate the levels of soil P extracted by $NaHCO_3$ to the response of three different high-yielding wheat varieties to P fertilization in the semiarid Central Anatolia region of Turkey.

MATERIALS AND METHODS

This paper reports a two-year, out of a three-year, study of P response to three wheat varieties (Haymana 79, Gerek 79, and Bolal 2973) in dryland conditions in Central Turkey. Data for the first year had been reported earlier in this Soil Test Calibration Workshop series (Ryan and Matar, 1990; Yurtsever and Gedikoğlu, 1990). As experimental and growing conditions varied from year to year, the results for the two years are pooled. All two-year trials were researcher-managed on local farms in the vicinity of Ankara.

Rainfall, and consequently soil moisture, is the dominant constraint to crop production in the region. It is sparse and erratically distributed in any one season and from year to year. The overall average is 371 mm/year, most of which falls from November to March, i.e., in winter when temperature is mostly below zero and there is no plant growth at all.

Ten experimental sites (26 field trials) were selected based on productivity and representativeness of major soil types in the region. The soils of this region are medium to shallow in depth, moderately sloping, and brown to reddish brown in color. Their texture is loam and clay loam. They are calcareous in nature and low in organic matter and phosphorus, but rich in potassium. Composite soil samples were collected before seeding from each plot to a depth of 20 cm, and analyzed for available P by the Olsen (1954) method. The pH was determined on a saturated paste using a glass electrode, and free carbonate was determined by acid-neutralization (Table 1).

The five basic treatments used were: 0, 12, 24, 36, and 48 kg P/ha. The experimental design was a randomized block with four replications. Each plot was 1.3 x 11 m with eight rows of wheat 16 cm apart. Ammonium sulfate (% 21 N) at 40 kg N/ha was broadcast before seeding, while 30 N kg/ha as ammonium nitrate (% 26 N) was hand applied to all the plots between the rows in April. Phosphorus as triple superphosphate (20% P) was drill applied in bands at seeding time.

After a growth cycle of approximately 9 months, the plots were harvested and yields were weighed. Data from the six middle rows only were used as estimates of yield. Data obtained from the 0, 12, 24, and 36 kg P treatments were then expressed

Table 1. Soil properties at 26 experimental sites (0-20 cm sampling depth), Central Anatolia, Turkey, 1987-89.

						Available	
Expt.	Texture[1]	pH	C.C.E.[2]	Total salts	Organic matter	P_2O_5	K_2O
			(%)			(mg/kg)	
1	L	7.7	30.3	0.048	1.78	24.6	298
2	L	7.7	24.3	0.057	1.95	24.0	309
3	L	7.7	23.0	0.083	2.05	24.3	300
4	L	7.7	12.4	0.042	1.87	15.6	229
5	L	7.9	10.9	0.040	1.87	15.4	229
6	L	7.8	11.3	0.040	1.81	16.7	293
7	L	7.3	16.1	0.049	2.54	19.8	717
8	L	7.7	11.8	0.049	2.33	23.4	711
9	L	7.7	13.4	0.048	2.07	23.7	634
10	CL	7.5	24.7	0.094	1.87	12.7	710
11	CL	7.5	24.0	0.085	1.95	11.3	593
12	CL	7.7	23.4	0.094	1.87	15.9	591
13	CL	7.9	10.4	0.085	1.10	17.4	804
14	CL	7.9	10.6	0.082	1.14	19.0	867
15	CL	7.9	10.8	0.089	1.27	18.8	910
16	C	7.8	15.5	0.108	1.22	22.3	963
17	CL	7.8	18.8	0.076	1.32	8.1	544
18	CL	7.7	19.3	0.087	1.12	8.1	544
19	CL	7.8	23.8	0.077	1.59	10.0	354
20	CL	7.7	22.4	0.074	1.68	11.6	341
21	CL	7.7	21.4	0.094	1.71	9.2	354
22	CL	7.8	19.0	0.077	1.60	14.4	445
23	CL	7.8	17.5	0.065	1.60	14.4	458
24	CL	7.7	18.5	0.098	1.60	14.4	445
25	CL	7.7	22.8	0.070	1.84	13.1	337
26	CL	7.7	25.6	0.068	1.72	13.1	328

[1] D = Loam; C = clay; CL = clayey loam.
[2] C.C.E. = calcium carbonate equivalent.

as percentages of those from the corresponding 48-kg P plots, i.e., as relative yields.

These figures for relative yield were then correlated with P contents of the corresponding soils, using the Mitscherlich equation as given by Bray (1945, 1958):

$$\text{Log}\,(A\text{-}Y_0) = \text{Log}\,A\text{-}c_1b_1 \quad (1)$$
$$\text{Log}\,(A\text{-}Y) = \text{Log}\,A\text{-}c_1b_1\,\text{-}cx \quad (2)$$

Where:

A = maximum relative yield = 100
Y_0 = relative yield from the check plots
Y = relative yield from any given P rate
b_1 = the soil test value
x = a given fertilizer rate
c_1 = constant for b_1
c = constant for x

The "c_1" values were calculated from equation (1) for each experiment, giving finally a mean value for the constant "c_1", and "c" values were calculated from equation (2) for the fertilizer rates between zero and 48 kg P, finally giving a mean value for the constant "c".

In some experiments, yields obtained from the 24 and/or 36 kg P/ha rates were 96% or more of maximum yields, so they were not used in calculation of the constant "c". Because of the logarithmic nature of growth curves, c values calculated from relative yields close to 100 are not reliable (Arnold, 1953). In many cases, wheat yields from 36 and 48 kg P/ha were essentially equal, indicating that the 36 kg rate had corrected the deficiency. Therefore, wheat yields from the 48 kg treatments should present a valid "A" for the Mitscherlich equation. The economic amounts of P fertilizer, as a function of available soil P, were also determined. In other words, net revenues and rates of return for different fertilizer application levels were calculated. For these calculations, the theoretical maximum yield "A" of the Mitscherlich-Bray equation was defined by the formula given below:

$$A = \frac{(yk-y_0)}{k-1} \qquad (3)$$

Where:

A = theoretical maximum yield
y_0 = yield from OP plots
y = yield for any given P rate
k = the antilog of cx
x = any P rate
c = average of c values calculated by equation (2)

Using the theoretical maximum yield "A" and average values of "c_1" and "c", total yields and yield increases obtainable with different amounts of applied P for different soil-test values were calculated, and the sum of the increments for which the last increment still produces an increase in profit was taken as the most economical P fertilizer rate.

RESULTS AND DISCUSSION

The yields obtained in 1987/88 (Expt. no 1-16) and 1988/89 (Expt. no 17-26) are given in Table 2. Yields of all varieties progressively increased with increasing P application

Table 2. Wheat response (kg/ha) to P fertilization for the years 1987-89, Central Anatolia, Turkey.

			Applied P (kg/ha)				
			X_0	X_1	X_2	X_3	X_4
			0	12	24	36	48
			Yield				
Expt.	Experimental site	Variety	Y_0	Y_1	Y_2	Y_3	Y_4
1	Haymana-Sinanli	Haymana	3352	3620	3964	4553	4150
2	Haymana-Sinanli	Gerek	4033	4438	4628	5047	5055
3	Haymana-Sinanli	Bolal	3447	3944	4130	4143	4217
4	Bala-Merkez	Haymana	2205	2517	2637	2818	3524
5	Bala-Merkez	Gerek	2500	2804	2988	3137	3255
6	Bala-Merkez	Bolal	1874	2179	2311	2616	2734
7	Polatli-Hagci	Haymana	3173	3708	3903	4226	4265
8	Polatli-Hagci	Gerek	3916	4483	4473	5000	4873
9	Polatli-Hagci	Bolal	3300	3575	3740	3910	4172
10	Polatli-Temelli	Haymana	5359	5733	6337	6624	6939
11	Polatli-Temelli	Gerek	3885	4315	4682	4885	5083
12	Polatli-Temelli	Bolal	3154	3843	4197	3980	3856
13	Bala-A.Tepe	Haymana	2249	2484	2524	2575	2721
14	Bala-A.Tepe	Gerek	3227	3728	3774	4113	4210
15	Bala-A.Tepe	Bolal	2306	2675	2917	3155	3300
16	Bala-Masat	Bolal	3250	3422	3542	3696	3745
17	Polatli-Sakarya	Gerek	1430	1723	1915	2019	2177
18	Polatli-Sakarya	Bolal	1220	1576	1899	1936	2049
19	Gölbasi-Ahiboz	Haymana	2050	2694	3596	3956	4066
20	Gölbasi-Ahiboz	Gerek	2725	3579	4058	4150	4650
21	Gölbasi-Ahiboz	Bolal	2917	3298	3658	3772	3981
22	Polatli-Temelli	Haymana	1406	1611	1792	2137	2202
23	Polatli-Temelli	Gerek	2154	2756	2756	3145	3271
24	Polatli-Temelli	Bolal	1760	1863	2321	2495	2877
25	Gölbasi-G.Höyük	Haymana	1652	1853	2079	2261	2445
26	Gölbasi-G.Höyük	Gerek	1801	2173	2198	2308	2621
	Average		2695	3099	3366	3618	3720

rates. Large differences in wheat yields according to location and season were obtained, but the statistical analysis indicated that the effects of P fertilizer rates on grain yield were significant.

The suitability of a soil test for predicting P status of a soil can be evaluated by correlating P extractable with plant growth parameters such as yield, percent relative yield, and P uptake by the plant. To correlate yields with soil test values and fertilizer application rates, Bray (1958) modified the Mitscherlich equation. Using the relative yields given in Table 3, constants c_1 and c were calculated for each experiment. The constant c_1 was calculated using yields from control plots as Y_0, and the relevant Olsen soil test values as b_1. The constant c was calculated by using the wheat yields obtained from plots receiving 30, 60, and 90 kg P/ha as y, the previously calculated c_1 value for that field, and then Olsen soil test value for b_1. Relative yields higher than 96% were not used in calculation of c values. In most trials relative yields

Table 3. Relative yields and Mitscherlich constants for the 26 experiments conducted during 1987-89, Central Anatolia, Turkey.

	Applied P (kg/ha)					Maximum yield (kg/ha)		Mitscherlich constant			
	X_0	X_1	X_2	X_3	X_4	(A)[1]		c_1 for b_1	c values for		
Expt.	0	12	24	36	48	Calculated	Obtained		x_1	x_2	x_3
	Obtained yield (%)										
	Y_0	Y_1	Y_2	Y_3	Y_4						
1	80.8	87.2	95.5	109.2	100	4362	4150	0.012	0.006	0.011	-
2	79.8	87.8	91.6	99.8	100	5133	5055	0.012	0.007	0.006	-
3	81.7	93.5	97.9	98.2	100	4465	4217	0.012	0.015	-	-
4	62.6	71.4	74.8	108.3	100	3459	3524	0.011	0.004	0.003	-
5	76.8	86.1	91.8	96.4	100	3298	3255	0.016	0.007	0.008	-
6	68.5	79.7	84.5	95.7	100	2717	2734	0.012	0.006	0.005	-
7	74.4	86.9	91.5	99.1	100	4439	4265	0.012	0.010	0.008	-
8	80.4	92.0	102.1	102.6	100	5300	4873	0.012	0.013	-	-
9	79.1	85.7	89.6	93.7	100	4087	4172	0.011	0.005	0.005	0.006
10	77.2	82.6	91.3	95.5	100	6829	6939	0.020	0.004	0.007	0.008
11	76.4	84.9	92.1	96.0	100	5124	5083	0.022	0.006	0.008	-
12	76.1	92.8	101.3	107.0	100	4680	4143	0.016	0,017	-	-
13	82.7	91.3	92.8	94.6	100	2741	2721	0.017	0.010	0.006	0.006
14	76.7	88.6	89.6	97.7	100	4316	4210	0.013	0.010	0.006	-
15	61.7	81.1	88.4	95.6	100	3496	3300	0.009	0.010	0.009	0.010
16	86.8	91.4	94.6	98.7	100	3754	3745	0.016	0.006	0.006	-
17	65.7	79.1	88.0	92.7	100	2203	2177	0.023	0.007	0.008	0.007
18	59.5	76.9	92.7	94.5	100	2172	2049	0.019	0.008	0.012	0.010
19	50.4	66.3	88.4	97.3	100	4238	4066	0.012	0.006	0.011	-
20	58.6	77.0	87.3	89.2	100	4782	4650	0.013	0.008	0.009	0.007
21	73.3	82.8	91.9	94.8	100	4020	3981	0.025	0.006	0.009	0.008
22	63.9	73.2	81.4	97.0	100	2145	2202	0.012	0.004	0.005	-
23	65.9	84.3	84.3	84.3	100	3399	3271	0.013	0.011	0.006	-
24	61.2	64.8	80.7	80.7	100	2597	2877	0.011	0.011	0.005	0.005
25	67.6	75.8	85.0	85.0	100	2365	2445	0.015	0.004	0.006	0.007
26	68.7	82.9	83.9	83.9	100	2584	2621	0.015	0.009	0.005	0.005
					Average	3796	3720	0.015		0.074	

[1] Theoretical maximum yield.

obtained from the 36 kg P/ha (in some cases, even from the 24 kg/ha) treatments were 96% or more of maximum yield. Therefore, they were not used in calculations of the constant c for x (Table 3).

Average c_1 and c values with average and relative yields by the varieties are given in Table 4. Relative yields, and consequently average c value for the variety Haymana, were different from the c values obtained for the other two varieties. This means that the variety Haymana responded differently to applied P fertilizer than the varieties Gerek and Bolal. Therefore, two calibrations and P fertilizer application rates are suggested, namely for the variety Haymana (Table 5) and for the varieties Gerek and Bolal (Table 6).

Once the constants in the Mitscherlich-Bray equation are known, it is possible to determine the percent sufficiencies for any given soil test value. Using average c_1 value in equation (1), it is possible to determine the percent sufficiency for any given Olsen soil test value. That is, using soil test values as b_1 in equations: $\log (100-y_0) = \log 100-0.014\, b_1$ and $\log (100-y_0) = \log 100-0.015\, b_1$, and solving them for y_0, percent sufficiencies of different soil test values were calculated for the variety Haymana and varieties Gerek and Bolal, respectively (Tables 5 and 6, column 3).

According to the percent sufficiencies, if the available P extracted by $NaHCO_3$ gives percent sufficiency less than 50, the P content of that soil is classified as "very low"; if the percent sufficiency is between 50 and 75, the soil content is classified as "low"; between 75 and 90 as "medium"; between 90 and 95 as "good"; between 95 and 98 as "high"; and with soil having percent sufficiency more than 98, P is classified as "very high". This means that under rain-fed conditions of Central Anatolia, any calcareous soil having Olsen soil test value of 36 kg P/ha or more will be unresponsive to P fertilization. That is, in the absence of applied P fertilizer, the critical level of available P in the soil by Olsen is 36 kg/ha (Fig. 1). In a previous calibration study with low-yielding wheat varieties, the critical available soil-P level was 24 kg/ha (Yurtsever, 1986).

Furthermore, equation (2), which incorporates relative yield, can be utilized to predict the amount of P fertilizer required to give various percentages of maximum yield as affected by the level of available soil P at sowing. Calculated quantities of P fertilizer required to attain five levels of sufficiency (90, 92, 94, 96, and 98%), based on the Olsen soil test, are presented in Tables 5 and 6 for the variety Haymana, and for the varieties Gerek and Bolal, respectively. Table 5 shows, for example, that, for

Table 4. Average and relative yields (kg/ha) of varieties at different locations and average Mitscherlich constants.

	Applied P (kg/ha)										Mitscherlich constant	
	0		12		24 Yield		36		48		c_1 for b_1	c for x
Variety	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%		
Haymana 79	2681	71.2	3027	80.4	3229	85.8	3641	96.7	3764	100	0.014	0.0062
Gerek 79	2852	72.9	3333	85.2	3552	90.8	3755	96.0	3911	100	0.016	0.0076
Bolal 2973	2581	74.4	2931	84.5	3189	91.9	3351	96.6	3469	100	0.015	0.0077
Average (G+B)	2717	73.8	3132	85.1	3371	91.6	3553	96.6	3680	100	0.015	0.0077

Table 5. Calculated P fertilizer[1] required to attain various percent sufficiency levels for Haymana wheat based on Olsen test, Central Anatolia, Turkey, 1987-89.

Soil test	Test values and fertility index	Percent sufficiency	Required P_2O_5 for relative yields of:				
			90%	92%	94%	96%	98%
5		15	149.52	165.13	185.25	213.61	262.09
10	< 20 (Very low)	28	138.00	153.61	173.73	202.09	250.57
15		39	126.48	142.09	162.21	190.57	239.05
20		48	114.97	130.57	150.69	179.05	227.53
25	20-40 (Low)	56	103.45	119.05	139.17	167.53	216.01
30		63	91.93	107.53	127.65	156.01	204.49
35		68	80.41	96.01	116.14	144.49	192.97
40		73	68.89	84.50	104.62	132.97	181.45
45		77	57.37	72.89	93.10	121.46	169.93
50	40-70 (Medium)	81	45.85	61.46	81.58	109.94	158.41
55		84	34.33	49.94	70.06	98.42	146.90
60		86	22.81	38.42	58.54	86.90	135.38
65		88	11.29	26.90	47.02	75.38	123.86
70		90	-	15.38	35.50	63.86	112.34
75	70-90 (Good)	92	-	3.86	23.98	52.34	100.82
80		93	-	-	12.46	40.82	89.30
85		94	-	-	0.95	29.30	77.78
90	90-120 (High)	95	-	-	-	17.78	66.26
95		96	-	-	-	6.27	54.74
100		96	-	-	-	-	43.22
110	> 120 (Very high)	97	-	-	-	-	20.19
120		98	-	-	-	-	-

[1] All fertilizer rates and P test values in kg/ha.

the variety Haymana, if the Olsen soil test value of a given soil is 30 kg P/ha, this soil produces only 63% of the yield possible with adequate P. To raise the yield to 90% requires 31.9 kg P/ha; to raise it to 92, 94, 96, and 98% of maximum yield requires 107.5, 127.6, 156.0, and 204.5 kg P/ha, respectively. But, for the varieties Gerek and Bolal (Table 6), if the Olsen soil test is 30 kg P/ha, this soil is producing 65% of the maximum yield possible, and to raise the yield to 90, 92, 94, 96, and 98% of maximum yield requires 70.8, 83.5, 99.7, 122.7, and 161.9 kg P/ha, respectively. These parts of Tables 5 and 6 present suggested fertilizer rates for Haymana and Gerek and Bolal wheat varieties for five upper levels of sufficiency, when P fertilizer is applied in bands with the seed at seeding time.

But, such data are not sufficient basis for fertilizer recommendations; the calculations must be evaluated economically. In other words, the net revenues and rates of return must be calculated for different levels of fertilizer application. To conduct such an analysis, the parameter "A"--the theoretical maximum yield of

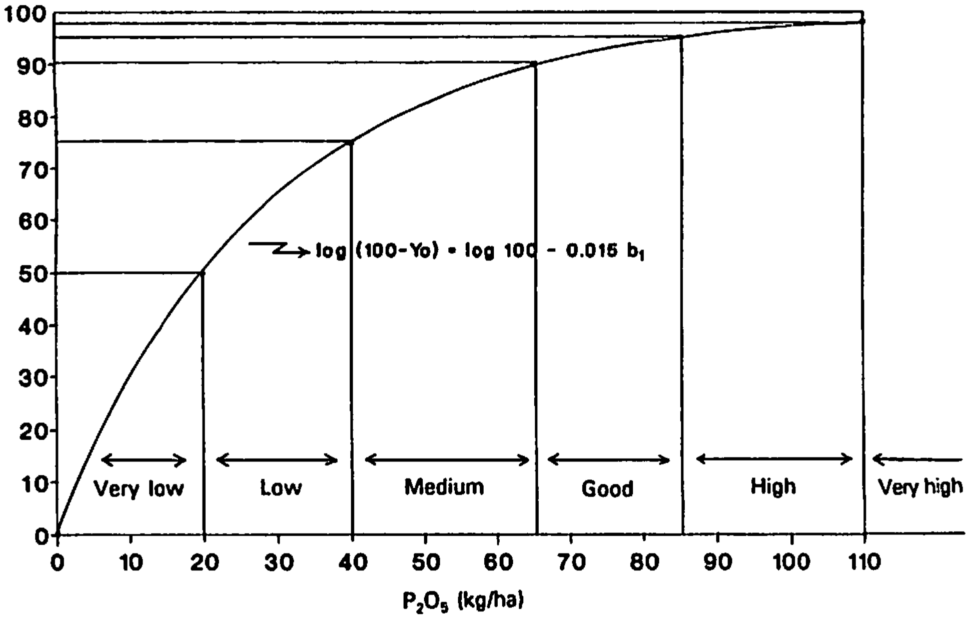

Fig. 1. Relation between levels of (Olsen) soil P and relative wheat yields.

Mitscherlich-Bray equation--must be defined. To calculate theoretical maximum yields for each rate on each field, equation (3) was used. The calculated "A" values for each P rate were averaged and used as the "A" value for that field. Averages for Haymana, Bolal, and Gerek varieties are presented in Table 7.

After these calculations, the Mitscherlich equation can be expressed as the following mathematical functions:

$$\text{Log } (3829 - y) = \log 3829 - 0.014\, b_1 - 0.0062\, x \text{ (Haymana)}$$
$$\text{Log } (3758 - y) = \log 3758 - 0.015\, b_1 - 0.0077\, x \text{ (Gerek and Bolal)}$$

Using these equations, one can calculate total yields and yield increases obtainable with different P applications for different Olsen soil test values (Tables 8 and 9).

If we consider only fertilizer as a variable cost, the most economic amount of fertilizer will be the sum of increments for which the last increment still produces an increase in profit. For example, in Table 8, when soil test value (b_1) is 30 kg P/ha Olsen, the first 10 kg gives a yield increase of 189.9 kg/ha of wheat. The net return is 94950 Turkish Lira (TL)/ha. Each successive 10 kg P/ha fertilizer gives a smaller yield increase and net return; the 17th increment, which gives a 19.3 kg/ha yield increase valued at 9600 TL, is the last successive 10 kg P/ha increment of fertilizer for which the value of the increased yield exceeds the cost of the fertilizer (9210 TL). Therefore, the economically optimal rate of fertilizer is 170 kg P/ha when the Olsen

Table 6. Calculated P fertilizer[1] required to attain various percent sufficiency levels for Gerek and Bolal varieties based on Olsen test, Central Anatolia, Turkey, 1987-89.

Soil test	Test values and fertility index	Percent sufficiency	Required P_2O_5 for relative yields of 90%	92%	94%	96%	98%
5		16	120.36	132.99	149.26	172.20	211.42
10	< 20 (Very Low)	30	110.45	123.08	139.35	162.29	201.51
15		41	100.55	113.17	129.45	152.39	191.60
20		50	90.64	103.26	119.54	142.48	181.69
25	20-40 (Low)	58	80.73	93.36	109.63	132.57	171.79
30		65	70.82	83.45	99.72	122.66	161.88
35		71	60.92	73.54	89.82	112.76	151.97
40		75	51.0	63.63	79.91	102.85	142.06
45		79	41.10	53.72	70.00	92.94	132.15
50	40-70 (Medium)	83	31.19	43.82	60.09	83.03	122.25
55		85	21.28	33.91	50.18	73.12	112.34
60		88	11.38	24.00	40.28	63.22	102.43
65		90	1.47	14.09	30.37	53.31	92.52
70		91	-	4.19	20.46	43.40	82.62
75	70-90 (High)	93	-10.55	33.49	72.71		
80		94	-	-	0.65	23.58	62.80
85		95	-	-	-	13.68	52.89
90		96	-	-	-3.77	42.98	
95		96	-	-	-	-	33.08
100		97	-	-	-	-	23.17
110	> 110 (Very Low)	98	-	-	-	-	3.35
120		99	-	-	-	-	-

[1] All fertilizer rates and P test values in kg/ha.

soil test value (b_1) is 30 kg P/ha, and 120 kg P/ha when soil test value (b_1) is 50 kg P/ha. Comparing the economically optimum rates with the quantities of P fertilizer required to attain various sufficiency levels (Table 5), it can be seen that it would not be economic to recommend P fertilizers for a yield more than 96% of maximum.

CONCLUSIONS

Calibrations for Olsen bicarbonate soil test values for available P and the response of three high-yielding wheat varieties to P fertilizer applications are presented for rainfed conditions of the Central Anatolia region of Turkey. Using the Mitscherlich-Bray equation, the constants c_1 for the soil test value b_1 and c for the fertilizer rates x were calculated. On the basis of these constants, calibrations and P fertilizer application

Table 7. Theoretical maximum yields for different P rates used in the experiments calculated by the formula $A = (yk - y_o) / k-1$ for the Haymana, Bolal, and Gerek varieties, Central Anatolia, Turkey, 1987-89.

		Applied P (kg/ha)				
Expt.	Variety	12	24	36	48	Average
1	Haymana	4120.34	4414.61	4983.54	4324.96	4460.86
4		3099.49	2955.07	3051.85	3813.19	3229.90
7		4706.82	4440.49	4627.71	4504.42	4569.86
10		6431.24	5320.80	7106.59	7285.42	6536.01
13		2922.73	2726.48	2699.37	2824.49	2793.27
19		3896.31	4734.30	4683.12	4508.01	4455.44
22		1993.72	2076.21	2415.87	2376.52	2215.58
25		2228.26	2393.39	2493.33	2375.02	2372.50
3	Bolal	4654.63	4491.78	4321.11	4321.91	4447.36
6		2615.10	2542.48	2805.89	2851.17	2703.66
9		3968.21	3973.06	4066.11	4290.80	4074.54
12		4828.16	4749.47	4760.31	4277.74	4653.92
15		3202.61	3240.64	3372.27	3435.42	3312.74
16		3667.93	3696.67	3810.14	3812.44	3746.79
18		2085.02	2243.36	2119.23	2161.94	2152.39
21		3842.77	4050.50	3990.80	4125.96	4002.51
24		2010.27	2618.16	2683.09	3029.18	2585.18
2	Gerek	5017.08	4943.17	5306.49	5194.24	5115.25
5		3238.67	3246.49	3300.01	3357.86	3285.76
8		5293.72	5532.88	5277.41	5003.38	5276.85
11		4929.83	5104.16	5135.89	5246.22	5104.02
14		4444.35	4063.74	4339.74	4343.93	4297.94
17		2141.94	2171.90	2169.73	2278.77	2190.59
20		4800.08	4764.08	4514.67	4912.26	4747.77
23		3616.76	3074.87	3398.61	3423.18	3378.36
26		2704.90	2408.29	2437.75	2732.72	2570.91

rates for wheat varieties are suggested. These recommendations apply to average general farming conditions in the region under current fertilizer and wheat prices.

In the application of these results to fertilizer recommendations in practice, the following points should be taken into consideration:

1. The fertilizer response data given in this study represent the average relationship between the available soil and fertilizer P and wheat yields for

Table 8. The calculated total yield, yield changes with successive increments of fertilizer use, and economic optimum fertilizer rates for the variety Haymana, Central Anatolia, Turkey, 1987-89.

P_2O_5		Triple super-phosphate	P_2O_5 cost[2]	b_1 = 30*			b_1 = 50			b_1 = 70		
Applied[1]	Increment			Total yield[3]	Yield increase	Value yield increase[1] (TL)	Total yield	Yield increase	Value yield increase (TL)	Total yield	Yield increase	Value yield increase (TL)
0	0	-	-	2403.8	-	-	3091.6	-	-	3447.5	-	-
10	10	23.8	9210	2593.7	189.9	94950	3189.8	98.3	49150	3498.3	50.9	25450
20	10	23.8	"	2758.3	164.6	82300	3275.0	85.2	42600	3542.4	44.1	22050
30	10	23.8	"	2901.0	142.7	71350	3348.9	73.8	36900	3580.6	38.2	19100
40	10	23.8	"	3024.6	123.7	61850	3412.8	64.0	32000	3613.7	33.1	16550
50	10	23.8	"	3131.8	107.2	53600	3468.3	55.5	27750	3642.4	28.7	14350
60	10	23.8	"	3224.7	92.9	46450	3516.4	48.1	24050	3667.3	24.9	12450
70	10	23.8	"	3305.3	80.5	40250	3558.1	41.7	20850	3688.9	21.6	10800
80	10	23.8	"	3375.1	69.8	34900	3594.2	36.1	18050	3707.6	18.7	9350
90	10	23.8	"	3435.6	60.5	32150	3625.5	31.3	15650	3723.8	16.2	8100
100	10	23.8	"	3488.0	52.4	26200	3652.6	27.1	13550	3737.8	14.0	-
110	10	23.8	"	3533.5	45.5	22750	3676.1	23.5	11750	3750.0	12.2	-
120	10	23.8	"	3572.9	39.4	19700	3696.5	20.4	10200	3760.5	10.6	-
130	10	23.8	"	3607.0	34.1	17050	3714.2	17.7	8850	3669.7	9.1	-
140	10	23.8	"	3636.6	29.6	14800	3729.5	15.3	-	3777.6	7.9	-
150	10	23.8	"	3662.3	25.7	12850	3742.8	13.3	-	3784.5	6.9	-
160	10	23.8	"	3684.5	22.2	11100	3754.3	11.5	-	3790.4	6.0	-
170	10	23.8	"	3703.8	19.3	9600	3764.3	10.0	-	3795.6	5.2	-
180	10	23.8	"	3720.5	16.7	8350	3772.9	8.6	-	3800.1	4.5	-
190	10	23.8	"	3735.0	14.5	-	3708.4	7.5	-	3803.9	3.9	-

* b_1 values in kg P_2O_5 /ha.

[1] Fertilizer application in kg/ha, yield in kg/ha, crop value in TL (Turkish Lira) per hectare.

[2] Prices used for calculation were 387 TL/kg triple superphosphate and 500 TL/kg wheat (1990).

[3] Log (3829-Y) = Log 3829-0.014 b_1 - 0.0062 x used to calculate total yields.

Table 9. The calculated total yield, yield changes with successive increments of fertilizer use, and economic optimum fertilizer rates for Gerek and Bolal varieties, Central Anatolia, Turkey, 1987-89.

P_2O_5				$b_1 = 30$*			$b_1 = 50$			$b_1 = 70$		
Applied[1]	Increment	Triple super-phosphate	P_2O_5 cost[2]	Total yield[3]	Yield increase	Value yield increase[1]	Total yield	Yield increase increase	Value yield	Total yield	Yield increase increase	Value yield
0	0	23.8	-	2444.0	-	-	3105.9	-	-	3434.4	-	-
10	10	23.8	9210	2656.9	212.9	106450	3211.6	105.7	52850	3486.9	52.5	26224
20	10	23.8	"	2835.3	178.4	89200	3300.1	88.6	44300	3530.8	44.0	21976
30	10	23.8	"	2984.8	149.5	74750	3374.3	74.2	37100	3567.6	36.8	18415
40	10	23.8	"	3110.1	125.3	62650	3436.5	62.2	31100	3598.5	30.9	15432
50	10	23.8	"	3215.1	105.0	52500	3488.6	52.1	26050	3624.4	25.9	12931
60	10	23.8	"	3303.1	88.0	44000	3532.3	43.7	21850	3646.0	21.7	-
70	10	23.8	"	3376.8	73.7	36850	3568.9	36.6	18300	3664.2	18.2	-
80	10	23.8	"	3438.6	61.8	39900	3599.5	30.7	15350	3679.4	15.2	-
90	10	23.8	"	3490.4	51.8	25900	3625.2	25.7	12850	3692.2	12.8	-
100	10	23.8	"	3533.8	43.4	21700	3646.8	21.5	10750	3702.9	10.7	-
110	10	23.8	"	3570.1	36.4	18200	3664.8	18.0	9000	3711.8	9.0	-
120	10	23.8	"	3600.6	30.5	15250	3679.9	15.1	-	3719.3	7.5	-
130	10	23.8	"	3626.1	25.5	12750	3692.6	12.7	-	3725.6	6.3	-
140	10	23.8	"	3647.5	21.4	10700	3703.2	10.6	-	3730.9	5.3	-
150	10	23.8	"	3665.4	17.9	8950	3712.1	8.9	-	3735.3	4.4	-
160	10	23.8	"	3680.4	15.0	-	3719.6	7.5	-	3739.0	3.7	-

* b_1 values in kg P_2O_5/ha.

[1] Fertilizer application in kg/ha, yield in kg/ha, crop value in TL (Turkish Lira) per hectare.

[2] Prices used for calculation were 387 TL/kg triple superphosphate and 500 TL/kg wheat (1990).

[3] $\text{Log}(3758-y) = \text{Log}\ 3758 - 0.015\ b_1 - 0.0077\ x$ used to calculate total yields.

the soil test method employed and the varieties used. A change in the method, growing conditions, or varieties will change the response data, with a resulting change in the recommendations. Although the growing conditions were selected to represent the general practices in the region, deviations from average conditions should be expected because of variations in soil and climate, especially in amount and distribution of precipitation.

2. In calculating the economically optimum P recommendations, the current prices prevailing in 1990 were used. A change in the price of P fertilizer and wheat causing a significant change in the factor-product price ratio will also change the economic optimum P levels. In this case, adjustments should be made in the recommendations. Small changes in this ratio, however, will not cause a significant change in the recommendations for practical purposes.

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DISCUSSION

A. Abdelmalek

Knowing the constants (c_1, c_2) for the equation, how do you make recommendation based on cropping systems (rotation), and how do you account for residual P and P buffering capacity to make fertilizer recommendation adjustments?

N. Yurtsever

Rotation is not taken into consideration in our fertilizer recommendations, because they are based on the soil samples taken every year before seeding.

K. El Mejahed

The regression coefficients (c_1) for b_1 for the varieties are low and close to each other. Are they significantly different? And how do all the errors related to soil sampling and laboratory analysis affect them, i.e., do we really need to have different critical levels of P for these varieties?

N. Yurtsever

No, they are not significantly different, but c value for the variety "Haymana" is significantly different from the c values for the other two varieties.

Evaluation of the P_i Soil Test in Egyptian Soils and its Development as a Rapid Field Test

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ABSTRACT

The P_i test is a new approach for available soil phosphorus which uses a strip of iron oxide-impregnated paper as a sink to sorb and extract P from the soil solution. To evaluate this test, 10 Egyptian soils with widely different properties were tested for available P using the Olsen method in comparison with the new P_i test. Corn plants were grown on these soils in the greenhouse. Dry-matter weight and P uptake were determined. Phosphorus extracted by the P_i test correlated significantly with P extracted by the Olsen test ($r = 0.94^{***}$). Likewise, P uptake and the P_i test were well correlated ($r = 0.90^{***}$). A rapid field test for P was developed using the P_i test strips. This new technique will help in quick estimation of available soil P, which can provide the basis for fertilizer recommendation.

INTRODUCTION

As fertilizer is an expensive input in crop production, particularly after the rapid increase in fertilizer prices on the world market in the 1970's, improving fertilizer-use efficiency is a crucial economic factor in the agricultural production process. Applying suitable rates of fertilizer has become an economical as well as environmental necessity. The various steps in establishing optimal fertilizer rates include choosing a soil extract that provides the best indication of the "available" nutrient in soil (Smilde, 1987).

Numerous procedures have been developed over the past several decades to extract and estimate the plant available phosphorus (P) in soils. There is still no testing procedure suitable for all soils, given the complex chemical nature of P in soils; forms of P in acid soils differ greatly from those in calcareous soils. In reviewing the range of procedures used to test soils for P, Thomas and Peaslee (1973) cited the use of water, dilute and strong acids, bases, neutral salts and buffered solutions, radioactive P^{32}, and ion exchange resins. In dryland regions, the most suitable test for calcareous soils, that using $NaHCO_3$ developed by Olsen in 1954, is now standard for most countries of the Mediterranean zone as reported by Ryan and Ayubi (1981), Orphanos (1988), Rashid *et al.* (1988), Yurtsever and Gedikoglu (1990), Abdel Monem *et al.* (1990) and Matar *et al.* (1988).

A new approach to P soil testing has recently been developed and is being evaluated (Menon *et al.*, 1989). The principle of the P_i test is similar to that of the anion exchange resin. The procedure, however, uses a strip of iron oxide-impregnated filter paper (P_i strip) as the sink to adsorb P mobilized in soil-solution suspension. The P sorbed on the P_i strip is dissolved in dilute acid and measured. The use of iron oxide-impregnated filter paper has proved to be an effective method for P extraction from soil. The P_i test is suitable for use in acidic as well as alkaline and calcareous soils. Menon *et al.* (1990) reported a high correlation between P_i test and Olsen-P. As the majority of the soils in the Mediterranean are calcareous, the foregoing greenhouse experiment was conducted using 10 soils from Egypt, including calcareous soil with high pH and high calcium carbonate content as well as heavy clay and sandy soils, to evaluate the suitability of the P_i test to measure the P availability status among widely differing soils.

MATERIALS AND METHODS

Selected properties of soils used are presented in **Table 1**, including values for $NaHCO_3$-extractable or Olsen-P. Pots were filled with 1 kg of each soil. Nitrogen was applied at a rate of 300 mg N/pot as urea. Potassium chloride was added to adjust the K to 200 mg/pot. Other necessary nutrients were applied. The pots were placed in a randomized block with three replications, and irrigated on a daily basis.

Four seeds of maize (*Zea mays* L., var. Pioneer) were planted per pot and then thinned to two/pot after germination. At six weeks' growth, the above-ground plant parts were harvested and dried at 60°C, and the dry-matter weight was recorded. The plant material was then ground and digested. Soil samples from each pot were taken

Table 1. Physical and chemical characteristics of 10 soils from Egypt.

Soil no.	Location	pH	OM[1]	$CaCO_3$	Olsen-P (ppm)	Texture
			-------- (%)	--------		
1	Fayum	7.9	1.8	4.8	16	clay loam
2	Bahtim	7.9	2.5	4.3	13	clay loam
3	Kalubia	8.0	2.9	3.0	13	silty clay
4	N-Tahrir	7.6	1.5	35.0	6	sandy loam
5	N-Tahrir	8.2	1.0	50.0	8	loamy sand
6	Burg El Arab	7.9	1.1	19.9	17	sandy clay loam
7	Burg El Arab	8.1	1.0	30.0	7	sandy loam
8	Inshas	7.9	0.6	4.2	7	sand
9	Inshas	7.9	1.8	3.8	11	sandy clay loam
10	Inshas + Seway	7.9	10.0	2.9	55	sandy loam

[1] OM = organic matter.

for P analysis. Soil P was determined by the Olsen and P_i tests. For the P_i test, 1-g soil samples were shaken with 40 ml 0.01 M $CaCl_2$ solution and the P_i strips for 16 h. The P_i strip was then taken out, washed, and P sorbed by the strip was dissolved in 40 ml 0.1 M H_2SO_4 (Menon *et al.*, 1989). Phosphorus in the plant digest and soil extracts was determined using the ammonium molybdate-sulfuric acid method with ascorbic acid as the reducing agent (Murphy and Riley, 1965).

To use the P_i new test for quick estimation of the available soil P in the field, the P_i strips were shaken with 40 ml 0.01 M $CaCl_2$ solution. Two drops of the coloring solution (ammonium molybdate-sulfuric acid with ascorbic acid) were then added to each strip. The density of the blue color was compared with strips from different standard solutions.

RESULTS AND DISCUSSION

When the 10 soils were extracted by both extraction methods, P extracted by P_i strips (P_i - P) was correlated significantly with P extracted by the Olsen test, with r = 0.94*** (Fig. 1). Menon *et al.* (1989) reported similar relationship in their study for calcareous soils from the USA.

The correlation coefficient (r) between dry-matter yield of corn and Olsen-P was r = 0.40. Likewise, P extracted by P_i strips correlated with dry-matter yield (r = 0.70). These results are generally in agreement with those found by Menon *et al.* (1990). Phosphorus extracted by both Olsen and P_i methods correlated significantly

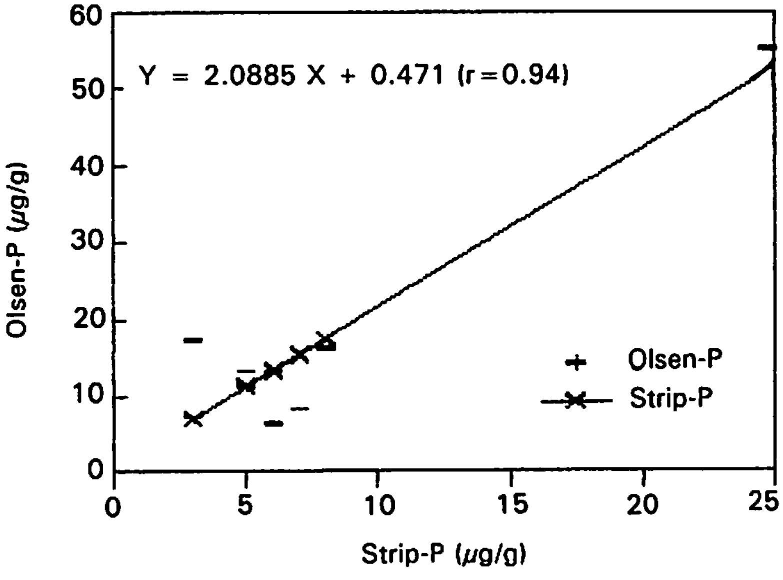

Fig. 1. Correlation between P extracted by Pi strips and Olsen test.

with P uptake by corn. When data were plotted, a high correlation with P_i-P (r = 0.90***) and with P-Olsen (r = 0.91***) occurred, as shown in Figs. 2 and 3. Menon *et al.* (1990) reported a high correlation between P_i - P and P uptake by plants from calcareous soils.

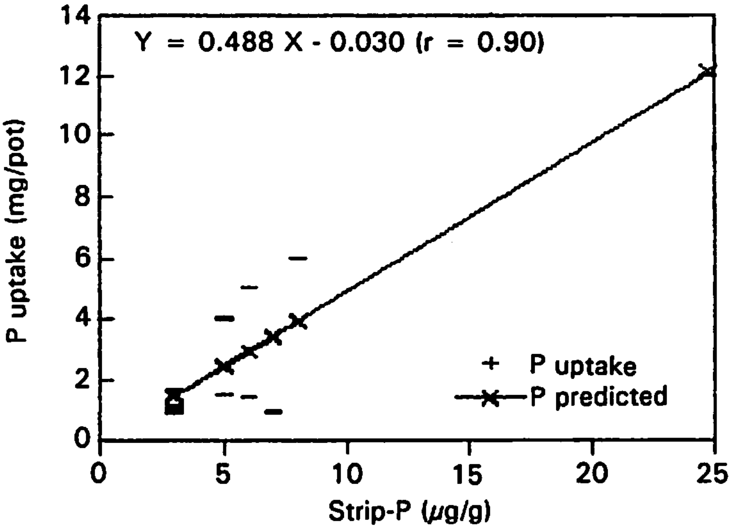

Fig. 2. Correlation between P extracted by Pi test and P uptake.

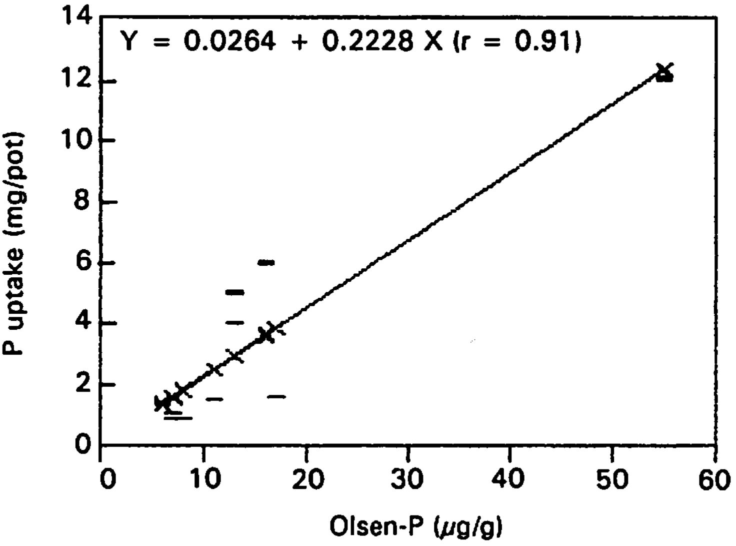

Fig. 3. Correlation between P extracted by Olsen-P test and P uptake.

From the data presented, it appears that the P_i test is a reliable test for plant-available P in Egyptian soils. Because the P_i strips do not react with the soils or have any destructive influence, they should be applicable in calcareous soils. Experimental evidence indicates that the P_i test works as good as Olsen test in alkaline soils (Menon *et al.*, 1989).

For this greenhouse experiment using 10 soils, Fig. 4 represents the Cate-Nelson graphical method used to define the critical level of P using P_i test for a relative yield of 80%. It shows that 6 µg P/strip is the critical level of P when the new P_i soil test is used.

The P_i test appears to have potential for much wider use than is possible with the other test. This should work well on the soils of the Mediterranean region, particularly as it is made from filter paper strips. With the additional development, these strips can be used for rapid P determination. When the coloring solution is added to the strips, visual differences can be detected due to the differences in P concentration. Strips for the soil samples can be compared to strips of standard solutions to estimate the soil P.

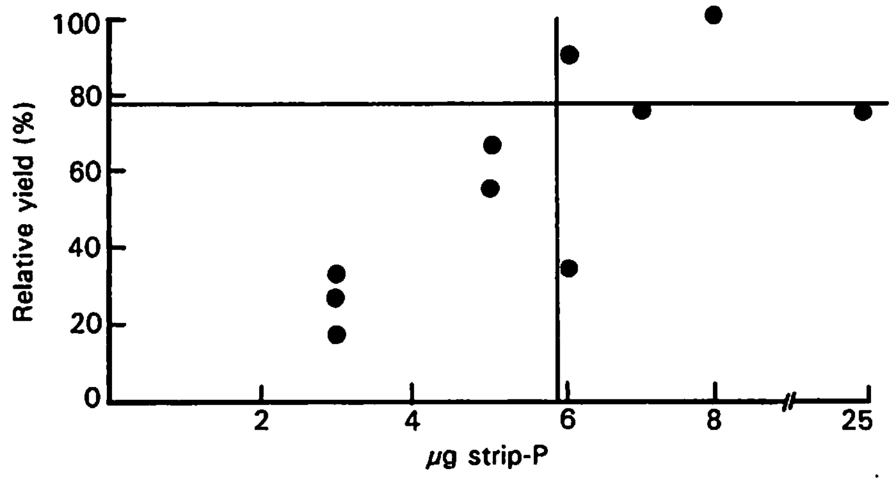

Fig. 4. Cate-Nelson graphical method for P_i-P critical level.

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DISCUSSION

A. Abdelmalek

We have a problem with spatial variability that we try to solve by subsampling something like 20 composites per uniform area. Do we have to put 20 strips in a field and determine P the next day or just one strip per unit area and determine P.

M. Abdel Monem

The spatial variability problem concern the soil sampling as much as the strips method. I think that the number of strips in each field can be the same as for the samples taken.

A. Gharbi

What are the advantages of this method over the Olsen-P procedure?

M. Abdel Monem

This method can be used as a quicker test qualitatively.

J. Ryan

I am concerned about the practicality of shaking for 16 hours. May be you could reduce this by changing the acid concentration!

M. Abdel Monem

We found that at least 14 hours were needed to adequately extract the adsorbed P. The strength of this method lies in the fact that it is a quick method.

Contribution to Soil-Phosphorus Test Calibration for Wheat in Morocco

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ABSTRACT

Phosphorus fertilizer recommendations for wheat in Morocco are based on the climatic regions regardless of soil P fertility. Previous studies showed that the $NaHCO_3$-P soil test is best suited for Moroccan soils. This research was conducted in order to calibrate the $NaHCO_3$-P soil test for irrigated wheat. Two and three field experiments with increasing P rates were conducted in the Tadla and Gharb regions, respectively. The $NaHCO_3$-P soil test level of these soils ranged between 7.7 and 18.3 mg/kg (ppm). The rates applied to bread wheat were 0, 20, 40, 60, 80, and 100 kg P/ha. The crop was irrigated in the Tadla region, but no irrigation was applied in the Gharb region. Three of the five locations responded to applied P. The $NaHCO_3$-P soil test levels of the responsive sites were lower than the critical level, 12 mg/kg, as determined by the Cate-Nelson graphical and Analysis of Variance methods. The optimum P requirement of wheat was negatively related to the $NaCO_3$-P soil test level.

INTRODUCTION

Nutrient deficiencies in soils can be corrected by applying appropriate fertilizers, but it is not economical to eliminate these deficiencies by execessive fertilizer applications. Therefore, fertilizers should be applied to crops allowing for all practical and economic factors involved as well as actual deficiency levels in the soils. Estimates should be made of the yield responses that will be obtained for various application rates and of the economic returns to be expected from money spent on fertilizers.

A successful fertilizer recommendation program requires selection of the most suitable soil test and its calibration with crop response to applied fertilizer. Soil testing is a method accepted worldwide, which permits the determination of deficiency in nutrients that are ssential for plant growth. Several soil-P tests are used throughout the world, but none has gained universal acceptance. The utility of a specific soil testing procedure depends on the local soil types. The work of Agbani and El Mejahed (1983) and Azzaoui (1987) showed that the $NaHCO_3$-P soil test (Olsen *et al.*, 1954) is most suitable for Moroccan soils. Similar results were generally reported for calcareous soils (Nesse *et al.*, 1988) which are typical Moroccan soils.

The selection of a soil test necessitates its calibration with crop response to added fertilizers. A soil-P test calibration experiment is conducted at each site with increasing P rates and other nutrients under nonlimiting conditions. The soil test calibration allows the determination of a critical level above which the chance of obtaining a response to fertilizer application from a given crop is decreased. It also permits the development of a model to predict P requirement of a given crop from the soil-P test level. Different response functions are used in order to describe crop yield response to fertilizers. The model that has attracted many workers is the Mitscherlich equation (Mitscherlich, 1913), which is also called the negative exponential model. It is based on the observation that the response to an increment of fertilizer is proportional to the reduction from the maximum yield. Its mathematical form is:

$$Y = A\,(1 - \exp(-cX)) \qquad (1)$$

where Y is the predicted yield, A is the asymptotic maximum yield, and c is a response coefficient.

The response function most frequently used in fertilizer response studies is the quadratic equation (Mead and Pike, 1975). Its popularity is explained by the fact that it has a simply-defined maximum and produces estimates of parameters without complex computations. One disadvantage of the quadratic model is that it does not allow for asymmetry around the maximum in the yield response pattern.

Some models contain polynomials with transformed variables, the most common being the square root model:

$$Y = b_0 + b_1X^{½} + b_2X \qquad (2)$$

Heady *et al.* (1963) recommended this model for fertilizer recommendation purposes, and so did Abraham and Rao (1965). The Australian National Soil Fertility Project has adopted the square root model as a method of analysis for field data (Colwell, 1979).

This paper deals with the calibration of the $NaHCO_3$-P soil test (Olsen *et al.*, 1954) for wheat response to P fertilizer. The specific objectives were to: i) determine wheat response at different growth stages to preplant P application, ii) establish a critical soil-P test level for wheat, iii) determine the optimum P fertilizer requirement of wheat grown on different soils, and iv) assess the ability of the $NaHCO_3$-P soil test to predict the optimum P fertilizer application rate.

MATERIALS AND METHODS

Field experiments with a commonly used bread wheat (Nesma 149, *Triticum aestivum* L.) were conducted at two locations each in the Tadla and Gharb regions. The four trials were established in late November, 1986. The experimental design was a randomized complete block with four replications. The individual plots were 10m long and 3m wide. Phosphorus was applied as superphosphate (8% P) at the rate of 0, 20, 40, 60, 80, and 100 kg P/ha. Blanket rates of N as NH_4NO_3 (33.5% N) and K as potassium sulfate (42% K) were applied at rates of 40 kg N and 55 kg K/ha, respectively. Mixed with the soil as uniformly as possible, these fertilizers were manually broadcast immediately prior to planting 140 kg seed/ha using a mechanical planter. A top-dressing of 80 kg N/ha as urea (46 % N) was applied at the tillering stage for all treatments.

Irrigations were applied to prevent water stress at the Tadla sites (Locations 1 and 2). No irrigation was applied at the Gharb sites because precipitation was well distributed over the cropping season, except at the end. Herbicides were applied to control weeds as needed throughout the growing season.

Eight to ten soil cores (to a depth of 20 cm) were collected from each plot, prior to fertilizer application. The soil samples were air-dried and stored for analysis. Various chemical and physical properties of the soils collected are given in Table 1.

Plant samples were taken at the tillering (Feekes 5) and heading stages (Feekes 10.5) by cutting duplicate 0.5-m rows from each plot. These were dried at 70°C and weighed in order to estimate the total dry-matter yield. Sub-samples were ground and digested using the method of Thomas *et al.* (1967). Phosphorus was determined by the vanadomolybdate method. At maturity, a $2m^2$ area was harvested manually. The samples were used to estimate grain and straw yields, and P was similarly determined.

Data were analyzed with SYSTAT statistical package (Wilkinson, 1986). The Cate and Nelson (1965) graphical method and the Cate and Nelson (1971) analysis

Table 1. Selected physical and chemical characteristics of the soils collected from field experiment locations in the Tadla and Gharb regions.

Characteristic	Tadla		Gharb	
	Location no.			
	1	2	3	4
Clay (%)	45	38	55	65
Silt (%)	31	38	44	33
Sand (%)	24	24	1	2
pH	8.1	8.1	8.2	8.3
EC (dS/m)	0.5	0.4	0.4	0.3
OM (g/kg)	11	17	9	22
$CaCO_3$ (% equivalent)	14	13	16	8
CEC (cmol(+)/kg)	46	45	58	70
P-$NaHCO_3$ (mg/kg)	11.7	7.7	11.6	13.2
K-NH_4OAC (mg/kg)	328	366	322	416

of variance method were used to determine the soil-P test critical level. Wheat grain yield response data were described using the Mitscherlich, quadratic, and square root equations. Selection of the best models was based on the R^2 value.

RESULTS AND DISCUSSION

Dry-Matter Production and P Uptake

The average wheat dry-matter yield of the check plots at tillering varied from 0.41 to 1.02 t/ha (Table 2). Significant yield increases from added P were observed at locations 2 and 4. Locations 1 and 3 were relatively low in $NaHCO_3$-P, but wheat still did not respond to P at this growth stage. This difference in response to P may be attributed to the low dry-matter production at this stage, especially at low $NaHCO_3$-P locations, which resulted in large heterogeneity in dry-matter production. In fact, locations 2 and 4, which showed a significant difference in response to P had relatively high yields. Table 2 shows, in general, high coefficients of variation with dry-matter yields at this stage. The tissue-P concentration of the check plots at tillering ranged between 3 and 4 g/kg (Table 3). All four locations responded significantly to P fertilization.

The total dry-matter production of the check plots at heading ranged from 5.9 to 10.2 t/ha (Table 4). There was a significant response to P fertilizer at locations 1, 2, and 3. The response at location 4 was significant at $\alpha = 0.10$. These results suggest

Table 2. Wheat dry matter yield[1] at tillering (Feekes 5) at the four locations.

	Location			
P (kg/ha)	1	2	3	4
	(t/ha)			
0	0.43	0.43a	0.41	1.02a
20	-	0.59ab	0.48	1.51ab
40	0.57	0.78b	0.61	1.74b
60	0.64	0.79b	0.59	1.89bc
80	0.68	0.85c	0.57	1.99c
100	0.72	0.85c	0.67	1.91c
Statistical significance	NS	*	NS	**
Coefficient of variance (%)	56	41	36	25

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

Table 3. Tissue-P concentration[1] of the wheat check plots at tillering.

P (kg/ha)	Location 1	2	3	4
	(g/kg)			
0	4.0a	3.7a	3.0a	3.7a
20	-	4.3ab	3.8a	3.8ab
40	4.6ab	4.3ab	3.9a	4.5ab
60	4.5ab	4.4ab	4.5ab	4.9ab
80	5.6c	5.2c	5.4b	4.9ab
100	5.1bc	5.0bc	5.4b	5.1b
Statistical significance	**	**	**	**

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

Table 4. Aboveground dry matter wheat yield[1] at heading (Feekes 10.5 stage) at four locations.

P (kg/ha)	Location 1	2	3	4
	(t/ha)			
0	7.4a	10.2a	5.9a	9.4a
20	-	13.6ab	8.4b	9.9a
40	14.4b	14.5ab	11.8c	11.9 b
60	13.6b	11.1a	9.4bc	10.4ab
80	17.2b	15.7ab	9.9bc	10.8ab
100	17.5b	18.1b	9.2b	10.5ab
Statistical significance	**	*	**	+

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

that the limit between responsive and nonresponsive soils at this wheat growth stage should be between 12 and 13 mg/kg.

The tissue-P concentration in the check plots at the heading stage varied from 1.9 g/kg at locations 3 and 4 to 2.2 g/kg at location 2 (Table 5). These values are smaller than those at the tillering stage because of the dilution effect with the increase of dry-matter production. Again, there was a significant effect of P application at all

Table 5. Tissue-P concentrations[1] of aboveground wheat dry matter at heading in the check plots.

P	Location			
	1	2	3	4
(kg/ha)	(g/kg)			
0	2.0a	2.2a	1.9a	1.9a
20	-	0.21a	2.3b	1.8a
40	2.2ab	2.1a	2.1b	2.1ab
60	2.3ab	2.5ab	2.1b	2.1ab
80	2.4ab	2.8ab	2.6b	2.3b
100	2.4ab	3.0b	2.5b	2.6b
Statistical significance	**	**	*	**

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

locations except location 3. The tissue-P concentrations were either at or above 2 g/kg, which was considered as the critical level at this growth stage (Ward *et al.*, 1973).

Grain Yield and P Uptake

The maximum wheat grain yield response to P fertilizer occurred at location 2, while there was no increase at location 4 (Table 6). The grain yield increase from P

Table 6. Wheat grain yield[1] as influenced by P fertilizer at four locations.

P	Location			
	1	2	3	4
(kg/ha)	(t/ha)			
0	3.28a	3.62a	2.79a	3.65
20	-	4.35ab	3.67b	3.72
40	3.75ab	5.06b	3.59b	3.43
60	4.47b	5.11b	3.66b	3.83
80	3.52ab	5.05b	3.09ab	3.48
100	4.48b	5.09b	3.19ab	3.72
Statistical significance	**	*	*	NS

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

fertilization ranged between 0.88 and 1.49 t/ha. All the responding soils had extractable P levels of less than or equal to 12 mg/kg. This increase in yield above the check plots was 49, 41, and 31% at locations 1,2, and 4, respectively. Yields in the Tadla region were, in general, higher than those in the Gharb region.

Values of total P uptake by the above-ground plant parts at the five locations are presented in Table 7. Phosphorus uptake by the check plots varied from 13.8 kg P/ha in location 1 to 20.3 kg P/ha in location 4. Applied P had a significant effect on total P uptake at locations 1, 2, and 3. However, location 4 did not respond to applied P. This location had the highest $NaHCO_3$-P value, i.e., 13.2 mg/kg.

The apparent P fertilizer efficiency was calculated by subtracting P uptake in the check plot from P uptake in a given P treatment. The difference was expressed as a percentage of the applied P rate. In general, apparent P fertilizer efficiency decreased as applied P increased (Table 8). If we assume that applied P and soil P

Table 7. Above-ground wheat total P uptake[1] at maturity.

P	Location			
	1	2	3	4
(kg/ha)	(kg/ha)			
0	14.4a	17.5a	14.5a	20.3
20	-	19.9ab	19.4ab	20.5
40	18.9b	26.2b	23.3b	19.7
60	20.4bc	25.3ab	22.6b	22.1
80	18.9b	25.9b	23.2b	20.8
100	23.1c	26.4b	20.8b	22.4
Statistical significance	**	**	**	NS

[1] Means in the same column followed by the same letter were judged to be the same at the specified α.

Table 8. Apparent P fertilizer efficiency at the four locations.

P	Location			
	1	2	3	4
(kg/ha)	(%)			
20	-	12	25	1
40	11	22	22	0
60	10	13	14	3
80	6	11	11	1
100	9	9	6	2
Average	9	13	15	1

have similar efficiency, these results suggest that as P rate increased, wheat plants absorb relatively less P applied as fertilizer. Nonabsorbed P will increase residual P level in the soil. Phosphorus fertilizer efficiency, averaged across all P rates, ranged from 1 to 15%. Location 4, which had the highest $NaHCO_3$-P value, showed small P fertilizer efficiency values. This indicates that as the soil-P test value increases, P fertilizer efficiency decreases. In soils with large available P values, the contribution of soil P is high, thus rendering fertilizer P uptake small.

Critical Soil-P Test Determination

The critical soil test level is the value of a soil test below which the probability of a crop's response in question to added fertilizer is high, and above which the probability of such a response is low. **Figure 1** gives the plot of RY vs soil-P test. The Cate-Nelson (1965) graphical method gave a critical level of 12 mg P/kg. The Analysis of Variance method of Cate and Nelson (1971), gave a critical level of 11.9 mg P/kg with R^2 = 0.91 (Table 9).

The above critical level should be considered only tentative at this time, since such a small data base were used to establish this value. More field experiments over a wide range of climates and soils in Morocco are needed in order to substantiate the

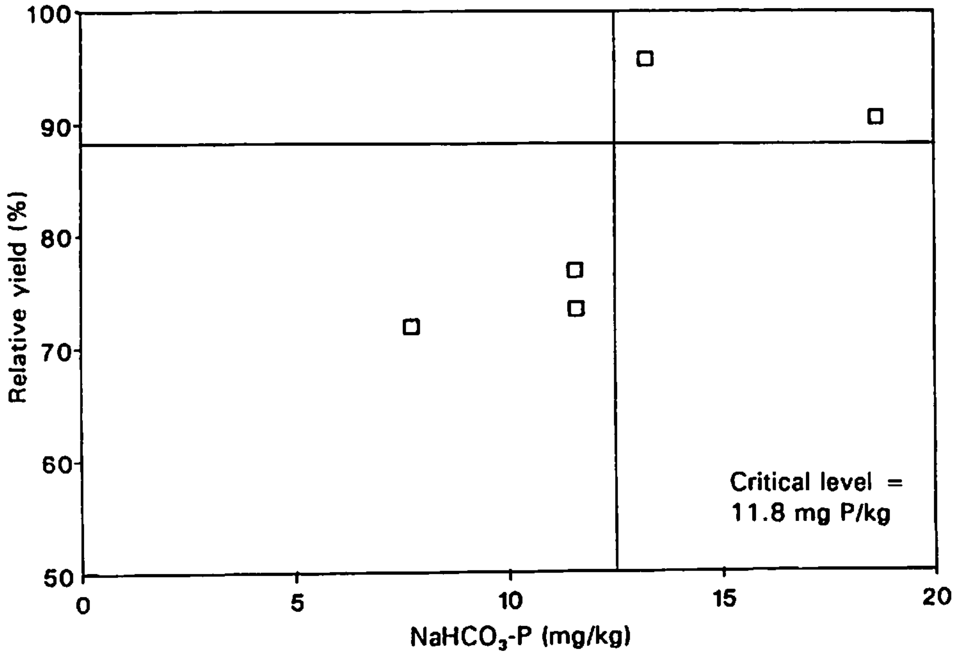

Fig. 1. The $NaHCO_3$-P critical soil test level as determined by the Cate-Nelson graphical method.

Table 9. Critical soil $NaHCO_3$-P levels as determined by two methods.

Method	Critical P level (mg/kg)	R^2
Cate-Nelson Graphical	11.8	-
Analysis of Variance	11.9	0.91

soil-P test critical level. However, these data are similar and agree with those of Colorado State University (Soltanpour *et al.*, 1985) and other American universities, where soil-P test critical levels were established to generally range between 12 and 14 mg P/kg using the $NaHCO_3$-P procedure. Soltanpour *et al.* (1987) reported a critical level of 5 to 8 mg/kg for wheat grown in the Chaouia region of Morocco. This critical level is lower than the one reported herein because of the fact that their experiments were conducted on a dryland area which received a rainfall of 200-300 mm. Khera *et al.* (1972) reported that in addition to grain yield, a value of 12.5 mg/kg of $NaHCO_3$-P was found to be the critical level of wheat quality measured by amino acid analysis.

Determination of P Fertilizer Requirement

Among the models evaluated, the square root equation was found to be the most convenient for locations 2 and 3 (Figs. 2 and 3). The data of location 1, however, were poorly described when all the P levels were considered. If the grain yield corresponding to P at 80 kg/ha, appearing to be an outlier, was deleted, the result was better (Fig. 4). However, as expected, no model described well the nonresponsive location 4.

The fact that the quadratic response function did not adequately describe the yield data illustrates the major limitation of this model, which requires a symmetry of the data around the maximum. Also, the Mitscherlich equation was not sufficient for describing the yield data. However, the square root equation described the data adequately and was therefore used to determine the optimum P fertilizer requirement of wheat. For the square root function of the form:

$$Y = b_0 + b_1X^{1/2} + b_2X \qquad (4)$$

the optimum P fertilizer requirement is given by:

$$X_{op} = (b_1/2(S - b_2))^2 \qquad (5)$$

where S = cost of 1 kg P/value of 1 ton of wheat.
The prices used in this study are 2,000 Dirhams (Dh) per ton of wheat and 6.14 Dh/kg P (1 US $ = 8.53 Dh).

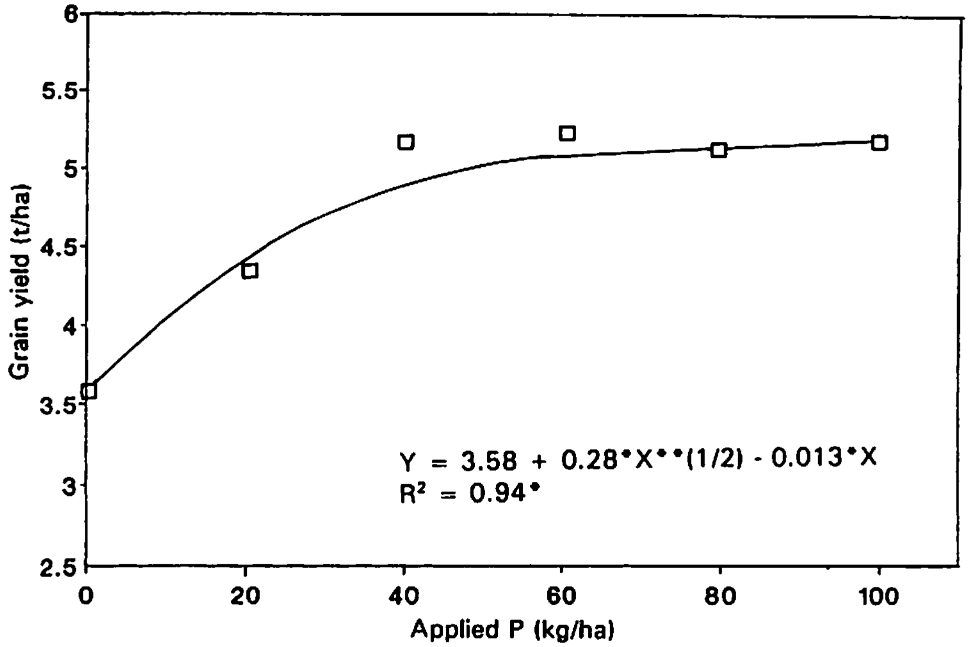

Fig. 2. Wheat grain yield response to P fertilizer at location 2 as described by the square root model.

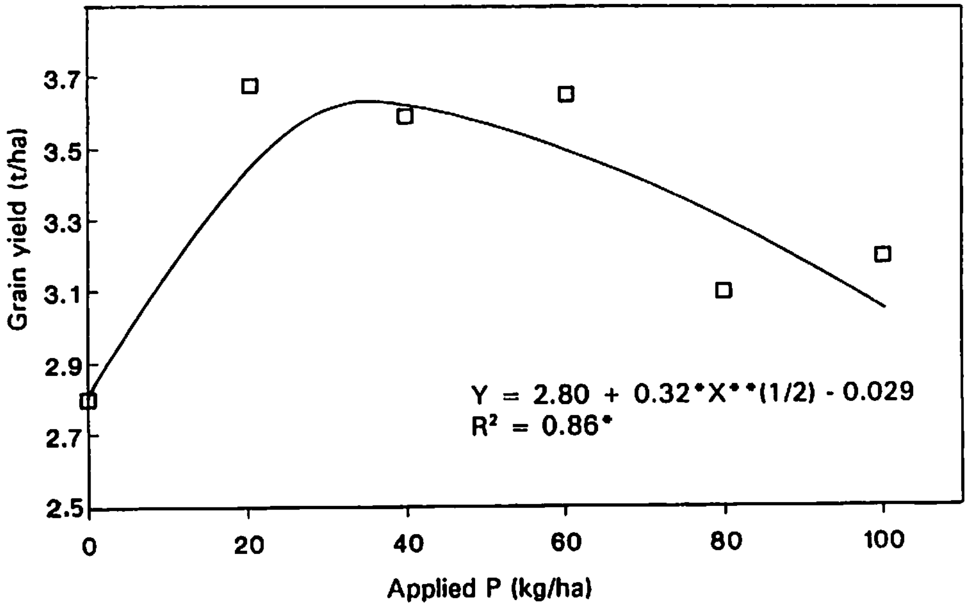

Fig. 3. Wheat grain yield response to P fertilizer at location 3 as described by the square root model.

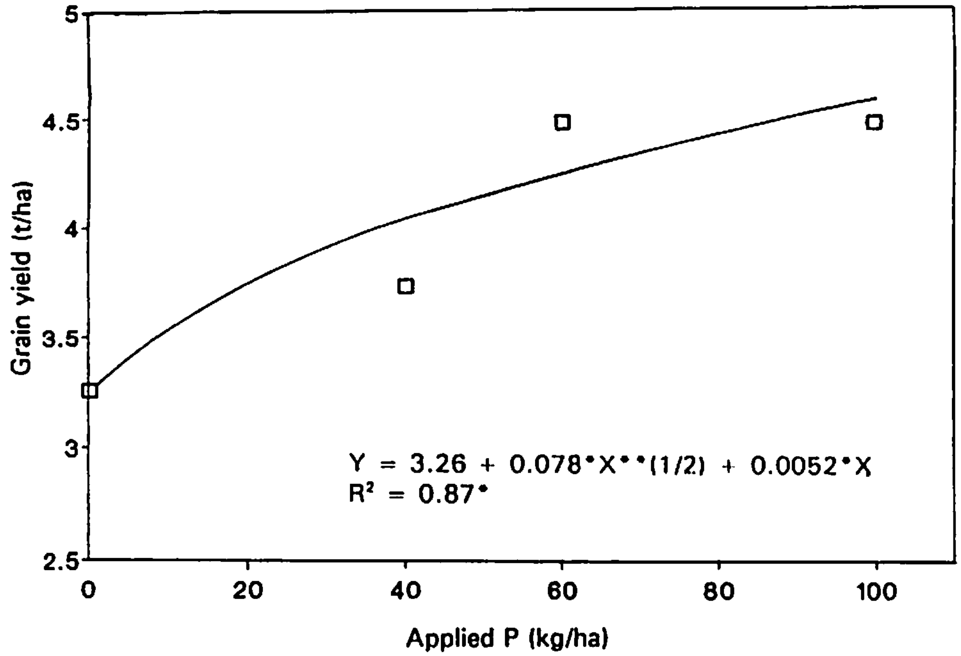

Fig. 4. Wheat grain yield response to P fertilizer at location 1 as described by the square root model.

In addition to this equation, an optimum P fertilizer rate for each location was determined based on the net return obtained by farmer from each P application rate. The cost of fertilizer application and extra labor cost for harvest of fertilized fields over that of the check fields were assumed to be negligible compared to fertilizer cost.

The values of P requirement of wheat in the other four locations are presented in Table 10. The optimum P fertilizer rate of location 4 was zero because there was no significant response to applied P (Table 6). This location had the highest $NaHCO_3$-P level, 13.2 mg/kg. The optimum P fertilizer rate determined using the net return method is 20 kg/ha for location 3, and 60 kg P/ha for location 1 which had a soil test level of 11.6 mg $NaHCO_3$-P/kg. This difference in optimum P rate is related to the fact that the response curve of location 1 (Fig. 4) had a pattern which can not allow for a precise determination of the optimum rate. Location 2 had the lowest $NaHCO_3$-P level, 7.7 mg kg^{-1}, and required the largest optimum P fertilizer rate.

The optimum P fertilizer rate determined by the square root model for location 3 was similar to the one determined using the net return method. However, the P requirement of locations 2 and 3 determined by the square root equation were higher than those determined by the net return method. In fact, even though the square root function described the yield data adequately, it is clear from Figs 3 and 4 that this function underestimated the yields in the intermediate region because the parabolic curve was not flexible enough to accommodate the sharp initial yield rise and the

Table 10. The optimum P requirement of wheat determined by the square root equation and the net return method.

Location	$NaHCO_3$-P	Optimum P requirement using Square root equation	 Net return method
		(kg/ha)	
1	11.7	314	60
2	7.7	77	40
3	11.6	25	20
4	13.2	0	0

subsequent flattening. Also, it was found earlier that if a plateau is reached at low or intermediate levels of added nutrient, the optimum rate will be biased upwards. The biases in regression coefficients are pronounced when the nutrient being studied is insufficient initially and, therefore, the response to the first increment of fertilizer is large.

These results show that the net return method was reasonable in detecting the optimum P fertilizer requirement of wheat. The P requirement decreases as the soil $NaHCO_3$-P level increases, supporting the results from the greenhouse studies. The square root equation overestimated the P requirement even though it was appropriate in describing the yield response data.

The optimum P requirements were 20 and 40 kg P/ha for the soils having 11.6 and 7.7 mg P/kg, respectively. These results justify the use of the 12 mg/kg soil $NaHCO_3$-P critical level which was determined earlier (**Table 10**).

Based on these experiments, it can be concluded that the $NaHCO_3$-P test critical level should initially be set at 12 mg/kg. However, further research is needed to establish a final critical soil-P test level in Morocco. Even though the square root model function best described the yield data, wheat P requirements determined by this model were unrealistic. The net return method gave reasonable optimum P requirements. This method may be appropriate when a small data base is disposed as is the case in this study. The P requirements determined by the square root model and the net return method were both negatively related to the soil $NaHCO_3$-P level.

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Characterization and Distribution of Nitrogen Forms in Selected Soils of Morocco

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ABSTRACT

Both the nature and relative quantity of different soil-nitrogen (N) fractions influence biodegradability of native organic-N in the soil. The present study was conducted on 10 soils from four agricultural regions of Morocco : Tadla, Chaouia, Gharb, and Zaer. The objectives were to (i) quantify all organic-N fractions in surface horizons and (ii) examine the vertical distribution of amino acid-N and fixed ammonium through the soil profiles.

Hydrolyzable-N values ranged from 56.9 to 74% of total N. The other fractions of hydrolyzable-N, expressed as percent of total N, represented 24.1 to 33.5%, 11.4 to 20.5%, 4 to 8.6%, and 5.9 to 18.7% , respectively, for amino acid-N, ammonium-N, amino sugar-N, and nonidentified-N. Both the composition and the proportions of organic-N forms were comparable to those reported for subtropical and Mediterranean areas.

The total amino acid-N fraction decreased with depth. Chromatography analysis showed that: (i) each amino acid decreased in the same proportion as total amino acid-N, (ii) relative proportions of different amino-acids were similar for all soils and at any depth, and (iii) basic amino acids occurred in higher quantities than other forms and tended to accumulate in the subsurface horizons. Native fixed ammonium ranged from 67 to 411 kg/ha and its proportion, with respect to total N, increased with depth. The mineralogical composition of the soil clay fraction was not sufficient to explain differences in measured fixed ammonium.

INTRODUCTION

Both the nature and the relative quantities of the different soil nitrogen fractions have a large influence on the biodegradability of native organic-N in the soil. The reduction in N mineralization rate with depth is attributed to a decrease in the amino acid-N fraction (Soudi *et al.*, 1990); in fact, amino acid-N decreased more rapidly than did total N in several soils of Morocco. This was attributed to the trapping of amino acid-N in complex organic compounds less amenable to biological degradation. The effect of cropping management on distribution of N forms in agricultural soils was examined by many authors (Keeney and Bremner, 1964; Porter *et al.*, 1964; Stevenson, 1956). Decau (1968) demonstrated the influence of abiotic factors on the distribution of N forms in soil.

The fractionation of organic-N into its different pools is accomplished by using acid hydrolysis under reflux (Bremner, 1965). The hydrolyzable-N is composed of amino acid-N, amino sugar-N, and ammonium-N. The relative proportions of these fractions are 30-45%, 5-10%, and 20-35% of total N, respectively (Stevenson, 1982). These proportions vary with soil types and climatic conditions (Stevenson, 1982; Sowden *et al.*, 1977). Most of the previous studies focused on distribution of either total amino acid-N (Hadas *et al.*, 1986) or amino polysaccharide-N (Stevenson, 1957; Sowden, 1959) and ammonium- and inorganic-N. Very few studies investigated the vertical distribution of individual amino acids through the soil profile (Soudi *et al.*, 1990).

Also, native fixed ammonium is a very important N fraction available for plants. This fraction represents 3.8 to 43.8% of total N (Stevenson and Dhariwal, 1959; Hinman, 1964; Nommik, 1965; Sparks *et al.*, 1979). The fixation process of ammonium is strongly influenced by clay content and by the nature of the layer silicates present in the soil. The 2:1 clays, such as vermiculite and illite, are highly ammonium-fixing (Nommik, 1965; Baethgen and Alley, 1986). It seems that the ammonium ion is fixed by the same mechanism as for potassium (Stevenson, 1959; Nommik and Vahtras, 1982). The most important clay minerals generally present in arid and semiarid soils can be classified with regard to their K-fixing capacity as follows: vermiculite > beidellite > montmorillonite > illite > palygorskite > kaolinite = chlorite (Badraoui, 1988).

The objectives of this work were to (i) evaluate the proportions of organic-N forms in soils of some major agricultural regions of Morocco, (ii) examine amino acid-N distribution in the soil profile, and (iii) determine native fixed ammonium and its distribution through the soil profiles. This study would help understand bioavailability through mineralization processes occurring in soils.

MATERIALS AND METHODS

Ten soils were sampled from four agricultural regions of Morocco : Tadla, Chaouia, Gharb, and Zaer (Table 1). The soils had contrasting physicochemical and mineralogical properties. Samples were air-dried and ground to pass a 2-mm sieve prior to analysis. Particle-size distribution was measured by pipette (Day, 1965), and pH was obtained in a 1:2.5 soil/water suspension. Subsamples were ground to < 0.5-mm size fraction and analyzed for total N and organic-C using the Kjeldahl and Walkley-Black methods, respectively (Jackson, 1958a; 1958b). Organic fractions were obtained by acid hydrolysis using 6*M* HCl for 12 hours at 120°C with soil-to-acid ratio of 1:5 (Bremner, 1965). The hydrolysates were vacuum-concentrated in a rotary evaporator at 40°C. The residue was removed with water and the amino acids present were determined using high-performance liquid chromatography (Series 3B HPLC instrument, Perkin ELmer Corp., Norwalk, CT). Fixed ammonium was determined by the Silva and Bremner (1966) method. The mineralogical composition of selected soils was determined by X-ray diffraction using a Phillips Norelco diffractometer operating at 40 KV and 35 mA with CuKα radiation.

Table 1. Taxonomic names, locations, and selected soil properties of 10 soils from four agricultural regions of Morocco.

Soil symbol/ location	Taxonomy	Depth (cm)	Clay (%)	pH	Total N	Organic-C
					---------- (g/kg)	--------
VC Chaouia	Typic Chromoxerert	0-20	62.5	8.9	1.3	13.7
		20-60	67.0	9.0	0.9	8.6
FC Chaouia	Palexeralf	0-10	18.4	7.7	1.6	17.6
		10.32	40.6	7.6	1.2	12.3
		>32	30.8	7.9.	0.8	7.4
IVC Chaouia	Vertic Calcixeroll	0-11	35.6	8.4	2.2	23.3
		11-36	48.0	8.7	1.9	17.3
CR Chaouia	Lithic Xerochrept	0-10	23.5	8.8	2.3	21.9
		10-32	34.2	8.5	1.5	16.0
CB Chaouia	Typic Xerochrept	0-13	26.2	8.6	2.5	27.5
		13-49	32.7	8.6	1.9	22.2
IVT Tadla	Vertic Calcixeroll	0-10	40.7	8.7	1.4	13.0
		10-20	41.6	8.8	1.3	12.0
		20-40	41.6	8.8	1.3	12.0
		40-60	43.1	8.8	1.0	11.0
		60-100	44.8	8.8	0.6	6.0
		100-120	47.1	8.8	0.5	5.3
ICT Tadla	Typic Calcixeroll	0-10	29.7	8.8	1.1	10.2
		10-35	35.4	8.9	1.0	9.3
		35-55	39.5	8.9	0.9	7.3
		55-75	40.3	8.9	0.8	6.0
		75-105	41.8	8.9	0.5	4.1
		105-125	40.9	8.9	0.4	3.7
IBT Tadla	Typic Xerochrept	0-10	28.4	9.0	1.3	13.0
		10-20	33.3	9.2	1.6	13.0
		20-30	38.5	9.2	1.6	14.0
		30-60	38.8	9.2	0.6	5.4
		60-100	39.5	9.2	0.4	3.3
		100-120	38.8	9.2	0.4	3.0
VG Gharb	Typic Palexerert	0-20	66.4	8.4	2.2	18.2
SZ Zaer	Typic Palexeralf	0-20	4.4	6.7	0.7	7.8

RESULTS AND DISCUSSION

The clay content varied between 4.4 and 67%, organic-C between 7.8 and 27.5 g/kg, pH between 6.7 and 9.0, and total N between O.71 and 2.5 g/kg (at the surface layer and decreased with depth). Calcixerolls and Xerochrepts of the Chaouia region had highest values. The mineralogical composition of the clay fraction of representative soils was dominated by smectites (Table 2). The nature of these smectites was further investigated using the lithium test (Badraoui and Bloom, 1990) to distinguish between montmorillonite and beidellite. The Chaouia soils contained beidellite exclusively, whereas the Gharb Vertisol showed a mixture of both montmorillonite and beidellite. The Chaouia Palexeralf (FC), however, contained large quantities of illite and kaolinite.

Table 2. Mineralogical composition of clay fractions in selected soils, Morocco.

Soil[1]	Smectites	Chlorite	Kaolinite	Illite	Palygorskite	Quartz
VG	+ + + + + (B-M)	-	+	tr	-	+
VC	+ + + + + (B)	tr	+	-	-	+
IVC	+ + + + (B)	+ +	-	+	+	+
FC	-	-	+ + +	+ + +	-	+
CR	+ + + + (B)	-	+ + +	+		
CB	+ + + +	tr	+	-	+ + +	+
ICT	+ + + +	+	+	+ + +	+ + +	tr

[1] For soil identification see Table 1.
B = beidellite; M = montmorillonite.
+ + + + + = 70%; + + + + = 50-70%; + + + = 30-50%
+ + = 15-30%; + = 5-15%; tr = traces.

The hydrolyzable-N fraction (HN) ranged from 57 to 74% of total N (Table 3). No relationship was found between this fraction and any soil characteristic. The other hydrolyzable-N fractions, expressed as percent of total N, represented 24.1-33.5%, 11.4-20.5%, 4.0-8.6%, and 5.9-18.7% for amino acid-N (AAN), ammonium-N (AMN), amino sugar-N (ASN), and nonidentified-N (NIN), respectively. Nonhydrolyzable-N (NHN) is composed of a complex combination between amino acids and heterocyclic compounds (Bremner, 1967; Decau, 1968). This fraction, which made up 26 to 46% of total N could be considered unsusceptible to biological mineralization and thus potentially unavailable to plants. Based on this consideration, the hydrolyzable N fraction of total N is the most important fraction involved in N fertility assessment.

The protein-N fraction (AAN x 1.1) represented 27 to 37% of total N (Table 3). Particular attention was attached to this N form because amino acids are easily ammonifiable substrates after peptide hydrolysis; as much as 75% of mobilized N by crops can form the deamination of the amino acids present in the soil (Stevenson, 1956).

The nature and the mean relative proportions of the amino acids are reported in Fig. 1. It is interesting to note that the qualitative composition was similar for all

Table 3. Organic forms of nitrogen in surface layers of 10 soils from four agricultural regions of Morocco.

Soil[1]	Organic-N form[2]								
	Total N (g/kg)	HN	AAN	AMN	ASN	NNIN	NHN	NHN+NIN	Protein-N
		(% of total N)							
VC	1.30	74.0	28.2	20.5	6.6	18.7	26.0	44.7	31.0
FC	1.60	64.3	32.7	15.8	7.0	8.8	35.7	44.6	36.0
IVC	2.20	54.2	23.9	18.4	4.7	8.2	45.8	54.0	26.5
CR	2.30	62.3	24.1	17.0	4.4	16.8	37.7	54.5	26.5
CB	2.50	69.4	31.0	11.4	8.6	18.4	30.6	49.0	34.1
IVT	1.40	65.4	30.6	19.4	7.9	7.5	34.6	42.1	33.7
ICT	1.10	66.0	29.4	17.8	4.5	14.3	34.0	48.3	32.3
IBT	1.30	68.1	30.4	18.5	4.5	14.7	31.9	46.6	33.4
VG	2.17	56.9	26.0	21.0	4.0	5.9	43.1	49.0	28.6
SZ	0.71	59.2	33.5	12.8	6.6	6.3	40.8	47.1	36.9

[1] For soil identification see Table 1.

[2] HN = hydrolyzable-N; AAN = amino acid-N; AMN = ammonium-N.
ASN = ammino sugar-N; NIN = nonidentified-N.
NHN = nonhydrolyzable-N.

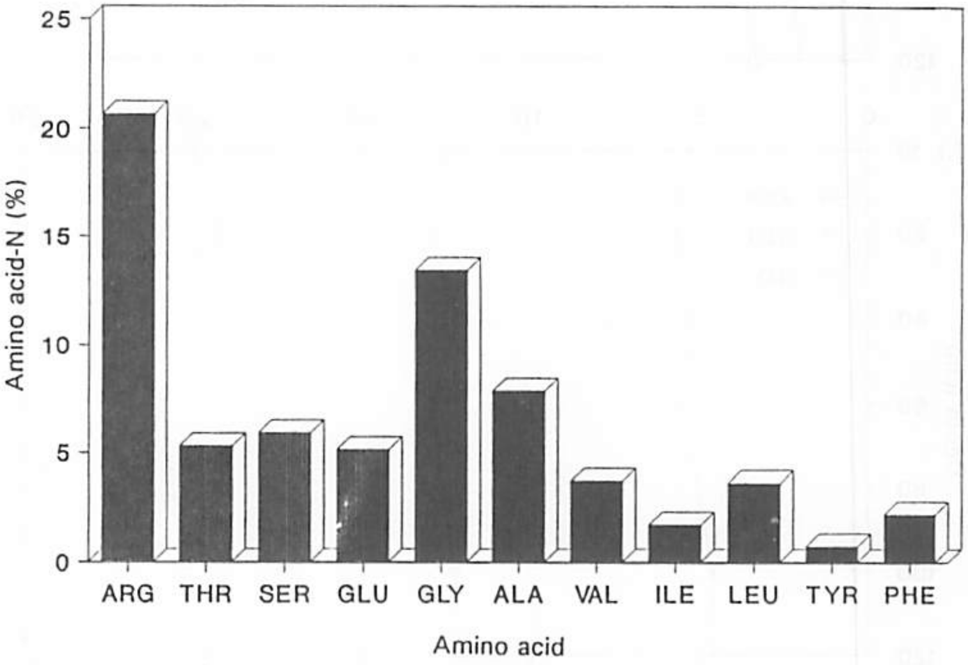

Fig. 1. Distribution of the different amino acid-N expressed as percent of total soil-N.

soils and all layers. Nonsulfoned amino acids were detected. Asparagine, glycine, alanine, and basic amino acids (histidine, arginine, and lysine) were dominant. The absolute quantity of individual amino acids varied from one soil to another and decreased systematically with depth (Fig. 2a). However, relative quantities with respect to total N were almost constant throughout the profile (Fig. 2b). The

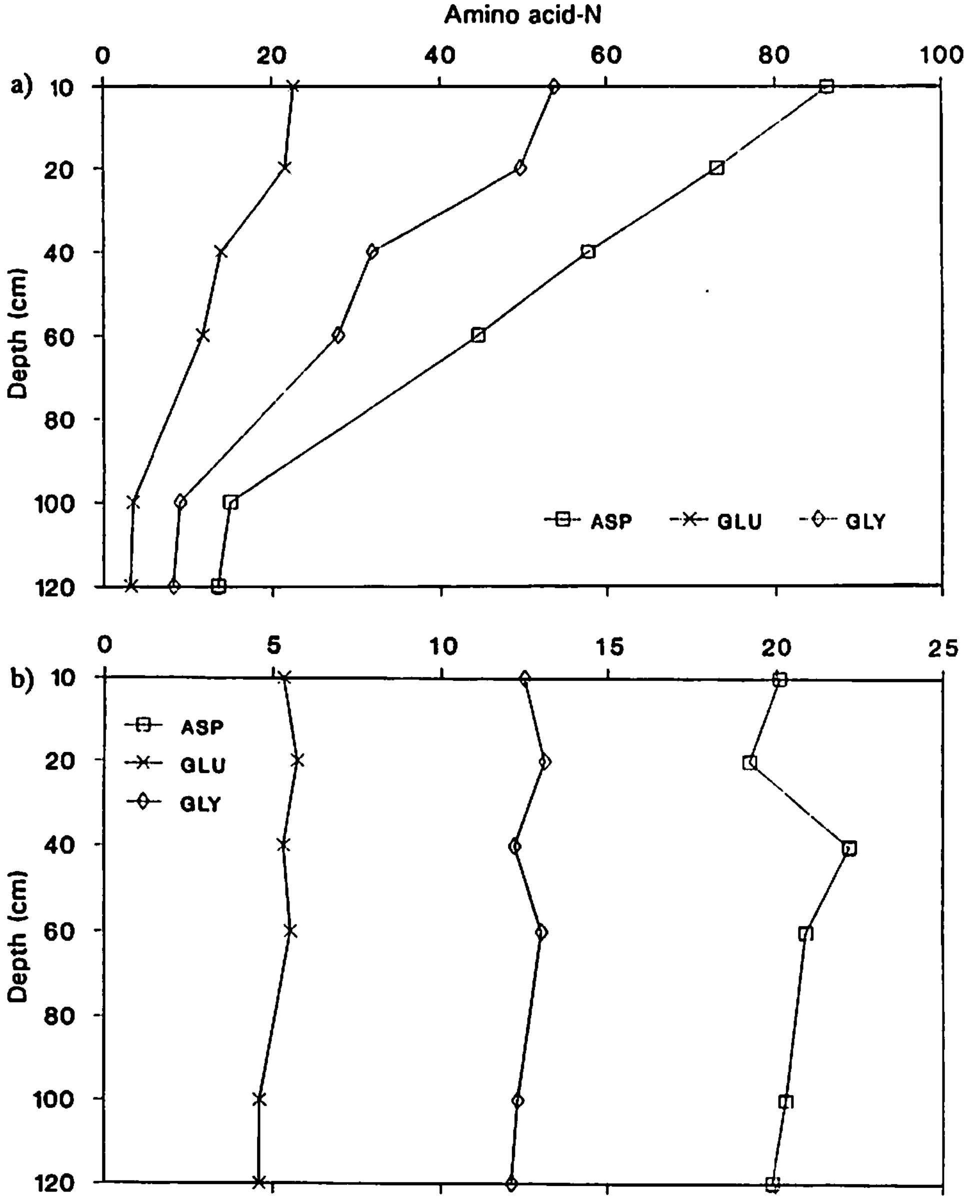

Fig. 2. Variation of amino acid-N for selected amino acids with depth in a Vertic Calcixeroll of the Tadla region: a) absolute values, b) relative proportions in percent.

distribution of acidic, neutral, and basic amino acids, expressed as percentage of total amino acid-N, in the Mediterranean soils studied was very close to that observed in tropical and subtropical soils (Table 4). This indicates that climatic conditions affect the distribution of these amino acid categories.

Table 4. Percentage of amino acid-N as acidic, neutral, and basic compounds for soils of different climatic zones[1].

Amino acid	Climatic Zone				
	Arctic	Cool temperate	Subtropical	Tropical	Mediterranean[2]
Acidic	16.6	20.8	21.7	26.2	26.5 + 4.4
Neutral	53.8	50.7	50.3	50.8	47.2 + 2.9
Basic	25.7	24.0	24.9	19.9	26.4 + 3.1

[1] From Data summarized by Sowden (1977).

[2] Data for the surface layers of Tadla and Chaouia soils.

Native fixed ammonium ranged from 22.4 to 137 mg/kg (Table 5). These quantities represented 3.2 to 25.3% of total N. Native fixed ammonium tended to increase with depth. This tendency could be explained by a reduction of nitrification in deeper layers which is caused by a limited oxygen diffusion rate (Stevenson, 1957). In fact, the accumulation of exchangeable ammonium leads to more ammonium fixation. The relatively low values of fixed ammonium at the surface layers were attributed to optimal conditions of nitrification and to N uptake by plants. A highly significant linear correlation ($r = 0.51^{**}$, $P < 0.001$) was found between the amount of ammonium fixed (y) and clay content (x) : $y = 52.4 + 0.834\,x$.

The high intercept and the relatively low r^2 suggest that other soil characteristics and previous soil management explain most of the variation in native ammonium fixed.

Clay mineralogy alone was not enough to explain the variation of fixed ammonium. In fact, the Chaouia Vertisol, which is rich in beidellite, fixed less ammonium than did the Gharb Vertisol which contains a mixture of beidellite and montmorillonite (Table 5). It is, therefore, believed that previous management and soil moisture regime strongly influence ammonium fixation. In fact, the soils studied have different management histories with respect to the amount of N fertilizer previously added. The Gharb Vertisol, which showed the maximum native ammonium fixed, is more frequently submerged and thus ammonium accumulates in the profile. We are far from the understanding of ammonium dynamics in the soil system. More research is needed to clarify the relationship between clay mineralogy, N fertilizer management, and ammonium fixation under the Mediterranean conditions.

Table 5. Native fixed ammonium in the experimental soils of four agricultural regions of Morocco.

Soil symbol[1]	Depth (cm)	Fixed ammonium (mg/kg)	Fixed ammonium (% Total N)
VC	0-20	90.3	6.9
	20-60	92.5	10.3
FC	0-10	64.1	4.0
	10-32	81.5	6.8
	>32+	89.0	11.1
IVC	0-11	120.8	5.5
	11-36	105-3	5.5
CR	0-10	108-4	8.3
	10-32	119.2	7.9
CB	0-13	88.0	3.5
	13-49	75.5	4.0
IVT	0-10	71.3	5.1
	10-20	77.8	6.0
	20-40	72.6	5.6
	40-60	71.4	7.1
	60-100	74.6	12.4
	100-120	77.2	15.4
ICT	0-10	71.6	6.5
	10-35	81.64	8.1
	35-55	73.9	8.2
	55-75	73.0	9.1
	75-105	85.5	17.1
	105-125	83.2	20.8
IBT	0-10	73.0	5.6
	10-20	71.5	4.5
	20-30	82.0	5.1
	30-60	86.3	14.4
	60-100	101.3	25.3
	100-120	98.9	24.7
VG	0-20	137.0	6.2
SZ	0-20	22.4	3.2

[1] For soil identification see Table 1.

CONCLUSIONS

This characterization showed that 50-75% of total soil-N is chemically hydrolyzable. The remaining fraction would not be of interest agronomically. The determination of hydrolyzable-N fraction seems to be more interesting than total N with respect to soil-N fertility assessment. The amino acid-N fraction, which is an easily ammonifiable substrate, represented the major part of hydrolyzable-N; it was most concentrated at the surface layers and decreases systematically with depth.

Native fixed ammonium represented 3.2 to 25.3% of total N. Neither clay content nor clay mineralogy of the soils studied was sufficient to explain the differences in fixed ammonium. Previous agricultural management (N fertilization, intensive cultivation) and ecological conditions would explain the observed ammonium fixation. Further research is needed to elucidate the effect of previous management of the soil on the qualitative and quantitative modifications of organic-N forms. It is also important to understand the relationship between clay mineralogy and ammonium fixation.

The recognition of soil-N mineralization capacities and biochemical characterization of organic N could help answer the fundamental question "Why soils, incubated under the same optimal conditions of temperature and moisture content, show a high variability in their N mineralization capacities." In fact, N mineralization potential varied between 62 and 273 mg/kg in 38 soils throughout Morocco (unpublished data). Preliminary results showed that the decrease of N mineralization rate with depth is closely related to the decrease of the amino acid-N fraction (Soudi *et al.*, 1990). The ultimate goal of this basic-type research is to evaluate the contribution of soil N to plant nutrition during the growing season.

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Barley Response to Nitrogen Fertilization under Varying Soil Nitrate

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ABSTRACT

Several barley experiments were initiated in farmers' fields during the 1988/89 and 1989/90 seasons to monitor response to N fertilization using fields grown continually with barley. The N rates were 0, 30, 60, 90, and 120 kg/ha, all applied at sowing as ammonium nitrate. Rainfall was low in both seasons (250 mm, 1988/89; 200 mm, 1989/90), resulting in low yield (2.5 t/ha grain). Concentrations of NO_3-N in the 0-60 cm soil layer at sowing were mostly between 2 and 7 ppm. This limited range did not permit the determination of a critical value of soil-N beyond which response to applied N would not be expected. However, even in the 2 to 7 ppm NO_3-N range, response to N was most variable; but in all cases, 30-60 kg N/ha was sufficient. Possible reasons for this variability include uneven N distribution in the profile and varying mineralization. In only one experiment did excess N cause a significant reduction in yield. Increasing N increased K % in the straw, particularly in the 1989/90 season, which was wetter in March-April. At the highest N rate (120 kg/ha), unused N was mostly recovered as increased NO_3-N in the 0-60 cm layer.

INTRODUCTION

Barley growing in Cyprus continued to increase steadily in the last few years at the expense of wheat; it presently occupies 95% of the cereal land. Barley is harvested as grain and straw or, to a lesser extent, as green matter at the dough stage for making hay. Because of serious land shortage, fallow has virtually disappeared. As barley produces more dry matter under semiarid conditions than do legumes (Hadjichristodoulou, 1973; Droushiotis, 1989), it has been established in Cyprus as a monoculture for the production of feed grain and roughage, and is grown under full mechanization.

Past work on NP fertilization of wheat and barley was carried out on fallowed land (Littlejohn, 1946; Loizides, 1958; Krentos and Orphanos, 1979). Responses to N alone, P alone, and to both N and P were obtained depending on the degree of limitation of either nutrient and of rainfall. The availability of a reliable test for soil P, i.e., bicarbonate-extractable (Olsen) P, has enabled us to determine the threshold value of soil-P beyond which applied P will not increase the wheat or barley yield, even in low-rainfall years during which response to P is relatively more marked (Matar, 1977; Krentos and Orphanos, 1979). Based on extensive research conducted in the region, this value was established at about 6 ppm P in the plough layer (Krentos and Orphanos, 1979; Matar, *et al.*, 1988; Orphanos, 1988; Pala and Matar, 1988; Abdel Monem *et al.*, 1990).

The dominance of the continuous barley monoculture necessitated a fresh look at N relationships under these conditions. This coincided with ICARDA's initiative to pursue soil test calibration for N in the region. Based on guidelines set by ICARDA, a series of long-term experiments were initiated in the 1988/89 season. This report covers the first two years of research.

MATERIALS AND METHODS

Initiated in the 1988/89 season, the study involved 10 experiments; the number was increased to 14 in 1989/90 and the subsequent seasons. The experiments were conducted on permanent sites in farmers' fields in the main barley-growing areas: Alambra, Latsia, Menika, and Dromolixia, with 3-4 trials at each site, referred to as A_1 .. A_4, L .. L_4, etc. The N relationships of the crop will be monitored over the years under on-going farmers' practice.

The soils are medium-textured, moderately calcareous, and low in organic matter. They are inherently high in exchangeable K, but low in P. Exchangeable K was markedly higher than the normal value of 300 ppm (Table 1). However, because of past inorganic P fertilizing, and possible farmyard manure application, Olsen-P levels were mostly above the 6 ppm threshold value.

Table 1. $NaHCO_3$-P and exchangeable K in the 0-15 cm soil layer of the four N_0 plots at the initiation of the experiments, 1988-90.

		$NaHCO_3$-P		
Experiment		Range	Mean	Exchangeable K
		(ppm)		
Alambra	A_1	16.8 - 18.8	17.7	380
	A_1	21.7 - 25.4	23.7	400
	A_1	9.2 - 11.8	10.5	590
	A_1	18.9 - 20.5	20.0	610
Latsia	L_1	5.3 - 6.7	6.0	440
	L_1	5.6 - 8.9	7.7	340
	L_1	14.2 - 20.4	17.7	570
	L_1	-	-	230
Meniko	M_1	6.1 - 12.4	10.1	200
	M_1	5.8 - 10.8	7.5	330
	M_1	5.7 - 8.0	6.7	290
Dromolaxia	D_1	6.0 - 8.8	7.7	620
	D_2	7.2 - 15.6	11.8	920
	D_3	7.9 - 8.6	8.2	640

Prior to cultivation in the second half of November 1988, the four control (N_0) plots were sampled to 60-cm depth (four cores per plot) using a Giddings coring machine. The concentration of NO_3-N in these samples was determined using the chromotropic method as described by Hadjidemetriou (1982). This method gave almost identical results to the standard digestion-distillation method. Incidentally, determination of NO_3-N with an ion-selective electrode was imprecise. Additionally, the top 15 cm of the soil of N_0 plots was sampled separately to determine Olsen-P. From 1989, NO_3-N was also determined in plots receiving the highest N rate (120 kg N/ha).

Consistent with present practices in Cyprus, the fields were tine-cultivated in autumn. Stubble available in appreciable quantity was burned prior to cultivation. The seed was drilled in early December by a tine-type seeder, equipped with a metal or wooden drag for closing the furrows. The barley test variety was Athenais. The experiments' five N test levels (0, 30, 60, 90, and 120 kg N/ha) were broadcast as ammonium nitrate prior to sowing.

In the first year, 30 kg P/ha was applied to all plots of three experiments (erroneously so in one), in which soil-P was close to the critical value. However, from the second year onwards, 30 kg P/ha was applied to two replicates of each experiment, to demonstrate the validity of the critical soil-P value and monitor soil-P with time.

Plot size was 6 x 6 m and the plant rows were spaced at 17.5 cm. A randomized complete block design with four replications was used. In certain experiments, a 2,4-D spray was applied to control charlock (*Sinapis arvensis*) and fumitory (*Fumaria officinalis*). In the second season (1989/90), straw weight was recorded. Grain and straw were analyzed for N, P, and K. The data were analyzed using Analysis of Variance procedures.

RESULTS AND DISCUSSION

Two experiments had to be abandoned. Therefore, only 8 were harvested in 1988/89 and 13 in 1989/90. Total seasonal rainfall was below average in both seasons; 250 mm for 1988/89 and 200 mm for 1989/90 (Table 2), but had contrasting distribution. In 1988/89, virtually 90% of the rain occurred during the November-January period, whereas in 1989/90, about 70% occurred in February and March, after the crops had seriously been water-stressed. Other weather vagaries in 1988/89 included extraordinarily low temperatures in January-February, and high temperatures in April at the grain-filling period. As the water requirement of barley in Cyprus is 300 mm, water stress was severe during both seasons, and consequently yields were low.

Because of the low rainfall, response to N was, inevitably, limited. Indeed, in only three experiments in 1988/89 and two in 1989/90 a significant increase in yield was obtained with the 30 or 60 kg N/ha rate. In fact, increasing the N rate up to 60 kg/ha resulted in decreased 1000-grain weight (Table 3). Contrary to the general belief, and in agreement with previous work in Cyprus (Krentos and Orphanos, 1979), the "haying off" effect was not significant, except in one experiment (L1). This could

Table 2. Total rainfall (mm) for two growing seasons at four experimental areas, Cyprus, 1988-90.

Area	Season 1988/89	 1989/90	Long-term average
Alambra	-	200	300
Latsia	265	190	270
Meniko	225	205	260
Dromolaxia	260	195	350

Table 3. 1000-grain weight (g) as affected by the N rate (kg/ha) applied, 1989/90.

N	Mean	Maximum reduction	Minimum reduction
0	38.3	39.4	38.1
30	36.2	35.3	37.8
60	34.2	31.0	37.9
90	33.7	31.4	36.9
120	33.0	28.5	36.0

Maximum reduction occurred in experiment M_1 and minimum reduction in experiment D_1.

be attributed, on the one hand, to the fact that being usually subjected to water stress even in early to mid season, the crop is conditioned to stress, and on the other hand, once full cover has been achieved, evapotranspiration is virtually independent of the size of the crop.

With the exception of three experiments, NO_3-N in the 0-60 cm soil layer was at, or mostly below, 10 ppm (Table 4). Even in the case of Experiment D_3 in which the soil, fallowed in the preceding season, tested 23 ppm NO_3-N in November 1988; NO_3-N declined to 2.2 ppm in 1989 and to 1.2 ppm in 1990. Other work (Matar *et al.*, 1990) suggested a threshold value of 8.5 ppm for wheat; however, 12 ppm would perhaps be more appropriate. In any case, even if a threshold value can be determined, the important problem awaiting solution in soil N calibration work is the unpredictable response to N at low soil NO_3-N values. The present data, as well as the data provided by Matar *et al.* (1990) suggest the question why response to NO_3-N is or is not obtained at low soil-N values.

One of the factors which could be responsible for this is NO_3-N distribution in the 0-60 cm layer. It can be visualized that if most of this N were in the deeper part of the profile and the latter was not wetted, then obviously the crop could not take up sufficient N. Conversely, if this N were mainly in the surface layer and the soil dried out during the course of the season, then similarly sufficient N could not be taken up. Unlike N, P is predominantly in the surface soil, which is wet early in the season when

Table 4. Nitrate (0-60 cm) at sowing time per year in plots that received no N (N_0) or 120 kg N/ha (N_4), 1988-90.

Location/ experiment no.		N_0				N_4			
		1989		1990		1988		1990	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
		(ppm)							
Alambra	A_1	3.1 - 11.0	6.8	2.5 - 4.3	3.5			7.9 - 8.4	8.2
	A_2	5.3 - 7.8	6.8	1.5 - 4.4	2.9			4.7 - 8.1	6.4
	A_3	4.0 - 8.1	5.6	3.1 - 5.2	3.7			11.1 - 14.0	12.6
	A_4		10.2*	5.6 - 12.0				5.6 - 12.0	8.8
Latsia	L_1	1.0 - 1.5	1.2	0.3 - 0.7	0.5	3.1 - 4.2	3.7	19.0 - 36.4	27.7
	L_2	2.6 - 5.9	4.5	8.0 - 16.2	11.9	4.5 - 9.1	9.1	18.1 - 20.3	19.2
	L_3	1.1 - 2.4	1.9	0.7 - 1.6	1.0	1.5 - 3.6	2.6	2.3 - 4.5	3.4
	L_4	6.8 - 23.5	13.0	1.7 - 6.7	3.2	-	-	-	-
Meniko	M_1	2.0 - 4.6	3.4	-	-	5.4 - 6.7	6.1	-	-
	M_2	2.0 - 2.5	2.3	1.5 - 3.1	2.2	3.6 - 3.8	3.7	9.0 - 12.7	10.9
	M_3	1.0 - 1.5	1.3	1.0 - 1.2	1.1	5.1 - 10.7	7.9	7.2 - 11.3	9.3
Dromolaxia	D_1	1.7 - 2.5	2.1	-	-	3.6 - 5.2	4.4	-	-
	D_2	2.5 - 5.2	4.1	2.0 - 3.7	2.9	5.2 - 6.3	5.8	9.3 - 10.4	9.9
	D_3	1.9 - 2.5	2.2	0.0 - 1.9	1.2	9.0 - 10.4	9.7	8.1 - 14.9	11.5

*0-30 cm.

Values for N_0 at Latsia, Meniko, and Dromolaxia only were reported in 1988.

Means and range were : Latsia = 4.0 (4-5), 10.3 (8-13), 4.6 (3-7); Meniko = 5.2 (4-8), 3.7 (3-5), 3.1 (3-4); and Dromolexia = 5.5 (4-7), 1.8 (1-17), 23 (20-27).

most P uptake occurs; hence the vastly better agreement between soil-P and yield is justified. Additionally, the course of N mineralization in any one soil could also be crucial. Until this can be understood, the static NO_3-N value determined at sowing time will not be sufficient for judicious N fertilization.

As shown in Table 4, N fertilizer applied in excess of crop requirements was, with a few exceptions, recovered to a great extent as NO_3-N in the soil (1 ppm NO_3-N = 8 kg N/ha). Despite the complexity of mineralization-fixation processes, this clearly shows that N applied in excess remains available to the following crop. This could be tested by discontinuing N fertilization and monitoring the residual effect of accumulated N.

Applied P (30 kg/ha) maintained the top 15-cm layer higher in Olsen-P by about 10 ppm until sowing time the following year (Table 5). Discrepancies in certain values were presumably caused by variable depth of mixing of the fertilizer with the soil.

Finally, as already shown by Orphanos and Krentos (1980), increasing N application in most cases caused higher K concentration in the straw. The K ranged from about 1.3% with no N added to about 2.8% at the highest N rate. The amount of K removed in the grain and straw increased linearly up to the 90 kg N/ha rate (Table 6). This is wasteful if yield is not also increased by N. The amounts of N removed in the grain and straw were influenced in the same way as for K, but the amounts of P removed were not affected.

Table 5. Olsen-P in surface samples on different dates in plots with no P (P_0) or 30 kg P/ha (P_1) applied in mid December, 1989.

Location/ experiment no.		P_0		P_1	
		17/11/89	6/11/90	17/10/89	6/11/90
		(ppm)			
Alambra	A_1	17.6	19.5	17.8	27.5
	A_2	23.9	19.0	23.6	29.8
	A_3	11.5	11.0	9.5	18.0
	A_4	19.3	17.0	20.3	37.0
Latsia	L_1	7.7	5.8	8.1	14.0
	L_2	42.0	20.0	51.6	43.5
	L_3	48.5	26.5	41.6	34.5
	L_4	4.7	6.0	5.4	25.0
Meniko	M_1	29.2	11.0	25.3	31.0
	M_2	7.7	9.9	6.1	15.6
	M_3	8.2	8.2	10.4	22.0
Dromolaxia	D_1	11.9	-	12.0	-
	D_2	10.4	10.9	9.8	22.0
	D_3	12.8	13.5	13.9	25.5

P_1 was applied to all plots on 10 December 1988 (incomplete incorporation into the soil).

Table 6. Total N, P, and K removed in grain and straw under the five N rates, 1988-90.

Nutrient	N rate (kg/ha)				
	0	30	60	90	120
N	41.0	51.0	58.8	66.3	67.2
P	4.9	5.1	5.1	5.5	5.2
K	46.7	59.5	67.9	76.5	76.1

Values are means of 12 experiments conducted in 1989/90.

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DISCUSSION

M. Badraoui

1) Can you comment on:
    a. The use of the Cate-Nelson method for determining critical level for mineral N?
    b. Levels of yields of barley in the study?
2) Why was P uptake very low (4-6 kg P_2O_5/ha) during the season?

P. Orphanos

1) a. It gives a rough idea and can only be used, provided a broad range of soil NO_3-N is represented in the experiments.
    b. 1.0 to 2.5 t/ha.
2) Because rainfall and yield were low.

J. Ryan

Here in Morocco's semiarid zone where K, and often P, is adequate in many soils, farmers still use

N,P,K compounds, which is a waste of K and P. Are the high levels of K and P in Cypriot soils related to actual fertilizer use? i.e., do they reflect the low need for the elements?

P. Orphanos
Yes. However, the farmers' practice has changed, as a result of our research, to reflect actual crop needs.

Nitrogen and Phosphorus in Rain-fed Regions of Tunisia: Wheat Responses and Soil Impacts

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ABSTRACT

Uni-factor multilevel P and N experiments were conducted in cereal growers' fields during 1986-90 to evaluate the critical level of available P and mineral N in soils for durum wheat grown in rainfed regions of Tunisia. In P trials, soil samples were taken prior to sowing and tested for Olsen-P. Tests were correlated with wheat grain yield at harvest. The critical P level was derived using the Cate-Nelson graphical method. The scatter diagram indicated that a P test of 6 mg/kg (or ppm) divided soils into responsive and nonresponsive to P fertilizer. In N experiments, mineral N was tested in preplant soil samples, and plotted against relative grain yield. The critical level was found to be equal to 10 mg/kg for durum wheat. To evaluate soil response to applied P, samples from three common soils supporting cereals were placed in plastic pots and equilibrated with four P rates for 12 weeks under field conditions. Olsen-P was then measured in each pot. Tests were plotted against P rates, and regression equations were determined. Such equations could be used as a guide to make acceptable recommendations for durum wheat fertilization.

INTRODUCTION

Data from field research relating fertilizer rates to cereal yields are of little value *per se* in soil fertility. Soil testing is used nowadays as a pertinent tool to improve crop fertilization practices. Its success depends on the amount and quality of research data available for calibration and interpretation of the tests. In North Africa and West Asia, few data on cereal fertilization were available before the International Center for Agricultural Research in the Dry Areas (ICARDA) established the Soil Test Calibration Network in 1986. Since then many N and P on-farm trials have been carried out in the area in order to generate sufficient reliable data on soil extracting procedures and on cereal response to N and P fertilizers.

Data showed that sodium bicarbonate-extractable P correlates very well with plant response in soils with medium-to-high cation exchange capacity (Amar and Aït Houssa, 1990; Yurtsever and Gedikoglu, 1990). The $NaHCO_3$-P critical level, which divides soil into responsive and nonresponsive to fertilizer application, was found to range between 5 and 6 mg/kg (Soltanpour *et al.*, 1988, Matar *et al.*, 1988, Gharbi *et al.*, 1990). With respect to N, it was shown that NO_3-N in the top 0 to 40 cm soil at sowing correlated best with cereal grain yield and that a critical NO_3-N level for wheat ranged between 8 and 8.5 mg/kg (Matar *et al.*, 1990). Previous work in Morocco had shown that NO_3-N critical level ranges between 9 and 9.5 mg/kg (Soltanpour *et al.*, 1988). Critical levels are of paramount importance in making nutritional diagnosis, and help interpret farmers' soil tests, but they give no indication of the amount of fertilizer required by a crop to reach maximum yield when other factors are adequate.

Fertilizer recommendations depend on a knowledge of the initial soil nutrient level and the amount of fertilizer needed to raise the initial soil nutrient concentration to the critical level (Kamprath and Watson, 1980). Several mathematical models have been developed to predict amounts of fertilizer needed to raise the nutrient level to its optimum. The p73 Mitscherlich-Bray equation was successfully tested in calibrating Olsen-P in soils of the Central Anatolian region of Turkey (Yurtsever and Gedikoglu, 1990). Matar *et al.* (1990) proposed a model for N recommendation for wheat relating N requirement to the level of NO_3 in 0 to 40 cm depth and to the N fertilizer use efficiency. Fertilizer recommendation can also be based on field or greenhouse experiments relating fertilizer rates to soil nutrient level after fertilization, assuming that the fertilizer added releases a fairly uniform amount of nutrients in the soil solution over a growing season. Smyth and Crave (1990) reported that Mehlich I and Bray I extractable soil-P increased exponentially with increasing P rates.

This paper aims to: (1) refine, using additional data, the Olsen-P critical level previously established for wheat in Tunisia (Gharbi *et al.*, 1990), (2) derive the mineral-N critical level for durum wheat, and (3) examine the relationship between added P and Olsen-P after 12 weeks of fertilization of three common cereal-growing soils in Tunisia.

MATERIALS AND METHODS

Critical P Level

Thirty on-farm trials on durum wheat were conducted at various sites of the cereal-growing area in Tunisia during the last four growing seasons(1986-90). Soils were classified as Vertic Xerochrept, Calcixeroll, Rendoll, Chromoxerert, and Reddish Mediterranean. Soils were selected so as to contain varying Olsen-P concentrations. Each trial was a unifactor multilevel experiment arranged in a randomized complete block with four replications. Treatments involved four rates of triple superphosphate (0, 9, 18, and 36 P/ha). Test plants were two common durum wheat varieties (Karim and Razzak). Before sowing, soil samples were taken from each replication and analyzed for $NaHCO_3$-extractable P. At harvest, grain yields were recorded for each plot. The relative yield, ratio of yield at the 0 level to maximum yield, was computed for each site. The P values were averaged so that there was a single relative yield and one soil test value for each site. The critical P level for wheat was derived according to the Cate-Nelson graphical method (Nelson and Anderson, 1975).

Critical Mineral-N Level

Twenty on-farm uni-factor multilevel N trials were conducted. Treatments consisted of four rates of ammonium nitrate (0, 40, 80, and 120 kg N/ha), applied to durum wheat. Prior to planting, soil samples were taken at 0-60 cm depth in 20-cm increments and analyzed for mineral-N by the Kjeldahl method. At harvest, grain yields were determined and relative yield computed for each site. Relative yields were finally plotted against averaged N tests, and the critical mineral-N level was derived by the Cate-Nelson technique.

Added P vs. Olsen-P Test

Three soil samples were collected from three common soils in the cereal-growing area (Vertic Xerochrept, Calcixeroll, and Xeralf). Soils were selected with low available P in the top 0-20 cm layer. Soil samples were placed in plastic pots (2 kg/pot) which were arranged in a split-plot design. The main factor was soil type, while treatments were four rates of triple superphosphate (30, 60, 90, and 120 kg P/ha) with two replications. Pots were placed in field conditions for 12 weeks. Later, Olsen-P was determined in each pot. Averaged P tests were plotted against P additions. Regression equations were developed for each soil type in order to make P fertilizer recommendations for durum wheat.

RESULTS AND DISCUSSION

Added P fertilizer enhanced grain yield in nearly 50% of the sites (Fig. 1). Nonresponsive soils were initially high in available P. The Cate-Nelson graphical

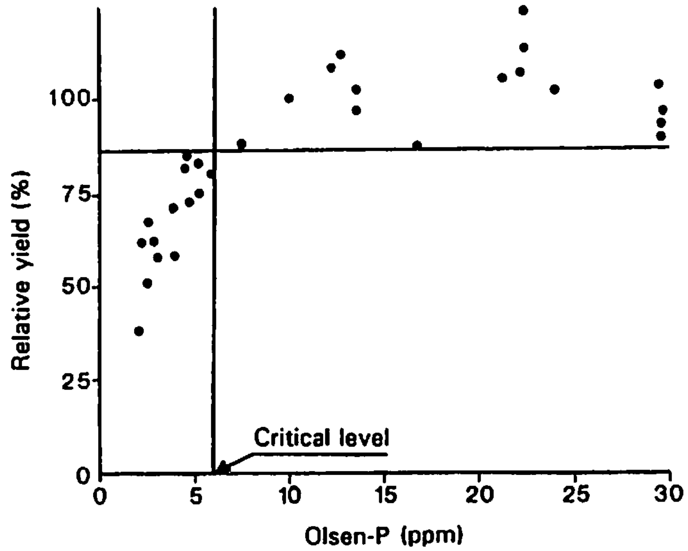

Fig. 1. Scatter diagram of relative yield of wheat vs Olsen-P, Tunisia, 1986-90.

method for determining the critical level indicated that 6 mg/kg of available P at preplant maximize the durum wheat grain yield when other factors are adequate. Such a result is in line with previous findings with cereals and P fertilizers in the region.

The N trials showed that durum wheat yield increased with increasing amounts of N fertilizer at some sites (Fig. 2). However, adverse effects were observed at other sites. A mineral N value of 10 mg/kg to a depth of 60 cm at sowing represents the critical level that divides soil into responsive and nonresponsive to N fertilizer.

Olsen-P values increased linearly with increasing P rates for the three soils under study (Fig. 3). Correlation coefficients were significant. The regression equations derived could be used to evaluate the amount of P fertilizer required to raise available P to its optimum level. Such equations indicated that Calcixeroll, Xeralf, and Vertic Xerochrept soils required 60, 150, and 200 kg/ha superphosphate, respectively, to reach their critical level.

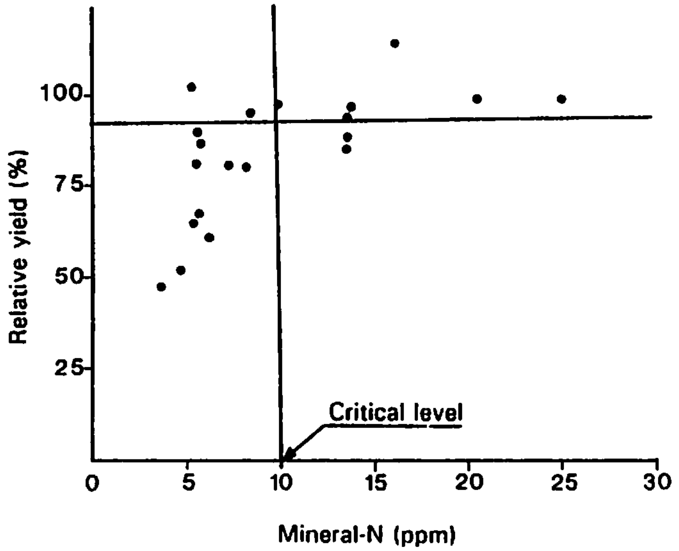

Fig. 2. Scatter diagram of relative yield of wheat vs mineral-N, Tunisia, 1986-90.

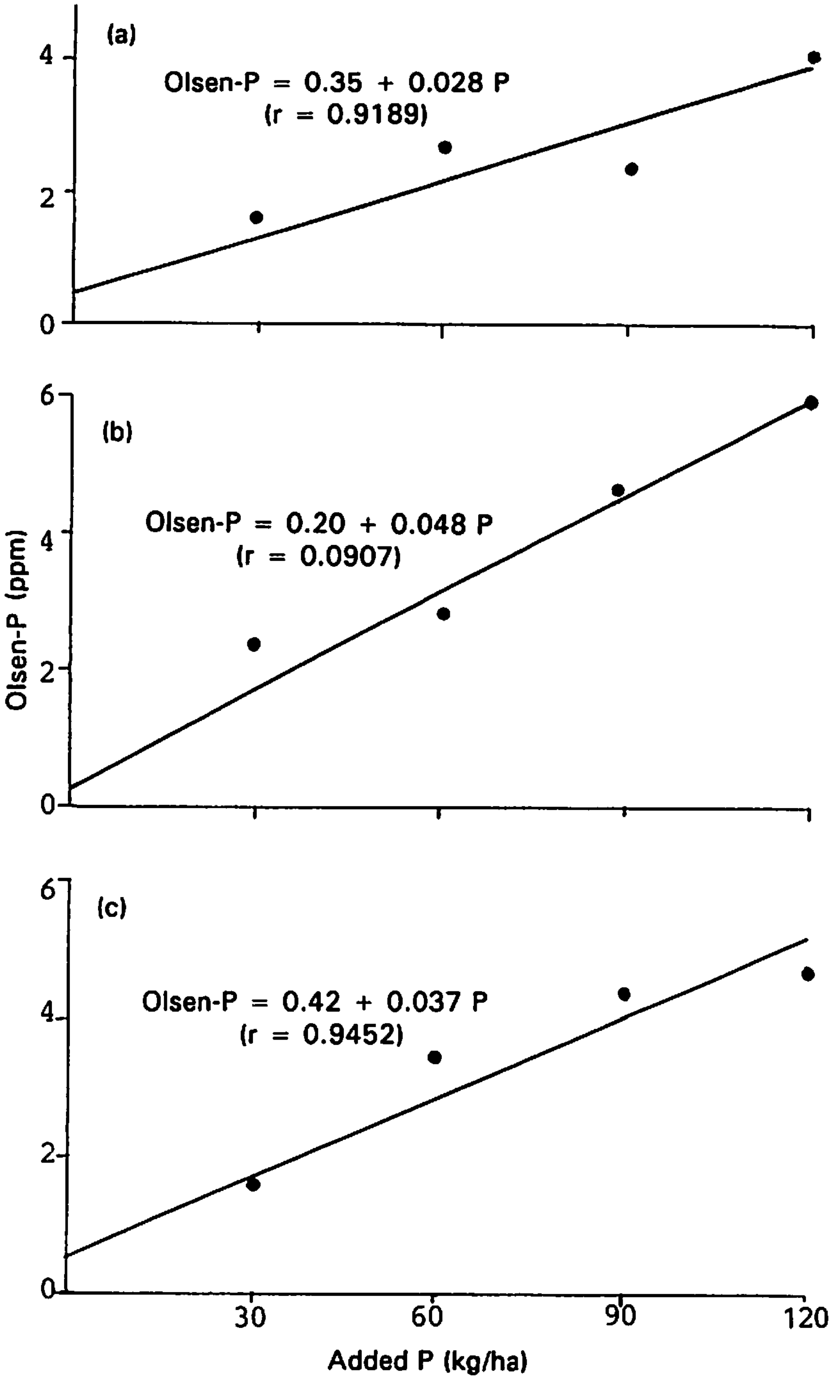

Fig. 3. Relationship between Olsen-P and applied P in (a) Vertic Xerochrept, (b) Calcixeroll, and (c) Red Mediterranean, Tunisia, 1986-90.

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Calibration of $NaHCO_3$, NH_4HCO_3-DTPA and Mehlich 3 Tests for Phosphorus Fertilization of Rain-fed Wheat in Pakistan

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ABSTRACT

Field experiments were conducted on rain-fed wheat during the *rabi* seasons of 1988/89 and 1989/90, at seven locations in the Islamabad Capital Territory. Phosphorus fertilizer was applied at the rates of 0, 22, 44, 66, and 88 kg P/ha during 1988/89 and 0, 20, 40, 60, and 80 kg P/ha during 1989/90. Soil-P test levels extracted by the $NaHCO_3$, AB-DTPA, and Mehlich 3 tests were correlated with wheat grain yield according to the modified Mitscherlich-Bray equations, i.e., the equation $\text{Log (A-Y)} = \text{Log A} - c_1b_1$ for relating the soil test values with grain yield, and the equation $\text{Log (A-Y)} = \text{Log A} - c_1b_1 - cx$ for calculating fertilizer application rate.

The calculated and obtained yields of wheat grain for various soil test values and P fertilizer rates are reported. By using the equations, levels of soil-P were determined which may produce very low, low, medium, and high yields, compared with potential yield. Optimum yield (95% of the maximum) may be obtained if soil test P level is not less than 16 mg P/kg soil by the $NaHCO_3$ test, 9 mg P/kg soil by the AB-DTPA test, and 24 mg P/dm^3 by the Mehlich 3 test, provided yield is not limited by other agronomic factors.

INTRODUCTION

The total cultivated area of Pakistan is 20.8 million ha, of which 25% entirely depends on rainfall. One-fifth of the country's wheat acreage is rain-fed, but rain-fed areas contribute only 10-12% of the national production of this staple food (Razzaq *et al.*, 1990). About 90% of the agricultural soils in Pakistan are deficient in P (Saleem and Ahmed, 1990); farmers frequently apply P fertilizers to the wheat crop.

Soil testing is an effective approach for evaluating P fertility of soils, but can be useful only after proper calibration with nutrient uptake and crop yield. The $NaHCO_3$ test (Olsen *et al.*, 1954) is the routine test in Pakistan. However, it has not been adequately calibrated locally. Therefore, soil test calibration for P is highly warranted in the country.

The recently-developed multi-element "universal" soil tests, AB-DTPA (Soltanpour and Workman, 1979) and Mehlich 3 (Mehlich, 1984), have the advantages of being more efficient and economic than the $NaHCO_3$ test (Jones, 1990). In our greenhouse and laboratory investigations, the "universal" tests correlated very well with the $NaHCO_3$ test (Rashid *et al.*, 1988; Rashid and Din, 1990). This paper reports a tentative calibration for the three soil tests with wheat response to P fertilizer in rain-fed conditions of Pakistan.

MATERIALS AND METHODS

Four field experiments were carried out during *rabi* 1988/89 and three during *rabi* 1989/90 in the Islamabad Capital Territory to calibrate soil-P for fertilization of rain-fed wheat. Soil samples were collected at surface (0-15 cm) and subsurface (15-45 cm) depths separately from each replication. Some soil properties of the experimental fields are given in Table 1.

Table 1. Soil properties of seven field locations in Islamabad Capital Territory, Pakistan, 1988-90.

Expt.	Location	Soil depth (cm)	pH (1:1)	Organic matter (%)	DTPA-extractable (mg/kg)			
					NO_3-N	K	Zn	Cu
				Rabi 1988/89				
1	NARC-I	0-15	8.2	0.64	1.31	48	0.9	1.4
		15-45	8.3	0.66	1.04	45	0.7	1.5
2	Tarlai	0-15	8.1	0.46	1.10	46	0.7	1.6
		15-45	8.1	0.58	1.00	42	0.6	1.7
3	Mohranoor-I	0-15	8.1	0.75	1.05	148	0.8	2.4
		15-45	8.1	0.59	0.91	123	0.7	2.2
4	Phulgran	0-15	7.3	0.55	0.94	46	0.6	1.7
		15-45	7.5	0.69	0.91	40	0.6	1.8
				Rabi 1989/90				
5	Sehala	0-15	7.8	0.28	1.29	76	1.0	1.1
		15-45	7.8	0.28	2.79	57	0.9	1.0
6	Mohranoor-II	0-15	7.7	0.74	0.80	80	0.6	1.5
		15-45	7.8	0.52	1.50	83	0.6	1.5
7	NARC-II	0-15	7.9	0.71	0.91	72	0.5	1.7
		15-45	7.9	0.50	1.04	60	0.5	1.7

Fertilizer P (as diammonium phosphate, DAP) was applied at the rates of 0, 22, 44, 66, and 88 kg P/ha during 1988/89 and 0, 20, 40, 60, and 80 kg P/ha during 1989/90. Basal fertilizers were 120 kg N/ha as urea and 100 kg K/ha as K_2SO_4. All the fertilizers were applied before crop sowing by broadcasting, and mixed in with a power rotavator. The experiments were laid out in a randomized complete block design with four replications. Wheat (*Triticum aestivum* L.; cv. PaK-81) was the test crop for both years. Grain and straw yields were recorded at maturity.

Extractable P contents (Table 2) of the soils were determined by the $NaHCO_3$ test (Olsen *et al.*, 1954), AB-DTPA test (Soltanpour and Workman, 1979), and Mehlich 3 test (Mehlich, 1984). The modified Mitscherlich-Bray equation (Bray, 1945; 1958) was used to determine the relationship between extractable soil-P levels and grain yield.

The grain yields obtained in the experiment were expressed as percentages of the maximum yield obtained in that particular experiment. The figures for relative yield were then correlated with P contents of the corresponding soils using the Mitscherlich equation:

$$\text{Log}\,(A-Y_0) = \text{Log}\,A - c_1 b_1 \qquad (1)$$
$$\text{Log}\,(A-Y) = \text{Log}\,A - c_1 b1 - cx \qquad (2)$$

Where:

A = Maximum yield at a certain site from the plot receiving optimum level of fertilizer
Y_0 = Yield from the plot receiving no fertilizer
Y = Yield from any P rate, the efficiency of which is being calculated
c_1 = Calculated efficiency of soil-P (constant for b_1)
b_1 = The soil test value of P
c = The efficiency of applied P (constant for x)
x = A given fertilizer rate

Values of "c_1" were calculated from equation (1) for each experiment, and a mean value for the constant "c_1" was calculated for all sites (Table 3). Using the average "c_1" value, "b_1" values (calculated soil test levels) were determined from equation (1) for various Baule units. The "c" values were calculated from equation (2) for all P rates, except control and the P rate giving maximum yield. A mean value for the constant "c" was calculated. Using the "b_1" values for various Baule units in equation (2), the P fertilizer rates (x) were calculated for various Baule units. Finally, "y" values (grain yield) were calculated from equation (2) using average "c_1" for b_1, average "c" for x, and experimental maximum yield (A) for each site.

RESULTS AND DISCUSSION

Soil-P test values of wheat grain yield and percent relative yields of each experiment are given in **Table 2**. Without P fertilization, the percent relative yields were < 66%

Table 2. Soil-P test levels of experimental fields and wheat response to P fertilization, Islamabad Capital Territory, Pakistan, 1988-90.

Expt.	Extractable P[*] (mg/kg)	Applied P (kg/ha)	Grain yield (t/ha)	Relative yield (%)
		Rabi, 1988/89		
1	4.8[a]	0	3.7	63
	2.4[b]	22	4.7	79
	7.8[c]	44	5.5	92
		66	5.9	100
		88	5.3	90
2	5.6[a]	0	2.0	52
	4.2[b]	22	2.9	74
	4.8[c]	44	3.1	80
		66	3.9	100
		88	3.3	85
3	3.3[a]	0	1.8	49
	3.0[b]	22	2.4	64
	8.3[c]	44	2.9	76
		66	3.7	100
		88	3.0	80
4	2.9[a]	0	1.0	32
	1.5[b]	22	1.9	62
	3.7[c]	44	2.8	88
		66	3.2	100
		88	3.0	94
		Rabi, 1989/90		
5	4.4[a]	0	2.4	49
	1.8[b]	20	2.9	61
	7.0[c]	40	3.2	67
		60	4.8	100
		80	3.6	75
6	4.4[a]	0	2.4	57
	2.1[b]	20	3.3	77
	5.9[c]	40	3.7	86
		60	4.3	100
		80	3.6	85
7	4.6[a]	0	3.1	66
	2.3[b]	20	3.5	75
	6.8[c]	40	3.9	83
		60	4.7	100
		80	4.3	92

[*] Extractable P; a = $NaHCO_3$; b = AB-DTPA; c = Mehlich 3.

of the potential yield and response to P application exceeded 34%, thereby indicating P deficiency in all soils.

Large differences in wheat yields at various locations were obtained, but yield differences among years at the same location were not significant . As the variety was the same for both years, the results obtained during 1988/89 and 1989/1990 were pooled for calibration of soil test methods. The procedures adopted by Yurtsever (1989) and Rehman and Ghani (1990) were followed for calibration of soil-P test with grain yield of wheat. Soil-P test values and grain yield data (Table 2) were used for calculating the efficiency of soil-P (c_1 value) by applying the modified Mitscherlich equation:

$$\text{Log}\ (A-Y) = \text{Log}\ A - c_1 b_1 \qquad (1)$$

The "c" values for all sites are given in Table 3. Using the average c_1 value for each soil test, different soil-P test values (b_1) were calculated for the respective test for various Baule units using equation (1). The calculated soil-P test levels (b_1) are given in Table 4. For example, the data indicated that the AB-DTPA P content for producing 1 Baule unit (50% of the maximum yield) should be 2.13 mg P/kg soil, and for 97% yield the P content should be 10.78 mg P/kg soil.

Table 3. Calculated efficiency values of soil-P tests (c_1) for various sites, Islamabad Capital Territory, Pakistan, 1988-90.

	c_1 value		
Experiment	$NaHCO_3$	AB-DTPA	Mehlich 3
1	0.09001	0.1767	0.05574
2	0.05801	0.0759	0.06768
3	0.08746	0.0954	0.03530
4	0.05657	0.1088	0.04556
5	0.06777	0.1578	0.04260
6	0.08273	0.1729	0.06240
7	0.10246	0.2014	0.06961
Mean	0.07786	0.1413	0.05413

The next step was computing the efficiency of fertilizer P ("c" value) for the three soil tests. This was done using Bray's (1958) equation:

$$\text{Log}\ (A-Y) = \text{Log}\ A - c_1 b_1 - cx \qquad (2)$$

The "c" values for all sites are given in Table 5. These calculated values indicated an acceptable degree of constancy.

Table 4. Calculated soil-P test values (b_1) and corresponding wheat grain yield for various Baule units, Islamabad Capital Territory, Pakistan, 1988-90.

Baule unit	Corresponding yield (%)	Calculated soil-P test (mg/kg) (b_1)		
		$NaHCO_3$	AB-DTPA	Mehlich 3
1	50	3.87	2.13	5.6
2	75	7.73	4.26	11.1
3	88	11.83	6.52	17.0
4	94	15.69	8.65	22.6
5	95	16.71	9.21	24.0
6	97	19.56	10.78	28.1

Table 5. Efficiency values (c) of added P for different sites, Islamabad Capital Territory, Pakistan, 1988-90.

Experiment	Applied P (kg/ha)	c value		
		$NaHCO_3$	AB-DTPA	Mehlich 3
1	22	0.02252	0.01543	0.02517
	44	0.02168	0.01814	0.02301
	88	0.00955	0.00778	0.01021
2	22	-	-	-
	44	0.00877	0.00260	0.01108
	88	0.00562	0.00253	0.00677
3	22	0.00951	0.00066	0.01282
	44	0.00890	0.00447	0.01055
	88	0.00545	0.00324	0.00628
4	22	0.01367	0.00920	0.01534
	44	0.01820	0.01597	0.01904
	88	0.01296	0.01185	0.01338
5	20	0.01309	0.00710	0.01533
	40	0.00863	0.00573	0.00975
	80	0.00582	0.00432	0.00638
6	20	0.02440	0.01765	0.02693
	40	0.01726	0.01388	0.01852
	80	0.00825	0.00656	0.00887
7	20	0.02122	0.01377	0.02400
	40	0.01524	0.01152	0.01664
	80	0.01171	0.00984	0.01240
	Mean	0.01312	0.00911	0.01462

Table 6 gives soil-P test values for the three procedures in relation to various Baule units and the quantity of P fertilizer required to raise grain yield to a certain percent relative yield. The data indicated that for attaining near-maximum (95% of maximum) yield, the soil test levels should be: $NaHCO_3$, 16 mg P/kg; AB-DTPA, 9 mg P/kg; and Mehlich 3, 24 mg P/dm^3.

Table 7 presents actual grain yields from the experiments and yield (y) calculated using equation (2). The two constants, i.e., c_1 for b_1 and c for x, for the

Table 6. Relationship between soil-P test values, relative wheat grain yield, and fertilizer quantity (x) required to raise yields to a desired level, Islamabad Capital Territory, Pakistan, 1988-90.

Soil-P test (b1) (mg/kg)	Percent relative yield	P (kg/ha) required to raise yield to:				
		97%	95%	94%	88%	75%
		$NaHCO_3$				
3.9	50	93	76	70	47	23
7.7	75	70	53	47	24	-
11.8	88	46	29	-	-	-
15.7	94	23	6	-	-	-
16.7	95	17	-	-	-	-
19.6	97	-	-	-	-	-
		AB-DTPA				
2.1	50	134	110	101	68	33
4.3	75	101	77	68	35	-
6.5	88	66	42	33	-	-
8.6	94	33	9	-	-	-
9.2	95	24	-	-	-	-
10.8	97	-	-	-	-	-
		Mehlich 3				
5.6	50	84	68	63	42	21
11.1	75	63	48	42	22	-
17.0	88	41	26	21	-	-
22.6	94	21	5	-	-	-
24.0	95	15	-	-	-	-
28.1	97	-	-	-	-	-

Table 7. Actual and calculated wheat grain yields (t/ha), Islamabad Capital Territory, Pakistan, 1988-90.

		Grain yield			
			Calculated		
Expt.	Applied P (kg/ha)	Actual	NaHCO$_3$	AB-DTPA	Mehlich 3
1	0	3.7	3.4	3.2	3.6
	22	4.7	4.6	4.2	4.8
	44	5.5	5.2	4.8	5.4
	66	5.9	5.6	5.2	5.7
	88	5.3	5.7	5.5	5.8
2	0	2.0	2.4	2.9	1.7
	22	2.9	3.1	3.3	2.9
	44	3.1	3.5	3.5	3.4
	66	3.9	3.7	3.6	3.6
	88	3.3	3.8	3.7	3.8
3	0	1.8	1.7	2.3	2.4
	22	2.4	2.7	2.9	3.1
	44	2.9	3.2	3.2	3.4
	66	3.7	3.5	3.4	3.6
	88	3.0	3.6	3.5	3.7
4	0	1.0	1.3	1.2	1.1
	22	1.9	2.2	1.9	2.2
	44	2.8	2.7	2.4	2.7
	66	3.2	2.9	2.7	2.9
	88	3.0	3.0	2.9	3.1
5	0	2.4	2.6	2.2	2.8
	20	2.9	3.6	3.1	3.8
	40	3.2	4.1	3.7	4.3
	60	4.8	4.4	4.1	4.5
	80	3.6	4.6	4.3	4.7
6	0	2.4	2.3	2.1	2.2
	20	3.3	3.2	2.8	3.2
	40	3.7	3.7	3.3	3.7
	60	4.3	3.9	3.6	4.0
	80	3.6	4.1	3.9	4.1
7	0	3.1	2.6	2.5	2.7
	20	3.5	3.6	3.2	3.7
	40	3.9	4.1	3.7	4.2
	60	4.7	4.4	4.1	4.4
	80	4.3	4.5	4.3	4.6

respective soil tests were used in the equation for recalculating all values of y, using the experimental maximum grain yields (A values) for each site. The data in Table 7 indicate that actual and calculated yields are in agreement, thus suggesting that the equation can be used for formulating fertilizer requirements for rain-fed wheat using soil-P test data obtained by any of these tests.

Yurtsever (1989) suggested that when the crop yield is < 50% of its potential and if the fertilizer material is not applied, the native nutrient level may be considered very low. If the yield is 50 to 70%, the level is low; medium is between 70 and 90%, good between 90 and 95%, high between 95 and 98%; and very high between 98 and 100%. Based on this concept, the tentative levels of soil-P by the three tests are presented in Table 8.

Table 8. Tentative critical P levels by the three soil tests, Islamabad Capital Territory, Pakistan, 1988-90.

Class	Soil-P test level		
	$NaHCO_3$	AB-DTPA	Mehlich 3
	---------------- (mg/kg)	------------	(mg/dm^3)
Very low	< 4	< 2	< 6
Low	4-7	2-3	6-10
Medium	7-13	3-7	10-19
Good	13-17	7-9	19-24
High	17-21	9-11	24-29
Very high	> 21	> 11	> 29

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Plant Analysis for Diagnosing Nitrogen Fertilizer Requirements of Wheat and Barley

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ABSTRACT

In the Mediterranean-type environment, rainfall starts, in an average year, in November and stops in May, with December through February being the wettest months. Nitrogen fertilizer can be applied all at sowing (November), or can be split in two applications, one at sowing and another, as a top-dressing, at the tillering stage (February). Thus, the second N application is done when most of the rainfall has occurred. The answer to whether N fertilizer is needed can be determined by plant analysis. Nitrate (NO_3) concentration in cereal stems indicates the N nutrition status when grown under different fertility levels, and is a diagnostic criterion for maximum growth, and also a prognostic criterion for maximum grain yield. Test strips is a practical method for measuring NO_3 in plant sap, based on which the farmer can make his decision of whether or not to apply N fertilizer. The principles and factors to be considered in the development of diagnostic criteria are elaborated.

INTRODUCTION

Plant analysis has several advantages over soil testing for determining nutrient status, particularly in the case of mobile nutrients such as nitrogen (N). Soil sampling is very demanding in the amount of work needed, especially when considering soil variability, and there is a need for equipment and specific knowledge for sampling and analysis. Soil testing has not been successful in predicting optimum economic response of cereals to N (Storier, 1975). On the other hand, plant analysis, which is based on the principle of nutrient concentration within the plant, is an integral part of all the factors that have interacted to affect it (Munson and Nelson, 1973). It is not only cheaper and easier to perform but has had considerable success as a prognostic and diagnostic tool.

Diagnosis of plant nutrition status can be done nowadays by simultaneously analyzing several elements and using a computer to determine the limiting nutrients. For the average farmer, however, analysis of only one nutrient which is most critical is an adequate diagnostic technique, especially if analysis can be carried out *in situ* by the farmer himself in a practical way (Elliott *et al.*, 1967; Papastylianou, 1989a). In the present report, the stages in developing diagnostic and prognostic criteria for N nutrition of crops will be described based mainly on a series of studies (Papastylianou 1980, 1986, 1987, 1989a; Papastylianou and puckridge, 1981; papastylianou *et al.*, 1984) which aimed at determining the N fertilizer requirements of cereals.

BACKGROUND CONSIDERATIONS

In initiating a program to establish diagnostic criteria for plant nutritional status for a certain element, it is important to take into consideration the factors involved in the uptake and assimilation of the nutrient. Specific steps should be followed during the program. In the following sections these steps will be discussed for N.

Form of the Nutrient

Among the N forms used to evaluate the plant's nutritional status, total N is less sensitive than NO_3 (Ulrich, 1948; Scaife and Bray, 1977; Papastylianou, 1986). Also, the latter has potential for rapid *in situ* tests (Scaife and Stevens, 1977; Papastylianou, 1989a). However, the NO_3 diagnostic criterion has been regarded as insensitive in the deficient zone (Greenwood, *et al.*, 1965). In fact, the NO_3 method is more useful as a means for preventing deficiencies than for correcting them after they occur (Ulrich and Hills, 1973).

Sampling of Plant Tissue

The following factors should be considered when sampling for NO_3 in plants, and are synthesized from a detailed review of Papastylioanou (1980):

Time of Day

The diurnal variation in NO_3 concentration has been discussed in many studies. Even though the diurnal variation in NO_3 is not considered critical for the diagnostic value of plant analysis (Ulrich, 1952), it would still be better to consider a specific time of the day when sampling. For the cereal studies, the standard time of sampling was found to be one or two hours after sunrise (Papastylianou, 1989a).

Plant Growth Stage

Because of the decline in NO_3 with aging of the plant tissue (Papastylianou and Puckridge, 1983), the diagnostic criterion should be set at the optimal stage for response to N application.

Plant Parts

Accumulation of NO_3 differs between plant parts. Translocating tissues, such as stems or petioles, are considered for diagnostic purposes. In vegetables, where there is a continuous leaf production, the best tissue for NO_3 analysis is the petiole of the youngest fully-matured leaves (Ulrich *et al.*, 1959). For cereals at tillering stage, the stem part, which is actually a complex of stem, leaf sheaths and juvenile leaves, have been suggested for diagnostic purposes (Gardner and Jackson, 1976).

Plant Condition

Plants to be used for plant analysis should have no pest pathogen or water stress, factors that adversely affect nutrient uptake and assimilation.

Weather Conditions

Temperature and sunlight are two factors which affect soil N mineralization, NO_3 uptake, and assimilation. Therefore, the condition under which the diagnostic criteria have been set should be specified.

Sample Analysis

Because of the possibility of nutrient assimilation after sampling while uptake has stopped, NO_3 concentration will be affected. For these reasons, samples should be processed immediately after sampling.

Plant Concentration vs Supply

It is important that concentration within the plant of the form of the nutrient, which will be used to establish critical levels, responds to changing supply in the soil pool. Nitrate has been shown to have this characteristic, increasing within the plant with increased fertility because of preceding legumes (Papastylianou, 1986; Papastylianou and Puckridge, 1981, 1983; Papastylianou *et al.*, 1982, 1984).

Nutrients and Growth

The nutrient under consideration should be a limiting factor for growth and production, the crop responding positively to supply. Nitrogen is the main plant nutrient, and is removed from the soil in large quantities. Outside supply is essential for most soils. In areas with a long cropping history, the soil N pool is usually exhausted and yields are very low if N fertilizer is not applied (Papastylianou, 1989b).

Concentration vs Growth

The relationship between the concentration of the nutrient under consideration and yield at sampling time may be detected at any growth stage. Fig. 1 shows that there is almost no increase in concentration while the crop is deficient in that particular nutrient. As soon as the needs of the crop for maximum growth are satisfied, the nutrient shows a rapidly increasing concentration in translocating plant tissues such as stems and petioles. The nutrient concentration which reflects the optimum yield (90-95% of maximum) is referred to as "the critical level" (Munson and Nelson, 1973). This is the basis of diagnostic techniques, because by knowing any growth stage, it is possible to determine the nutritional status of the crop at that particular stage. The critical level for small-grain cereals is 1000 ppm NO_3-N (Papastylianou, 1986).

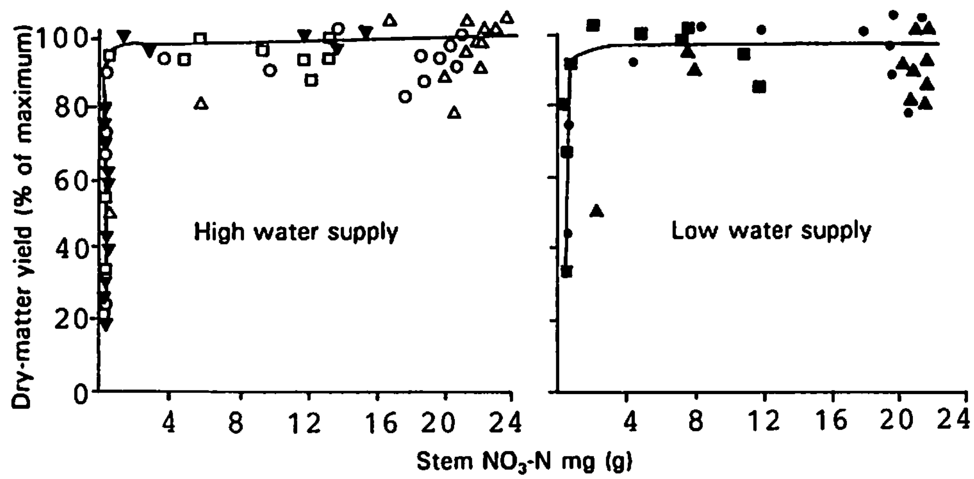

Fig. 1. Growth of wheat as a function of the NO_3-N concentration in stems at two levels of water supply. Growth stages: △ ▲ tillering, ○ ● jointing, and □ ■ anthesis for 1978; ▼ tillering for 1980 (Papastylianou *et al.*, 1982)

Concentration vs Early Stages, Final Yield

It has been shown that NO_3 concentration in plant tissue declines during aging, given any initial supply (Munson and Nelson, 1973; Papastylianou, and Puckridge, 1983). It is important that the nutrient concentration is maintained above the critical level; otherwise, the crop will fall into the deficiency zone with an adverse effect on yield. It is obvious that concentration at the early stages should be sufficiently high that, even with the decline during the season, it remains within the critical level. This is particularly important for crops for which fertilization is only possible at the early growth stages, such as cereals under Mediterranean rainfall conditions.

Concentration at the early stages, which maintains the crop in an optimal nutrition state throughout the season, so that maximum yield is obtained, should be determined through research. Regression analysis of final yield at early NO_3 concentration is one way to determine the optimum level for the early stages (Papastylianou *et al.*, 1984). For crops where fertilization is possible at different growth stages, the optimum nutrient concentration at any stage for maximum final yield can be determined by studies throughout the season(Tyler and Lorenz, 1962; Gardner and Jackson, 1976).

At a field experiment in which wheat was supplied with fertilizer at 0, 20, 40, 60, 80, 100, 150, 200, or 400 kgN/ha, a correlation existed between NO_3 concentration in wheat stems at tillering and subsequent grain yield. At early tillering, NO_3-N values of about 8,000 ppm were indicative of sufficient N in the crop-soil system for maximum grain yield (Fig. 2). Averaging the results of this experiment with those from another seven-field experiment, we conclude that, at tillering, prognostic levels of NO_3-N in stems below 4,000 ppm are considered low; between 4,000 and 6,000 ppm, intermediate; between 6,000 and 10,000 ppm, sufficient; and above 10,000, excessive for maximum grain yield. These values are applicable to a wide range of soil moisture conditions and to a number of cereal genotypes (Papastylianou *et al.*, 1984).

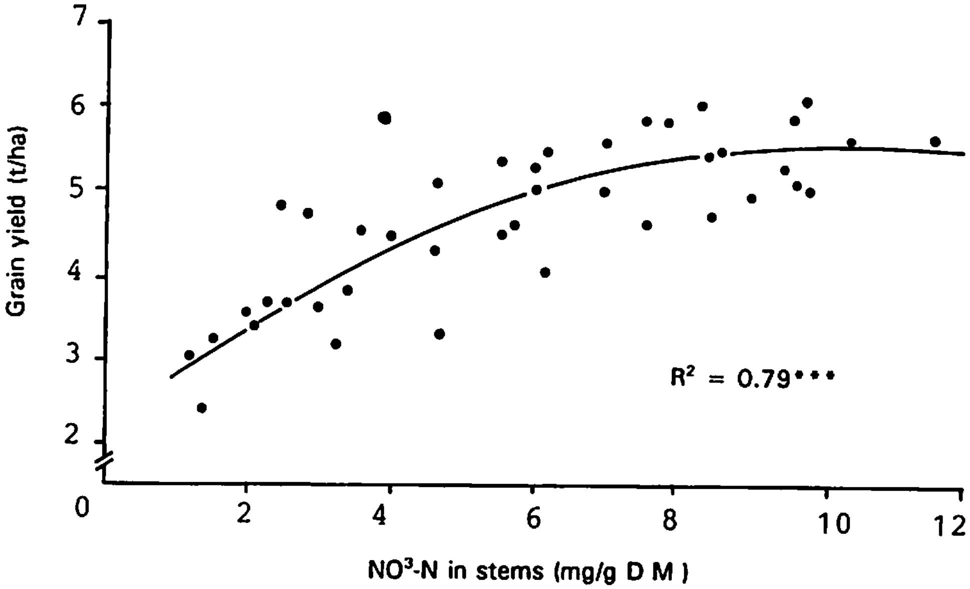

Fig. 2. Relationship between NO_3-N concentration in stems of wheat at tillering (8 weeks after sowing) and grain yield. (Values are means of paired observations from each of 36 plots in four replicates.)

Critical Levels : Species and Cultivars

A literature review (Papastylianou, 1986) revealed that critical NO_3 levels for many species ranged between 1,500 and 2,000 ppm, with only a few exceptions, but the optimum early concentration differed markedly among species. It is therefore important that, for a particular nutrient and a specific crop, critical levels and optimum early concentrations be determined through research. For wheat and barley, species and cultivar did not pause a critical factor, thus general criteria could be used for the N nutrition status (Papastylianou, 1987).

APPLICATION BY FARMERS

The critical level and optimum concentration at early stages will not be of any value if plant tissue analysis is not done immediately. Where possible, the rapid *in situ* test can be of great value, because it enables the farmer to decide whether there is a need for fertilization so he can act on time. Rapid tests have been developed for detecting NO_3 in vegetables (Scaife and Stevens, 1977) and cereals (Elliott *et al.*, 1987; Papastylianou, 1989a).

The "Merckoquant" test strips were found to be a satisfactory method for determining NO_3 in cereal stems, and can be used *in situ* by farmers to predict the N fertilization needed for maximum grain yield. If the NO_3-sensitive area on the test strip is colored to match the standard 500-ppm NO_3 color in less than 30 seconds after the application of sap, this is an indication of adequate N nutrition. If the 500-ppm NO_3 color standard is reached between 30 to 60 seconds, this is an indication of intermediate N nutrition, and fertilization is recommended under favorable weather conditions only. If color development of the test strip for the 500-ppm NO_3 standard takes more than 60 seconds, or the color developed does not reach this standard, this is an indication of deficiency in N nutrition (Papastylianou, 1989a).

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DISCUSSION

A. Avcin

What is the soil test value of mineral N at the critical level of tissue NO_3 content?

I. Papastylianou

It cannot be determined because NO_3 content in the plant is an indirect indication of soil NO_3, and only after all other factors for plant growth have been considered.

A. Gharbi

1) Is NO_3-N in the stem the most adequate N form? Is it correlative with yield? We should know before we establish the critical level.

2) Plant sampling has limitations such as sampling date, plant part, data interprediction...,etc.

I. Papastylianou

1) I studied other forms of N in the plant. NO_3 was found to be the best form for establishing critical levels.

2) That is why I emphasized the need for setting standards for specific time of sampling and specific part of the plant to be sampled.

A. Matar

At ICARDA, we started an experiment on N testing. We had difficulties in getting samples at 1-2 hrs after sunrise.

I. Papastylianou

Sampling can be done later but new standards should be set. However, due to diurnal variation, the later in the day the sampling is set, the less sensitive the method would be.

T.M. Abu-Sharar

The proposed methods do not tell us how much N-fertilizer to apply?

I. Papastylianou

The methods tell how much N to apply only when the plant is deficient in N. Otherwise, the N rate to be recommended should be determined through field experimentation.

F. Mosseddaq

We know that NO_3 reduction may occur either in the roots or leaves. In case of NO_3 reduction in the roots, NO_3 concentration in the upper parts including stems will be lower, but this does not mean that there is N deficiency. However, according to the literature, it seems that for cereals most of the NO_3 reduction is located in the leaves. Could you please elaborate on this subject?

I. Papastylianou

This is a strong reason behind the need to establish standards for a particular species and even cultivar (if necessary), as to consider in what form is N translocated from the soil to the upper parts of the plant.

Nitrogen Fertilization of Cereals: Soil-Plant System Nitrogen Dynamics

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ABSTRACT

A more promising approach for the study of nitrogen fertilization would seem to be to describe the effects of N or its deficiency in terms of the processes that determine crop growth and yield, and to predict on that basis the nutrient requirements for a certain target yield. In this review, the research done on N fertilization and nutrition in Morocco was analyzed to try to describe the processes involved and to come up with some references related to N balance in the soil-plant system. It appears that despite the large amount of work that has been done on the subject, large gaps in the understanding of important basic processes still exist. Interesting contributions of this review are however, the relationships and references generally found for dry-matter accumulation, N uptake, grain yield, and yield component formation as affected by N. The grain yield-N uptake relationship was largely dependent of environmental conditions. Nitrogen-use efficiency, expressed as kg grain produced per kg N taken up was 13 to 32 in Merchouche, 20 in Meknes, and 25 to 31 in the Gharb area. Apparent recovery rates of N fertilizer were low; 50% on the average for seven trials in Merchouche and Meknes, and 65% in the Gharb. Finally, in order to avoid N loss and coincide N applications with plant N requirements, a first application of 40 kg N/ha at floral initiation is sufficient for tillering needs. The remaining, to be applied at the onset of stem elongation, is to be determined according to the crop state at that stage.

INTRODUCTION

Nitrogen must be viewed as the central element in crop production because of its role in substances such as protein and nucleic acids which form living material. As a result of nitrogen's critical roles and low supply, the management of N resources is an extremely important aspect of crop production. Several methods have been developed and used for N fertilizer recommendations. Nitrogen soil test calibration is based on the relationship observed between a soil test (mineral N, NO_3^--N, N availability index) and crop response. Another method is to draw up a balance sheet in which N requirement of the crop is given on the one side and contribution of N fertilizer, soil mineral N, and the amount of N mineralized during the growing period on the other (Hebert, 1969; Meynard, 1983; Machet, 1984). A more refined method of N recommendation is the use of a simulation model that predicts the daily N requirement of a crop and N supply to the crop from various pools during the growing season (Neteeson *et al.*, 1987). Also, according to Greenwood (1982) a promising approach for N fertilizer recommendation would seem to be to describe the effect of N or N deficiency in terms of the processes that determine crop growth and yield, and to predict on that basis the requirements for a target yield. In this endeavor, research in the field of N fertilization and nutrition was reviewed to come up with some of the required relationships and references regarding N dynamics in the soil-plant system.

NITROGEN ON DRY-MATTER PRODUCTION

Dry-matter production is the product of the length of the growing period and the mean rate of dry-matter accumulation during that period.

Length of Growing Period

The phenological development of the plant is governed both by genotype and by environmental factors, notably daylength and temperature. According to Van Keulen *et al.* (1989), N does not have a direct effect on plant phenology, but N deficiency may cause stomatal closure at higher plant water potentials, or a reduction in water uptake by increased root resistance and a consequent reduction in transpiration. The result is higher plant temperature which, in turn, leads to accelerated plant development, i.e., shorter growth periods.

Dry-Matter Accumulation

Nitrogen application rate strongly affects dry-matter production, increasing total dry-matter yield (TDMY) proportionally to the amount of N applied (Fig. 1). However, rates higher than 120 kg N/ha on Nesma did not increase dry-matter production relatively to 120 kg N/ha (Damou, 1983; Maarad and Merzouki, 1985; Hamdaoui and Akodad, 1987). Timing of N application was associated with the magnitude of the response (Fig. 1). Application early in the growing season (up to the onset of stem elongation) induces a larger production of dry matter compared to late N application (Ghazzali, 1988; BelAouja, 1988; Kallida, 1989; Mosseddaq, 1990). Rates of dry-matter accumulation during the linear phase (onset of stem elongation to anthesis) varied from 68 to 290 kg/ha/day. They were, on the average, 150 kg/ha/day in the Gharb area compared with only 35 kg/ha/day from floral initiation up to the onset of stem elongation.

In the Gharb, Ghazzali (1988), BelAouja (1988), and Kallida (1989) found that, throughout the growing season, TDMY was strongly related to total N uptake (Table 1). These results showed that the N present in the plant was strongly correlated with the weight of the plant's aerial parts. Fluctuation in plant growth and development, which caused variation in plant weight, also seemed to cause a change in plant N uptake. This confirms earlier results by Austin *et al.* (1977).

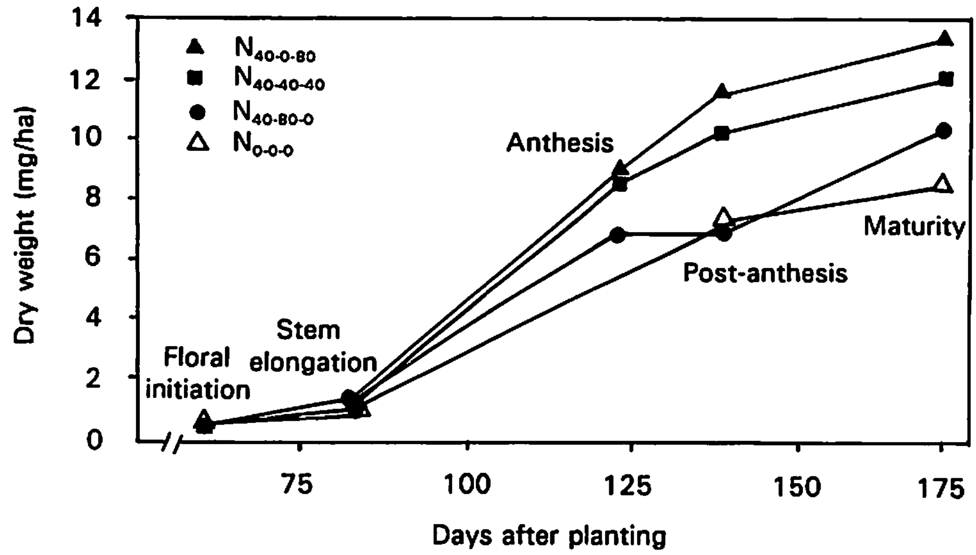

Fig. 1. Total dry-matter yield for Tegyey wheat grown under four N treatments during 1986/87. (Treatment codes indicate N application rates at floral initiation, stem elongation, and anthesis, respectively.)

Table 1. Correlation of total dry-matter yield with N content for two spring wheats according to development stage for two seasons (1986-88).

Season	Variety	FI	Anthesis	Post-anth.	Maturity
1986/87	Nesma	0.60*	0.94***	0.91***	0.94***
	Tegyey	0.94**	0.95***	0.87***	0.91***
1987/88	Nesma	0.94***	0.98***	0.98***	0.97***
	Tegyey	0.93***	0.98***	0.94***	0.90***

*, **, *** significant at the 0.05, 0.01, and 0.001 levels, respectively.
FI = floral initiation.
Post-anth. = 15 and 30 days after anthesis for 1986/87 and 1987/88, respectively.

Kallida (1989) reported that leaf area was affected by N supply; treatments receiving N early in the growing season developed larger leaf area (LA) compared with no or late N application treatments (Table 2). LA was strongly related to N uptake at anthesis (r = 0.9 for Nesma), and to grain yield (r = 0.8), indicating the role of assimilating surfaces in grain production.

Table 2. Leaf area for two field-grown spring wheats under four N treatments during 1987/88.

Variety	N[1]	Boot stage	Anthesis	30 DAA
			(cm²/plant)	
Nesma	$N_{0\text{-}0\text{-}0}$	197	150	75
	$N_{40\text{-}80\text{-}0}$	356	305	110
	$N_{40\text{-}40\text{-}40}$	280	235	110
	$N_{40\text{-}0\text{-}80}$	230	148	143
Mean		266	209	109
Tegyey	$N_{0\text{-}0\text{-}0}$	192	174	131
	$N_{40\text{-}80\text{-}0}$	384	362	168
	$N_{40\text{-}40\text{-}40}$	319	334	176
	$N_{40\text{-}0\text{-}80}$	227	291	125
Mean		280	290	150
LSD (0.05)	N	25	36	26**
	var.	NS	77	26

[1] subscripts added to N treatments indicate N application rates at floral initiation, stem elongation, and anthesis, respectively.

- LSD = value for comparison of interaction means.
- DAA = days after anthesis.

NITROGEN CONCENTRATION

Nitrogen uptake is dependent both on the demand by the plant and the availability of N in the soil. As more structural carbohydrate is accumulated, the ratio of N to total biomass in each of the plant parts declines, even with the availability of excess N. N concentration for the whole plant decreased progressively with an advance in development stage from, on the average, 45.2 at floral initiation to 13.0 g/kg at maturity for the 1987 and 1988 growing seasons in the Gharb area. The effect on N content as a proportion of dry matter was generally highly significant, increasing plant N concentration proportionally to the amount of N applied early in the growing season (Mosseddaq, 1980; Ghazzali, 1988; BelAouja, 1988; Mosseddaq, 1990). Nitrogen concentration in the leaves declined from 14.3 at anthesis to 7.5 g/kg at maturity; the corresponding figures in the stems were 12.7 and 5.5 g/kg, respectively.

Nitrogen concentration in wheat grains varies roughly between 14 and 35 g/kg. For a large part, this variation is caused by environmental influences (Kaddouri, 1978; Mosseddaq, 1980; Hamdaoui and Akodad, 1987; Mosseddaq, 1990). Grain N concentration (GNC) at maturity was 16.5 for the control and 24.5 for the 120 kg N/ha treatment, indicating the favorable effect of N on GNC (Mosseddaq, 1990). Late applications of N mainly improves GNC (Ghazzali, 1988; BelAouja, 1988;

Kallida, 1989; Oulmaati, 1990 Mosseddaq, 1990). Compared with the GNC observed elsewhere (Kramer, 1979; Hucklesby *et al.*, 1971; Rao *et al.*, 1977; Cox *et al.*, 1985), the GNC observed under Moroccan conditions (Meknes, Merchouche, as well as the Gharb area) falls within the rather high range. The limitation of synthesis and/or transport of carbohydrates into the grain by adverse environmental conditions does not seem to operate on the entry of N into the grain. This agrees with earlier results reported by Barlow *et al.* (1983) and Donovan *et al.* (1983). The result is a low dilution of grain N. Ghazzali (1988) and BelAouja (1988) confirmed the favorable effect of late N application; GNC varied from 25 to 36 g/kg following application of N at anthesis.

NITROGEN UPTAKE

Emergence--Floral Initiation

During this period, N uptake is generally low but largely dependent on the environmental conditions. In the Gharb area (1986/87 growing season), N uptake by wheat during this period was 12 to 15 kg N/ha (Ghazzali, 1988; BelAouja, 1988), while in Meknes it reached 30 kg N/ha according to Maarad and Merzouki (1985) and 35 kg/ha according to Hamdaoui and Akodad (1987). It appears thus that N requirement during this period is quite low and can be satisfied from soil-N. Therefore, N application at planting is not necessary.

Floral Initiation--Onset of Stem Elongation

The largest amount of N uptake (120 kg N/ha) during this period was observed in Merchouche for a rainy growing season and for a soil initially rich in N (Kaddouri, 1978). In the same area, Rachad (1979) observed N uptake of only 30 kg/ha because of drought early in the growing season. The corresponding value was 90 kg/ha for Mosseddaq (1980) and Mnaili (1981). Uptake during this period is thus dependent on environmental conditions, and is higher for early planting.

Onset of Stem Elongation--Anthesis

This period corresponds to the linear phase of N uptake. Daily rate of N accumulation, reported from Meknes, varied between 1.5 and 2.7 Kg N/ha (Fadel and Nam, 1980; Zaoui and Alami, 1984; Hamdaoui and Akodad, 1987). In Merchouche, the rates observed were 1.25 (Rachad, 1979), 2.3 (Mosseddaq, 1980), and 3.4 kg N/ha (Kaddouri, 1978). Under arid conditions, rate of N accumulation is lower remaining below 1 kg/ha/day (El Haouta, 1980). Similar values (2-2.5 kg N/ha/day) were reported from France (Hebert, 1969; Machet, 1984).

Anthesis--Maturity

The few studies where the postanthesis phase was surveyed showed that N uptake continued during this period. Maximum N accumulation was observed at the dough stage in Meknes (Benaouda and Sadak, 1986). In the Gharb area, N uptake reached up to 15 DAA (Ghazzali, 1988), up to 30 DAA (Kallida, 1989), and even up to maturity (BelAouja, 1988).

NITROGEN DISTRIBUTION IN PLANTS

The nitrogen taken up by the plant is partitioned between leaves, stems, roots, and grains in proportion to their relative demand. Average leaf- and stem-N at anthesis represented, respectively, 30 and 42% of total plant-N in the Gharb area (Mosseddaq, 1990). As the leaves age, some of their N can be transferred to other tissues where some unsatisfied demand for N exists. In 1987, N content in leaves and stems of Nesma wheat decreased from 42.5 and 61.2 kg/ha, respectively, at anthesis to 23.7 and 20.2 kg/ha at maturity, indicating N remobilization to the developing grains (Mosseddaq, 1990).

YIELD COMPONENTS

Formation of yield components, i.e., tillers, ears, spikelets, florets, and grains is governed by the assimilate supply necessary to create a viable organ. The effect of N status of the vegetation on yield component formation is thus mediated largely through its effect on gross assimilation. However, tiller formation is directly affected by the N status of the plant as well as by assimilate availability (Yoshida and Hayakawa, 1970).

Grain yield can be broken down into its two main components. Kernel number/m^2 (KN/m^2) and kernel weight (KW). A large part of grain variation can be associated to change of KN/m^2, $r = 0.92$ in Meknes (Fadel and Nam, 1980) and 0.79 in the Gharb (Mosseddaq, 1990). Kernel number/m^2 is a function of tiller number per unit area which was increased by early application of N. During the 1986/87 and 1987/88 growing seasons, the control treatments with no N application produced fewer tillers than did the other N treatments which all received 40 kg N/ha at floral initiation. A rate of 40 to 50 kg N/ha seems to be sufficient for the tillering phase (Rachad, 1979; Mosseddaq, 1980; Mnaili, 1981). This agrees with earlier results by Hebert (1969) and Spiertz *et al.* (1984). Under arid conditions, El Haouta (1980) estimated the need for this phase to be 30 kg N/ha. Furthermore, NK/m^2 is largely dependant on TDMY at the onset of stem elongation. On the average, correlation coefficients between these two variables were 0.75 and 0.63, respectively, in Merchouche and in the Gharb. Early application of N had a positive effect on spikelet number per spike (Ghazzali, 1988; BelAouja, 1988), and spike fertility was increased by N application at the onset of stem elongation (Mosseddaq, 1990).

Early N application had a negative effect on kernel weight, thus confirming earlier work by Gardner and Jackson (1976), and Bruckner and Morey (1988). Less or no N applied early in the growing season resulted in fewer grains per unit area and, thus, less competition for assimilates among kernels. However, late application of N significantly increased kernel size over that of early application (Mosseddaq, 1990). This agrees with earlier results by Mc Neal *et al.* (1972), Evans *et al.* (1975), and Spiertz *et al.* (1984).

YIELD, UPTAKE: APPLICATION RELATIONS

Yield--Uptake

Research undertaken in different areas of Morocco showed large variability of nitrogen use efficiency (NUE), expressed as kg grain produced per kg N taken up depending on environmental conditions. On the average, only 16.5 kg of grain were produced in Merchouche for each kg of N taken up (Kaddouri, 1978; Rachad, 1979; Mosseddaq, 1980; Mnaili, 1981), 20 in Meknes (Zaoui and Alami, 1984), and 30 in the Gharb (Mosseddaq, 1990). The effectiveness of N utilization was greater for the control in the Gharb, clearly indicating that, under field conditions, N application did not increase grain yield at the same rate it did for N accumulation. The efficiency of N utilization seems to be rather low under Moroccan conditions compared with 33 kg grain/kg N absorbed, reported by Hebert (1969) and Machet (1984) in France, and 55 kg grain/kg N taken up, reported by Van Keulen *et al.* (1989) at low uptake rates. At increasing uptake rates, N concentration in the harvest product increases and NUE declines (Fig. 2). Finally, a plateau level is reached, where increased uptake does not lead to higher yields, because N is no longer the growth-determining factor.

Uptake--Application Rate

Nitrogen uptake was proportional to N application over the full range of application rates (Fig. 2). The recovery fraction of N fertilizer, i.e., the ratio

$$\frac{Npf - Np0}{Nf} * 100$$

Npf = N uptake (kg/ha) of a fertilized plot.
Np0 = N uptake (kg/ha) of the control.
Nf = amount (kg/ha) of N applied.

is quite variable. In Merchouche, values of 44 to 92.3% were observed (Kaddouri, 1978; Rachad, 1979; Mosseddaq, 1980; Mnaili, 1981), while in the Gharb the average

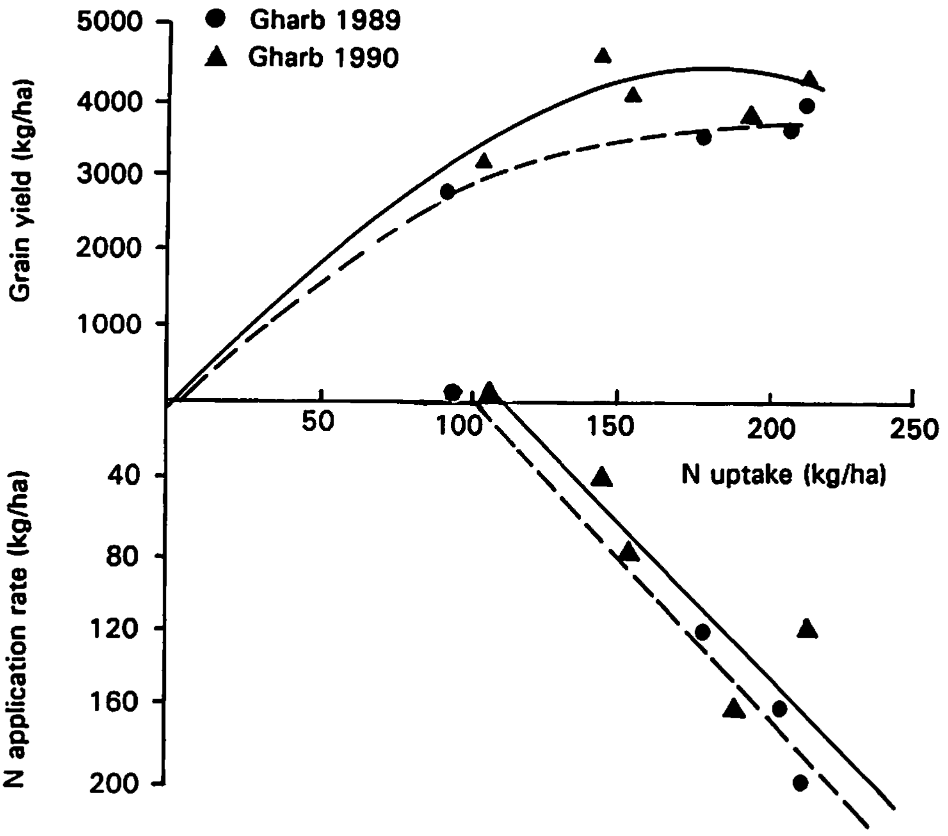

Fig. 2. Relation between N uptake and grain yield, and between N application and N uptake for a spring wheat crop (Tegyey 32).

was 65% (Ghazzali, 1988; BelAouja, 1988; Kallida, 1989; Oulmaati, 1990). This agrees with the findings of Harmsen (1986) who found that from 172 experiments conducted by ICARDA, 50% of the recovery fraction of N fertilizer were between 25 and 45%, whereas 75% were between 20 and 60% with an average of 43.8%.

CONCLUSIONS

Despite the large amount of work that has been done on the subject, N fertilizer recommendations are not yet mastered, and large gaps in the understanding of important basic processes still exist. Systems analysis in which an attempt is made to put things together, would seem to be an important research tool to fill the gaps, and may help formulate goals for future research. Nitrogen use efficiency is intimately related to carbon metabolism and partitioning; leaf area and tillering responses to N are important since they result in increased source and sink capacities. Remobilization of N also seems to be of great importance. At the crop level, environmental conditions have a strong impact on N use efficiency.

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DISCUSSION

J. Ryan

Your data show that higher N rates increase grain protein. However, is there any means for rewarding the farmer for producing higher quality grain?

F. Mosseddaq

No, not in Morocco. Grain yield is more of a problem than grain protein. Our emphasis here was research, to assess the effect of late N application on grain and protein yields.

A. Matar

As far as grain exports are concerned, quality is important in international markets as far as grain exports are concerned. Italy, for example, insists on a minimum of 12% protein for durum wheat.

K. El Mejahed

Nitrate in the 0-60 cm profile depends on the nitrate in the upper 0-20 cm, therefore high correlation (r) is expected between NO_3 of the 0-20 cm and that of the 0-60 cm. In order to estimate NO_3 in the 0-60 cm would it not be better to predict NO_3 in the 20-40 cm instead of the 0-20 cm profile?

F. Mosseddaq

I see what you are saying, dependency between the two variables: NO_3 for the 0-20 cm and NO_3 for the 0-60 cm, but we wanted to predict the whole profile not only the 20-60 cm from the upper horizon.

Fertilization of Cereals: Soil-Nitrogen Test Calibration in Morocco's Gharb Area

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ABSTRACT

Information about wheat growth and development in relation to N fertilizer has implications for rate and timing of N applications to prevent deficiency. This study analyzed grain-yield production in relation to fertilizer and soil N to determine the appropriate soil-N test for N fertilizer recommendations. Six (1988/1989) and four (1989/1990) trials were conducted in the Gharb area taking into account various environmental conditions, cropping systems, and soil types. The spring wheat Tegyey 32 was treated with 0, 120, 160, and 200 kg N/ha in 1989 and 0, 40, 80, 120, and 160 kg N/ha in 1990. Measured traits were dry-matter production, yield and grain yield components, and N uptake. Soil moisture and mineral N content were also determined. Measurements were performed at floral initiation, onset of stem elongation, anthesis, and maturity. Grain yield was low with a highly significant effect of N. No significant difference was observed among treatments receiving N in 1989; while in 1990, different optima were observed depending on the location. Grain yield was largely determined by kernel number per unit area (R^2 = 0.78 in 1989; R^2 = 0.85 in 1990). Nitrogen uptake was low because of the low dry-matter production. Treatments receiving N absorbed similar amounts of N, but significantly more than did the control with no N application. Grain N was proportional to the amount of applied N. Nitrate N (1990) and N availability index (1989 and 1990), determined by the anaerobic incubation method, seemed to provide good estimation for some agronomic traits such as total dry-matter, grain, and N yields.

INTRODUCTION

Bread wheat (*Triticum aestivum* L) is grown in Morocco on approximately 20% of the land cropped to cereals, which occupies 67% of the total cropped area. Thus improvement of bread wheat productivity constitutes a large potential for increased economic returns to Moroccan farmers.

Nitrogen management is critical to economical wheat production, and efficient use of N is necessary for major enhancement of productivity and profitability of wheat. Usually it is the amount of available N that limits wheat and other cereal yields. Nitrogen availability depends on soil type and several other plant factors, including previous crop, moisture, temperature, soil pH, and the amount of organic matter. Furthermore, both excessive and inadequate N availability can be detrimental to plant growth. Therefore, developing accurate methods for predicting N needs for cereal crops constitutes an important concern for efficient cereal production. An accurate soil test is the step in determining an economically sound N management program. The soil test will provide basic information a researcher needs to help project the amount of N fertilizer required.

The present study analyzed wheat grain-yield production in relation to fertilizer and soil N to determine the appropriate soil test for N fertilizer recommendations.

MATERIALS AND METHODS

Spring wheat (Tegyey 32) was grown in field plots in the Gharb area (Allal Tazi, Souk Tlat, and Souk Larba) during the 1988/89 and 1989/90 growing seasons. Six on-farm trials were conducted in 1989 and four in 1990 to take into account different previous crops and soil types. The locations for both seasons are presented in Table 1. Soil characteristics are given in Table 2. The seeding rate was calculated based on seed size in an attempt to obtain a final plant population of 250 plants/m^2 with a 20-cm row spacing. The rate was about 140 kg/ha, which is commonly used in the area. Plot size was 10 x 6 m in 1988/89 and 15 x 7 m in 1989/90. Blocks were separated by a 4-m alley. Treatments consisted of 0, 120, 160, and 200 kg N/ha in the first growing season and 0, 40, 80, 120, and 160 kg N/ha in the second (Table 3). Nitrogen fertilizer in the form of ammonium nitrate (33.5%) was applied. The experimental design was a randomized complete block with four replications.

Wheat Growth

Plants were harvested from two stations for each plot at selected stages during the growing season for dry weight determination. A station consisted of two 50-cm

Table 1. On-farm trial details for the 1988/89 and 1989/90 growing seasons.

Season	Location	Previous crop	Soil type	Planting date
1988/89	1. Souk Larbaa	Wheat	Vertisol	13-12-88
	2. Souk Larbaa	Sunflower	Vertisol	09-12-88
	3. Souk Larbaa	Wheat	Vertisol	10-12-88
	4. Allal Tazi	Wheat	Inceptisol	14-12-88
	5. Souk Tlat	Sugarbeet	Inceptisol	15-12-88
	6. Souk Larbaa	Melon	Vertisol	22-12-88
1989/90	1. Allal Tazi	Wheat	Inceptisol	25-12-89
	2. Souk Larbaa	Sugarbeet	Vertisol	16-12-89
	3. Souk Larbaa	Clover	Vertisol	14-11-89
	4. Souk Larbaa	Oat	Vertisol	14-11-89

Table 2. Soil characteristics of the on-farm trials for the 1988/89 and 1989/90 growing seasons.

Season	Sample[1]	S	L	C	N	P_2O_5	K_2O	FC	WP
	depth (cm)	-------	(%)	-------	(g/kg)	-- (ppm)	--	---- (%)	----
1988/89	0-20	6.1	37.5	56.4	0.71	5.4	179.4	30.3	15.3
1	20-40	6.1	36.4	57.5	0.65	1.9	167.7	30.9	16.2
	40-60	7.0	35.4	57.5	0.77	1.8	300.3	32.9	14.8
	0-20	4.9	39.2	55.9	0.93	4.3	347.1	33.9	15.1
2	20-40	5.6	35.7	58.7	0.92	3.5	335.4	37.3	19.4
	40-60	4.5	33.1	62.4	0.86	6.9	347.1	37.4	17.2
	0-20	6.0	38.7	55.3	0.69	6.7	327.6	34.1	16.5
3	20-40	5.5	36.0	58.6	0.69	4.9	296.4	35.6	16.5
	40-60	4.6	30.8	64.6	0.78	4.8	269.1	35.5	16.3
	0-20	2.6	47.2	50.2	1.79	18.8	456.3	27.6	14.3
4	20-40	1.3	47.1	51.6	1.37	3.9	179.4	28.4	15.2
	40-60	1.5	50.1	48.4	1.32	4.9	241.8	30.9	16.2
	0-20	15.2	49.3	35.6	1.04	8.5	249.6	22.4	10.7
5	20-40	11.1	59.2	29.7	0.60	1.8	66.3	22.3	11.3
	40-60	-	-	-	0.40	1.9	58.5	21.2	11.4
	0-20	6.5	38.1	55.4	0.67	10.8	202.8	34.7	19.5
6	20-40	6.6	34.8	58.6	0.55	5.1	347.1	36.4	19.4
	40-60	6.2	42.4	51.4	0.65	5.1	284.7	36.1	19.1
1989/90	0-20	5.4	56.8	35.1	0.79	6.3	326.0	29.3	13.3
1	20-40	4.6	53.2	38.1	0.54	7.2	231.0	27.7	14.5
	40-60	5.1	50.9	42.5	0.60	6.3	393.0	29.5	15.2
	0-20	5.4	39.3	53.0	1.32	10.1	405.0	36.4	16.2
2	20-40	5.6	37.3	56.8	1.09	9.4	343.0	34.2	16.3
	40-60	6.2	35.8	55.2	0.98	7.5	295.0	35.6	16.2
	0-20	5.4	37.8	52.7	0.93	9.2	238.0	37.9	15.8
3	20-40	5.6	35.3	55.9	0.78	8.5	295.0	35.9	16.3
	40-60	5.2	33.3	58.5	0.76	8.4	263.0	36.3	16.2
	0-20	5.3	37.5	55.7	0.63	6.8	330.0	34.2	15.6
4	20-40	5.7	33.1	59.9	0.66	7.2	272.0	34.5	15.9
	40-60	5.5	34.0	53.4	0.70	6.4	299.0	35.0	16.2

[1] For locations see Table 1.

S = sand; L = loam; C = clay; N = total N (g/kg);

FC = water holding at field capacity; WP = wilting point.

sections of row, i.e., an area of 0.2 m^2. Sampling dates were floral initiation, onset of stem elongation, anthesis, and maturity. Plant samples were dried to constant weight at 70°C for 48 hours and weighed.

Table 3. Rate and timing of N application for the 1988/89 and 1989/90 growing seasons.

Season	N rate	Floral initiation	Onset of stem elongation	Total
		(kg/ha)		
1988/89	N_1	0	0	0
	N_2	40	80	120
	N_3	40	120	160
	N_4	40	160	200
1989/90	N_1	0	0	0
	N_2	40	0	40
	N_3	40	40	80
	N_4	40	80	120
	N_5	40	120	160

Nitrogen Uptake

Dry weight samples were ground and digested for total N using the Kjeldahl method for digestion and steam distillation for determination (Bremner and Mulvaney, 1982). Sampling dates were the same as for dry-matter measurement.

Yields and Grain Yield Components

Plant density was determined two weeks after emergence at three stations for each treatment and each replication. Tillers were counted on dry weight samples at the onset of stem elongation, and ears, at anthesis. An area of 2 m^2 was harvested at maturity to determine total biomass, grain yield, and yield components. Total and grain yields were measured on the whole plot while number of spikelets (potential and sterile), number of grains per spike and kernel weight were determined on 30 spikes from this plot.

Soil Water and Nitrogen

Soil moisture was determined by gravimetry before planting, as well as at floral initiation, onset of stem elongation, anthesis, and maturity. Core samples were obtained at 20-cm increments to a depth of 60 cm. Soil mineral N was determined by the distillation method (Bremner, 1965) using the same samples as for soil moisture and the same sampling dates. In 1989/90, ammonium and nitrate N were analyzed separately before planting. Nitrogen availability index for soil samples before planting was determined in both seasons, using the anaerobic method (Keeney, 1982).

Data Analysis

Statistical procedures and interpretation were based on standard methods outlined by Steel and Torrie (1980) and Gomez and Gomez (1984). Analysis of Variance was performed for all measured variables and linear correlation analysis was used to evaluate relationships among the dependent variables.

Environmental Conditions

Climate

Mean temperature and precipitation per 10-day period are provided (for Souk Tlat, which is halfway between Allal Tazi and Souk Larbaa) to characterize and compare the two growing seasons (Figs. 1 and 2). Seasonal accumulated precipitation was 556 mm in 1988/89 and 570 in 1989/90. An important feature of the rainfall pattern in this Mediterranean environment is its irregularity during the growing season. Thirty percent of the seasonal precipitation was concentrated in Nov. 1988/89 was, while in 1989/90, 70% of the seasonal total was received in Nov., Dec., and Jan. Except for Dec. (1988/89) and February (1989/90), which were dry, rainfall was distributed during the whole growing season. Souk Tlat received in the first growing season 57 mm less rainfall than Allal Tazi but 55 mm more than Souk Larbaa. In the second growing season, it received 62 and 7 mm less than Allal Tazi and Souk Larbaa, respectively. Cooler temperature predominated during the 1989/90 growing season.

Soil Water

No water limitation was observed in either seasons (data not shown). A dryer profile was observed at maturity because of no rainfall and greater ET at the end of the growing season.

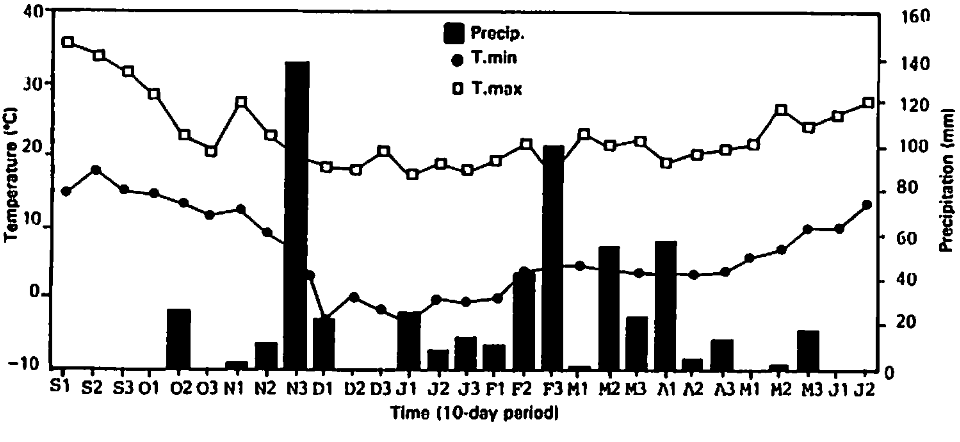

Fig. 1. Precipitation, minimum, and maximum temperature per 10-day period at Souk Tlat, 1988/89.

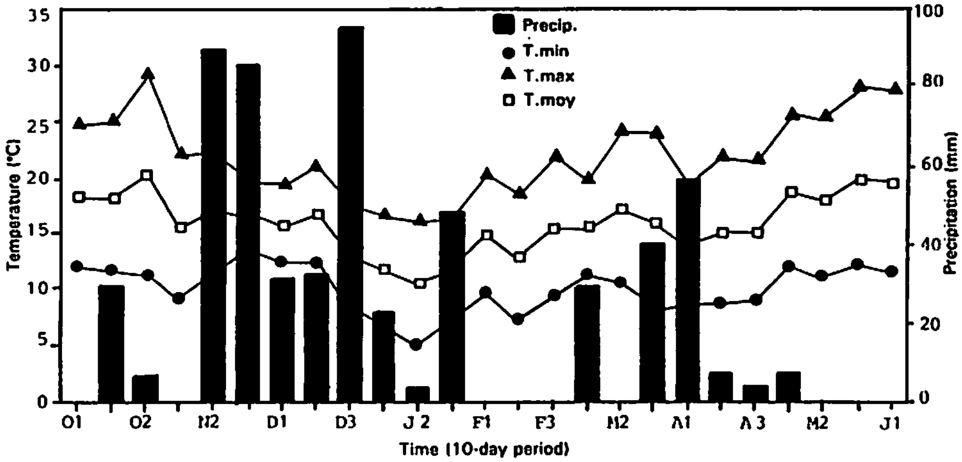

Fig. 2. Precipitation, minimum, and maximum temperature per 10-day period at Souk Tlat, 1989/90.

Soil Residual N

Average soil residual N was 77 kg N/ha in 1988/89 and 100 kg N/ha in 1989/90 for the whole profile (0-60 cm). It was different among locations (Table 4) mainly because of the previous crop. The lowest values were observed for cereals as previous crop in both seasons. In 1989/90, when NO_3^-- N and NH_4^+-N were separated, NH_4^+ - N was found to be surprisingly high compared to NO_3^- - N probably because of the excess soil water at sampling which may inactivate the nitrifying microorganisms.

Table 4. Soil mineral N and average N availability index (NAI), 1988-90.

	1988/89		1989/90			
Location	Min. N (kg/ha)	NAI (ppm)	Location	Min. N	NO_3-N	NAI (ppm)
				-------- (kg/ha) ---------		
1	28.3	10.6	1	98.4	24.4	16.9
2	104.4	23.8	2	122.7	34.7	29.6
3	64.4	21.3	3	111.9	34.2	26.8
4	64.9	44.9	4	84.3	26.5	23.0
5	105.3	30.9				
6	97.9	28.9				

Sampling depth = 0 to 60 cm.

Average availability index for the 0-20, 20-40, and 40-60 cm horizons varied from 11 to 45 ppm in 1988/89 and from 16 to 30 ppm in 1989/90. While this index varied in 1989/90 in the same way soil residual N did (Table 4), no special trend in relation to soil type and previous crop was observed in 1988/89.

RESULTS AND DISCUSSION

Wheat Growth vs. N Fertilizer

Dry-Matter Production

In 1988/89, the only significant difference observed in response to N treatment occurred from the onset of stem elongation up to maturity between the control and the other N treatments (Fig. 3). No significant difference was observed between the 120, 160, and 200 kg N/ha treatments, mainly because dry-matter production was limited by other factors such as infestation by weeds. In 1989/90, the 80 kg N/ha treatment was not high enough as to induce a significantly different response than the control except at maturity (Fig. 4). While the 120 and 160 kg N/ha treatments produced more dry matter than did the control and the 80 kg N/ha treatment both at anthesis and maturity. Average total dry-matter yield (TDMY) at maturity over all locations and N treatments was 8520 in 1988/89 and 7480 kg/ha in 1989/90.

Nitrogen Uptake

Nitrogen uptake (TDMY x N concentration) had a similar trend to that of dry-matter production during both seasons, indicating rather constant plant N concentration compared with dry-matter variation in response to N. However, in 1989/90, the 80 kg

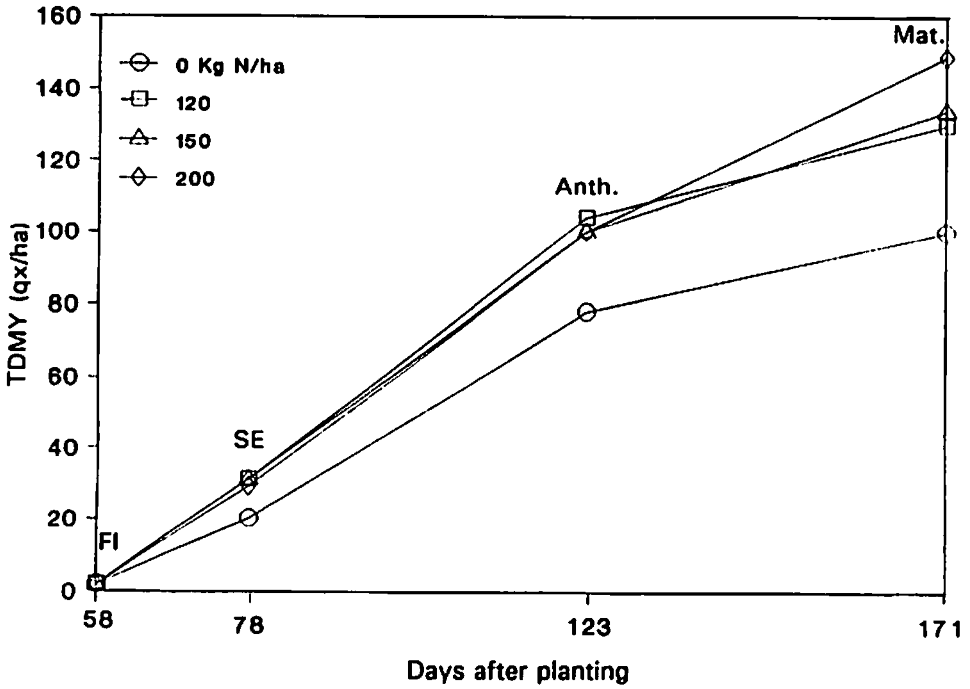

Fig. 3. Total dry-matter yield for Tegyey wheat grown under four N treatments at Allal Tazi, 1988/89.

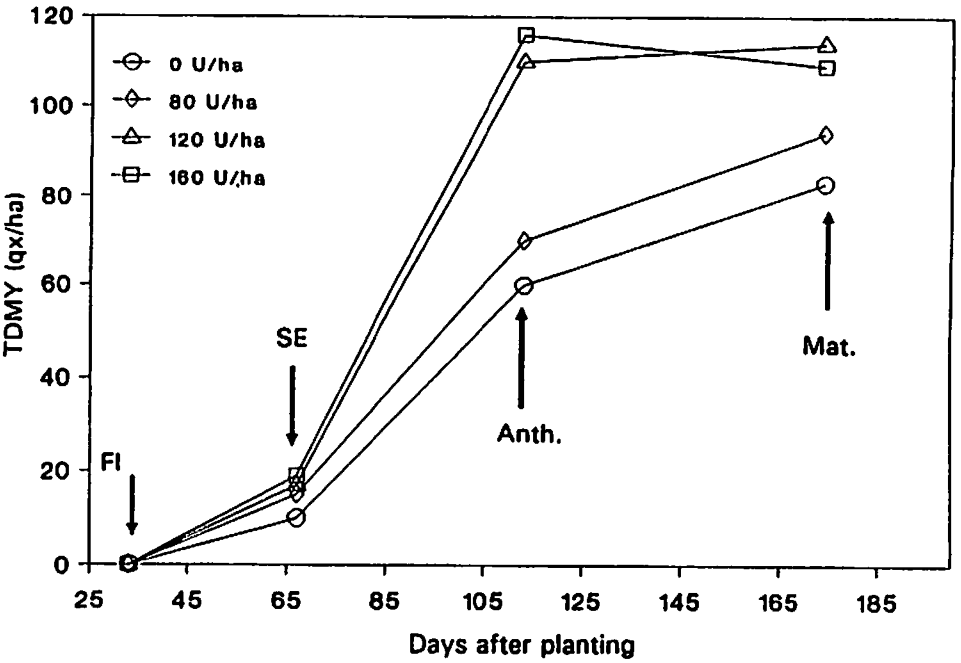

Fig. 4. Total dry-matter yield for Tegyey wheat grown under four N treatments at Souk Larbaa, 1989/90.

N/ha treatment enhanced plant N concentration and induced a larger N content compared with the control, despite the similarity in TDMY between these two treatments (Table 5). This agrees with the significant correlations observed between TDMY and N uptake for all development stages; the correlation coefficient at maturity was 0.93** for both seasons.

Grain Yield

Grain yield can be divided into two main components, i.e., kernel number/m^2

Table 5. Total dry-matter yield (TDMY) and N uptake (kg/ha) for the 1988/89 and 1989/90 growing seasons (averaged over locations).

1988/89			1989/90		
N	TDMY	N uptake	N	TDMY	N uptake
0	6630	65.6	0	6470	63.5
120	9540	127.1	40	7200	103.8
160	8950	128.8	80	7450	114.5
200	8950	132.2	120	8190	143.3
			160	8080	140.7

(KN/m^2) and kernel weight (KW). Kernel number/m^2 was low both in 1988/89 and 1989/90 (Table 6), compared with what was reported earlier (15000 KN/m^2) for the same area (Mosseddaq, 1990). Nitrogen application positively affected KN/m^2, the maximum was observed for 120 kg N/ha. In 1988/89, no significant increase in KN/m^2 was observed for rates higher than 120, while in 1989/90 the 160 kg N/ha rate had a negative effect on kernel number, probably because of the lodging observed in this case. Kernel number/m^2 is a function of spike number/m^2 (Nsp/m^2) and kernel number per spike (KN/sp). In both seasons, Nsp/m^2 was low because of the low plant population obtained (150 and 170 plants/m^2, respectively), which in turn was attributed to dry conditions after planting in Dec 1988/89 and excess water in 1989/90. Waterlogging, which was also observed in 1988/89 after emergence, explained, for both seasons, the lack of increase in Nsp/m^2 resulting from low plant population. Another result of waterlogging was the low number of spikelets per spike which, in turn, lead to low KN/sp (data not reported).

Table 6. Yields and main grain yield components averaged over locations for 1988/89 and 1989/90.

Season	N	Grain	Straw	HI	KN/m^2	KW
		------- (100 kg/ha)	-----	(%)		(g)
1988/89	0	19.5b	34.8c	36.0a	6523b	39.4a
	120	26.9a	50.1a	34.5b	9846a	36.5b
	160	25.4a	47.8b	34.3b	9114a	36.9b
	200	25.4a	47.4b	34.7b	9356a	35.8b
1989/90	0	16.7e	40.7d	27.8d	5364e	40.1b
	40	29.1b	59.4c	32.0a	8258c	41.9a
	80	27.2c	61.4b	30.8b	8442b	39.5c
	120	31.0a	66.8a	31.6ab	9961a	38.5d
	160	25.4d	58.6c	29.3c	8157c	36.8e

HI = harvest index; KW = kernel weight; KN = kernel number.

Nitrogen application had a positive effect on spike fertility, supporting earlier results reported by Masle-Meynard (1980). In addition to the small sink size (KN/m^2) observed in both seasons, grain filling was affected by weed competition also in both seasons and by lodging in the 1989/90 season, the result of which was small grains. Kernel size was negatively affected by N, mainly because of competition among kernels for treatments receiving N compared with the controls which had fewer K/m^2. Grain yield was significantly influenced by KN/m^2; correlation coefficients were 0.86^{***} and 0.83^{***}, for 1988/89 and 1989/90, respectively.

Soil Test vs. Crop Response

Mineral N

No significant correlation was observed in either season between crop response for the different crop components, i.e., TDMY, grain yield, N uptake, and soil residual N. This disagrees with the findings of Soper *et al.* (1971) and Giles *et al.* (1975). It seems, thus, that mineral N at the beginning of the growing season cannot be used as a prediction criterion for crop response on plots with no N application, i.e., as an index of soil natural fertility. This lack of correlation may either be related to differences in sampling date (relative to date of first rainfall) which induce differences in proportions of $NH_4{}^+$-N, or to the form analyzed ($NH_4{}^+$ + $NO_3{}^+$). Harmsen (1986) reported that $NH_4{}^+$-N do not affect plant N needs in Syria, and Matar *et al.* (1988) found that the addition of $NH_4{}^+$-N changed the critical level but did not improve the correlation with $NO_3{}^-$ - N.

Nitrate N

Correlation between crop response for the controls and soil initial $NO_3{}^-$-N was calculated for 1989/90 only. TDMY, grain yield, and N uptake were all highly related to $NO_3{}^-$-N (Table 7), indicating that nitrate constitutes a good estimator of crop response to N. This agrees with earlier results by Hergert (1987). However, the number of observations is limited here and further research is needed to confirm this relationship.

Table 7. Correlation (5%) between $NO_3{}^-$ N and crop response for 1989/90.

Dependant variable	Intercept	Slope	Correlation coefficient
TDMY	-1.19	2.16	0.97***
Grain yield	-33.94	1.70	0.94**
N uptake	-50.69	3.98	0.95***

Nitrogen Availability Index

Nitrogen availability index (NAI) significantly influenced crop response to N during both growing seasons. Large proportions of the variability of agronomic traits such as TDMY, grain yield, and N uptake were associated with variations in this index (Table 8). NAI is more of a soil characteristic, and provides more information than would an instantaneous measure of soil mineral or $NO_3{}^-$-N. However, determination of NAI by the anaerobic method (Keeney, 1982) is time-consuming, and may not be convenient for a nitrogen management program. For that purpose, a rapid chemical method would of great interest.

Sampling Depth

For large-scale application, the practicability of a soil test is very important. The right sampling depth is an element of this practicability, since it is tedious and time-

Table 8. Correlation (5%) between N availability index and crop response for 1988/89 and 1989/90.

Season	Dependent variable	Intercept	Slope	Correlation coefficient
1988/89	TDMY	8.77	1.96	0.99***
	Grain yield	4.30	0.57	0.89**
	N uptake	10.99	2.05	0.97***
1989/90	TDMY	2.23	12.28	0.93***
	Grain yield	-25.61	1.85	0.95***
	N uptake	-23.11	4.00	0.89***
Combined years	TDMY	-3.24	0.46	0.96***
	Grain yield	8.91	0.87	0.80**
	N uptake	1.38	0.35	0.87***

consuming to sample the whole rooting profile. Soil was sampled to a depth of 60 cm, at 20 cm increments. In 1988/89 as well as 1989/90, results in the upper horizon were found to be related to the total (Nmin, NO_3^--N) or the average (NAI) of the whole profile:

1989 Nmin 0-60 = 5.75 + 2.64 x Nmin 0-20 r = 0.86 *

NAI 0-60 = 8.45 + 0.93 NAI 0-20 r = 0.91 ***

1990 NO_3^- 0-60 = 2.66 + 1.04 NO_3^- 0-20 r = 0.99 ***

NAI 0-60 = 4.61 + 0.714 NAI 0-20 r = 0.97 ***

It seems, therefore, possible to limit soil sampling to the upper horizon without actually losing much information.

CONCLUSIONS

The wheat plant responded positively to N fertilizer. No further increase in grain yield was observed for rates higher than 120 kg N/ha because of lodging and infestation by weeds. The relationships between nitrate N and NAI on the one hand and crop response on the other were predictable, whereas mineral N values did not correlate to agronomic traits (TDMY, grain yield, and N uptake). Soil test results for the upper horizon (0-20 cm) were significantly related to the total or average result of the whole profile (0-60 cm).

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DISCUSSION

A. Matar

1) Can you recommend N fertilization at anthesis without depressing yields?

2) It is interesting to see that late N application increases N grain content and quality.

F. Mosseddaq

Yes, this is what we found, but we cannot recommend late N application for cereals in the semiarid areas. The Gharb area where we conducted the experiment is quite humid. In our experiments we found that N application at anthesis mainly increased grain protein and sometimes, under favorable grain-filling conditions, yield. However, under semiarid conditions, it is not a question of applying N at anthesis, mainly because recommending N application at anthesis depends on several factors including:

- Farmer's objective (grain yield or grain quality)
- Economical aspect (considerations).

A. Haddad

It is just a question about the effectiveness of using the 0-20 cm layer only for sampling.

F. Mosseddaq

Under the Mediterranean conditions the high temperatures in the summer intensify the evapotranspiration that lift up, through capillarity, N to the upper layers. Moreover, the top layer is more aerated for a better activity of the aerobic microorganisms. Since soil samples are taken at preseeding and probably before the first rainfall, the 0-20 cm layer could be adequate for sampling.

A. Abdelmalek

In semiarid regions, we limit soil sampling to 0-60 cm depth because of low rainfall and the fact that most of the nitrates stay within the 60 cm layer. Do you think that it is the same in the Gharb area (higher rainfall) and probably higher leaching beyond the 60 cm?

F. Mosseddaq

We limited our soil sampling to 0-60 cm because most of the N and of the rooting system are concentrated in the upper 0-20 or at most 0-40 cm. Another consideration is the practicability of soil sampling, it is tedious and time-consuming to go beyond 60 cm.

J. Ryan

We have to consider practicability. It is important to consider the difficulty of sampling to a depth of 60 cm. Therefore, I am glad that there seems to be some relationship between data from 0-20 cm and 0-60 cm. The shallow sampling is easier.

SECTION IV

Economics of Fertilizer Strategies

An Economic Analysis of Fertilizer Allocation Strategies in the Syrian Arab Republic

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ABSTRACT

The main purpose of this research is to develop an economic-decision framework that can be applied to analyze alternative allocation strategies of nitrogen (N) and phosphorus (P) fertilizers in Syria among the main crops and under varying levels of aggregate fertilizer availability constraints. Based on fertilizer trial data, quadratic production functions were estimated for the following crops: irrigated wheat (*Triticum* spp), rain-fed improved (HYV) wheat varieties, rain-fed local (LYV) wheat varieties, rain-fed barley (*Hordeum vulgare* L.), irrigated cotton (*Gossypium lirsutum* L.), irrigated yellow maize (*Zea maize* L.), irrigated fall and summer sugar beets (*Beta vulgaris* L.), and irrigated fall and summer potatoes (*Solanum tuberosa* L.). These are the main crops in Syria, accounting for about 86% of N consumption and 78% of P consumption for all field crops. The estimated production functions were first used to calculate economically the optimum fertilizer rates for each crop, which constituted the basis for proposing adjustments in the current fertilizer recommendations. Second, the estimated production functions were incorporated into a Separable Linear Programming model which allowed the estimation of optimum fertilizer rates under varying levels of the constraints on fertilizer availability, and constituted the basis for comparing alternative fertilizer allocation strategies.

The results showed that fertilizer-recommended rates should be substantially reduced for wheat and increased for barley. As for cotton, the N rate should be increased while the rate of P should be reduced. The results also showed that the N rates recommended for maize, sugar beet, and potato should be increased. An economic analysis of the profitability and riskiness of the proposed fertilizer rates has clearly shown that these rates are economically feasible and represent safe investments for all the crops studied, both from the viewpoint of farmers and that of the economy as a whole. The shift from the current to the proposed recommendations is estimated to result in an average increase of 18.3% in the net returns due to fertilizer application on the crops covered by this study, which is equivalent to an estimated increase of 2.7% in Agricultural Gross Domestic Product.

Based on the results obtained from the LP model, it was possible to conclude that the most economically rational fertilizer policy would be for the government to allocate enough foreign exchange for fertilizer imports so that at least 80% of the total (local plus imported) fertilizer requirements would be available, with 100% fertilizer availability being the target level that would maximize economic returns from fertilizer use. Hence, if the current fertilizer availability levels (60-70% of total requirements) are increased to 100% by increasing fertilizer imports, net returns from fertilizer use would increase by an amount ranging from 8 to 18 million US dollars.

Comparisons of the economic impact of alternative fertilizer allocation strategies for the winter season have shown that, under the current levels of fertilizer availability, allocation strategies based on fixing the rates for irrigated crops would be at the expense of barley fertilization. The analysis has also shown that it would be more economical to allow the rates for irrigated crops to be reduced by a relatively small amount, making it possible to allocate some fertilizer to barley. This reallocation of fertilizer would result in a slight reduction in total increase in production due to fertilizer use in the case of potatoes, sugar beets, and wheat, but in return it would result in substantial increases in barley production, with an estimated additional 2 to 2.4 million US dollars per year in net returns due to fertilizer use.

INTRODUCTION

Theoretically, in a competitive market economy, the forces of supply and demand would ensure that the limited amount of fertilizer available would be allocated in an efficient way. In Syria, fertilizers as well as most other agricultural inputs are allocated to farmers by the government. Given the constraints facing domestic fertilizer production in Syria, the government is faced annually with the problem of a large amount of fertilizer imports which consume a great deal of foreign exchange. The result is that total fertilizer quantities available for distribution are below total demand for fertilizers by farmers. In order to properly implement such a comprehensive, centrally planned allocation system, government planners need to have access to a large and comprehensive information system on which to base their estimates. In the case of fertilizers, the information required would have to include technical data on the response of the main crops to fertilizer applications, in addition to economic information on fertilizer and crop prices in order to estimate economically optimum rates for each crop. Since the 1960s, the Soils Directorate (SD) of the Ministry of Agriculture and Agrarian Reform (MAAR) has undertaken major fertilizer research efforts, especially on wheat, cotton, sugar beet, potato, and maize, which allowed the estimation of reasonably accurate fertilizer recommendations that constitute the basis for the current fertilizer allocation system.

The potential problem related to the centrally planned fertilizer allocation system is the underlying assumptions based on which allocation decisions are made. The decision on how to allocate the limited fertilizer quantities available is often made based on a system of priorities whereby every effort is made to ensure that the "strategic crops" would receive all their fertilizer requirements. These crops are defined as those providing substantial export earnings (e.g., cotton) and those substituting for the major food imports (e.g., wheat and sugar). Another important factor influencing fertilizer allocation decisions is whether crops are irrigated or rain-fed, with the general rule that irrigated crops should receive all their fertilizer requirements, given that economic returns to fertilizer investments in rain-fed crops, especially in the dry areas, are lower and riskier than for irrigated crops. Given the existing fertilizer availability constraints, the practical implications of the above allocation strategies are that irrigated crops and rain-fed wheat in the high-rainfall zones usually receive most if not all of their fertilizer requirements, with very little fertilizer left for allocation to rain-fed barley. In fact, the first time that any fertilizer was allocated to barley was in 1986/87 but not in the dry areas (below 250 mm average annual rainfall).

However, recent results from field experiments by the Soils Directorate and by ICARDA have thrown some doubts on the economic rationale of the above-mentioned allocation strategies. These research findings strongly suggest that barley fertilization in the dry areas might be much more economical and less risky than was previously thought to be the case (Soils Directorate/ICARDA, 1990). Moreover, similar research results also suggest that the current fertilizer rates, specifically P rates, applied on rain-fed wheat are excessive due to the buildup of available soil P as a result of years of continuous application of P fertilizers (Soils Directorate/ICARDA, 1989). These findings suggest that fertilizer rates applied on barley should be increased and, in the event that additional fertilizers cannot be imported to satisfy this increase, it might be more economical to reallocate some of the fertilizer basically allocated for wheat to be applied to barley grown in the dry areas.

The above problems facing the proper implementation of the centrally-planned allocation of fertilizers in Syria, and the allocation policy issues related indicate the need for a systematic review of the current fertilizer recommendations and for the development of an economic framework for estimating the efficient allocation of fertilizer and addressing some of the policy issues related to fertilizer allocation.

OBJECTIVES

The purpose of this study is to develop an analytical framework for estimating the efficient allocation of fertilizers in Syria. Such a framework can serve as a valuable decision tool to assist planners and policy makers in determining the most efficient fertilizer allocation strategies, and for comparing the economic impact of alternative fertilizer allocation strategies. The specific objectives of the study can be summarized as follows:

1. To review current fertilizer recommendations for the major crops in Syria, and to propose new ones that would reflect better the current prevailing economic and physical environments.

2. To develop a decision model to assist government planners in formulating annual plans for the allocation of fertilizer among alternative uses in the most economically efficient way, given the existing constraints on fertilizer availability.

3. To analyze the economic implications of the existing constraints on fertilizer availability, and to propose possible solutions.

4. To analyze the economic impact of alternative fertilizer allocation strategies under different fertilizer availability constraints, and to make policy recommendations as to the most economically appropriate strategies.

METHODS

The main objective of this research is the development of an economic model for the allocation of fertilizer among alternative uses under constrained fertilizer availability. This involves the following steps:

1. Estimation of yield response functions to fertilizer application for each of the crops included in this study, based on the results of fertilizer trials.

2. Calculation of economically optimum fertilizer rates in the case of no constraints on fertilizer availability, and estimation of their economic impact. This is done based on the estimated response functions and the fertilizer and crop prices set by the Higher Agriculture Council.

3. Development of the fertilizer allocation model, allowing for the calculation of optimum rates under constrained fertilizer availability, and for the estimation of the economic impacts of alternative allocation strategies. This is done based on Separable Linear Programming techniques.

Estimation of Production Functions

Crop responses to varying levels of fertilizer applications can be estimated based on results from the experimental fertilizer trials undertaken in Syria by the Soils Directorate (SD) or by ICARDA. Production functions were estimated for the following crops: irrigated wheat, rain-fed HYV wheat, rain-fed LYV wheat, rain-fed barley, irrigated cotton, irrigated yellow maize, irrigated fall and summer sugar beet, and irrigated fall and summer potatoes (Table 1).

Calculation of Optimum Fertilizer Rates

Calculations of optimum fertilizer rates are based on a "profit maximizing" assumption by equating the first derivative of the production function with respect to N or P with the ratio of fertilizer price to crop price. Domestic prices of fertilizers and crops are estimated based on the concept of "field price" as follows:

Crop field price = official price — harvest costs — handling costs — transport costs

Fertilizer field price = official price + application costs + handling costs + transport costs.

International prices are estimated based on the concept of Import Parity Price (IPP) for imported commodities or import substitutes, and Export Parity Price (EPP) for exported or exportable commodities:

Table 1. Estimated production functions for the crops included in the allocation model, 1989/90.

Parameter	Irrigated wheat	Rain-fed HYV wheat	Rain-fed LYV wheat	Rain-fed barley
Constant	2819.70897 (141.82)***	-2701.72097 (256.71)***	-837.17162 (214.27)***	-2942.6078 (130.55)***
R	NA	18.71003 (1.0055)***	5.06276 (0.68745)***	25.23397 (0.72855)***
RR	NA	-0.01519 (0.00102)***	NA	-0.03069 (0.00102)***
N	16.31740 (2.7439)***	2.55165 (2.6284)NS	NA	-1.31934 (2.5466)NS
P	13.82600 (4.5307)***	8.10822 (4.5663)*	NA	10.84186 (1.7852)***
RN	NA	0.02213 (0.00428)***	0.04279 (0.01718)**	0.03530 (0.00541)***
RP	NA	0.00663283 (0.00532)NS	0.02218 (0.02180)NS	0.0002699 (0.00361)NS
NN	-0.05623 (0.01385)***	-0.05589 (0.01376)***	-0.22875 (0.12855)*	-0.08542 (0.03030)***
PP	-0.10126 (0.03961)**	-0.10034 (0.04324)**	-0.13995 (0.17359)NS	-0.04971 (0.01347)***
NP	0.01713 (0.01775)NS	-0.00172954 (0.01723)NS	NA	0.05283 (0.01616)***
RNP	NA	NA	0.00024581 (0.00028)NS	NA
PAP	NA	NA	NA	-0.76066 (0.11024)***
Adj. R^2	0.09859	0.51014	0.46814	0.59811
Std. Error	1692.94	1060.69	516.44	593.69
n	1152	1352	288	2400

Parameter	Cotton	Yellow maize	Fall sugar beet	Summer sugar beet
Constant	2581.35554 (119.57)***	4451.64739 (232.93)***	47.05994 (1.8874)***	29.60876 (1.1829)***
N	9.68536 (1.5562)***	23.47845 (6.8620)***	0.14243 (0.03868)***	0.15056 (1.1829)***
P	5.64925 (2.4735)**	NA	NA	NA
NN	-0.02167 (0.00594)***	-0.08042 (0.04181)*	-0.00030093 (0.00016)*	-0.00036409 (0.00010)***
PP	-0.02698 (0.01490)*	NA	NA	NA
NP	0.009710793 (0.00861)NS	NA	NA	NA
Adj. R^2	0.16400	0.05442	0.07584	0.14668
Std. Error	1127.51	2824.66	22.656	14.809
n	852	594	522	570

Cont'd...

Table 1 (cont'd). Estimated production functions for the crops included in the allocation model, 1989/90.

Parameter	Fall potato		Spring and summer potato	
Constant	16.95057	(0.87842)***	17.77837	(232.93)***
N	0.04387	(0.01763)**	0.04372	(0.01876)**
P	NA		NA	
NN	-0.000116065	(0.00007)NS	-0.000128643	(0.00007)*
PP	NA		NA	
NP	NA		NA	
Adj. R^2	0.02834		0.02723	
Std. Error	8.691		7.427	
n	372		240	

Figures in brackets are the standard errors of the estimated coefficients.
Significance levels: *** = 1%; ** = 5%; * = 10%; NS = nonsignificant.
NA = not applicable; R = total average seasonal rainfall (mm/year).
RR = quadratic term in R; N and P = fertilizer rates.
RN and RP = interaction terms between R and N or P.
NN and PP = quadratic terms in N and P.
NP = interaction between N and P.
RNP = interaction between R, N, and P.
PAP = interaction term between applied and available phosphate.

IPP ($US) = CIF Price ($US) + (domestic costs SL/40 SL/$US)
EPP ($US) = FOB Price ($US) — (domestic costs SL/40 SL/$US).

Based on the above approach, domestic and international fertilizer and crop prices were estimated (Table 2).

Two sets of "optimum" rates are calculated: the first based on domestic prices and the second on international prices of fertilizers and crops (Table 3). The differences between optimum rates calculated based on domestic and international prices are not always very significant.

Comparison between the proposed and the current SD recommendation indicates that fertilizer application rates should be substantially reduced for wheat and increased for barley.

As for cotton, the N rate should be increased, while the P_2O_5 rate should be decreased in the case of maize, sugar beet, and potatoes. The calculated optima indicate that N rates should be increased for maize, sugar beet, and potatoes.

Constrained Optimization: The Allocation Model

Constrained vs Unconstrained Optimization

The calculation of optimum N and P rates is based on unconstrained optimization, i.e., if farmers decide to apply the rates that would maximize their profits, the government

Table 2. Estimated domestic and international prices of fertilizers and major crops in Syria, 1989/1990.

Commodity	Domestic price		International price ($US/kg)
	SL/kg	$US/kg	
Fertilizer			
N	11.52	0.288	0.38
P_2O_5	12.17	0.304	0.55
K_2O	16.20	0.405	0.64
Crop			
Wheat grain (HYV)	7.00	0.175	0.22
Wheat grain (LYV)	7.60	0.19	0.22
Barley grain	4.90	0.1225	0.15
Chickpea grain	11.45	0.286	0.47
Lentil grain	9.95	0.249	0.56
Raw cotton	13.42	0.3355	0.5676
Sugar beet roots	1.025	0.0256	0.03125
Potato tubers	4.00	0.10	0.20
Yellow maize grain	5.90	0.1475	0.148

Table 3. Optimum fertilizer rates and comparison of proposed and current fertilizer recommendations (kg/ha) for the crops included in the fertilizer model, 1989/90.

Crop	Biological maxima		Domestic price[1]		International price[1]		Proposed rate[2]		Current recommendation	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Irrigated wheat	157.5	81.6	141.4	71.6	140.1	67.8	138.0	69.0	150.0	100.0
Rain-fed HYV wheat zone 1	100.7	52.8	86.6	44.2	85.9	40.4	92.0	46.0	100.0	80.0
Rain-fed HYV wheat zone 2	81.1	49.6	66.9	41.1	66.2	37.3	69.0	41.4	80.0	60.0
Rain-fed LYV wheat zone 1	47.8	48.5	42.9	41.1	41.7	37.4	41.4	41.4	80.0	60.0
Rain-fed LYV wheat zone 2	33.3	32.5	28.9	25.7	27.9	22.2	27.6	23.0	60.0	60.0
Rain-fed LYV wheat zone 3	26.8	25.7	22.6	19.1	21.7	15.6	23.0	18.4	30.0	30.0
Rain-fed barley zone 1	98.2	108.6	72.5	70.0	66.8	55.1	69.0	55.2	50.0	40.0
Rain-fed barley zone 2	73.4	95.2	47.7	56.5	42.0	41.6	41.4	41.4	40.0	40.0
Rain-fed barley zone 3	60.9	88.4	35.2	49.8	29.6	34.9	27.6	36.8	20.0	20.0
Cotton	257.3	151.0	232.7	129.8	237.0	129.4	230.0	128.8	200.0	150.0
Yellow maize	146.0	na[3]	133.8	na	130.0	na	133.4	na	120.0	80.0
Fall sugar beet	236.6	na	218.0	na	218.5	na	207.0	na	200.0	120.0
Summer sugar beet	206.8	na	191.3	na	191.8	na	197.8	na	180.0	120.0
Fall potato	189.0	na	176.6	na	180.8	na	174.8	na	150.0	120.0
Spring and summer potato	169.9	na	159.0	na	162.5	na	156.4	na	120.0	120.0

1. See Table 2.
2. Optimum rates based on international prices, rounded to the nearest 10 kg of Urea (46% N) or TSP (46% P_2O_5).
3. Not applicable, since production functions were estimated in terms of response to N only.

is capable of supplying all the fertilizer demanded by the farmers, either from domestic production or from imports.

The above assumption is unrealistic given the serious problems facing domestic fertilizer production and the limited foreign exchange for the import of fertilizers. Therefore the problem faced by the government is how to best satisfy the fertilizer requirements of the various crop production activities which are competing for the use of the limited fertilizer resources. The constrained optimization problem is based on the principle of equimarginality. In unconstrained optimization, marginal revenues should equal or exceed marginal costs. In the case of constrained optimization, the fertilizer levels should be found across crops so that the marginal revenues per unit of fertilizer used are the same in each crop activity. This is to account for the fact that these activities are competing for the same limited fertilizer resources.

There exist several methods to solve the constrained optimization problem. Linear programming (LP) is an optimization technique to solve "allocation problems" in which limited resources are allocated to a number of economic activities (Taha, 1987). The LP problem consists of optimizing (maximizing or minimizing) a specific quantity, called the "objective," which depends on a finite number of input variables, subject to a set of constraints (Bronson, 1982).

LP Formulation of the Fertilizer Allocation Problem

A simple version of the fertilizer allocation model can be defined in terms of maximizing the net returns from the use of fertilizers on all the major crops in Syria, subject to the constraints imposed by the amount of fertilizer available, and to the physical input/output relationship between the amounts of fertilizer applied and yields obtained[1]. Hence, the model would solve for the optimum levels of N and P for each crop that, given the constraints, will maximize the yield increase and, therefore, net returns from fertilizer use. Hence, in this model crop and fertilizer prices, areas, and the fertilizer availability constraints are exogenous, i.e., they are fixed by the analyst. However, the input/output relationships between fertilizer applied and yield increase are the estimated coefficients from the production functions presented in Table 4.

It should be noted that since the production functions are not linear, this contradicts one of the basic assumptions of LP. Fortunately, there are techniques such as Separable Programming (SP) that can be used to modify the standard LP model in order to handle nonlinear constraints. SP involves dividing the production functions into segments for which linear approximations are obtained and incorporated into the standard LP model.

Hence, the basic formulation of the fertilizer allocation LP model is presented below[1]:

$$\text{Maximize } Z = \hat{E}_i(PC_i * TY_i) - (W_n * TNU) - (W_p * TPU)$$

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[1] This formulation of the fertilizer allocation model is a modification of the model developed by Nordblom and Al-Ashram (1989).

Table 4. Costs and benefits of fertilizer use under varying levels of total fertilizer availability, 1989/90.

	% of total fertilizer requirements available					
	100	90	80	70	60	50
Fertilizer use						
N (tons)	202,191	181,679	161,841	141,664	121,405	101,157
P_2O_5 (tons)	142,487	128,537	114,003	93,957	77,492	71,253
Fertilizer cost (million $US)	155.200	139.733	124.202	105.509	88.775	77.629
Gross return (million $US)	400.081	385.683	367.502	342.766	316.400	293.855
Net return (million $US)	244.880	245.949	243.300	237.258	227.646	216.227

Subject to:

$$
\begin{aligned}
\Sigma \quad & \hat{E}_s SEG_{is} = 1 \\
& \hat{E}_s(SEG_{is} * N_s) = N_i \\
& \hat{E}_s(SEG_{is} * P_s) = P_i \\
& \hat{E}_s(SEG_{is} * Y_{is} * A_i) = TY_i \\
& \hat{E}_i(N_i * A_i) = TNU \\
& \hat{E}_i(P_i * A_i) = TPU \\
& TNU \le NLIM \\
& TPU \le PLIM
\end{aligned}
$$

and $SEG_{is} \ge 0,\ N_i \ge 0,\ P_i \ge 0,\ TY_i \ge 0$
$TNU \ge 0$, and $TPU \ge 0$

where Z = net returns (millions SL, or any other monetary unit)
PC_i = price of $crop_i$ (SL/kg)
W_n and W_p = price of N and P_2O_5 (SL/kg)
TY_i = aggregate increase in output of $crop_i$ due to fertilizer use (thousand tons)
Y_i = increase in yield of $crop_i$ due to fertilizer use (kg/ha)
TNU = aggregate use of N (thousand tons)
TPU = aggregate use of P_2O_5 (thousand tons)
NLIM and PLIM = upper limits of N and P_2O_5 available in the country (in thousand tons)

N_i and P_i = optimum N and P_2O_5 rates applied on $crop_i$ (kg/ha)
A_i = total area planted with $crop_i$ (million hectares)
SEG_{is} = the optimum values associated with each segment for $crop_i$
N_s, P_s, and Y_{is} = the rates of N and P_2O_5 and the yield increases corresponding to these rates, associated with each segment for $crop_i$.

RESULTS AND DISCUSSION

Current and Proposed Fertilizer Recommendation Impacts

The economic impact of the shift from current to proposed fertilizer recommendations is estimated, and the aggregate economic impact are summarized in Table 5. The first thing to note is that the total fertilizer requirement for the crops included in the model would decline significantly, total N requirements would decline by 14,693 tons which is equivalent to a 6.8% reduction, and total P requirements would decline by 34,726 tons, which is a 19.6% reduction. The total savings in fertilizer costs would amount to 24.7 million US dollars, and the net returns would increase by 18.3% amounting to 37.8 million US dollars.

Table 5. Aggregate economic impact of current and proposed fertilizer recommendations for the crops included in the model, 1989/90.

	Current rate	Proposed rate	Net change	% change
Gross return (million $US)	386.910	400.081	13.171	3.4
Fertilizer requirement				
N (tons)	216,884	202,191	-14,693	-6.8
P_2O_5 (tons)	177,213	142,487	-34,726	-19.6
Fertilizer cost (million $US)	179.883	155.200	-24.683	-13.7
Net return (million $US)	207.027	244.880	37.853	18.3
VCR[1]	2.15	2.58	0.43	20

[1] The VCR is the value of the increase in output due to fertilizer use divided by total fertilizer cost.

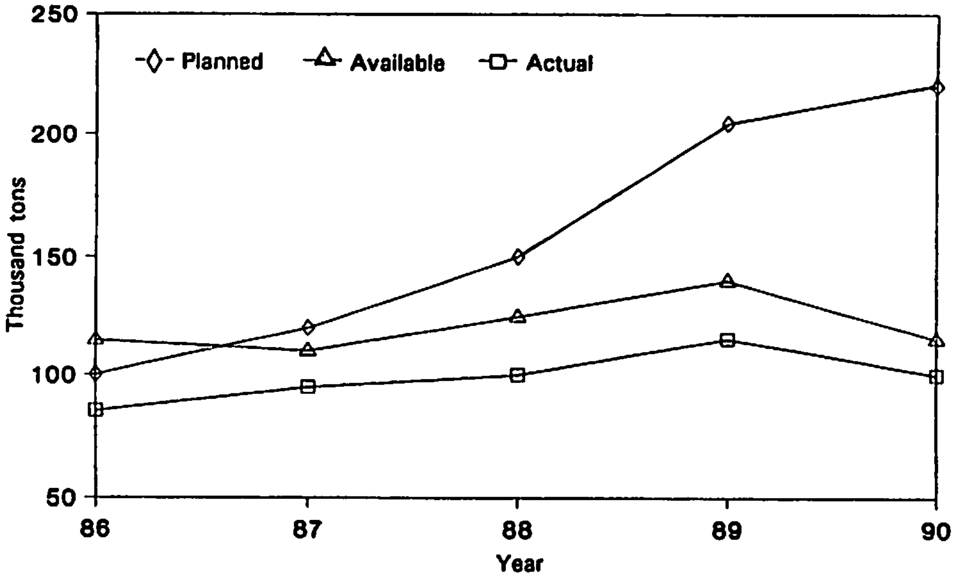

Fig. 2. Planned, available, and actual P_2O_5 fertilizer use in Syria, 1986-90.

the various crops in a way that would give the highest net returns to fertilizer use.

- the second question is to determine what is the net loss (foregone output increase minus the saving in fertilizer costs) to the Syrian economy in case the government does not ensure that all the fertilizer requirements are made available.

In order to answer the above two questions, and given that the fertilizer availability situation would probably vary from one year to another, the optimum fertilizer rates are estimated under several scenarios of fertilizer availability. Their economic implications are assessed in comparison with those obtained under the ideal scenario with no constraints on fertilizer availability. Hence, for the crops included in the model, the ideal scenario (100% of total fertilizer requirement available) would require the availability of 202,191 t of nitrogen and 142,487 t of P_2O_5. The next step is to make gradually decreasing assumptions about the percentage of the above ideal quantities actually available (90, 80, 70, 60, and 50%), and to estimate optimum fertilizer rates for each scenario, based on the allocation model.

The optimum rates for the above scenarios examined are presented in Table 6. The first thing to note in Table 6 is that, in the case of irrigated crops, the decline in optimum rates for both N and P_2O_5 is relatively small. The situation with rain-fed crops is much different. The estimated optimum rates decline substantially when fertilizer availability is reduced, especially in the case of barley; the model would predict that, if fertilizer availability is about 70%, it would be uneconomical to allocate fertilizer to barley in Zone 3, and if the percentage is down to 60, fertilization of

Fertilizer Availability Constraints: Economic Implications

The analyses presented previously were all based on the assumption that all the estimated requirements will be actually available, i.e., the estimated differences in economic impact are all hypothetical. Hence, the calculated increases in net returns should be viewed as the maximum potential increase in net returns due to fertilizer use. These gaps between planned and actual fertilizer use have become more accentuated in recent years, with the percentage of planned fertilizer requirements actually used declining steadily from 78.6% for N and 83.5% for P in 1985/86 to 51.2% and 41.6% for N and P, respectively, in 1989/90 (Figs 1 and 2).

It should be noted, however, that the above-mentioned decline in the ratio of actual use to planned requirement occurred in spite of a gradual increase in actual total fertilizer use, except for the 1989/90 season.

Implication of Fertilizer Availability Constraints

The fertilizer allocation model is designed to answer two basic questions related to the problem of limited fertilizer availability:

- the first question is how to allocate the limited fertilizer quantities available among

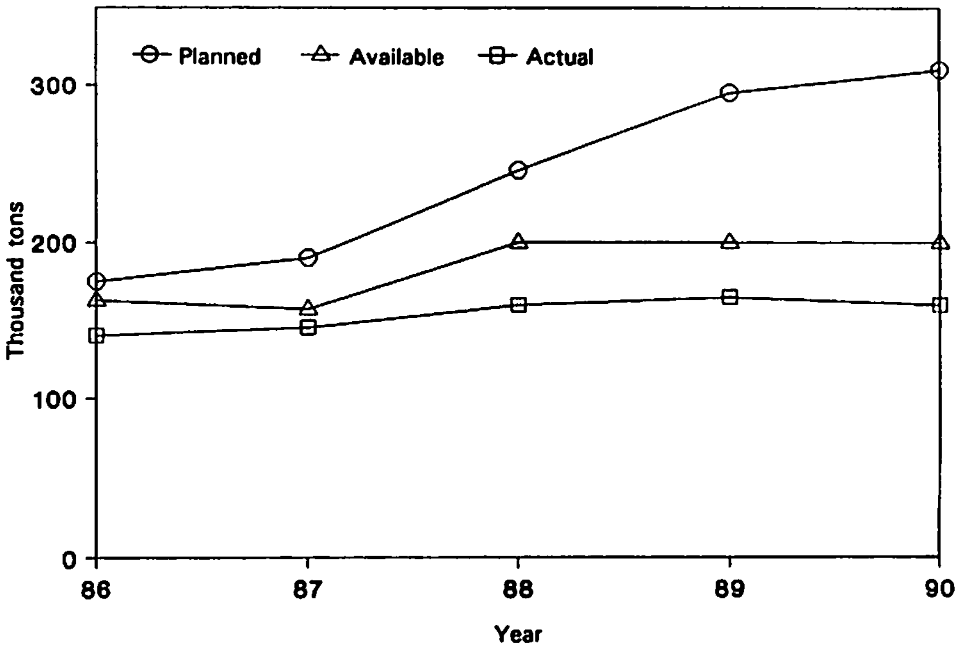

Fig. 1. Planned, available, and actual N fertilizer use in Syria, 1986-90.

Table 6. Optimum fertilizer rates (kg/ha) for varying levels of total (winter and summer) fertilizer availability, 1989/90.

	% of total fertilizer requirements available											
	100		90		80		70		60		50	
Crop	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Irrigated wheat	138.0	69.0	130.0	69.0	130.0	63.0	120.0	60.0	117.0	60.0	100.0	60.0
Rain-fed HYV wheat zone 1	92.0	46.0	80.0	40.0	70.0	40.0	61.0	40.0	60.0	40.0	40.0	30.0
Rain-fed HYV wheat zone 2	69.0	41.4	60.0	40.0	50.0	40.0	50.0	36.0	40.0	30.0	20.0	30.0
Rain-fed LYV wheat zone 1	41.4	41.4	40.0	40.0	40.0	40.0	40.0	40.0	30.0	30.0	30.0	300
Rain-fed LYV wheat zone 2	27.6	23.0	27.6	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Rain-fed LYV wheat zone 3	23.0	18.4	20.0	18.4	20.0	10.0	20.0	10.0	10.0	10.0	10.0	10.0
Rain-fed barley zone 1	69.0	55.2	60.0	50.0	50.0	40.0	40.0	30.0	30.0	20.0	10.0	10.0
Rain-fed barley zone 2	41.4	41.4	33.0	34.0	29.0	29.0	20.0	20.0	0.0	0.0	0.0	0.0
Rain-fed barley zone 3	27.6	36.8	20.0	30.0	10.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0
Cotton	230.0	128.8	230.0	128.8	220.0	120.0	210.0	120.0	210.0	120.0	190.0	110.0
Yellow maize	133.4	80.0	110.0	66.0	100.0	60.0	90.0	54.0	80.0	48.0	60.0	36.0
Fall sugar beet	207.0	120.0	190.0	110.0	180.0	104.0	170.0	99.0	150.0	87.0	139.0	81.0
Summer sugar beet	197.8	120.0	170.0	103.0	160.0	97.0	150.0	91.0	140.0	85.0	120.0	73.0
Fall potato	174.8	120.0	170.0	117.0	160.0	110.0	160.0	110.0	150.0	103.0	150.0	103.0
Spring and summer potato	156.4	120.0	150.0	115.0	150.0	115.0	140.0	107.0	140.0	107.0	130.0	100.0

barley in Zone 2 would also become uneconomical. In order to examine the aggregate economic impact of the constraints on fertilizer availability, fertilizer costs and gross returns from fertilizer use are compared for the above six scenarios (Table 4). It is clear from Table 4 that reduced fertilizer availability levels also mean a corresponding reduction in fertilizer import costs, which is the main reason for reduced fertilizer availability.

The net economic loss resulting from reduced fertilizer availability would amount to more than 2, 8, 18, and 29 million US Dollars in the case of 80, 70, 60, and 50% availability, respectively, compared with the 90% level. Hence, it is possible to conclude that the most economically rational decision would be to invest the foreign exchange to import all the fertilizer needed to fill the gap between domestic production and at least 80% of total fertilizer requirements, with 100% fertilizer availability being the target level that would give the highest economic returns.

Fertilizer Availability Constraints--Winter Season

Reduced fertilizer availability for the winter season is a problem facing Syrian policy-makers every year to varying degrees. Hence, at the beginning of every season the question is posed as to how to allocate the limited fertilizer resources for winter crops. In order to answer the above question, the fertilizer allocation model developed in this study is used to compare the economic impact of alternative allocation strategies based on realistic assumptions about fertilizer availability levels. For this purpose, five hypothetical allocation strategies for the winter season are examined:

Strategy 1	is defined as the theoretically ideal strategy whereby all the fertilizer requirements for the winter crops are assumed to be available.
Strategy 2	assumes that 70% of total fertilizer requirements for the winter season are available.
Strategy 3	also assumes a 70% availability level, but with the condition that irrigated crops should receive all their fertilizer requirements.
Strategy 4	same as Strategy 2, but with 60% assumed level of fertilizer availability.
Strategy 5	same as Strategy 3, but with 60% assumed level of fertilizer availability.

Optimum fertilizer rates estimated based on the above five strategies are presented in Table 7. Optimum rates for Strategy 1 are presented as a base scenario, but the appropriate comparisons should be made between the rates for Strategy 2 and those for Strategy 3, if we assume a 70% availability level, or between Strategy 4 and Strategy 5 if this level is assumed at 60%.

Hence, if 70% of total fertilizer requirements for winter crops is available, and if we compare optimum rates for rain-fed wheat obtained under Strategies 2 and 3, it is interesting to note that, except for a lower P_2O_5 rate for HYV wheat in Zone 2 in the case of Strategy 3, these rates would be exactly the same for the two strategies. The biggest difference is in optimum rates for barley in Zone 3 whereby, under Strategy 2, optimum N and P_2O_5 rates would be 10 and 20 kg/ha, respectively, while these rates would drop to zero in Strategy 3. Hence, if the rates for irrigated crops are reduced by a relatively slight amount, it would be possible to allocate some fertilizer for barley in Zone 3.

On the other hand, if the more pessimistic 60% fertilizer availability scenario is assumed, it would be uneconomical to allocate fertilizer for barley in Zone 3 based on either Strategy 4 or 5. As shown in **Table 7**, applying all the fertilizer requirements on irrigated crops would be at the expense of reducing N and P_2O_5 rates for HYV wheat in Zone 2 and N rate on LYV wheat in Zone 3, in addition to reducing fertilizer rates for barley.

Comparisons of the economic impacts of the above alternative strategies are summarized in **Table 8**. First, comparing Strategies 2 and 3 which assume about 70% fertilizer availability (the differences in total quantities of fertilizer use are due to rounding errors), the figures on net returns due to fertilizer use are higher for Strategy 2, regardless of the expected rainfall, with the difference in net returns amounting to 2.4 million US dollars in normal years. Similarly, for a 60% fertilizer availability level, net returns under Strategy 4 would exceed those for Strategy 5 by 2 million US dollars in a normal year.

Therefore, it is possible to conclude that, under the current fertilizer availability situation (60 to 70%) for winter crops, a fertilizer allocation policy prescribing that irrigated crops should receive all their fertilizer requirements, which would be at the expense of barley fertilization, would cost the Syrian economy at least 2 million US dollars per year. Although such a policy would reduce imports of wheat and sugar, it would only be achieved at the expense of reduced barley production. Therefore, if the rates for irrigated crops are reduced (depending on the prevailing fertilizer availability situation), the increased barley production and the foreign exchange earned from exporting this extra production (or the reduced foreign exchange expenditures on barley imports in dry years) would cover the increased costs of the extra imports of wheat and sugar, with at least an additional 2 million US dollars per year in net gains.

Table 7. Optimum fertilizer rates (kg/ha) under alternative fertilizer allocation strategies for winter crops, 1989/90.

	Fertilizer allocation strategies for winter crops--% fertilizer availability									
	Strategy 1		Strategy 2		Strategy 3*		Strategy 4		Strategy 5*	
	100%		70%		70%		60%		60%	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Irrigated wheat	138.0	69.0	120.0	60.0	138.0	69.0	120.0	60.0	138.0	69.0
Rain-fed HYV wheat zone 1	92.0	46.0	70.0	40.0	70.0	40.0	60.0	40.0	60.0	40.0
Rain-fed HYV wheat zone 2	69.0	41.4	50.0	32.0	50.0	40.0	50.0	30.0	40.0	30.0
Rain-fed LYV wheat zone 1	41.4	41.4	40.0	40.0	40.0	40.0	30.0	30.0	30.0	30.0
Rain-fed LYV wheat zone 2	27.6	23.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Rain-fed LYV wheat zone 3	23.0	18.4	20.0	10.0	20.0	10.0	20.0	10.0	10.0	10.0
Rain-fed barley zone 1	69.0	55.2	46.0	36.0	40.0	40.0	40.0	30.0	30.0	20.0
Rain-fed barley zone 2	41.4	41.4	20.0	20.0	20.0	21.0	13.0	15.0	10.0	10.0
Rain-fed barley zone 3	27.6	36.8	10.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0
Fall sugar beet	207.0	120.0	170.0	99.0	207.0	120.0	170.0	99.0	207.0	120.0
Fall potato	174.8	120.0	160.0	110.0	174.8	120.0	160.0	110.0	174.8	120.0

* Strategies 3 and 5 stipulate that irrigated crops will receive all their fertilizer requirements.

Table 8. Costs and benefits of fertilizer use under alternative fertilizer allocation strategies for winter crops, 1989/90.

	Fertilizer allocation strategies--% fertilizer availability				
	Strategy 1	Strategy 2	Strategy 3*	Strategy 4	Strategy 5*
	100%	70%	70%	60%	60%
Fertilizer use (winter season)					
N (ton)	148,306	103,819	103,343	89,103	89,031
P_2O_5 (ton)	111,459	77,972	71,494	61,281	60,482
Fertilizer cost (million $US)	117.659	82.336	78.592	67.563	67.097
Gross return (million $US)	253.502	214.009	207.860	193.563	191.107
Net return (million $US)	135.844	131.673	129.268	126.000	124.010

* Strategies 3 and 5 stipulate that irrigated crops will receive all their fertilizer requirements.

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A Comparison of Maximum Yield and Maximum Net Revenue with Nitrogen Fertilizer on Barley in Morocco

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ABSTRACT

Barley is planted on over one-fourth of the cropped land in Morocco, which exceeds the combined area of bread wheat and durum wheat. It is typically produced in drier areas, on poorer soils, and without chemical fertilizer.

Recent on-farm experiments have shown a response of barley grain and straw yields to nitrogen fertilizer. While the researcher tends to be interested in production, the farmer is interested in profit. Utilizing a basic economic analysis, nitrogen fertilizer rates which produced maximum yield and maximum net revenue were compared.

Yield data from three experiments along a rainfall gradient in central Morocco were utilized in this analysis. Nitrogen was applied at rates of 30, 60, 90, 120, and 150 kg/ha.

At one site, the maximum yield was produced with 150 kg N/ha, while the maximum net revenue occurred at 60 kg N/ha. At the two other sites, maximum net revenue and maximum yield occurred at the same nitrogen rates.

Given the climatic and other production risks, and limited funds for purchasing fertilizer, farmers may only apply rates of nitrogen which have a high probability of producing a substantial response. A benefit cost ratio of 2 has been suggested as a minimum for consideration in developing farmer recommendations. If a benefit cost ratio of 2 is employed as a decision rule in this study, nitrogen would be applied at rates of 60, 0, and 30 kg/ha at the three sites, while rates for maximum yield were 150, 90, and 30 kg N/ha, respectively.

This study suggests that the application of nitrogen fertilizer on barley can be profitable in Morocco. Since the largest response to an increment of nitrogen is typically from the first, or first and second increments, future field trials should concentrate on validating responses to these lower levels under varying soils and climatic conditions.

INTRODUCTION

Barley (*Hordeum vulgare* L) occupies nearly one-fourth of the cropped land in Morocco. The area planted to barley is approximately equal to the combined areas of bread wheat (*Triticum aestivum* L) and durum wheat (*T. turgidum* var *durum* L). Barley is typically produced in dryland areas, often on poorer soils. It tends to dominate in the 200 to 300 mm rainfall zone (Shroyer *et al.*, 1990).

Barley is a versatile crop. The grain is used to make bread and other staples for household consumption. It is one of the principal supplements fed to livestock, and its straw is also used as forage. It is often planted for use as the first green forage in the spring. In years when rainfall is insufficient to produce grain, the entire crop is grazed or harvested as forage. Thus, barley production is often part of the livestock production system on Moroccan farms (Primov *et al.*, 1987).

Traditionally, farmers have not applied chemical fertilizer to barley in Morocco. Much of the previous research with fertilizer on cereals has been with wheat. These studies have demonstrated the potential for significant increases in the production of wheat in dryland areas through proper fertilization (Ryan *et al.*, 1989; 1992a). Only recently has the response of barley to fertilizer been investigated. An experiment which included five on-farm sites along a rainfall gradient showed a response of barley to nitrogen (N) fertilizer, except in the driest two sites (Ryan *et al.*, 1992b).

While a yield response of barley to N fertilizer has been shown, the question remains, is it profitable? The objectives of this report were to: 1) compare the points of maximum production and maximum profit with respect to rates of N fertilizer applied, and 2) examine the effects of higher N fertilizer prices on the most profitable application rates.

THE ROLE OF ECONOMIC ANALYSIS

While the agronomic researcher is interested in yield response, the farmer is interested in profit. Estimates of the profitability of a practice, such as fertilizer application, are helpful in developing farmer recommendations. Economic analyses are also useful in guiding further agronomic research.

In areas with low and highly variable rainfall, economic analyses and farmer recommendations would ideally be based on data from several years of identical experiments. This would allow a sophisticated analysis of yield and profit variability, and an assessment of the relative financial risk associated with each nitrogen application rate. Unfortunately, we seldom have the luxury of this situation.

Conducting identical experiments over several years is expensive. Also, there are problems in achieving this in on-farm experiments. Differences in management, cropping history, and farming practices among farms become additional variables in multi-year experiments.

An additional dilemma relates to time. The farmer needs help now. If we have information that will help him, we have an obligation to get to him as soon as possible. But, we want to minimize the probability of making him worse off as a result of following our recommendations. As a result, fertilizer recommendations in developing countries are often conservative. Only application rates with high probability of producing a significant yield response are typically recommended. This is a simplistic, yet practical method of dealing with risk, and the lack of multiple-year data.

The field trials on which this study is based attempted to capture the results of rainfall variation in a one-year experiment, by placing experiments along a rainfall gradient. The economic analysis utilized in this study is basic. The N application rates which produced maximum yield and maximum profit were compared. An attempt was made to determine what we can conclude, and what we cannot conclude from one year's data in a low- and variable rainfall area.

SOURCE OF DATA

Data from experiments along a rainfall gradient in central Morocco were utilized in this study (Ryan *et al.*, 1992b). Three sites, where barley yields responded to N applications, were selected. These were on-farm trials near Settat, Khouribga, and Skhour Rehamna. Cereal had been the previous crop for all three locations. Five N application rates were used in each location. These were 30, 60, 90, 120, and 150 kg N/ha, in addition to a check with no N. Yields of total biomass were measured and separated into grain and straw yields.

METHODOLOGY

A marginal cost and benefit approach was utilized. Only costs which varied as a result of fertilizer application were considered. The benefits were based on yield increases above the check plot, or zero N application rate.

A market price of 130 dirhams (Dh) per 100 kg of barley grain was assumed (8 dirhams = 1 US$, approximately). An on-farm price of 115 Dh per 100 kg grain was used in the analysis, which reflected transportation and marketing costs of 15 Dh/100 kg. An on-farm price of 50 Dh/100 kg was used for straw. The straw harvesting and hauling cost was estimated at one half of the straw price, or 25 Dh/100 kg. This estimate was based on a custom in some areas of harvesting straw for one half of the crop. An N price of 5 Dh per kilogram of actual N was used as a base. When exploring the effect of increased N prices, 10 Dh per kilogram of N was used.

In addition to N cost, other costs that varied with N application rates were: hauling and application of N, interest (12% for 8 months) on added costs, and added harvest costs for straw. Net revenues, or profits, were calculated as the difference between the additional gross revenue resulting from an N application, and the added costs associated with it.

RESULTS

Settat

Rainfall at the Settat site during the 1989/90 season was 370 mm, approximately equal to the long-term mean of 386 mm. The grain and straw yields are presented graphically in Fig. 1. Maximum yields of grain and total biomass were produced with the highest N application rate, 150 kg/ha.

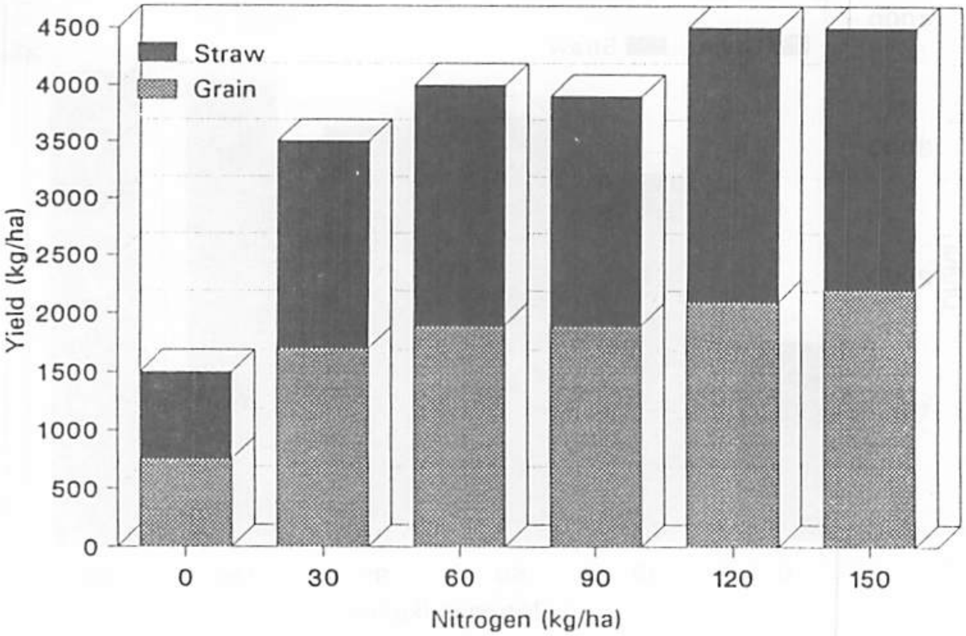

Fig. 1. Barley grain and straw yields, Settat, Morocco.

Gross revenues from grain and straw, shown graphically in **Fig. 2**, were also at maximum at the 150 kg N/ha rate. The gross revenues are compared to net revenues in **Fig. 3**. While the 150 kg N/ha rate produced maximum yield and gross revenue, the 60 kg N/ha rate produced maximum net revenue.

The question is should a farmer apply N at the rate of 60 kg/ha? Economic principles indicate that an additional increment of an input (N) should be applied if the marginal revenue from that increment exceeds its cost. But, the farmer faces many risks in producing a crop, including variable rainfall. Thus, it would be very risky to recommend applying N to the point at which marginal costs exactly equal marginal revenue. To incorporate a safety factor in fertilizer recommendations, some researchers have suggested that a benefit/cost ratio of 2:1 be used in making fertilizer recommendations for farmers in developing countries (CIMMYT, 1988). Thus, only application rates which produce added revenue at least two times the added cost should be considered for farmer recommendations.

The benefit/cost ratios for the Settat trial are displayed in **Table 1**. By applying 30 kg N/ha rather than zero N, gross revenues are increased 3.6 times the amount of increased cost. If the guideline of 2:1 is used, we would feel fairly safe in applying 30 kg/ha. The benefit/cost ratio of moving from 30 to 60 kg/ha is 2.0. In such a borderline situation, we would probably not suggest applying 60 kg/ha.

The estimated impact of increased fertilizer prices is presented graphically in **Fig. 4**. In addition to the information presented in **Fig. 3**, the net returns resulting from a doubling of the fertilizer price from 5 to 10 Dh/kg is shown.

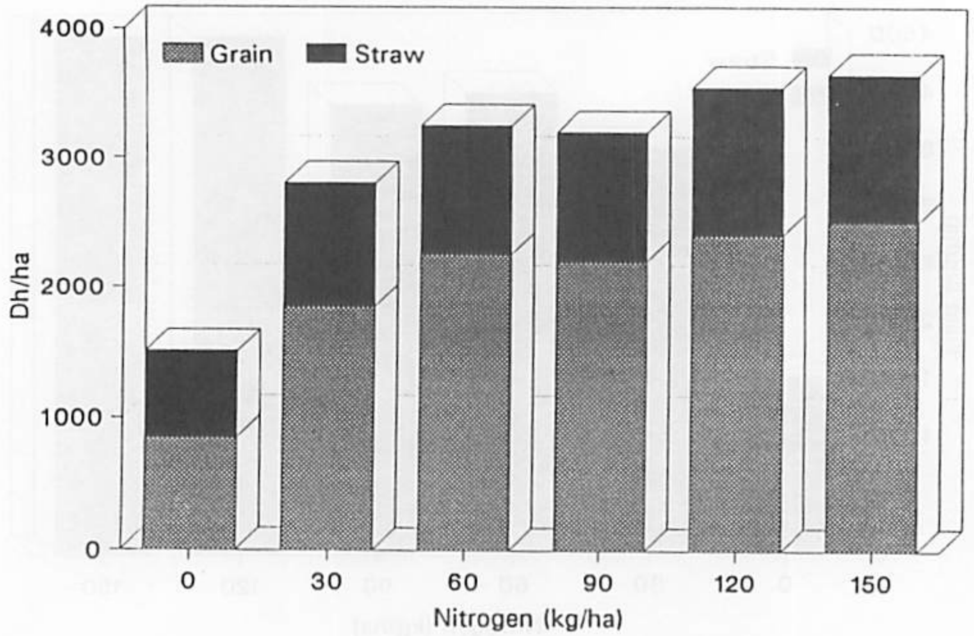

Fig. 2. Gross revenue from barley grain and straw, Settat, Morocco.

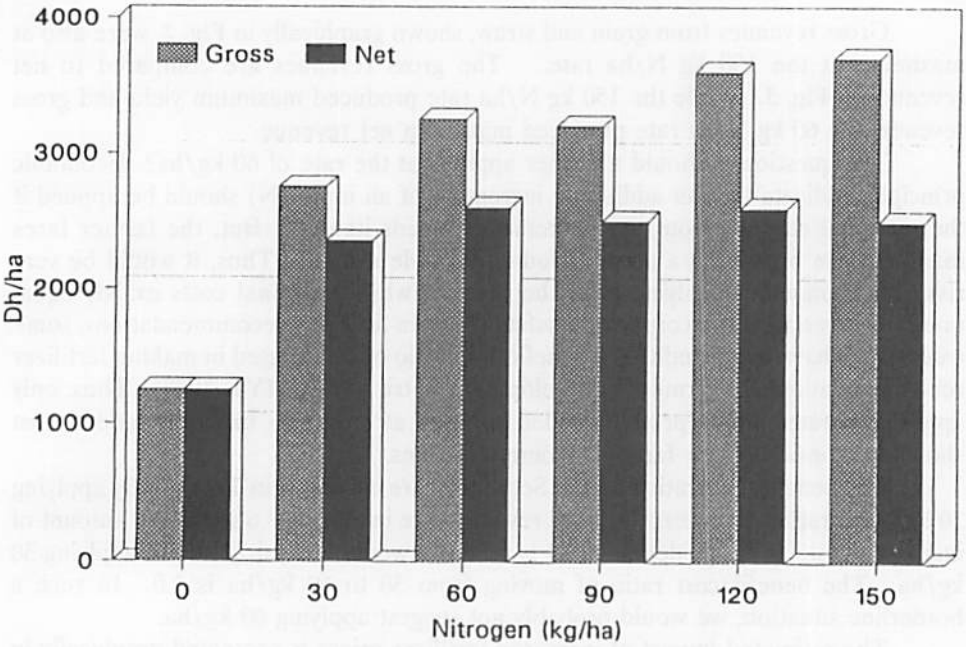

Fig. 3. Gross and net revenue from barley, Settat, Morocco.

Table 1. Revenue, costs and benefit/cost ratios (Dh/ha) of incremental nitrogen applications on barley, Settat, Morocco.

	N application (kg/ha)					
	0	30	60	90	120	150
Gross revenue	1268	2805	3286	3244	3594	3660
Variable costs	0	424	664	811	1050	1212
Marginal revenue		1537	481	-42	350	66
Marginal cost		424	240	146	239	162
Benefit/cost ratio		3.6	2.0	-0.3	1.5	0.4

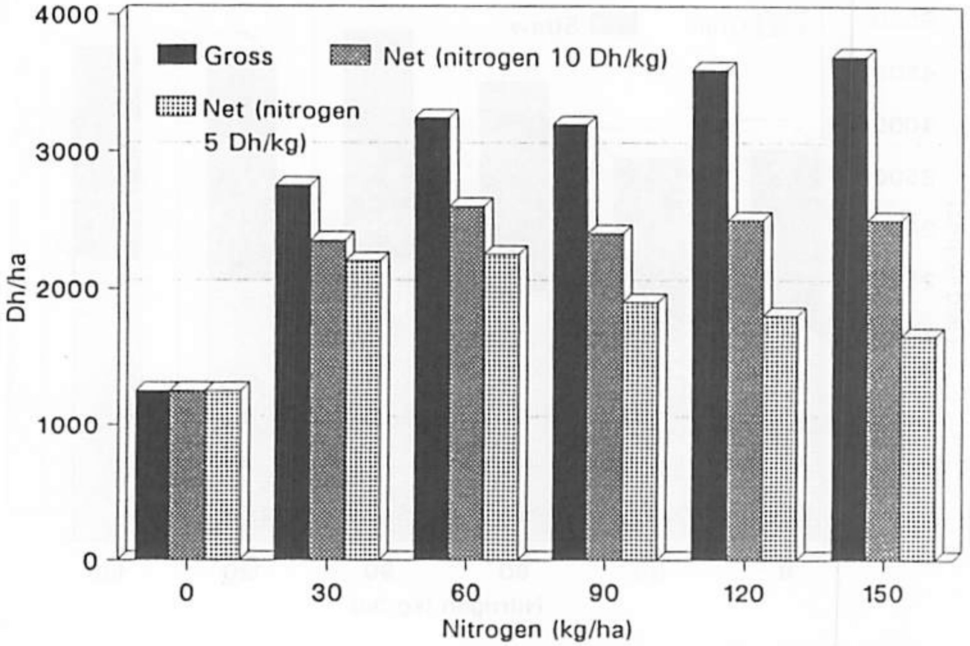

Fig. 4. Gross and net revenue from barley resulting from N cost of 5 and 10 Dh/kg, Settat, Morocco.

As fertilizer price subsidies in Morocco are reduced or eliminated, prices paid by farmers may increase further. In addition, prices paid by farmers for fertilizer in souks may be higher than the official prices. While the selection of 10 Dh/kg as the higher price is arbitrary, it does show whether a price increase of that magnitude would affect the application rates which produce maximum profit.

While the maximum net return at the higher fertilizer price is at the 60 kg/ha nitrogen rate, the increase from the 30 kg/ha rate is slight. The benefit/cost ratio associated with increasing the application rate from 30 to 60 is only 1.2. This is far short of 2. We could not recommend that a producer apply more than 30 kg/ha of N at the higher N price.

Khouribga

Rainfall at Khouribga during the 1989/90 season was 396 mm, as compared to the mean of 402. The grain and straw yields from the on-farm trial are presented graphically in **Fig. 5**. The 30 kg N/ha rate resulted in a slight decrease in yield from the zero rate. The maximum grain and total biomass yield occurred at the 90 kg N/ha rate.

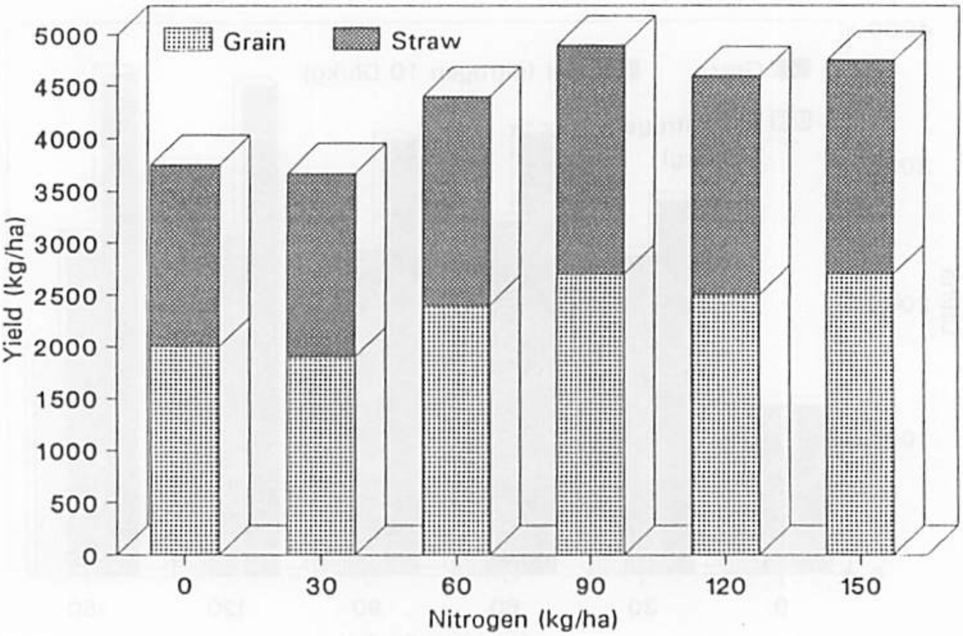

Fig. 5. Barley grain and straw yields, Khouribga, Morocco.

Gross and net revenue data are presented graphically in **Fig. 6**. While net revenue at the 5 Dh/kg N price is maximum at the 90 kg N/ha rate, the difference from the zero rate in terms of cost/benefit ratio, would not justify applying any N, based on this experiment. At the 10 Dh/kg N price, net revenues were reduced at all N application rates.

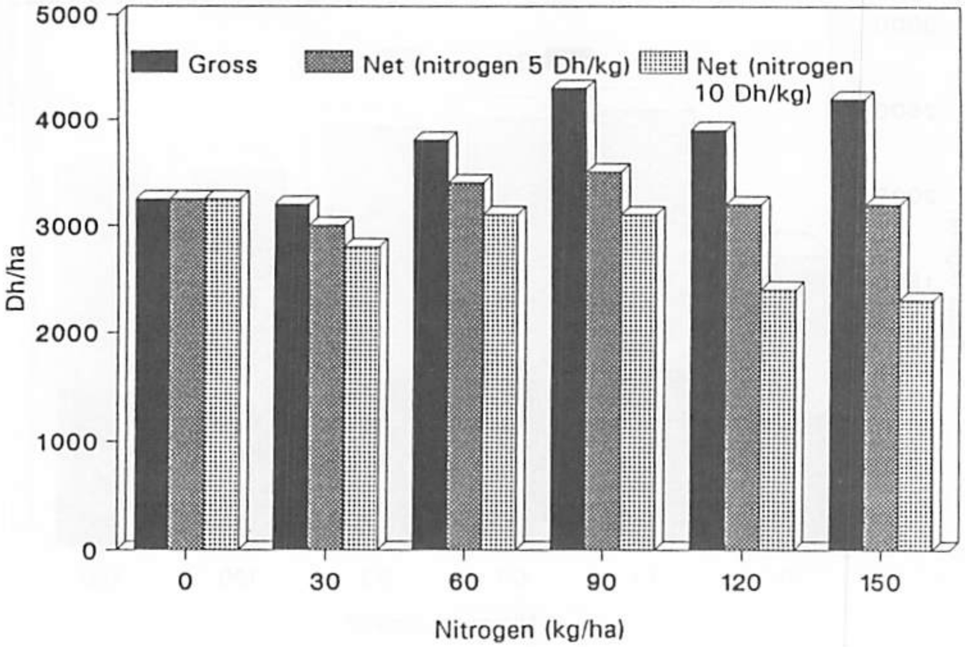

Fig. 6. Gross and net revenues from barley resulting from nitrogen costs of 5 and 10 Dh/kg, Khouribga, Morocco.

Skhour Rehamna

This was the driest of the three sites. Rainfall during the 1989/90 season was 270 mm, as compared to the mean of 280. Grain and straw yields are presented in **Fig. 7.** Maximum grain and total biomass yield occurred at the 30 kg N/ha rate.

Gross and net revenue data are presented graphically in **Fig. 8.** Net revenues at the 5 Dh/kg N price are maximum at the 30 kg/ha N rate, and a benefit/cost ratio of 2.2 would suggest fertilizing at that rate. At the higher N price of 10 Dh/kg, the maximum net revenue also occurs at the 30 kg/ha rate, but the benefit/cost ratio of only 1.4 would not justify applying 30 kg/ha. Thus, no N would be applied at the higher price.

SUMMARY AND CONCLUSIONS

Generally, N rates which produce maximum profit are lower than those which produce maximum yield. N fertilization of barley can be profitable in areas of high rainfall, and in years of high rainfall.

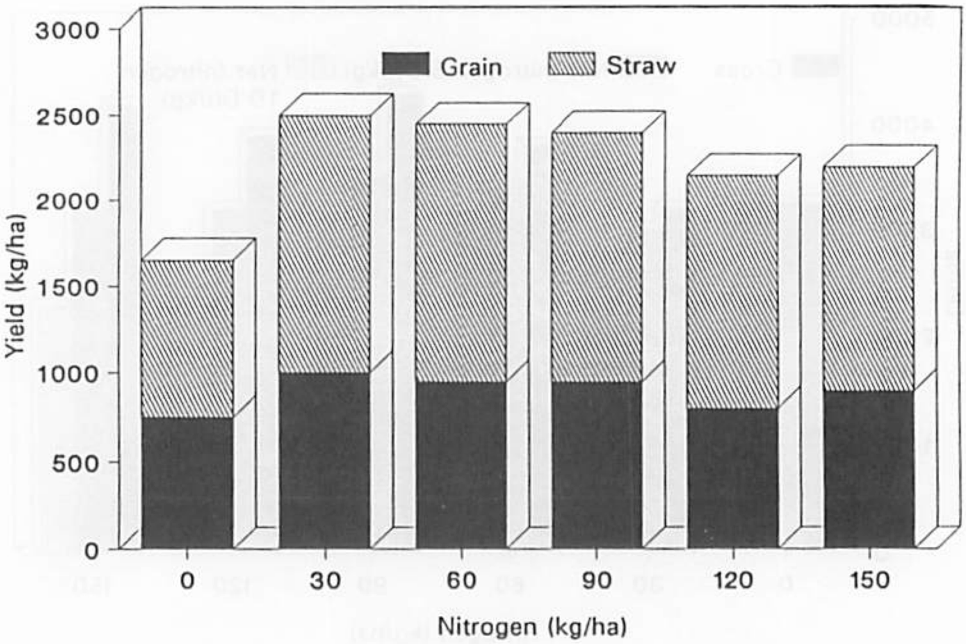

Fig. 7. **Barley grain and straw yields, Skhour Rehamna, Morocco.**

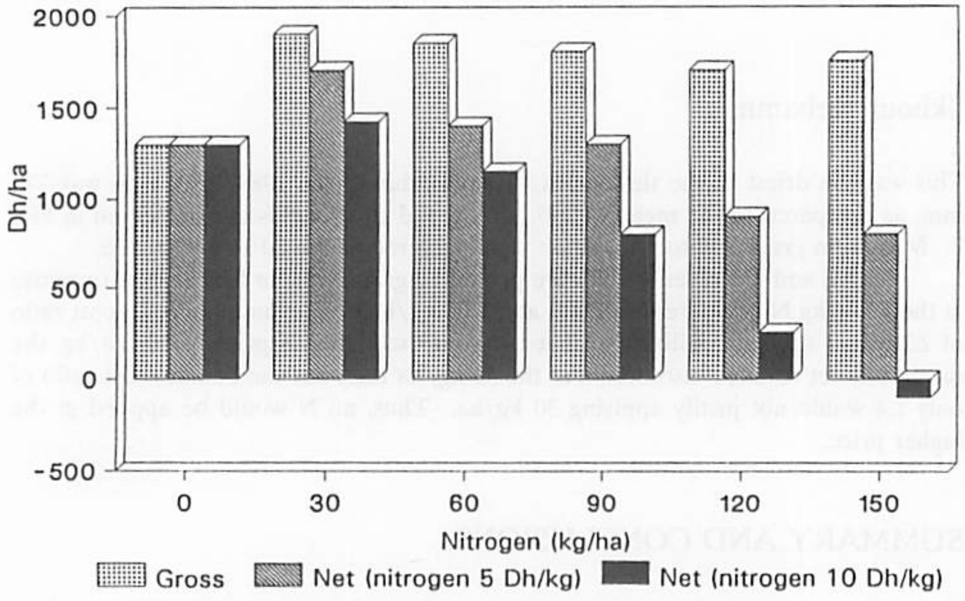

Fig. 8. **Gross and net revenues from barley resulting from nitrogen costs of 5 and 10 Dh/kg, Skhour Rehamna, Morocco.**

Even in regions where the probability of N fertilization producing a profit is high, barley producers may want to minimize their risk by applying only part of the N at planting time, and making a second application at tillering, if rainfall and other conditions justify it.

When planning further research, the following factors should be considered: 1) rainfall is variable from year to year; 2) barley yields can be depressed in low-rainfall years with higher N rates; 3) small- and medium-sized farmers typically have limited funds and/or credit for purchasing fertilizer; and 4) the largest response to N fertilizer is typically at the first increment. These factors suggest that further research should be directed at validating responses of barley to lower rates of N application under varying soil and climatic conditions.

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SECTION V

Country Reports

A Review of Fertilizer Studies of Dryland Wheat and Barley in Libya

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ABSTRACT

Rain-fed agriculture in Libya is mainly concentrated in the Western Jafara plain and the Eastern Jebel El-Akhdar region, which receive 150-300 mm and up to 600 mm of annual rainfall, respectively. The main constraints to increased productivity are poor and erratic rainfall and other climatological factors such as untimely Ghibili (a hot dry wind that blows at the time of crop maturity) and lack of adequate fertilization.

Numerous fertilizer experiments in rain-fed areas of the country have shown that crop yields can be substantially increased by applying proper levels of balanced fertilizers. Previous studies on western loamy sand soils indicated that application of nitrogen (N) at increasing rates, with or without phosphorus (P), increased yields. Similarly, P application with or without N fertilizers also increased yields. However, yield increases resulting from N applications were greater than those resulting from P application.

The opposite was found to be true in the Eastern region where P seems to be the most limiting fertility factor of the red brown clay soil, because of its high P-fixing capacity; banding ordinary superphosphate outyielded broadcasting treatments in all rates used. Potassium was also found to be limited, especially in the sandy soils of the Western region. More research is required to study fertilizer interactions with crop species and climate.

However, the results obtained to date have been valuable in understanding fertilizers' effects and in establishing an optimum practical program for fertilizer application in these regions. This paper summarizes the research activities carried out for the last 20 years on cereal production under dry farming conditions of Libya. Special emphasis is placed on fertilization trials aiming to maximize crop production.

INTRODUCTION

Rain-fed agriculture and natural rangeland are of great importance to the Libyan agricultural economy. Available land use data (ACSAD-ARC, 1988) indicate that the agricultural area occupies 3.645 million hectares or 2.03% of the total land area; out of which about 1.23 million ha is being utilized. Wheat and barley are the major cereal crops grown under rain-fed conditions, with barley occupying 71% and wheat about 21% of the area currently under rain-fed cereal production. In the dry farming areas of Libya, traditional agriculture is almost exclusively based on winter cereal monoculture of wheat in the higher rainfall areas, and barley in the less favored areas.

During the seventies, medics (*Medicago* spp) were introduced in rotation with wheat and barley, and accounted for about 9% of the cereal rain-fed area.

The climate is arid to semiarid, with an average annual rainfall of 150-300 mm in the Jafara plain and the coastal areas, and up to 600 mm in the Eastern region, being highest in the El-Akhdar mountain. Most of the rain-fed areas are located in these regions. Libyan soils are mainly of the arid to semiarid type and low in organic matter. Available P is generally low and available K moderate to high (GEFLI, 1972). Soils of the northeastern coastal region are heavy clays, and those of other regions, including the northwestern Jafara Plain, are light sandy.

The dominant factors contributing to lower crop yields are low, erratic, and poorly distributed rainfall, in addition to inadequate fertilizer use; less than 10% of the dry-farming cereals are properly fertilized. This paper summarizes and evaluates fertilizer application practices carried out to improve cereal production under dry farming conditions of Libya.

CLIMATE AND CROP YIELDS

Some of the major climatic factors affecting wheat in Libya (Seghaier, 1977) are rainfall, temperature, relative humidity, and the Ghibili (a hot dry wind blowing from the south and southwest). The two most critical periods in the life of the wheat plant (seeding establishment and seed formation) coincide with adverse climatic conditions. Little rainfall and low humidity occur at the early stages and high temperature with much Ghibili during seed formation. Winter, which is a transitional period between the two stages, receives more rain (61%) with high relative humidity and little Ghibili compared with fall and spring, which receive only 24 and 16% of the total seasonal rainfall, respectively.

Wheat and barley yields in Libya show large fluctuations over seasons. Figure 1 shows yield fluctuations over the 1975/76 to 1981/82 seasons in a representative site (El-Hera) in the Jafara plain (National Bureau for Agricultural Consulting and Studies, 1985). Most of the seasonal fluctuations in yield could be attributed to differences in climatic conditions, mainly rainfall (amount and distribution) and temperature. Mean wheat and barley yields plotted against the seasonal rainfall for the 1975-82 period (Fig. 2) indicated that seasonal rainfall is the major factor limiting cereal crop yields under dry-farming conditions in Libya. However, there is growing experimental evidence that in many cases, other factors, such as fertilizers, are effective in increasing rain-fed wheat and barley yields.

FERTILIZATION AND YIELD

The fertilizer trials that have been conducted to date dealt with applied priority problems, i.e., comparative effects of various N fertilizer sources, different application rates of N, P, and K fertilizers, time and method of application, and the importance of trace-elements in increasing yield.

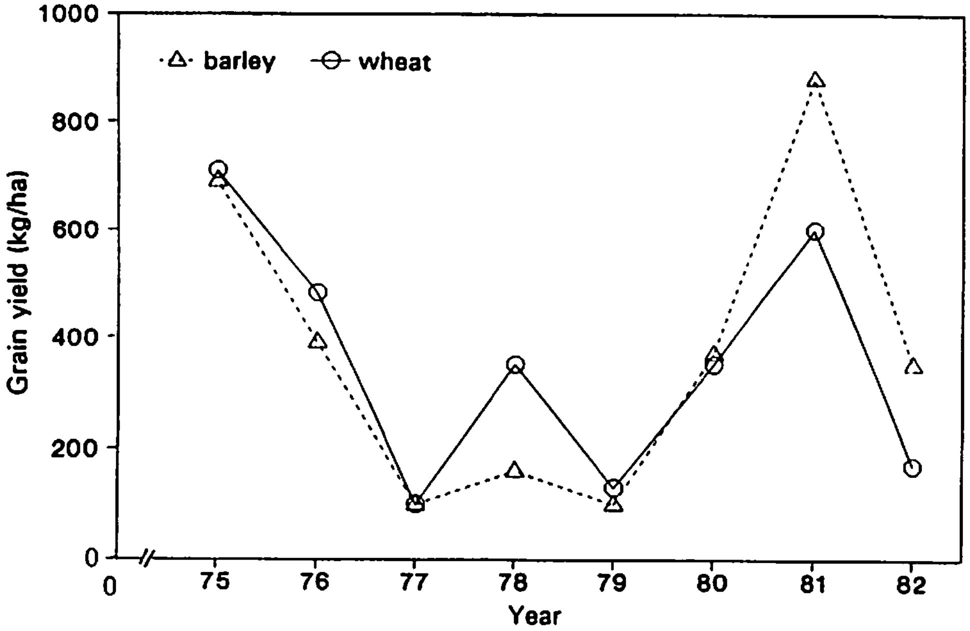

Fig. 1. Grain yield of wheat and barley during 1975 to 1982 at El-Hera in the Jafara plain, Libya (National Bureau for Agricultural Consulting and Studies, 1985).

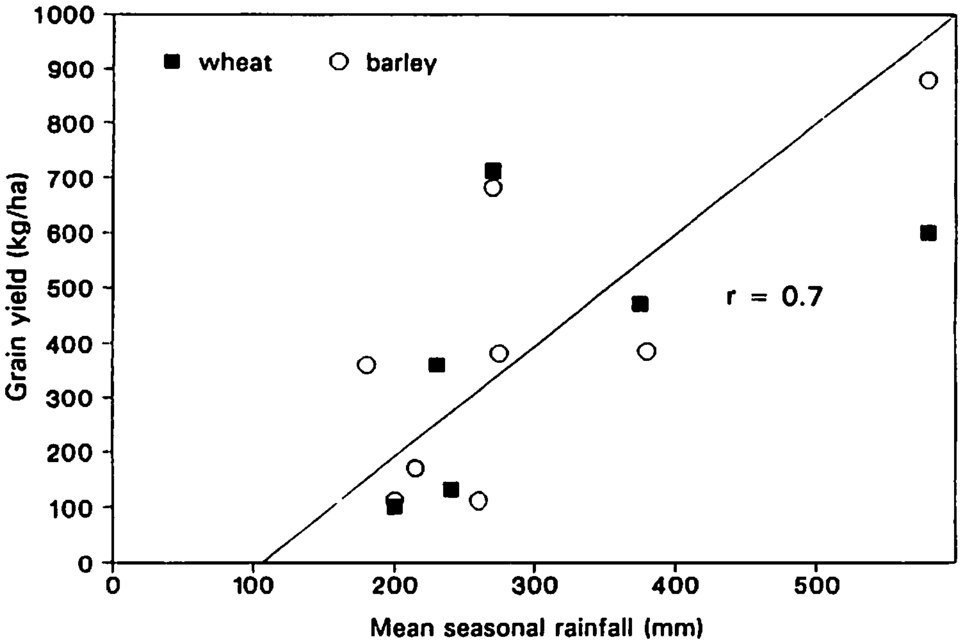

Fig. 2. Grain yield of wheat and barley as a function of estimated seasonal rainfall during 1975 to 1982 at El-Hera in the Jafara plain, Libya.

NITROGEN

Since urea is produced locally (Chaudhry and Abed, 1978), many field trials have been carried out to study urea efficiency as a fertilizer under local conditions. These studies have shown urea to be more effective than ammonium sulphate when applied on a sandy loam soil of Tripolitania (Chaudhry and Abed, 1978; Haggag *et al.*, 1979b; Salam *et al.*, 1974; 1977). However, other studies on a sandy loam soil showed no significant difference in wheat grain yield between urea and ammonium sulphate (Anonymous, 1978). Also, when applied on a red brown clayey soil at El-Marj, no significant difference was observed between these two N sources (Haggag *et al.*, 1979b).

On most Libyan soils, urea-N loss due to volatilization from surface or subsurface application does not, therefore, have a serious disadvantage over its counterpart, ammonium sulphate. In fact, losses from all N fertilizers are extremely great on alkaline calcareous, sandy soils of arid to semiarid zones; when urea and ammonium sulphate solutions were surface-applied in columns of sandy loam soils (Mattar and Doering, 1979), transformation of urea was complete after 11 days, having reached peak values in 2-4 days. Soil analysis from this experiment showed that mineral N was significantly higher in urea- than in ammonium sulphate-treated soils. Thus, the rate of urea hydrolysis may have initially limited ammonia losses. The data, though inconclusive, may explain the relative efficiency of urea in such light soils.

The advantage of using urea as a foliar application on wheat and barley at concentrations ranging from 0.4 to 9.6% was also considered (Abdelgawad and Arafa, 1974). Sprayed urea was quite effective in supplying part of the crop's N needs. Therefore the possibility of aerial spraying of urea was considered under the dry-farming conditions of large cereal projects in the western region where the soil is mainly light-textured.

Response of wheat to applied N was investigated in an experiment conducted on a calcareous, sandy-to-loamy sand soils at six locations under the cereal project in the Jafara plain. Grain yield of wheat (Gamenya) increased significantly; maximum yield was obtained when N was applied as urea at 75 kg N/ha (Fig. 2). Responses varied with location and were mainly because of differences in the quantity of rainfall received. Significant increase in yield was also obtained the following season (Anonymous, 1978).

Another experiment on sandy loam and clayey soil (Salam *et al.*, 1979) showed that N application at increasing rates gave a significant increase in grain yield (about 100% over those receiving no N) on the light soil. On the heavy soil, however, N did not result in any yield increase. On the same clayey soil of El-Marj, a pronounced grain yield increase, was obtained as a result to N application, reaching 2.92 t/ha at 30 kg/ha (Amer *et al.*, 1979a). Similarly, increases in grain and straw yields were obtained at rates up to 30 and 120 kg N/ha, respectively (Amer, 1977). However, wheat response to N fertilizer applications was inconsistent and sometimes conflicting, especially on the clayey soil of El-Marj. Further studies are therefore needed to clarify these inconsistencies.

Also, a number of field trials were conducted to find out whether splitting of N applied is advisable for rain-fed wheat. At El-Marj, grain yield decreased with splitting of N at rates of 45 kg/ha or less, while it increased with splitting at the 60 kg N/ha rate (2.82 vs. 2.28 t/ha). At Tajoura, split N had no significant effect on yield at any rate (Haggag *et al.*, 1979a). These findings are in agreement with those obtained at Abu Aisha (sandy soil) and Jandouba (loamy sand soil) in the Jafara plain (Anonymous, 1978; Haggag and Salam, 1977), which suggests that, in general, split N has no effect on grain yield, and that maximum yield is obtained when N is all applied at sowing.

PHOSPHORUS

The low available P in most Libyan soils has been considered in numerous trials. On the Jafara soils (Anonymous, 1976), four out of six locations responded to increased P rates; maximum wheat grain yield was obtained at 30 kg P/ha. Lack of response at the other two locations could be attributed to higher available soil-P content (8 ppm Olsen-P vs < 5 ppm Olsen-P in the responding locations). A similar trend was observed the following season at the same locations, though the response was less significant. The inadequacy of basal N might have limited the P response (Anonymous, 1978). However, the difference in yield response to P fertilizer was more pronounced on the heavy (clayey) than on the light (sandy) soils, the fact that was attributed to a lower soil-P value (1 ppm) in the former, as compared to that of the latter (10 ppm). Thus, using earlier data (Anonymous, 1976; 1978; Salam *et al.*, 1979), the categorization of available-P status of similar calcareous soils in other parts of the world may be applicable here, i.e., less than 10 ppm (sodium bicarbonate-extractable P) would indicate a need for P fertilization.

The degree of P fixation on different Libyan soils was clearly demonstrated in a number of studies. In a laboratory experiment (Amer *et al.*, 1979b) involving 14 soil samples collected from different locations, the percentage of P fixed by these soils ranged between 5.95 and 54.7. Fixed P correlated strongly with the clay content of these soils ($r=0.79$). However, the correlation with $CaCO_3$ was not statistically significant. In another laboratory experiment involving 32 soil samples (Rasheed *et al.*, 1977), the percentage of P fixed ranged from 30 to 75 of the added P. Clay, free iron oxides, organic matter contents, and CEC were significantly correlated with fixed P ($r=0.77$, 0.55, 0.42, and 0.79, respectively). Again, the correlation with $CaCO_3$ was not significant.

The method of P placement seems to have an effect on crops grown on such heavy soils, which are characterized by low native P and high P-fixing capacity. In a field trial conducted over two seasons at El-Marj clayey soil (Amer *et al.*, 1979b), localized P placement gave pronouncedly higher grain yields at rates up to 60 kg P/ha over broadcasting. The effectiveness of banding over broadcasting P fertilizer was further investigated on the same clayey soil (Amer, 1977). Similarly, banding at rates of 15, 30, and 60 kg P/ha outyielded broadcasting treatments by 13.8, 15.3, and 18.48%, respectively, in wheat grain yield and by 18% in straw yield for the same rates.

POTASSIUM-TRACE ELEMENTS

The lack of response to applied K fertilizers was reported by numerous workers (Abdelgawad and Mattar, 1977; Haggag and Salam, 1977; Salam *et al.*, 1979; Tabbakh *et al.*, 1974). It appeared that the high content of K (>100 ppm ammonium acetate-extractable K) available in the arid to semiarid soils meets the existing needs of cereals. Also, the need to apply trace elements has been studied at the Jafara plain (Chaudhry and Abed, 1978; GEFLI, 1972). The results have shown very little response to added Mn, Cu, Zn, or Mo, though symptoms of Mn deficiency often appeared in patches during the past growing seasons.

CONCLUSIONS

Based on the government policy, wheat is considered to be of strategic importance. This is explained by the fact that most of the fertility research has been directed at finding the proper fertilizer recommendations for wheat. Barley has been cultivated in marginal rain-fed areas, receiving less attention in this respect. The limitations to wheat production, imposed by different climatic factors, particularly rainfall, were reviewed. Also, other factors limiting crop yield were discussed in the light of fertilizer trials carried out during the last 20 years.

Initial studies, reported here, showed yield increases resulting from N and P, but not from K application, though the results are site- and climate-specific. Therefore, crop yield can be increased substantially under the prevailing conditions. Further research studies were conducted aiming to establish specific guidelines for the application of major fertilizer nutrients to Libyan soils. The approach was to correlate values of chemical analysis of nutrients, designated at "available," with actual crop yields.

Fertilizer recommendations were based on limited field trials of a maximum of two growing seasons, and therefore did not reflect seasonal and zonal climatic conditions or various soil types encountered in the vast dryland area of the country. Accordingly, the results obtained may serve as a guideline for general fertilizer recommendations advisable to some extent and for certain areas only.

In view of the inexplicable and conflicting results obtained, the need to conduct further detailed studies is evident. Sound fertilizer recommendations should be based on a 3-5 years of experimentation under different crop cultivars and variable annual rainfall. Also, a thorough climatological study, based on a zonal basis, is needed, the outcome of which would be useful in estimating yield expectations. Hence, fertilizer recommendations could be based on an expected yield level that would be reached.

Fertilizer use efficiency could be increased further by considering previous land use (crop-fallow), previous use of fertilizer or manure, soil type, and available nutrients in the soils as measured by soil tests. The possibility of using aerial spraying of concentrated fertilizer, especially in the large rain-fed areas of the government-run cereal projects, should also be considered.

In evaluating the fertilizer-use efficiency, it is important to consider residual effects, particularly with respect to P fertilizer. This will help enhance our understanding of the nutrients' behavior in the soils and their interaction with the crop, which, in turn, will help in making the fertilizer recommendations. Because of barley's adaptability to local pedoclimatic conditions and its importance as food and feedstuff, more attention should be given to assessing nutrient needs of barley.

Since less than 10% of the total dry farming area is usually fertilized, however inadequately, farmers are seldom engaged in fertility research. Therefore, on-farm fertilizer trials should be emphasized so that the experimental results can be highlighted and the economic aspects of fertilizer use clearly demonstrated. Extension services in this context should be fully exploited which will help increase farmers' income and national agricultural production. Future progress in agricultural research will depend on the cooperation between research institutions both at the national and regional level.

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DISCUSSION

N. Yurtsever

1) What is the yearly fertilizer consumption?
2) How many agricultural research institutes do you have in Libya?
3) How many soil lab. do you have?

R. Azabi

1) Consumption of fertilizer is very low.
2) We have one institution only.
3) We have a total of 12 labs.

S. Khattari

1) You mentioned that N and P are very low in the soil! How low are they?
2) Under such conditions of very low N and P, do you think that the recommended levels of N (30 kg/ha) and P (45 kg/ha) are adequate?

R. Azabi

This presentation is general and involves the work of many other workers. Detailed information regarding specific subjects will be provided in the future.

Rain-fed Cereal Fertilization in Algeria

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ITGC, Sidi Bel Abbes, Algeria

ABSTRACT

Fertilization of the major crops in semiarid regions is not well understood because of the complexity of the environment. Soil classification and diversity and the variable climatic conditions make it difficult to generalize all recommendations to a particular environment. Maximum yields for major crops are closely related to rational fertilization, considering constraints such as the rainfall distribution and nutrients deficiency in the soil. In fact, the little information available from soil and plant analyses, made in experimental trials and laboratories, make it difficult to improve the methods and recommendations specific to each type of cropping zone. Our approach involved the study and analyses of soils and climatic conditions in zones of different cropping potential, and the elaboration of adequate and maximum yield recommended for each crop and zone.

INTRODUCTION

Under a limited rainfall pattern, efficiency and profitability of cereal fertilization and method of fertilizer application are major concerns; identifying a particular formula is a difficult task. With limited moisture, the expected profits decrease irrespective of whether fertilizer is used or not. Similar trends have been observed on unbalanced soils where benefit was expected from uncertain fertilizer applications. Analytical data from the laboratory (soil and plant) and field trials are urgently needed to establish recommendation formulae for each zone. Our current research is based on soil and climatic conditions, yield components, and diagnostic surveys.

CEREAL PRODUCTION ZONE CHARACTERISTICS

The main crops in Algeria are grown in the coastal and "tellienne" zones which fall between the 600 and 300 mm isohyet from north to south. The main cereal lands are located on high and low "tellienne" plains, which are limited by the arid zone (steppe). The total area planted to cereals in 1988/89 was 3.6 million ha (RADP, 1989), out of which 1.65 m ha was devoted to barley (45%), 1.29 m ha to durum wheat (36%), 0.52 m ha to bread wheat (14%), and 0.17 m ha to oats (5%). A little less than half (47%) of the winter cereal lands is located in Wilayas (Tiaret, Oum El Bouaghi, Batna, Sidi-Bel Abbes, Medea, Setif, Tebessa, and Tlemcen) (RADP, 1989).

Soil Types

The soils are mainly calcareous, shallow with high pH (7.8 to 8.5) and low organic matter (1.2 to 2.0%). Assimilable potash is sufficient, but phosphorus levels are variable because of the limestone which exists in different forms (rocky or chalky). It is necessary to consider the balance and the standardization of these soil types.

Climate

Rainfall is insufficient and irregular, and the weather is accentuated by drought during winter and at the end of the growing cycle (**Fig. 1**). Because of the irregular climate, crops and planting dates should be carefully selected and N fertilizer cautiously applied.

FERTILIZATION JUSTIFICATION

The application of nutrient elements is influenced by several factors, including zone, rainfall, and soil type (**Table 1**), and species and crop variety (high-yielding or local); grain yield data from two new varieties (Oued Zenati, Waha) showed that these varieties outyielded the old INRAT #69 varieties by twofold [over 10 qx/ha (1000 kg/ha) compared to 5.9 qx/ha (590 kg/ha)]. Previous crop rotations (cereals/legumes/forage crops) and crop fertilization (N/P/K) are also important. Adequate fertilization should allow for acceptable profitability for a particular area. In this regard, the types of fertilizer used for the main crops in Algeria are ammonium nitrate (33.5% N) and triple superphosphate (20% P).

BASIS FOR RECOMMENDATION

Level of Crop Removal

Data dealing with nutritional elements (N, P, K) under the best conditions in Algeria indicate that for each quintal (100 kg) of grain, about 2.7 kg N, 0.56 kg P, and 1.77 kg K (for wheat and barley) and 3.06 kg K (for oats) are removed from the soil. These levels are acceptable and close to international norms. Fertilizer applications were made. However, for K, crop uptake was provided for by the large amounts available in the soil.

Efficiency Level

Fertilizer efficiency was studied for N and P only (**Table 2**), since K was not applied. For N, the efficiency varied according to the crop, i.e., it was twice as much for barley

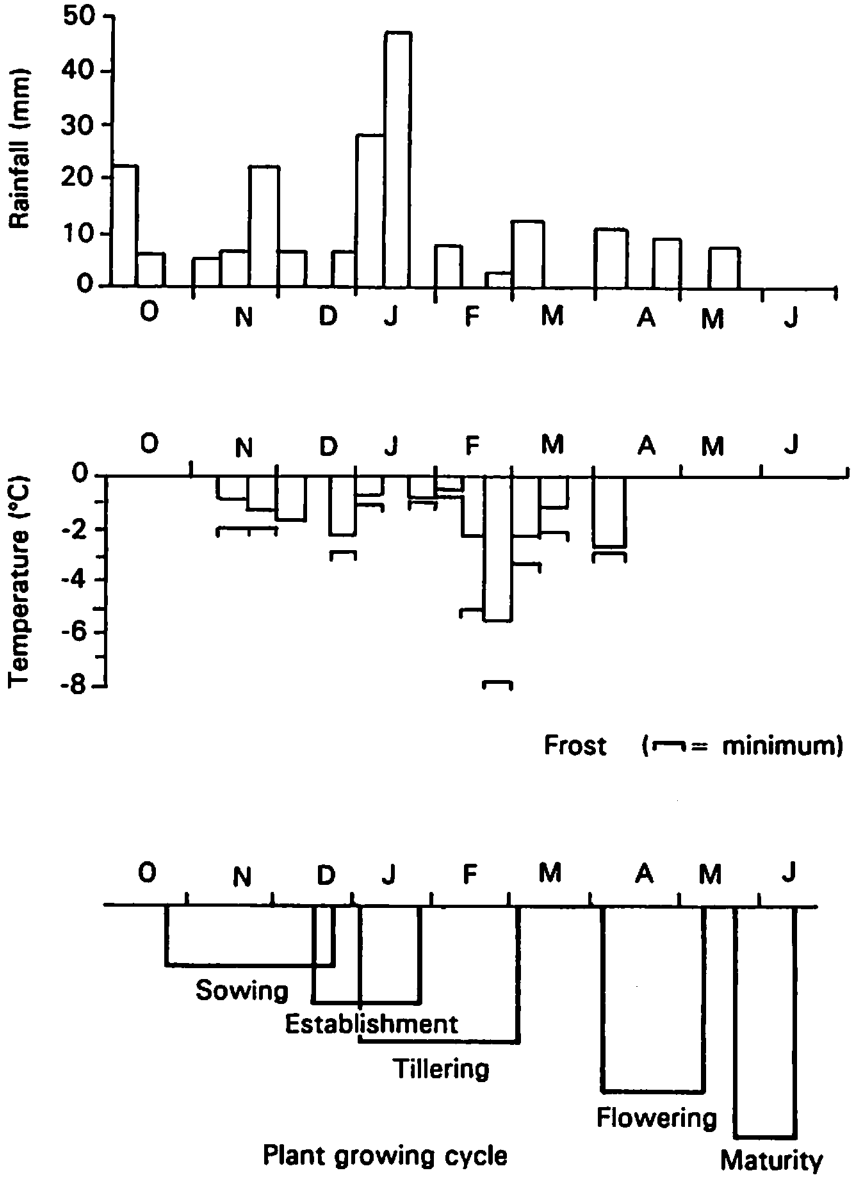

Fig. 1. Relationship between monthly climatic conditions and plant growing cycle.

Table 1. Cereal-growing agroclimatological zones, Algeria, 1988/89.

Zone	Characteristic	Location
1	< 600 m, rainfall > 500 m rainfall > 500 mm, heavy soils depth > 60 cm, nonfreezing, low drought risk.	Plain of Blida, Mitidja, Skikda, and Annaba
2	altitude < 600 m, rainfall 400 to 500 mm, medium to heavy soils, depth 30 to 60 cm, low freezing risk, light freezing risk.	Oran, Mostarrem, Sidi Bel Abbes North, Mascara, Chleff, El-Khemis, Medea North and Center, Bouira, Mila, Constantine, and Guelma
3	altitude > 600 m rainfall 400 to 500 mm, medium to heavy soils, depth 30 to 60 cm, freezing risk.	Tlemcen North, Sidi Bel Abbes, Tiaret Center and North, Setif and Oum-El-Bouaghi, Medea South Bouira, Mila, Constantine, and Guelma
4	altitude > 600 m rainfall 300 to 400 mm, light soils, depth <30 cm, much frost, high drought risk.	South of: Tlemcen, Tiaret, Setif, and Oum-El-Bouaghi, Batna and Tébessa.

Table 2. Fertilizer efficiency[1] for three cereal crops grown in Algeria, 1988/89.

Crop	Mean grain yield (qx/ha)	Efficiency (%)	
		N	P
Durum wheat	10.1	30	9.4
Bread wheat	17.9	53	17.0
Barley	24.7	70	23.8

[1] Fertilizer use per ha = 33.5 kg N, 20 kg P.
Source: ITGC.

as for wheat. The average fertilizer efficiency was 30% for durum wheat, 53% for bread wheat, and 70% for barley. It is noted that under favorable rainfall conditions, barley performs better in terms of fertilizer use, considering the crop removal level, followed by bread wheat.

RECOMMENDATIONS

Recommendations relative to fertilizer rates for the high-rainfall zones are summarized in Table 3. These are based on the following criteria: potential average yield of the zone, average crop removal level (kg nutrient elements/qx grain). For N, a correction coefficient was used because of the predominant calcareous soils in the cereal zones. For example, in zone A, where the expected yield is 20 qx/ha (2000 kg/ha) and the crop's N removal 3 kg N/qx, the applied rate is 60 units of N, i.e., 2 qx (200 kg) of ammonium nitrate (33.5% N). For P, the rate applied is 20 x 1.4 x 3 = 84 kg P_2O_5 [nearly 2 qx (200 kg) of triplesuperphosphate, 46% P_2O_5]. The correction coefficient (3) is used in order to account for chemical reversion arising from the influence of calcareous soils and assimilation problem.

DISCUSSION

The fertilization system should consider the edaphic and climatic conditions of a region, as well as the various technical and cultural practices (mono- or polyculture). Valuable results were obtained in the experimental stations, which were considered relatively reasonable. The results obtained in relation to seed production in an environment which is not well managed (Table 1), were variable. However, studying durum wheat and barley agrosystems in the region of Sidi Bel Abbes (4 zones), which involved producers' environments, a linear correlation was found between elements of soil fertility and yield components, taking into account soil characteristics and fertility contents for each zone (Table 1). Thus, the effects of environmental factors on yield and its components were evident. Fertilization and soil balance under rainfed conditions are serious factors that should be taken into consideration. Adequate N fertilizer application and good vegetative cover according to yearly rainfall are other important aspects to be maintained. Also, it is necessary to consider the correlation between environmental factors and rational fertilization (Tables 3 and 4), because neglecting one might jeopardize the other.

Table 3. Fertilizer recommendations for cereal crops according to zone, Algeria, 1988/89.

	Before seeding		Seeding	Tillering
Zone	P	K	N	
	(qx/ha)			
> 500 mm	1.5-2.0	0.5	1.0	1.0
400-500 mm	1.0-1.5	0.5	0.5	1.0
< 400	1.0-1.5	0.5	0.5	0.5

P as TSP (20% P); N as ammonium nitrate (33.5%); and K as potassium sulfate (50%).
Source: ITGC.

Table 4. Crop nutrient removal, Algeria. 1988/89.

Crop	Yield (qx/ha)	Fertilizer contribution (kg/ha)			Nutrient uptake (kg/ha)			Nutrients per qx grain (kg)		
		N	P	K	N	P	K	N	P	K
Wheat	27	66	90	0	78	16	47	2.88	0.6	1.74
Barley	22	33	45	0	57	11	40	2.6	0.5	1.2
Oats	29	66	90	0	83	18	89	2.86	0.6	3.06

Source: ITGC (1986/87).

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Rainfall Amount and Distribution in Relation to Cereal Response to Fertilizers

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ABSTRACT

In semiarid regions, rain-fed wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) yields are largely dependent on rainfall and its distribution. Under such conditions, the contribution of total rainfall to yield components is well characterized; the effects of rainfall distribution are less clear. field trial data for seven seasons (1980-88) in northern Jordan were used in stepwise multiple linear regression to determine the contribution of total and monthly rainfall, and nitrogen and phosphorus fertilizer rates to wheat and barley grain yield. Wheat yield depended first on December rain, followed by total seasonal rainfall , and then the amount of nitrogen fertilizer. For barley, total rainfall was the most predictive variable, followed by January rainfall and them the amount of applied Phosphorus fertilizer. The relatively lower sensitivity of barley's yield to rainfall distribution can be attributed to its greater drought tolerance compared with wheat.

INTRODUCTION

Although the total area of Jordan is 9.26 x 10^6 ha, only about 7.3% of that area is cultivable (0.68 x 10^6 ha). During the period 1974-1985, the average agricultural area was 275 x 10^3 ha of which 234 x 10^3 ha was cultivated under a rain-fed regime. In spite of its predominance (85% of the agricultural area), the rain-fed-managed area received less government investment compared with the remaining 15% representing the irrigated area. This can be attributed, partly, to the high economic risk characterizing rain-fed agriculture (Mitchell, 1986). In this context, the most important element embodied in the risk factor is the erratic manner of the annual rainfall and its distribution.

Under the above conditions, crop yield cannot simply be expressed as a function of N and P application rates or even their availability to plant unless other environmental factors are maintained at adequate levels. This, of course, is hardly attainable under the rain-fed agriculture. Unfortunately, research activity in Jordan has been focused on testing responses of different wheat and barley cultivars to N and P application rates. Data collected are limited mainly to grain and straw yields, weight of 1000 seeds, and plant height at maturity. Moreover, the data are usually statistically analyzed to test significant treatment differences.

Overlooking other environmental factors known to substantially affect plant development and performance may lead to erroneous and, occasionally, contradictory conclusions. For example, soil moisture deficiency can hasten maturity, shorten the grain-filling period, and, thus, reduce dry-matter production of winter wheat (Hang and Miller, 1983). Wheat is sensitive to drought stress during the reproduction stage (Fischer and Maurer, 1978). Subsequently, one may or may not observe an anticipated response to N or P if plants were subjected to undetected drought stress at a given phenotypic stage.

This study is a preliminary attempt to elucidate the significance of two environmental factors (annual and monthly fractional rainfall) on the response (grain yield) of wheat and barley to different application levels of N and P fertilizers. Both crops were cultivated under the rainfed agricultural conditions in Maro (wheat) and Ramtha (barley) in northern Jordan.

MATERIALS AND METHODS

Two rainfed randomized complete block field experiments were carried out for seven successive seasons at Maro (1980/81 to 1987/88, except 1981/82) and Ramtha Experiment Stations (1980/81 to 1987/88 except the 1986/87 season) to study the response of wheat (Horani and Deir-Alla-2 cultivars grown in Maro) and barley (Deir-Alla-106 cultivar grown in Ramtha) to variable levels of N and P fertilizers.

The Maro field experiment comprised four application rates of N (0, 40, 80, and 120 kg/ha) and P (0, 20, 40, and 80 kg P_2O_5/ha), with four replications. The Ramtha field experiment comprised a fixed application rate of 10 kg N/ha for the 1981-88 seasons. Five N rates (0, 10, 20, 40, and 80 kg/ha) were used only in the 1980/81 season. Phosphorus application rates (0, 20, 40, 60, 80, 120, and 160 kg P_2O_5/ha) were maintained constant over all seasons. The experiment involved seven replications, except in the 1980/81 and 1987/88 seasons where there were four replications.

For both sites, and before every growing season, composite surface soil samples were collected to determine particle-size distribution (pipette method), moisture retention characteristics, total N (Dewis and Freitas, 1970), and $NaHCO_3$-extractable P (Olsen *et al.*, 1954). During the course of the two experiments, conventional agricultural practices, including soil tillage and weed control, were adopted. At the end of each season, the crops were harvested and grain yield was measured. Also, rainfall data for each rainstorm were reported.

A stepwise multiple linear regression analysis was employed using Microstat program (Ecosoft Inc., 1978-85). For the Maro experiment, the dependent variable of grain yield obtained from each replication was considered as a function of the following independent variables: application rates of N and P, total rainfall (mm/yr), and monthly fractional rain falling from October to May. Such a functional relation of the 13 variables produced 523 cases. Concerning Ramtha Experiment station, the

N application rates were not sufficient to be included in the regression analysis. Subsequently, only 12 variables were used, which comprised 286 cases.

RESULTS AND DISCUSSION

Yield of rainfed cultivated wheat and barley fluctuates in accordance with the annual rainfall fluctuation. For example, Harmsen (1986) utilized long-term data from Syria to show that grain yield of wheat was linearly associated with that of barley which, in turn, was linearly dependent on seasonal rainfall. With respect to Jordan, El-Sherbini (1979) used data recorded over the period 1960/61 to 1974/75 to show that wheat yield depends linearly on annual rainfall. El-Sherbini's model for the Irbid area was:

Yield [kg/Donum (0.1 ha)] = 28.9 + 0.23 rainfall (mm/yr)

Because of such a dependence, grain yield of wheat and barley (both crops occupy 80-90% of the rainfed area planted to field crops) is expected to fluctuate from year to year. For example, during the successive nine seasons of 1978/79 to 1986/87, average wheat and barley grain yields were 677 and 493 kg/ha, respectively. The previous standard deviations correspond to respective coefficients of variation (CV) of 41 and 52%. The higher CV for barley grain yield reflects the fact that barley is always cultivated in areas receiving annual rainfall lower than that pertaining to the areas allocated to wheat. Since the CV for annual rainfall increases with increasing aridity (Linsley, Jr. *et al.*, 1981), that for barley yield is expected to be higher than for wheat.

Statistical analysis of rainfall during the course of the study on Maro (Table 1) and Ramtha (Table 2) experiment stations is presented. The CV for average annual rainfall on Ramtha (217.3 mm/yr ± 24.6%) is higher than that for the average

Table 1. Total rainfall and monthly rainfall distribution at Maro Agricultural Experiment Station, 1980-88, except for 1981/82, northern Jordan.

Season	Total rainfall (mm)	Rainfall distribution							
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
		%							
87/88	472.7	1.7	1.3	20.1	20.5	26.9	26.8	2.7	0
86/87	512.8	3.5	33.2	18.2	14.3	8.9	21.4	0.5	0
85/86	329.6	2.7	3.2	12.9	25.2	27.8	9.2	14.8	4.1
84/85	351.9	4.8	9.5	13.6	5.1	58.4	5.9	2.7	0
83/84	339.9	0.6	10.3	4.5	26.9	7.6	30.7	19.3	0
82/83	532.1	0.6	10.5	5.4	24.6	37.6	16.2	3.8	0.9
80/81	386.3	4.9	2.6	38.1	23.8	12.2	11.7	6.7	0
Mean	417.9	2.7	10.1	16.1	20.1	25.6	17.4	7.2	--
SD	85.9	1.8	10.9	11.3	7.8	18.3	9.3	7.1	--
CV (%)	20.6	66.7	107.9	70.2	38.8	71.5	53.4	98.6	--

Table 2. Total rainfall and monthly rainfall distribution at Ramtha Agricultural Experiment Station, 1980-88, except for 1986/87, northern Jordan.

Season	Total rainfall (mm)	Rainfall distribution							
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
		%							
80/81	181.3	1.9	1.5	40.5	13.3	27.5	9.9	5.3	0.0
81/82	168.9	0.0	17.5	5.8	20.2	25.0	18.5	8.6	4.3
82/83	274.2	2.5	15.6	5.7	20.1	32.7	19.1	4.3	0.0
83/84	191.1	0.0	11.4	4.8	26.2	8.0	41.6	8.1	0.0
84/85	244.5	3.7	13.2	12.6	4.1	56.2	7.0	3.3	0.0
85/86	165.4	3.9	4.2	6.7	18.7	32.4	14.8	11.4	7.9
87/88	295.4	2.4	2.2	18.2	31.0	26.8	19.3	0.0	0.0
Mean	217.3	2.1	9.4	13.5	19.1	29.8	18.6	5.8	1.7
SD	53.4	1.6	6.6	12.9	8.7	14.3	11.2	3.8	3.3
CV (%)	24.6	76.2	70.2	95.6	45.5	48.0	60.3	65.5	188.2

annual rainfall on Maro (417.9 mm/yr ± 20.6%). Although this represents a relatively short-term observation, it still conforms with the long-term trend of increasing CV with increasing aridity, e.g., 637 mm/yr ± 30%, 338 mm/yr ± 39%, and 42 mm/yr ± 52% for rainfall data pertaining to Ajlun (north), Madaba (middle), and Ma'an (south), respectively (Qasem and Mitchell, 1986).

In addition to total rainfall, other hydrological factors may play a significant role in determining wheat and barley yield. For example, one may add distribution, intensity, and duration of rainfall as the most important variables influencing crop yield. Moreover, rainwater use efficiency by plants depends on soil capacity to hold that water and on stability of soil aggregates, particularly at the surface. The latter factor is especially important since poor aggregate stability induces crust formation and subsequently reduces rainwater infiltration rates and increases soil erosion (Shainberg and Letey, 1984).

With respect to Maro (very fine, montmorillonitic, thermic, Entic Chromoxerert) and Ramtha (fine, montmorillonitic, thermic, Entic Chromoxerert) soils, their texture was clay. The silt and clay contents of the two soil samples were 41.8 and 43.4%, and 33.4 and 54.9%, respectively. Although these soils have similar texture, their moisture retention characteristics were different (Fig. 1); the Maro soil had a higher water-holding capacity at both low and high moisture tensions. This observation is especially important since it determines the soil capacity to retain rainwater and, subsequently, facilitates greater drought avoidance by plants.

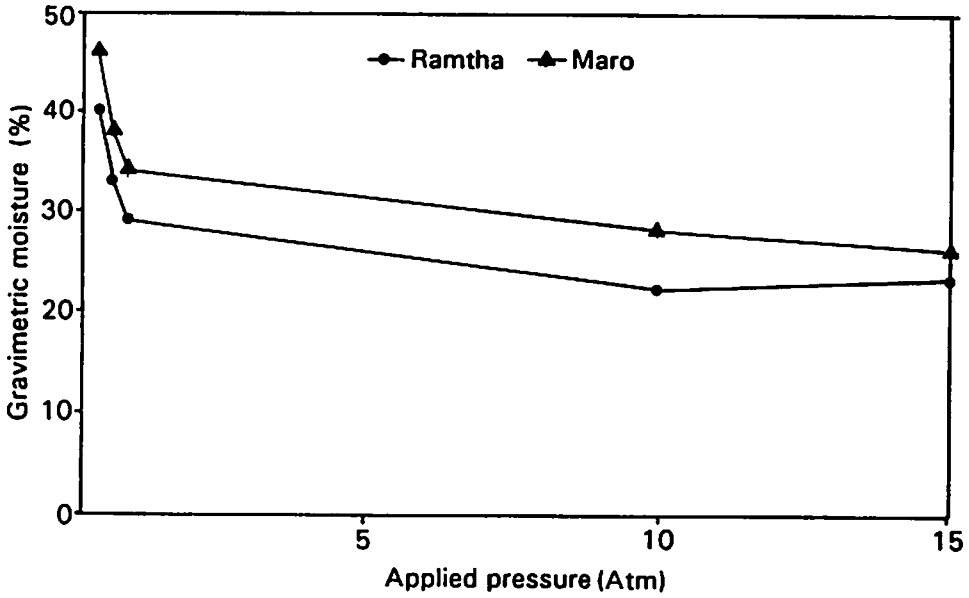

Fig. 1. Soil moisture characteristics of the two agricultural experiment stations in northern Jordan.

Wheat Grain Yield

Results of the stepwise regression analysis showed that wheat grain yield from Maro was first dependent on the fractional rainwater falling in December:

$$Y = 121.13 + 622.28[\text{Rain}]_D \text{ ...... } (r = 0.404)$$

This conforms with the previously outlined moisture retention characteristics of that soil (Fig. 1). However, next in significance to grain yield was the total annual rainfall (mm/yr):

$$Y = -205.56 + 699.50[\text{Rain}]_D + 0.78[\text{Rain}]_T \text{ ...... } (r = 0.527)$$

The dependence of grain yield on the above two variables slightly improved (multiple "r" value increased from 0.404 to 0.527). However, for both equations, the regression analysis of variance showed significant F values at probability levels smaller than 1% (zero or very close to zero). Such a significant relation continued when N application rate was introduced to the functional relation:

$$Y = -238.17 + 699.53[\text{Rain}]_D + 0.78[\text{Rain}]_T + 8.12[N] \text{ .... } (r = 0.542)$$

Although the above relationship shows a slight improvement in the dependence of grain yield on the three variables, the contribution of N application rate to grain yield is, obviously, low. For example, the increase in grain yield in response to the addition of urea at a rate equivalent to 100 kg/ha would be of the magnitude of 40 kg/ha. This is extremely low compared with the price of the urea applied.

Slight improvement in the value of multiple "r" continued with the further introduction of the fractional rainwater falling in April:

$$Y = -188.88 + 627.43[\text{Rain}]_D + 0.59[\text{Rain}]_T + 8.07[N] - 353.29[\text{Rain}]_T \text{ .... } (r = 0.549)$$

The former relationship indicates a negative response to the increasing fractional rainfall occurring late in the growing season. This is actually true since increasing the fractional rain of April will be at the expense of the early rainwater necessary for wheat germination and development.

Only two more independent variables (fractional rain for October and January) were further introduced and caused a slight increase in the multiple "r" to a common value of 0.559. Consequently, the most meaningful and representative functional relationship would be the one which entails the fractional December rain, total rainfall, and N application rate.

It is especially important to note the unimportance of P application rates in the functional relationship. This may be attributed to the relatively high levels of the $NaHCO_3$-extractable P (>8.5 ug/g soil) as shown in Table 3. According to Matar *et al.* (1988), rainfed cultivated cereal crops may not respond to P fertilization if the $NaHCO_3$-extractable P exceeds 10 ug/g soil. In fact, based on work in Morocco (Soltanpour *et al.*, 1989), the former level may be reduced down to 5 ug/g soil as a critical level separating responsive from nonresponsive soils for a relative wheat yield of 90% under the rainfed conditions.

Barley Grain Yield

Among the 11 independent variables used in the regression analysis, total rainfall was the most important parameter affecting barley grain yield in the Ramtha area:

$$Y = -212.17 + 1.76[\text{Rain}\}_T \ldots (r = 0.745)$$

The correlation coefficient was significant at the zero probability level. In fact, the "r" value is much greater than the multiple "r" corresponding to the full model describing wheat grain yield in Maro. This can be attributed to the local practice of cultivating barley in more arid areas and, subsequently, grain yield would be more responsive to increasing total rainfall. Second in significance to grain yield was the fractional

Table 3. Total N and $NaHCO_3$-extractable P for both station soils at the beginning of each field experiment, 1980-88, northern Jordan.

		Season							
Station	Parameter	87/88	86/87	85/86	84/85	83/84	82/83	81/82	80/81
		(mg/g soil)							
Maro	Total N	32.0*	19.0*	600	200	600	200	-	500
	$NaHCO_3$-P	10.4	9.4	8.5	10.0	9.5	10.0	-	9.5
Ramtha	Total N	-	-	500	500	500	600	800	560
	$NaHCO_3$-P	7.9	-	3.5	3.2	5.5	8.5	7.0	4.0

* Only NO_3- and NH_4-N measured for these years.

rainfall in January:

$$Y = -307.97 + 1.80[\mathrm{Rain}\}_T + 469.09[\mathrm{Rain}]_J \;.... \;(r = 0.816)$$

The above model shows a slight improvement in the "r" value. However, here, fractional rainfall in January becomes more significant. Such a variation in yield response to total and fractional rainwater between wheat and barley may be explained in terms of the greater drought tolerance of barley in comparison to wheat. In addition, early rainfall would be of minor significance to the more drought-tolerant barley growing in the Ramtha soil with relatively lower water-holding capacity (Fig. 1).

Next in importance is the P application rate:

$$Y = -327.10 + 1.80[\mathrm{Rain}]_T + 469.78[\mathrm{Rain}]_J + 2.65[P] \;.... \;(r = 0.825)$$

The above model shows a minor and, perhaps a nonsignificant, role of P fertilizer irrespective of the relatively low initial available soil-P content (Table 3). This may be explained by the overwhelming effect of total rainfall in comparison to the other independent variables. The introduction of fractional rainfall for April had a negative effect on grain yield and slightly increased the "r" value to 0.831:

$$Y = -110.80 + 1.07[\mathrm{Rain}]_T + 517.54[\mathrm{Rain}]_J + 2.56[P] - 1043.39[\mathrm{Rain}]_A$$

The concentration of annual rainfall in April would, obviously, have a negative effect. Because "r" value has slightly improved, and the concentration of rainfall in April is rare, the best model describing barley grain yield would be the one that comprises the total and fractional rainfall of January and P application rate.

In conclusion, the results showed that total and fractional rainfall in December were the most important parameters affecting wheat grain yield cultivated in Maro. However, the total and fractional rainfall for January were the most important factors affecting barley grain yield at Ramtha. The former findings were extracted from limited data. Therefore, further improvement in the above conclusion would be expected under better conditions, including:

1) More consistent wheat and barley field experiments that involve improved experimental design and fertilizer treatments.
2) Additional field observations made on factors such as plant growth development, leaf-water potential measurements, tissue analysis for major nutrients, changes in soil moisture, and fractional rainwater entering the soil profile.
3) More climatic data collected, such as air temperature, onset of chilling, and heat stress, particularly, during the spring season.

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DISCUSSION

M. Badraoui

How is the December rain measured in the regression equations?

T. M. Abu-Sharar

In fraction of total rainfall, not in mm of rain.

M. Abdel Monem

Did you correlate the response of N and P fertilizers to the total amount and distribution of rainfall?

T. Abu-Sharar

This correlation is included in the model.

J. Ryan

You referred to deep percolation as a loss mechanism. In view of our total rainfall and small rainfall events at any one time, could you comment on the significance of this loss mechanism for the Mediterranean rain-fed region?

T. M. Abu-Sharar

Excellent question for which we have no answer at this time! We need rainfall distribution data along with soil moisture measurements. This should be considered in future trials in the region.

A. Gharbi

Why did you include N application in the wheat model when in the barley model you included P application?

T. M. Abu-Sharar

Because P data were the only available data for barley while for wheat both P and N data were available.

L. Bousselham

1) How can we explain the importance of December rainfall for wheat and January rainfall for

barley? Is there any relation with stages of growth?
2) Did you try in the models "December rainfall + January rainfall" as a variable?

T. M. Abu-Sharar

1) This is related to moisture characteristics of the soils used.
2) Using bimonthly rainfall may be tried.

L. Moughli

1) For multiple regression, coefficients of determination should have been reported instead of the coefficients of correlation.
2) In order to compare the importance of different variables in the model, it is advised that variables are weighted by dividing the values of different variables by their mean for example.

T. M. Abu-Sharar

1) All the statistical analyses including coefficients of determination have been obtained.
2) This has also been considered in the study.

Response of Wheat to Nitrogen and Phosphorus in Rain-fed Areas of Jordan

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ABSTRACT

Data were obtained from three agricultural experiment stations representing different rainfall zones in Jordan. The experiments were conducted during the 1989/90 season, when different nitrogen (N) and phosphorus (P) rates were applied on wheat. Response to N was common, while response to P occurred only where soil $NaHCO_3$-P was less than 10 ppm.

INTRODUCTION

Jordan is mainly an agricultural country. Although the area available for agricultural cultivation is only 13% of the total land area, and the actual cultivated area is only about 6%, roughly 40% of the manpower of Jordan is involved in agricultural activities. Wheat is the most strategic crop in Jordan; however its production is not sufficient because of the increase of population (3.5%) and low, fluctuating rainfall. There is a big gap between local production (100,000 tons) and consumption (about 500,000 tons).

To meet the demand, the Government has made concerted efforts to increase wheat production by all available means, of which fertilization is one. Starting in 1986, Jordan began cooperating with ICARDA in conducting fertilization trials to improve wheat production in rain-fed areas.

In 1989/90, six trials were conducted at three agricultural research stations in different locations representing different rainfall zones: Maro (north, 350-450 mm); Mushakkar (central, 300-400 mm); and Rubbah (south, 250-350 mm). The objective of these trials was to determine wheat requirements of nitrogen and phosphorus in different rainfall zones.

MATERIALS AND METHODS

The soils were similar at all three experimental sites, i.e., Vertic Chromoxererts and very fine montmorillonitic and thermic with 1% slope. Available potassium was high at all stations, i.e., over 450 ppm at Mushakkar, and about 300 ppm at the other two sites. Soil $CaCO_3$ varied from about 23% at Rubbah to 13% at Mushakkar and 3-4% at Maro. The annual rainfall differed widely, being highest at Maro (432 mm) and just above 300 mm at the other two stations. Seasonal rainfall distribution followed a similar pattern (Table 1) for all stations, with the maximum generally in January.

The experimental design was a randomized complete block with one factor (N or P rates). The varieties used were "Horani-27" at Maro, "Deralla-2" at Mushakkar, and "Horani-Nawawi" at Rubbah. Spacing between plants at the three stations was 17-18 cm. Planting date was 5 Nov. at Maro, 28 Nov. at Mushakkar, and 21 Nov. at Rubbah. The plants were harvested on 17 June at Maro, 28 June at Mushakkar, and 20 June at Rubbah (Table 2).

For the N-requirement trials, six N rates (0, 20, 40, 60, 80, 100 kg/ha) were applied at planting time as urea. One absolute control treatment received no fertilizer. For the P-requirement trials, six P rates (0, 30, 60, 90, 120, 150 kg/ha) were applied as triple superphosphate along with 60 kg N/ha as urea. Both trials received blanket treatments (kg/ha) of the following: 10 Fe-sequestrene, 20 Zn as $ZnSO_4$, 30 Mn as $MnSO_4$, and 10 Cu as $CuSO_4$. The plants were harvested on June 17 at Maro, June 28 at Mushakkar, and June 25 at Rubbah.

RESULTS AND DISCUSSION

Nitrogen Requirements of Wheat

Rainfall was the greatest determinant of yield for all trials. At Maro, where rainfall and yield were highest, response to N applications was significant at the 1% level for the treatment 80 kg N/ha, compared with the control and the blanket control. No significant responses were detected among N treatments, despite the fact that increasing N rates did increase the yield.

Table 1. Rainfall distribution (mm) at three agricultural experiment stations, Jordan, 1989/1990.

Date	Maro	Mushakkar	Rubbah
Oct. 1989	7.0	4.0	0.8
Nov. 1989	27.6	6.8	2.9
Dec. 1989	43.2	30.0	14.9
Jan. 1990	161.3	95.1	95.6
Feb. 1990	63.9	77.9	60.2
Mar. 1990	90.0	48.5	50.7
Apr. 1990	39.2	51.7	97.3
Total	432.2	314.0	322.8

Table 2. Cultural practices, treatments, and soil test values at three agricultural experiment stations, Jordan, 1989/90.

Parameter	Maro	Mushakkar	Rubbah
Variety	Horani-27	Deralla-2	Horani-Nawawi
Fertilization and sowing	5 Nov.	28 Nov.	21 Nov.
Harvest date	17 June	28 June	20 June
Added N (kg/ha)	0, 20, 40, 60, 80, 100	0, 20, 40, 60, 80, 100	0, 20, 40, 60 80, 100
Added P (kg/ha)	0, 30, 60, 90, 120, 150	0, 30, 60, 90, 120, 150	0, 30, 60, 90, 120, 150
Previous crop	Wheat	Wheat	Wheat
Olsen-P (ppm)			
N trial	5.3	5.7	7.6
P trial	4.5	7.4	7.0
N trials			
$N-NO_3$ (ppm)	28.9	21.3	15.4
$N-NH_4$ (")	14.6	11.3	11.5

At Mushakkar, rainfall during the season was 314 mm and yield was low. Responses to N were significant at the 1% level for the treatments 60, 80, and 100 kg N/ha (Table 3), compared with the control and the blanket control. No significant response was noted for other N treatments.

At Rubbah, total rainfall during the season was 322.8 mm, and yield was low. The response to N fertilizer was significant at 1% for the 100 kg N/ha treatment, compared with the control and the blanket control. No significant response was observed for the other treatments (Table 3).

Phosphorus Requirements of Wheat

Response of wheat to P under our soil conditions depended on the level of soil $NaHCO_3$-extracted P. The response occurred only when the available P was less than 10 ppm.

At Maro, three treatments responded significantly (at the 1% level) to P applications, compared with the absolute control and the blanket control (Table 4). These were 90, 120, and 150 kg P/ha. No significant difference in responses was noted among P treatments.

At Mushakkar, responses to all the P treatments were significant at the 1% level, compared with the control. Responses to the 120 and 150 kg P/ha treatments

Table 3. Nitrogen fertilization of wheat at three agricultural experiment stations, Jordan, 1989/90.

Treatment (kg/ha)	Maro	Mushakkar	Rubbah
	-------------------------	(tons/ha)	--------------------------
Control[1]	2.6 b	0.9 b	1.2 b
Control[2]	2.3 b	1.0 b	1.4 b
20	2.9 ab	1.3 ab	1.5 ab
40	3.6 ab	1.5 ab	1.4 b
60	3.5 ab	1.8 a	1.5 ab
80	4.4 a	1.6 a	1.6 ab
100	3.8 ab	1.9 a	1.8 a
LSD (1% level)	1630	600	473
C V (%)	24.1	20.4	15.6

[1] No fertilizer.

[2] Blanket treatment.

Means with same letters are not significantly different.

Table 4. Phosphorus fertilization of wheat at three agricultural experiment stations, Jordan, 1989/90.

Treatment (kg/ha)	Maro	Mushakkar	Rubbah
	------------------------	(tons/ha)	--------------------------
Control[1]	2680 b	1030 c	1180 b
Control[2]	3320 ab	1480 bc	1550 ab
30	3460 ab	1930 ab	1590 b
60	3570 ab	1810 ab	1800 ab
90	4170 a	1960 ab	1890 ab
120	3770 a	2010 a	1770 ab
150	3900 a	2070 a	1860 a
LSD (1% level)	948	515	627
C V (%)	13.1	14.4	18.7

[1] No fertilizer.

[2] Blanket treatment plus N.

Means with same letters are not significantly different.

were significant, compared with the blanket control. However, no significant difference in response was detected for the other P treatments (Table 4).

At Rubbah, only 150 kg P/ha treatment had a significant effect (Table 4), compared with the absolute control and the blanket control. No significant differences in response were found among the other P treatments.

CONCLUSION

From the results obtained over several years at different agricultural experiment stations in Jordan, we recommended adding N at rates of 80 kg/ha in the northern area, 60 kg/ha in the central area, and 100 kg/ha in the southern area. As for P, the recommendation is to add 90 kg/ha in the northern area, 120 kg/ha in the central area, and 150 kg/ha in the southern area.

Conclusions and Recommendations

During the last session of the workshop, a general meeting was held to discuss and evaluate the achievements accomplished in the Agadir workshop and in previous workshops of the Network on Soil Test Calibration (NSTC) in the WANA region. The future of the Network was a major concern of the workshop, during which further work was recommended on the following topics:

1. Through cooperation among the national scientists, a lot was achieved in the region through NSTC, however, more still needs to be done to maintain the viability of the NSTC in the future.

2. Confidence in the phosphorus test (Olsen-P) was developed. However, some improvements in this test need to be made through more basic research.

3. The nitrate nitrogen ($_{NO3}$-N) test for cereals is not mature yet. It requires further study before it can be generalized and used by farmers of the region. National and ICARDA scientists were urged to fulfill these studies that involve N mineralization in soils in relation to moisture and temperature, fertilizer-use efficiency, interaction between soil moisture and N use, etc.

4. Determination of critical levels of nutrients in the soil should not be the only goal of the NSTC. Other goals should include the development of fertilizer recommendations based on soil testing, and the promotion of fertilizer-use efficiency.

5. To more efficiently attain the goals of the NSTC, biometrician, modelers, agricultural economists, and extension workers should be involved in the Network activities, including the planning of experiments; economic assessment of results; development of fertilizer recommendation models (using all soil, climate, and crop data collected by participants); and testing models at farm level by extension workers in pilot areas.

6. Soil testing and plant analysis procedures in WANA need to be further standardized. ICARDA should continue to exchange reference soil and plant samples with various laboratories of the WANA region to improve quality control.

7. The NSTC should encourage governmental agencies and the private sector to establish laboratories for soil and plant analyses.

8. Suggestions by several participants were made to the NSTC to accommodate fertilization studies and calibration of other nutrients--e.g., micronutrients, sulfur, and potassium--and other field crops and trees, where supplemental irrigation is used.

9. It was suggested by Dr John Ryan that ICARDA, as coordinator of the NSTC, should initiate a newsletter to improve the flow of information among participants to the Network and inform on major relevant research in the world.

10. On behalf of the Network participants, ICARDA was kindly requested to send a letter of appreciation and thanks to donor agencies (UNDP, IMPHOS, and IDRC regional office) which had sponsored NSTC activities.

11. It was proposed by several scientists that all the NSTC participants should follow the guidelines of joint experiments in the future to obtain a more homogeneous data set for the region.

12. As coordinator of the NSTC, and through its contacts, ICARDA is requested to prepare, on behalf of the region, a proposal for funding the NSTC for the coming 5 years (1991-96).

13. To further promote the level of cooperation among countries of the Mediterranean region, soil fertility researchers from Spain, France, Italy, and Greece should be invited to participate in future workshops.

14. More long-term experiments in the region should be encouraged to determine the maintenance rate of fertilizers needed to optimize crop production without any waste of fertilizers.

15. Modelers should be invited to assess the data collected during the last 5 years through NSTC activities, and any other data sets on fertilization available in countries of the region. This will help produce fertilizer recommendation models for wheat, barley, and other dryland crops.

16. The NSTC should grow and evolve; while continuing to focus on research, it should serve an educational function as well and increasingly focus on technology application.

17. It was suggested that an active steering committee could effectively assist the ICARDA Coordinator in promoting NSTC activities and goals.

18. A motion expressing appreciation to Dr. A. Matar for his work as coordinator of the Network was proposed by Dr. J. Ryan and enthusiastically endorsed by the participating scientists.

The workshop did not consider the funds needed to effectively implement these proposals. However, it was recognized that the success of the new work would depend on close collaboration between soil fertility scientists, economists, agronomists, agro-climatologists, and others.

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