# SOIL TEST CALIBRATION IN WEST ASIA AND NORTH AFRICA

Proceedings of the Third Regional Workshop
Amman, Jordan, 3-9 September 1988


John Ryan
Abdallah Matar

editors



ICARDA

International Center for Agricultural Research in the Dry Areas

# Soil Test Calibration in West Asia and North Africa

Proceedings of the Third Regional Workshop
Amman, Jordan, 3-9 September 1988

*Editors:*
John Ryan (MIAC, Settat, Morocco)
Abdallah Matar (ICARDA, Aleppo, Syria)

# Contents

Address by the Director General of ICARDA

Mr Minister of Agriculture,
Mr Rector of the University of Jordan,
Mssrs the Deans of Faculties of Agriculture,
Teaching staff,
Participating soil scientists from North Africa and West Asia,
Ladies and Gentlemen,

It gives me pleasure that the Third Symposium of the Regional Soil Test Calibration Network is being held in Jordan and that it is being attended by representatives of as many as 11 countries that constitute a cross section of the WANA region, from Morocco to Pakistan, and from Yemen to Turkey. In particular, I wish to single out our colleagues from Iraq and Yemen, who are with us for the first time and look forward to their full participation in the deliberations of this and future symposia. It is also gratifying that several regional and international organizations are taking active part in our work.

One of ICARDA's principal objectives in the region is to play an effective and supportive role with colleagues in the national agricultural research systems. One way of attaining this goal is to bring together—by way of symposia, workshops and coordination meetings—specialists in one discipline to share their expertise and formulate future plans for scientific cooperation.

The Soil Test Calibration Network is a good example of the role ICARDA seeks to play in the region. This network was created when soil scientists from the region's countries assembled in June 1986 to evaluate the program of rainfed crop fertilization conducted in various countries of the region, and assess the role of national soil laboratories in advising farmers on the optimal use of fertilizers. Participants recognised that the relationship between those working in the area of fertilizer application and the soil laboratories was, at best, weak. In consequence, soil laboratories in most of the countries within our region have not been able to achieve the desired benefits from the findings of fertilizer field experiments, and their contribution in providing fertilizer recommendations to farmers was generally inadequate. It was, thus, imperative that the necessary conditions for a more effective mechanism to ensuring appropriate fertilizer policy and approach be created. In this effort, a closer cooperation between fertilizer specialists and soil laboratory workers appears a necessary first step.

One of the results of the first symposium was the decision taken by participants to conduct joint fertilizer experiments on prevalent field crops, and establish reliable correlations between the results obtained and soil analysis. At the second regional symposium, held in Ankara, Turkey, in September, 1987, the similarity of the results obtained confirmed a broad uniformity in the responses to fertilizers obtained across the countries of the region and underlined the importance of pooling information in speeding up their research processes and agricultural development.

On this occasion, I would like to assure you that ICARDA shall spare no effort to maintain the momentum of this and other research networks and continue to support them with all the means available to it in the service of all the countries of the region.

In closing, we thank Jordan for hosting this symposium, and H.E. the Minister of Agriculture for according it his patronage. We are also indebted to our colleagues at the Faculty of Agriculture, University of Jordan, for sharing with us the task of organising this gathering. In the name of you all, we express our gratitude for their good welcome and unstinting generosity.

I wish you success in your deliberations.

Nasrat R. Fadda
Director General

**Acknowledgements**

Grateful thanks are due to Ms. Jouhayna Issa, ICARDA, for her valuable editorial assistance, and for her unstinted efforts in seeing this volume through the various stages of production.

Thanks are also due to the following staff of MIAC and ICARDA: Mr. A. Dan Mileski and Ms. Sossi Ayanian for wordprocessing; Mr. Mohamed Zaki, Ms. Sinam Youssef, and Ms. Zuka Istanbulli for their assistance in the preparation of the final draft; and finally Mr. Zakaria El-Etek and Mr. Abdul Rahman Hawwa for their assistance in the layout.

## Executive Summary and Conclusions

Having received results of soil test calibration studies from the various national programs and having discussed the scope, functions and role of the Soil Test Calibration Network, the Workshop arrived at the following conclusions and recommendations for action under three broad categories:

### Practical Application

1. The critical P value of 5 to 7 ppm P (Olsen $NaHCO_3$) was confirmed as being valid for countries of the North Africa - West Asia region.

2. Banding of P was considered more efficient than broadcasting, especially at low soil P levels; this is the Network's recommendation where drills are used. The Network further encourages the adoption of grain drills with capability for banding fertilizers.

3. Nitrogen fertilization is essential under most cropping conditions, except perhaps where a cereal follows a previous legume crop.

### Researchers

4. Scientists in cooperating countries were encouraged to use single element experiments rather than factorial ones; these are easier to conduct, involve less resources and are more appropriate to field conditions where N and P deficiencies do not occur at the same site.

5. The Network strongly urged delegates to have all proposed experimental sites sampled and analyzed for P and $NO_3$ before planting; experimentation should not take place where test levels for these elements are considered adequate, since no response is likely to occur.

6. In view of the delegates' concern about soil test variability within experimental sites, it was recommended that, at minimum, three composite samples be taken per replicate, and at maximum, a composite sample should be taken from each plot.

7. The meeting confirmed the general usefulness of the Olsen $NaHCO_3$ procedure as an index of available P in countries of the region; however, research arrived at improving soil testing or using other procedures was welcomed.

8. In view of the inconsistency in results obtained with $NO_3$ as an index of available N in wheat grown under dryland conditions, researchers were encouraged to continue their quest for as N

availability index as a basis for N fertilizer recommendation; and to continue searching for reliable model that could be used for N recommendations to farmers.

9. While the major focus should continue on N and P in dryland farming conditions, the importance of other elements, especially Fe and Zn, should not be ignored.

10. In view of inexplicable and conflicting results, detailed studies in the following areas were encouraged:

    i. impact of soil moisture on P placement efficiency,

    ii. organic matter in relation to soil mineralization potential, and

    iii. the dynamics of P in soils.

**Future Meetings**

11. The next Network meeting was scheduled for spring 1991. Morocco was considered a suitable venue. The Moroccan delegation warmly welcomed this proposal.

12. National delegates were exhorted to review their countries' findings in soil test calibration for the next Network meeting.

13. The Network welcomed the proposal that a special symposium be held on the general topic of soil fertility and soil test calibration at the American Society of Agronomy Meetings in San Antonio, Texas in October 1990. Delegates were encouraged to plan for a significant contribution of countries of the region to this international meeting.

**General Appreciation**

The Network unanimously and enthusiastically adopted a proposal to thank the following for their contribution to a successful workshop:

His Excellency, the Minister of Agriculture in Jordan,
The President, University of Jordan,
The Director General of ICARDA and
UNDP representative (as sponsors).

Thanks to Dr. John Ryan for accepting the major responsibility of editing the papers presented.

A special appreciation was extended to Dr. Abdallah Matar for coordinating the Workshop and making it a rewarding and enjoyable experience for all the delegates.

# AN OVERVIEW OF SOIL TESTING

F. E. Khasawneh

Jordan University of Science and Technology,
Irbid

## ABSTRACT

This article identified the various concepts of soil test calibration and its importance in relation to soil testing in general. It concludes in identifying factors that affect soil test calibration data as well as the constraints that impinge upon.

## INTRODUCTION

The subject matter of this workshop emphasizes the calibration aspects of soil testing. A brief review of the proceedings of the second regional workshop held in 1987 in Ankara, Turkey, reveals that much of the attention then was focused on calibration data related to N and P tests in the semi-arid region, and particularly on the $NaHCO_3$-extractable P and on nitrate N in the top 60 cm of soil.

Soil test calibration, however, represents one aspect of an overall soil test program. As Welch and Wiese (1973) pointed out, this is but one of four components which must be integrated together to form a successful soil testing program. These four components are educational, analytical laboratory operation, research to provide correlation and calibration data, and interpretation and recommendations. All these sectors need to develop simultaneously in order to achieve a beneficial soil testing program.

Before leaving the introductory part, it is necessary to point out a significant divergence in trends. As soil testing begins to take hold in the ICARDA region, the service is typically offered and promoted by the public sector, such as government and/or universities. This trend is expected to continue, even though the recent and current trend in the developed world is for soil testing to move from public to private laboratories. The impact of this trend will be discussed later.

## THE IMPORTANCE OF CALIBRATION

There is an enormous volume of field research and correlation data behind any successful soil testing program. The importance of this statement cannot be over-emphasized, especially for newly established programs, as is the case in many developing countries. The usual scenario consists of rapid adoption of the analytical methods of soil testing developed elsewhere, while the background data of calibration and correlation needed for proper and consistent interpretation of chemical test results are usually meager, if existent at all. A compounding factor in this is that there is no short-cut to the acquisition of data, which should be accumulated over a number of growing seasons and covering a multitude of permutations in crops, varieties, soil types, climates, and a number of other relevant factors. This requires many years of painstaking and dedicated work.

The task of refining the calibration of soil testing by an on-going program of field correlation studies, therefore, is not a one man effort, but rather a task that must be planned and implemented by a group of dedicated field research people. The nature of this work belies the futility of separating the task into two categories, one assigned to chemists in their air-conditioned laboratories, and the other to field agronomists toiling in the hot sun. Sometimes the separation is inadvertent and not intentional, but equally disastrous, especially when these tasks reside in two administratively separate units.

## THE DEFINITION OF CALIBRATION

The term calibration as related to the subject matter of this workshop is rather broad, and needs to be accurately defined. In this context, the meaning that readily comes to mind relates to the process of defining a relationship between the soil test result and the quantity of a fertilizer nutrient that should be added. This, however, is a protracted concept of calibration. But before we explore other meanings of this term, we have to grant the following basic assumption :

a. Field sampling has been executed in such a manner that the chemical test data on the soil samples collected do represent the nutritional status of the field unit for the particular crop under consideration.

b. Soil samples have been handled en route in a manner that conforms to the specific requirements set by soil test laboratories.

Because there is a multitude of variations in the chemical processing of soil samples, the term "Soil test calibration" may include, in addition to the above-mentioned meaning, one or more of the following :

a. Correlating soil test data obtained on samples collected from a restricted layer of the soil profile to data from a larger segment of the profile. Often a researcher may collect samples from the top 5 cm of soil, while another may choose the top 15 cm, and a third may choose an even thicker segment; such data need to be cross-indexed to be more useful.

b. Correlating test results obtained with one extracting reagent to those obtained with another? This is notoriously true for testing, since there are a number of extractants that have been used, and each is backed with a great deal of field work (Kamprath and Watson, 1980). Such calibration work is needed when dealing with data from various countries such as in a workshop like this.

Modifications of an established extractant, e.g., the $NaHCO_3$ reagent to the ammonium bicarbonate - DTPA reagent necessitates some cross-calibration. Another form of calibration work includes the relating of soil test data to plant response data as measured in pot experiments. The cross-correlation work which relates soil test data to leaf and plant tissue analysis is yet another form. While each of these is legitimate calibration work, the most relevant definition of calibration is that which was mentioned first, namely the relating of plant response in field experiments to results of soil testing.

## FACTORS AFFECTING SOIL TEST CALIBRATION DATA

In general factors which limit plant growth have a profound effect on the interpretation of soil test data. This is especially true in semi-arid dryland farming. Some of these factors are :

a. Moisture regime

When the amount of precipitation in a locality is insufficient, crop growth is reduced. Soil may not respond to fertilizer additions if native fertility is adequate to produce the crop yields permitted by the moisture regime. Response in such experiments will only reflect fluctuations in precipitation, and will complicate soil test calibration work.

b. Soil salinity

Increased soil salinity generally reduces yield potential, and therefore, confounds response to added fertilizers, and may suppress it.

c. Deficiency of certain nutrients

Micronutrient deficiency is another factor which constrains yield potential, and therefore confounds response to fertilizers. This is especially confusing when levels of certain micronutrients are marginal, such that they are adequate at low crop yield levels but result in deficiency symptoms when yield increases in response to the test fertilizer. Nutrient interaction is yet another factor which also complicates response and requires special attention in soil test calibration studies. A very good review of this was given by Adams (1980). Soil pH falls in this category of interactions.

d. Placement method of the test fertilizer

Placement effects are most pronounced with the less mobile nutrients, and generally result in higher efficiency of the test fertilizer when banded as compared to broadcast and incorporated. This, however, is further complicated by at least three other factors : native soil fertility, soil capacity to fix the test nutrient, and soil moisture patterns.

When native soil fertility is exceedingly low with respect to such a nutrient, broadcasting of low doses of fertilizer usually is better than banding. This is caused by a restriction on root proliferation and elongation beyond the proximities of the band. As native soil levels rise above such a threshold, the effect is reversed. This phenomenon is accentuated even more when the soil has a high capacity to fix the test nutrient.

The effect of soil moisture patterns is exhibited as a result of drying of the upper soil layers in semi-arid environments. Because proliferation of surface feeder roots in dry soil is limited, and because mobility of the test nutrient in dry soil is drastically reduced, the nutrient in surface soil is rendered positionally unavailable to the plant. All of these factors need to be kept in mind when planning a soil test program.

## SOIL TEST CALIBRATION - THE TASK

I have deliberately avoided, in this presentation, to enter into the details of soil testing from a purely chemical or analytical context. No doubt the recent advances in analytical tools and refinements in analytical methods have been tremendous. Also, advances in the logistics of managing a soil test laboratory have made it possible to process thousands of soil samples per week, with a throughput duration of nearly 48 hours or less. The establishment of a successful program is, therefore, not constrained by analytical capabilities. These are the easiest to transfer and can be readily acquired. The most significant constraint is the supporting correlation data from field work. This is the main topic of this workshop. It can only be accumulated in a systematic way; slowly, but surely. Team work is highly crucial in this effort. With team work and with little extra planning, many, if not most, field experiments can be utilized for calibration purposes. The task is not easy, but is surely within grasp. The list of contributions on the program is very reassuring. We are on our way, and together, with God's blessing, we shall succeed.

**REFERENCES**

Adams, F. 1980. Interactions of phosphorus with other elements in soil and in plants. In F. E. Khasawneh, E. C. Sample, and E. J. Kamprath (ed.). The role of phosphorus in agriculture. Amer. Soc. Agron., Madison, Wisc.

Kamprath, E. J., and M. E. Watson. 1980. Conventional soil and tissue tests for assessing the phosphorus status of soils. In F. E. Khasawneh, E. C. Sample, and E. J. Kamprath (ed.). The role of phosphorus in agriculture. Amer. Soc. Agron. Madison, Wisc.

Welch, C. D., and R. H. Wiese. 1973. Opportunities to improve soil testing programs. In L. M. Walsh, and J. D. Beaton (ed.). Soil testing and plant analysis. Soil Sci. Soc. Am., Inc., Madison, Wisc.

# SOIL AND FERTILIZER PHOSPHORUS STUDIES IN LEBANON

J. Ryan

American University of Beirut; Beirut, Lebanon;
currently, MidAmerica International Agricultural Consortium,
Aridoculture Center, Settat, Morocco

## ABSTRACT

Agricultural research is relatively new to Lebanon, beginning in the early fifties with the establishment of the Agricultural Research Institute and the American University's Faculty of Agriculture. One of the earliest topics to be investigated was soil phosphorus; initial pot studies showed that most of Lebanon's cultivated soils were responsive to P. Field trials demonstrated the need for fertilizer P for most irrigated and rain-fed crops, and served as a basis for fertilizer recommendations. Where soil P levels were low, band application was more efficient. With time, the importance of residual soil P from previous fertilizer additions became apparent. Though field studies have been curtailed since the civil unrest which began in 1975, investigation of soil P continued.

The $NaHCO_3$ extraction procedure for available P was shown to be most appropriate for Lebanese soils, as it had been elsewhere for calcareous soils in general. While $CaCO_3$ has a dominant influence on P behavior in calcareous soils, laboratory studies showed that P adsorption may be influenced by soil iron oxides. Changes which take place after P fertilization were also identified. While most previous studies involved conventional P fertilizers, a recent series of experiments dealt with an experimental N-P fertilizer, urea phosphate. Indications are that this material may be suitable for use in drip irrigation systems; it apparently promotes greater P movement into the soil and improves water infiltration. However, it may induce iron deficiency in plants.

Despite the accumulated scientific data on P in Lebanon's soils, little information reaches the farmer because of an array of adverse factors : a minimal and impotent extension system, and no available or reliable soil testing services - problems confounded by infrastructure disruption. Notwithstanding such obstacles, crop production in Lebanon continues - a tribute to the Lebanese farmer's indomitable spirit and resilience nurtured through centuries of turmoil. Future progress in agricultural research will depend on cooperation between research institutions at the national and regional levels.

## INTRODUCTION

In spite of its small area, Lebanon possesses a wide range of physiography. The five major divisions include a narrow coastal strip, the west (moist) slope of the Lebanon Mountains, the east (dry) slope, the interior valley (Beka'a), and the Anti-Lebanon Mountains lying east of this valley. The physiographic pattern largely determines the diverse climatic, vegetational and land-use patterns of the country. Climatically, Lebanon is more favored moisture-wise than many neighboring countries. Precipitation on the western side ranges from 600 mm annually on the coast to 1,500 mm at the top of the Lebanon Mountains. Even the driest areas, in parts of the interior valley and the Anti-Lebanon Mountains, have 400-500 mm of rainfall. The distribution is seasonal, with a dry season from May through October.

The soils reflect the effects of topography, parent material, and climate, and show striking differences, particularly between the relatively flat coastal and Beka'a regions compared to the mountainous areas. Previous reports have described the diversity of Lebanon's soils (Clawson et al., 1971) and soil chemical and physical properties of its main agricultural area - the Beka'a Valley (Sayegh and Salib, 1969). The distribution of Lebanon's soils has been described in a reconnaissance map (Geze, 1956) and in a detailed map of south Lebanon (Verheye, 1973).

Accelerated erosion is widespread and severe over a high percentage of the hilly lands. On the west side of the Lebanon Mountains especially, the soil has been removed down to the parent limestone on many slopes, giving the appearance of a new, raw landscape to one that is actually old and eroded. With land degradation a pervasive endemic problem, some site-specific studies were conducted to address this issue of national importance (Ryan, 1982a,b) along with efforts to highlight its economic and social implications (Ryan, 1983a,b). As the benefits of fertilizer use are more immediate and visible than erosion control and soil management strategies, the major focus of soil research has been with nutrient behavior and assessment of crop nutrient needs.

In view of its complex chemistry and crucial importance for crop production, phosphorus has, from the earlier days of agricultural research, been the major focus of soil fertility studies after nitrogen. Despite the avalanche of published reports on P (e.g., Khasawneh et al., 1980), the complete story of P is not yet told. The past two decades have seen increasing research attention on soils of arid and semi-arid regions (Dregne, 1976) and on P in such areas (Ryan, 1983a,b). Not surprisingly, soil and fertilizer P attracted the attention of researchers in Lebanon; a more detailed assessment of the overall soil fertility program has been presented elsewhere (Ryan and Hamze, 1987). A brief description of the agencies involved, and the context in which agricultural research in Lebanon took place, is pertinent.

Most of the agricultural research in Lebanon has been at the Faculty of Agriculture at the American university of Beirut (AUB), a private institution founded in 1866. Established in 1952, the history, programs, and management of the Faculty have been described by Ryan (1982a,b). A major asset to its applied field research program has been the acquisition of a 100-ha experimental station in the Beka'a Valley - the Agricultural Research and Education Center (Sleiman et al., 1988). This development coincided with the founding of the State-sponsored Institute of Agronomic Research at Tel Amara, also in the Beka'a Valley, with other sub-stations at Kfardane, Terbol, Abde, etc. While in the Soils Division was centered at Tel Amara, fertilizer trials took place at the other stations as well (FAO, 1969; Shammas, 1966). Given the unfortunate events that have occurred in Lebanon since 1975, and which paralyzed public institutions, agricultural research by the Institute has effectively ceased. Agricultural research is currently carried out almost exclusively at AUB, frequently with funding from the National Council for Scientific Research. A fledgling Faculty of Agriculture has recently been established at the Lebanese University.

## EARLY STUDIES

In the early years of agricultural research in Lebanon, few commercial fertilizers were used, a situation which was not radically different from that obtained in developed countries of the West. What fertilizers were applied were in the organic form : manure from goats, chickens, and cattle (FAO, 1969). While such materials may physically benefit soil structure, their fertilizing value is variable and has little impact on crop growth compared with inorganic fertilizers, when used at normal or acceptable application rates (Ryan et al., 1985c). These materials were primarily used on irrigated cash crops and with olives; dryland crops received little if any manure. As P deficiency is extensive in semi-arid soils (Dregne, 1976), it was not surprising to find that, with no prior fertilizer use, most Lebanese soils were low in available P.

Initial trials with a range of diverse soils in pots revealed a consistent response to P fertilizer. In a greenhouse study of Adams and Sayegh (1955) using 33 soils, virtually all were highly responsive to P. In another pot study by the Institute (FAO, 1969), all eight soils responded to applied P; their $NaHCO_3$-P levels ranged from 6 to 10 ppm. This study demonstrated the importance of applying adequate N in order to get the maximum effect of fertilizer P. Similarly, the study of Fuehring and Abi-Antun (1968) of soils from both Lebanon and Syria underlined the widespread response to P. In each of those studies, the degree of P deficiency varied with soils - not surprisingly, since the amount of native P available in soils is related to a host of factors, such as parent material, calcium carbonate, iron oxides, texture and degree of weathering (Ryan and Zghard, 1980; Ryan et al., 1985a).

An awareness of the dramatic crop responses to N and P was a major factor in the rise in fertilizer use by farmers in the late 1950's and early 1960's. This increase was reflected in fertilizer use statistics. For example, in 1965, total consumption was eight, three, and two thousand tons of N, P, and K, respectively; this averaged respective application rates of 40, 15, and 10 kg $ha^{-1}$ for these elements, which were used mainly on irrigated land.

## FIELD STUDIES

The growing interest in inorganic fertilizers provided the impetus to the establishment of field trials to reflect prevailing climatic, crop and soil conditions. A series of field crop trials reported by the Institute (FAO, 1969; Shammas, 1966) invariably showed increases due to N and P, but rarely due to K. Though site - and climate-specific, the studies at AUB's Agricultural Research and Education Center (AREC) considered aspects of P response for the major crops of economic importance. Most of this research was based on student theses and summarized as follows by Ryan et al. (1980).

Various field studies at AREC have stressed the need for P fertilizers for sugar beets. These recommended that P fertilizer be applied according to a soil test. Where test data were not available, 300 kg $P_2O_5$ $ha^{-1}$ was recommended where little or no fertilizer was applied previously, and 150 kg where fertilizer had been continuously used. Similar recommendations were made based on studies with potatoes. The significance of balanced nutrition, i.e., P along with N for potatoes was also stressed.

The responsiveness of a crop to P fertilizers depends on the type of crop, nature of the soil, fertilizing history and management. Phosphorus was recommended at a rate of 200 kg $P_2O_5$ $ha^{-1}$ for irrigated forage crops, vegetables, and soybeans, and at 60 kg for dryland forage crops. The importance of adequate P fertilization has been convincingly demonstrated for corn at AREC, with the generally recommended rate of 200 kg $P_2O_5$ $ha^{-1}$ for optimum yield.

In trials with small grains from 1958-1963, 50 kg $P_2O_5$ $ha^{-1}$ was used for four dryland wheat varieties and 200 kg for irrigated wheat. Subsequently, 140 kg $P_2O_5$ was used for optimum yield of irrigated Mexipak wheat. However, considerable variation has been shown with respect to crop responses. Addition of P had little effect on wheat yield in 1967 and, in fact, tended to reduce grain yield in 1968, in contrast to the effect on corn in an adjacent plot which showed a significant increase.

This points to variation in the levels of available P in individual plots due to different previous fertilizer treatments and, thus, different levels of residual P. Consonant with this viewpoint, recommended P fertilization of sugar beet was based on a soil test; the soil test values based on the Olsen test were marginal. Thus, there was probably adequate P without fertilization, and no response could have been expected. Besides, wheat is one of the least responsive crops to P application. Currently, P is applied to irrigated and non-irrigated cereals at rates of 100 and 50 kg $P_2O_5$ $ha^{-1}$, respectively. Phosphorus is generally applied with N in bands for irrigated cereals and broadcast for dryland cereals.

Though the normal field practice has been to broadcast P fertilizers and subsequently incorporate them by cultivation, several studies have shown that greater efficiency is obtained by localized or band application. However, studies elsewhere have shown that the advantage of placement over broadcast application is minimum or non-existent when levels of available P in the soil are adequate. Thus, the continued build-up of residual P in the intensively fertilized plots over the years has led to a questioning of previous application rates and methods of application, and highlighted the significance of soil testing as a basis for future fertilizing programs. Fertility build-up in soils of experimental stations for crop response, placement, and residual P studies have recently been discussed (Sleiman et al., 1988) in the context of Lebanon.

## PHOSPHORUS AVAILABILITY INDICES

Accurate and reliable estimation of nutrient element availability in soils is fundamental to fertilizer application. An effective test should reflect both the initial and the residual P availability. The Olsen $NaHCO_3$ procedure and its modifications generally give best correlation with P uptake in calcareous soils. However, there are exceptions to this generalization. For instance, there was a poor relationship between plant response and $NaHCO_3$-extractable P for a wide range of calcareous Syrian soils (Matar and Samman, 1975). Correlation coefficients became significant when the soils were classified according to physical, chemical, and mineralogical properties. These authors suggested that the comparatively low coefficients for the limestone soils may be due to variation in the nature and form of the $CaCO_3$.

Poor correlations of plant P uptake and $NaHCO_3$-P in calcareous soils might also be explained by the presence of significant amounts of Fe oxides. Presumably, extractants such as 0.3 N NaOH-0.5 N $Na_2C_2O_4$, which was the most effective of five procedures, especially in high pH soils, and which are specific for Fe-bound P forms, may be more suitable in such soils. Most Lebanese soils are calcareous, with relatively high levels of both amorphous and crystalline Fe oxides. In a preliminary study of some calcareous soils of the Middle East, Fuehring and Abi-Antun (1968) found a highly significant relationship between the decrease in plant yield from P omission and P extracted by the NaOH-oxalate method.

Other methods such as using anion exchange resin, which should more closely simulate plant uptake, merit re-evaluation in calcareous soils in view of recent encouraging results. In recent years, P behavior in soils has been studied using the Langmuir isotherm. Plant P uptake was shown to increase as the degree of saturation of the adsorption maximum increased, but P availability is negatively related to bonding energy. However, there is little or no information on the relationship between isotherm parameters and soil P test values. The objective of the greenhouse study by Ryan and Ayubi (1981) of 20 calcareous Lebanese soils was to compare the Olsen method for extractable P in relation to P uptake by wheat and tomato with the anion-exchange resin and other methods. Adsorption isotherm parameters were also considered.

Of the methods studied, only the anion exchange resin and $NaHCO_3$ methods were related to P uptake. This study highlights the use of the anion exchange resin method for the evaluation of P availability in calcareous soils. Heretofore, the $NaHCO_3$ method was generally most effective in such soils. Since its initial introduction to soil testing, this method has not been generally adopted for routine use. The results of this and other recent studies suggest a re-consideration of this method. That it was not adopted was attributed by Sibbensen (1978) to time-consuming analytical procedures. This author described the use of a resin bag procedure to overcome disadvantages of the conventional method, whereby ground soil samples are equilibrated with resin of different particle size range followed by retention of the resin on a sieve.

Effectiveness of the resin is influenced by both type and form, the relative amounts of resin, soil and water, shaking time and the nature of the equilibrating solution. While the relationship between any chemical index of P availability and crop uptake will remain tenuous, there seems to be little alternative in calcareous soils to the Olsen $NaHCO_3$ test.

## PHOSPHORUS SORPTION

Despite the voluminous literature dealing with the reactions of P fertilizers with soil and its components, this aspect of soil chemical reactions continues to tantalize and challenge soil scientists. Because of their implications for fertilizer efficiency and plant growth, soil reactions that result in decreased P solubility continue to be investigated. The concern about such adsorption-precipitation reactions ranges from the initial precipitation to longer-term reactions (Ibrahim and Pratt, 1982) and subsequent desorption. Soil factors dominating P behavior have been elucidated by studies on pure compounds with extrapolation to soil systems. Thus, adsorption and precipitation of P have been demonstrated for calcite and for Fe compounds. Consequently, in calcareous soils, solid-phase $CaCO_3$ is believed to govern P reactions, while in acid soils, Fe and Al forms dominate. However, reactivity of $CaCO_3$ is dependent on specific surface, which is related to carbonate particle size distribution, rather than to total chemically determined $CaCO_3$. Thus, P sorption characteristics of calcareous soils may not be well related to total $CaCO_3$.

In a multi-component, heterogeneous system such as soil, Fe oxides may also influence P sorption either by direct reaction, or indirectly through a modifying effect of coating the $CaCO_3$ phase. In one of the few studies addressing this issue, Holford and Mattingly (1975b) suggested that Fe present as impurities in limestone contributed to P sorption; localized adsorption of P on Fe oxide surfaces may provide P-rich nuclei for the precipitation of basic calcium phosphates. The possible occurrence of comparatively high levels of "free" or Na dithionite-extractable Fe in calcareous soils, e.g., up to 8.9 % in Holford and Mattingly's study (1975a), underlines the potential importance of this constituent for P behavior in such soils. This modifying effect may depend on the extent to which Fe occurs in the crystalline amorphous forms in soils.

Since Lebanese soils virtually all contain variable amounts of $CaCO_3$, and up to about 9 % Fe oxides (Arshad _et al_., 1980; Curtin _et al_., 1980), of which a variable portion is in the amorphous fraction (Lamaroux and Segalen, 1969), this study by Ryan _et al_. (1985a) was designed to assess the relative contribution of these constituents to P sorption. The 20 soils used varied naturally in these and other properties. These were equilibrated with P solutions of varying concentrations; adsorption isotherms were constructed from the resulting data. Sorption was correlated with soil properties. The process was repeated after the soils were chemically treated to remove Fe oxides. Similarly, adsorbed P was desorbed by successive extractions with water.

As anticipated, the amounts of P sorbed varied with soil type. However, conventional Langmuir isotherm plots were generally curvilinear, thus making it difficult to meaningfully calculate or use parameters such as adsorption maximum and bonding energy. Such curvilinearity was interpreted to reflect various phases or constituents involved in sorption. Actual loss of P from solution was significantly related to clay content and amorphous or oxalate-soluble Fe, but there was no relationship with $CaCO_3$, either total or active.

This study therefore suggests that Fe oxides, particularly the more reactive forms, have a dominant influence on P reactions in calcareous rapid removal from solution but also in the formation of less soluble compounds that are characterized by a slow dissolution rate. This influence on fertilizer efficiency in the field remains to be established. However, it may have implications for Mediterranean-type regions which have mainly carbonate-rich soils, some of which are also high in Fe oxides.

## PHOSPHORUS REACTIONS WITH TIME

The changes that occur in P-fertilized soils were addressed in a study by Sayegh and Majid (1969) using an inorganic chemical fractionation technique, and by Ryan et al. (1985b) who documented changes with time as reflected by availability indices, sorption characteristics, fractionation, and desorption.

### Inorganic Fractionation

Using two calcareous and one non-calcareous soil, Sayegh and Majid (1969) added two rates of P to potted soil and, after cropping for one season, fractionated both untreated and treated samples to examine the relative distribution of the different fractions in relation to soil type and identify the fractions which were enriched by the added P. As anticipated, the non-calcareous soil had little Ca-P but a relatively high proportion of Fe-P; the opposite was true for the calcareous soils. Similarly, differences existed with respect to the distribution of other fractions. Added P accumulated in the Ca-P fraction of the highly calcareous soil, and in the Al-P and Fe-P fractions of the others. However, no added P was found in the occluded or reductant-soluble fractions.

The concept of inorganic P fractionation has undergone considerable scrutiny in the years since that study. It is now generally accepted that the sequential extraction with various chemicals does not remove specific P compounds. Notwithstanding such criticisms, the procedure does indicate different chemical forms of P in soils and identifies relative changes in solubility with time.

**Availability - Transformation**

Phosphate reactions in soils have important implications for crop growth, fertilizer efficiency, and environmental pollution. While the commonly observed phenomenon of rapid removal of soluble P from solution in contact with soil has been exhaustively studied, much less attention has been given to the changes in soil-applied P with time. One of the earliest of such studies (Devine et al., 1968) showed that, over three years, added P was transformed from initially available metastable forms to stable, relatively insoluble forms. Such changes, over five years, were documented in a field study of calcareous soils using indices of available P and inorganic fractionation (Hooker et al., 1980). Other laboratory incubation studies dealt with the slow reaction in attaining equilibrium after P fertilization of some calcareous and acid tropical soils. The reversion rate is influenced not only by duration of P-soil contact but also by factors such as temperature, soil moisture, and the manner of incubation.

Since the rate of decrease in soluble P after soil reaction does not necessarily parallel the soil's initial P sorption capacity, the slow reaction and the resulting residual value of applied P is more relevant to crop needs over one or more growing seasons. Thus, actual plant availability of residual P should be estimated by appropriate availability indices (Bowman et al., 1978). The actual mechanisms whereby P reacts under prolonged contact with soil are somewhat unclear; postulates include migration of adsorbed P ions from original sites, occlusion of P on these sites, or slow crystal formation. The role of soil properties in relation to the slow reaction is similarly unclear; no relationship with pH, iron oxides, $CaCO_3$, organic C, or textural characteristics was apparent in Ibrahim and Pratt's (1982) study.

Though P fertilization of calcareous soils is believed to result in progressively less soluble Ca-P residues at the site of the fertilizer particle and precipitated Ca-P forms in the vicinity of the particle, such compounds may not necessarily dominate in calcareous soils rich in other P-reactive constituents such as Fe oxides. For instance, Holford and Mattingly (1975a) showed that, for a wide range of soils, varying in $CaCO_3$ from 0.8 to 24.2 %, high-energy adsorption capacities, based on the two-surface Langmuir equation, were closely associated with dithionite-soluble Fe. The sorption study of Ryan et al. (1985a) showed that actual P sorption in a range of 20 calcareous Lebanese soils was related to Fe oxides, especially the amorphous forms, rather than to solid-phase $CaCO_3$. The work of Holford and Mattingly (1975b), indicating the importance of specific surface of $CaCO_3$ in soils, may help to explain the reported variation regarding the relative importance of soil constituents in P sorption. Thus, this study of Ryan et al. (1985b) evaluated the availability and transformation of applied P in six calcareous soils containing varying amounts of Fe oxides on the basis of changes in plant available or $NaHCO_3$, changes in inorganic P fractions, relative changes in sorption isotherms, and desorption patterns of adsorbed P.

Consistent with other P-soil studies, removal of P from solution was rapid within the first 24 hours; after one day, the amounts of P extracted by $NaHCO_3$ ranged form 40 to 65 %. Subsequently, the amounts extracted at various intervals decreased consistently over the 200-day period; at the end of the incubation period, less than 25 % of the added P was extractable with $NaHCO_3$. Consistent with observations from the previous sorption study of Ryan et al. (1985a), P removal from solution was related to soil Fe as CDB-Fe; initial sorption was more closely related to the more amorphous or oxalate-soluble Fe fraction.

The desorption phase similarly indicated changes in added P in soils. As the duration of prior soil-fertilizer contact increased, the lower were the relative amounts of P that could be extracted by water. With successive water extraction, differences due to prior soil-P contact diminished. Total P recovery after eight extractions ranged from 8.3 to 40.8 % of the applied P. A relationship with soil Fe was also apparent, with the amounts of P desorbed being inversely related to CDB-Fe.

While the distribution of inorganic P reactions differed between the six soils, the apparent recovery of P decreased with increase of time of prior soil-P contact; recovery after 200 days varied from 27 to 78 % of added P. While most applied P accumulated in the $NH_4Cl$ and NaOH fractions, this varied with soil type. However, there was little P recovered in the HCL fraction, and none in the reductant-soluble fraction.

Similarly, adsorption isotherms showed changes with time consistent with those observed with the other procedures. Isotherms based on sorption with soil fertilized for 60 days were identical in slope, but moved to the right of the control soil, while soil which had been fertilized for 200 days caused the isotherms to move to the left.

This study demonstrated the dynamic nature of P in soils. Added P always decreases in solubility, however slow this process might be - years in some cases and days or weeks in others. Ultimately, metastable P compounds formed from reaction of fertilizer with soil components would decrease to the same solubility of native P minerals in the soil. The study provides a basis for explaining the observation that fertilizer P has a long-term effect in some soils and not in others. While the rate of change with time would obviously be faster in test tubes, or pots under optimum moisture conditions, the relative differences between soils in the field should remain the same.

## RESIDUAL SOIL PHOSPHORUS

With continued use of P fertilizers, various studies have documented a decreased response to P, especially in dryland agriculture (Jackson et al., 1983). The initial responses to P fertilizer led to routine AUB's AREC, liberal amounts of P were routinely used on experimental plots, especially where P was not a variable. In due course, little if any response to applied P was observed. This provided the rationale for the study of Ryan et al. (1980), who sampled all the station's experimental plots, with depthwise sampling of each soil type. The samples were extracted for various nutrient elements, including P.

In general, the P fertility varied widely with plots. There appeared to be no relationship with soil variation. Virtually all samples were well in excess of the critical level of 10 ppm. This suggests that the P fertility status of AREC had increased over the years due to annual applications of P fertilizers. Differences between plots were obviously due to different amounts of P applied to these plots. Plots which had been used in the past for intensive experimentation tended to have higher levels of available P, while other plots which were more frequently used for production had lower, though still satisfactory, levels of available P. This was particularly true for the A plots, which were mostly used for dryland farming and consequently would have received lower P application rates.

Evidence of a build-up of available soil P was also seen from the distribution of P with depth. The upper or plough layer was considerably higher than the lower layers in available P. For instance, in one plot, the topsoil value was 39 ppm, while values at 25, 50, and 90 cm were 8, 5, and 6 ppm, respectively. A similar trend was observed in plots from each soil type. Fertilizer P is normally found in the top 20 cm, which is the depth of cultivation, since it does not move readily within the soil. Thus, surface sampling from 0 to 20 cm should represent this layer.

These findings not only question the older concept of P fixation, whereby added P was mainly held by the soil and not available for the following year's growth, but also invalidate previous fertilizer recommendations. The data corroborate the currently accepted concept of residual P in soil, especially those which are calcareous (Bowman et al., 1978). This evidence suggests that previous P fertilizer recommendations can be reduced and, in some cases, omitted without any reduction in yield. Even when soil P levels are adequate, benefit can be expected from application of small amount of P, i.e., 20-30 kg $ha^{-1}$ as band applications, which have a "starter" effect in promoting root development at the seeding stage. With reduced application rates, it is important to monitor levels of available P on a yearly basis using the Olsen soil test, which reliably reflects changes in the P status of the soil. Fortunately, this test is simple, quick, and reliable for soils of the Middle East region (Ryan and Ayubi, 1981; Fuehring and Abi-Antun, 1968).

## FERTILIZER EVALUATION

The P fertilizers used for the various field trials were the same as used in commercial farming, i.e., either single or ordinary superphosphate (8 % P) or triple superphosphate (20 % P), both of which contain P in the orthophosphate form. In some studies, ammonium phosphate was used. However, in laboratory and greenhouse studies of soil-fertilizer P, reagent-grade monocalcium phosphate was used for accuracy and convenience. However, in no case was any study concerned with differences between P forms themselves. Nevertheless, developments in fertilizer technology continue to produce new experimental materials which have potential advantages over traditional forms. Urea phosphate is one such material, which is, as yet, in the experimental phase (Mortvedt and Kelsoe, 1987).

Although urea is the most common solid N fertilizer in use worldwide, it still has a number of drawbacks, i.e., seedling damage and being prone to volatile loss as ammonia when applied to calcareous soils. A new development in fertilizer technology, involving urea is the production of urea phosphate (UP). This acid or low pH fertilizer is the result of reacting urea, $CO(NH_2)_2$, with phosphoric acid, $H_3PO_4$, to produce a crystalline adduct, $CO(NH_2)_2\ H_3PO_4$. Solid UP can be applied directly or made into fluids. Adducts, or compounds thus formed, maintain the identity and most characteristics of the reactants. Urea may also form adducts with other acids, i.e., nitric ($HNO_3$) and sulfuric ($H_2SO_4$) acids.

The agronomic advantages of acid-based fertilizers have stimulated widespread interest in their use. In addition to being a good source of N and S, urea-sulfuric acid is effective in reclaiming or improving sodic soils by reducing exchangeable Na levels, and improving irrigation water quality by reducing excess bicarbonate. The acidic properties of UP have been shown to reduce seedling damage compared to urea alone. Having good physical properties and being an effective N and P source, UP has considerable potential as a fertilizer. The acid environment of the dissolving UP pellet also inhibits the urease enzyme and, as a consequence, reduces subsequent volatile ammonia loss (Stumpe et al., 1984). Aspects of its behavior, which are relevant to calcareous soils, were investigated in a series of laboratory and greenhouse studies.

## Nutrient Changes with Time

A prime concern with UP, in view of its acidity, is the effect on soil nutrient availability. Acid-forming fertilizers have been shown to enhance Mn and Zn availability, while $H_2SO_4$ alone, applied to calcareous soils, increases availability of Fe, Mn and Zn (Ryan et al., 1974) and P (Ryan and Stroehlein, 1979). However, UP, when co-granulated with soluble Fe sources, such as ferrous sulfate, may render the added Fe less soluble, presumably due to the formation of insoluble Fe-P compounds. Since UP can be applied in drip irrigation systems, and therefore involves relatively high concentrations of this acidic compound in a limited soil volume, it was not clear whether it would increase or decrease the levels of available soil micronutrients or those applied to the soil. Indeed, Westfall and Hanson (1985) found no increase in Fe or Zn, or decrease in soil pH, following addition of urea with $H_2SO_4$ and $H_3PO_4$ acids to a calcareous soil. This aspect was also examined by Mortvedt and Kelsoe (1987).

Accordingly, the objectives of the laboratory study of Ryan et al. (1986) with a highly calcareous soil were to monitor changes in pH, salinity, $NaHCO_3$-extractable P, DTPA-extractable Fe, Mn and Zn, and both $NH_4^+$ and $NO_3^-$ after application of UP to incubated soil samples. While the behavior of these Fe materials with time in soils is predictable (Ryan and Harik, 1983; Ryan et al., 1985d), their concomitant interactions with UP, which are subject to biological and chemical transformations, were not documented.

Over the 45-day incubation period, salinity increased, while pH initially increased and then decreased after 1 to 2 weeks. There was a tendency for Fe to decrease with UP treatment and for Zn and Mn to increase. The P availability from UP was influenced by concurrent addition of Fe fertilizers. The results pointed to the complex reactions and interactions when fertilizers such as UP are placed in a band with other materials. Thus, this material may affect plant nutrition and growth other than being a P source. This led to the second study, which examined possible effects of UP on Fe nutrition of soybean, on a crop sensitive to the supply of Fe in soils.

## Urea Phosphate and Fe-deficient Soybean

While an acidic material, such as UP, can potentially solubilize soil micronutrients, especially Fe, the net effect of UP on Fe is not simply a matter of dissolution of insoluble forms of these metals, as with $H_2SO_4$. This is dependent upon induced pH changes and on reactions with both soil and added P, and their resultant solubilities. Complex reactions occur when Fe sources are combined with NPK fertilizers. When granulated with $NH_4H_2PO_4$ or $(NH)_4HP_2O_7$, no response to $FeSO_4$ was observed. The soil P-Fe interactions in relation to plant uptake are similarly complex. Possible mechanisms for P-induced Fe deficiency include precipitation in the soil and on root surfaces, immobilization within the root and xylem vessels, and interference in Fe metabolism. Bicarbonate is also involved in inducing Fe deficiency in relation to P, depending on plant cultivar. Therefore, these considerations led to a greenhouse study with UP-treated calcareous soil cropped with Fe-deficient soybean. As method of UP application should theoretically alter its influence on Fe, the material was applied both broadcast and banded, and with simulated drip and flood irrigation (Ryan et al., 1988a,b).

While Fe chlorosis was extensive in this trial, chlorosis rating tended to increase with increasing UP rates. This effect was more accentuated when UP was flood irrigated rather than drop by drop as a point source. Similarly, banding the solid UP was more effective in reducing chlorosis and increasing growth than broadcast. As the highest yield with non-chlorotic plants occurred with Fe-EDDHA treatment and all treatments had the same level of applied N as UP or ammonium nitrate, the problem was one of chlorosis due to Fe deficiency. This negative impact of UP on soil must be evaluated under field conditions, especially where irrigation is involved.

## Urea Phosphate - P Mobility

Because of its propensity to react with soil components, inorganic orthophosphate P forms have long been recognized as being immobile, i.e., having limited capacity to move from the point of application or diffuse from the fertilizer pellet. While P may move to depths of 10 to 15 cm, this is dependent upon factors such as pH, soil texture and reactivity to added P, and the amount of P applied. As a consequence of immobility, plant uptake of fertilizer P is low and inefficient, i.e., generally less than 10 %. This problem may be mitigated by techniques such as band placement near the seed in row crops. However, it is less readily resolved for permanent crops, and in r arid regions where dryness of the surface soil limits plant root growth.

While early research considered alternative forms of P with respect to mobility, it was not until the energy crisis and subsequent escalation of fertilizer prices in the 70's that serious consideration was given to synthetic organic P sources (Rauschkolb et al., 1976). Some organic forms, when applied in water, penetrated to a greater depth in soil than conventional inorganic forms. Though subject to adsorption by soil colloids and enzymatic hydrolysis, glycerophosphate had potential for effective application with irrigation water. However, high costs are likely to limit its use in agriculture. Similarly, while research dealt with the reactions of inorganic polyphosphates (Khasawneh et al., 1979), these materials undergo hydrolysis to orthophosphate, and exhibit similar lack of mobility.

Studies on acidic fertilizers have generated continued interest in P application and mobility, especially in relation to drip irrigation. While orthophosphate P forms readily precipitate in alkaline irrigation water, $H_3PO_4$ does not precipitate, and it eliminates clogging within drip irrigation lines (Rauschkolb et al., 1976). When drip-applied, P movement from $H_3PO_4$ was greater than with $Ca(H_2PO_4)_2$ (O'Neill et al., 1979). Notwithstanding these attributes, the corrosivity of both $H_3PO_4$ and $H_2SO_4$ has militated against their widespread use. However, the chemical bonding of these acids with urea, as an adduct, reduces corrosivity and renders the $CO(NH_2)_2$ less susceptible to volatile loss and $NH_3$ (Stumpe et al., 1984). Of these experimental materials, urea phosphate (UP) has received the most attention, as it is a major carrier of both Na and P which compares favorably with conventional sources.

In view of the rapid expansion in drip irrigation and the technical benefits from using UP in irrigation water, it was important to examine the mobility of P from UP relative to $H_3PO_4$ and $H_2SO_4$ alone, and conventional fertilizers. Therefore, Ryan et al. (1988b) measured water-soluble and $NaHCO_3$-P in calcareous and sodic soil columns treated with those materials applied with water in simulated flood and drip irrigation. A series of four experiments was established according to the specific objective.

The highlights of the results were as follows : With comparable application rates, UP maintained a higher level of water-soluble P at any given soil depth within the column than $H_3PO_4$. Both materials caused greater P movement into the columns than non-acidic sources. When applied to boxes with simulated drip irrigation, UP tended to move laterally and depthwise more than monocalcium phosphate. When applied to a sodified soil column, both UP and $H_3PO_4$ produced greater water intake than non-acidic materials. The subsequent P distribution within the columns followed the same order. As UP is a major carrier of both N and P, it would be suitable for application in drip irrigation systems, especially if infiltration is impeded due to poor structure caused by Na. Thus, the fertilizer has a self-reclaiming effect.

## Water Infiltration

Water movement into and through soil in semi-arid regions is often impeded by adverse chemical or physical factors. Infiltration and hydraulic conductivity are affected by the soil's exchangeable sodium percentage (ESP), and the electrical conductivity (EC), and sodium absorption ratio (SAR) of the percolating solution. Permeability generally decreases with increasing ESP and SAR and decreasing electrolyte concentration. Apart from chemical dispersion associated with Na in soils, infiltration may also be hindered by aggregate destruction from raindrop impact and the resultant crust formation, and by depositional crusts from turbid irrigation water. In many areas of the world which are characterized by high intensity rains and Na-affected soils, both mechanisms, which are frequently interrelated, operate to reduce soil water intake. In such circumstances the deleterious effect of Na on water infiltration rates is accentuated.

Many chemical amendments have been used to reclaim Na-affected soils, but the most commonly used material is gypsum ($CaSO_4$). It is a standard for comparison with other materials. Both $CaCl_2$ and $CaSO_4$ had similar reclamation effects, but gypsum has a longer electrolyte effect. In contrast, on calcareous soils, $H_2SO_4$ was also shown to be more effective in reducing soil ESP than either $CaSO_4$ or $CaCl_2$. The combination of either $CaCl_2$ or $H_2SO_4$ with $CaSO_4$ hastened reclamation, compared with $CaSO_4$ alone. Since $H_2SO_4$ reacts with soil $CaCO_3$ to produce $CaSO_4$, it effectively increases water penetration and works toward reclaiming sodic calcareous soils. These and other fertility-related attributes have made $H_2SO_4$ a desirable chemical amendment in arid-region agriculture. However, gypsum and acid-based amendments add considerably to crop production costs. Acid-based fertilizers are relatively new. Liquid N-S fertilizers, containing urea and $H_2SO_4$, have been effective for sodic soil treatment and in improving irrigation water quality by reducing excess $HCO_3$. The agronomic benefits of acidic fertilizers have stimulated renewed interest in their commercial agricultural use.

With relatively high nutrient concentrations (177 g N and 196 g P $kg^{-1}$), experimental crystalline UP appears not only to have potential use as a fertilizer (Mikkelsen and

Jarrell, 1987), but also to have additional beneficial side-effects. Because of its acidic nature, UP should dissolve solid-phase $CaCO_3$ and increase $Ca^{++}$ concentration, thereby promoting exchange reactions to replace soil $Na^+$. Therefore, this potential effect was investigated by Tabbara et al. (1989). Though UP would not be applied as a general soil amendment because of its cost, its use may be feasible in a drip irrigation system. Other benefits due to $H_3PO_4$ - a component of UP - include greater distribution of P in the wetted soil volume, and elimination of clogging due to precipitates in the irrigation line (O'Neill et al., 1979; Rauschkolb et al., 1976). This study evaluated the infiltration of UP solutions into soil columns as well as subsequent infiltration of water alone. These data were related to soluble Na, EC, pH and SAR values in the leachates and saturated extract, and residual exchangeable soil Na.

The study involved leaching a clay soil in columns with solutions of varying amounts of Na, but with constant salinity. The columns were subsequently treated with urea-phosphate solutions of varying UP concentration. Infiltration rates were measured. Then water alone was applied to the columns and the infiltration rate again measured. The leachates were determined for pH, EC, and soluble Na. The residual soil was extracted for exchangeable Na while a saturated paste was made for determination of SAR. Initial infiltration rates were enhanced only with the dilute UP solutions, i.e., 1.0 and 2.5 g $kg^{-1}$, while all UP solutions improved subsequent infiltration with water alone. As the UP concentration of the infiltrating solution increased, decreases occurred in soluble Na from the saturation extract and exchangeable Na, and estimated SAR. The improvement in infiltration was probably due to $H_3PO_4$ solubilizing $CaCO_3$ for exchange reactions of $Ca^+$ with soil $Na^+$. Urea phosphate may therefore enhance water-use efficiency in some irrigated soils, serve as an effective source of N and P.

## OUTLOOK

Though agricultural research in Lebanon is in its infancy by comparison with developed countries in the West and elsewhere, a range of problems of major concern were tackled. As elsewhere, much of the soil fertility research focused on the universally intractable issue of soil-fertilizer P reactions. Specific topics identified ran the gamut of the applied to more theoretical laboratory research. It is reasonable to conclude that the initial studies provided impetus for the extensive use of chemical fertilizers. While work in the past decade was stymied by civil disorder, it did contribute to an awareness of the value of soil testing in relation to fertilizer P recommendation and use. However, a major drawback is the absence of effective and readily accessible laboratories to perform such tests.

With a virtual collapse of public institutions that purportedly serve the agricultural community, including the research and extension service, lack of communication has been the major bottleneck. Continuing efforts in the field of agricultural research will be fruitless unless there is a return to social, political, and economic conditions conducive to such communication with farmers or indeed between researchers themselves. Nevertheless, despite adverse conditions, considerable research results have filtered through to farmers. What research that has been conducted in the past turbulent decade or so is an act of faith in a better future for Lebanon and its people. Hopefully, more coordination will occur between various phases of education, research and extension. The research effort should address practical and on-going field problems with P fertilizers, as with other phases of agricultural research. Only in a climate of peace and national and regional cooperation can agricultural research agencies adequately fulfill their mandate to serve the agricultural community and the country as a whole.

REFERENCES

Adams, F., and A. H. Sayegh. 1955. Plant response to nitrogen, phosphorus and potassium in soils of Lebanon as indicated by greenhouse pot experiments. FAS-AUB Publ. No. 1.

Arshad, M., J. Ryan, and R. C. Paeth. 1980. Influence of organic matter, free iron and calcium carbonate on soil particle size distribution. Agrochimica 24:470-77.

Bowman, R. A., S. R. Olsen, and F. S. Watanabe. 1978. Greenhouse evaluation of residual phosphate by four phosphorus methods in neutral and calcareous soils. Soil Sci. Soc. Am. J. 42:451-54.

Clawson, M., H. H. Landsberg, and L. S. Alexander. 1971. The agricultural potential of the Middle East. Elsevier Sci. Publ. Co. New York.

Curtin, D., J. Ryan, and R. A. Chaudhary. 1980. Manganese adsorption and desorption in calcareous Lebanese soils. Soil Sci. Soc. Am. J. 44:947-50.

Devine, J. R., D. Gunary, and S. Larsen. 1968. Availability of phosphate as affected by duration of fertilizer contact with soil. J. Agric. Sci. 71:359-64.

Dregne, H. 1976. Soils of arid regions. Elsevier Sci. Publ. Co. Amsterdam.

F.A.O. 1969. Enquête pedalogique et programmes d'irrigation connexes. Rapport final - fertilité, Liban.

Fuehring, H. D., and M. D. Abi-Antun. 1968. Tests for available phosphorus, potassium and magnesium on ten soils of the Middle East. FAS-AUB Publ. No. 33.

Geze, B. 1956. Carte de reconnaissance des sols du Liban. Min. Agric. Beirut, Liban.

Holford, I. C. R., and G. E. G. Mattingly. 1975a. Surface area of calcium carbonate in soils. Geoderma 13:247-55.

__________, and G. E. C. Mattingly. 1975b. Phosphate sorption by Jurassic oolitic limestones. Geoderma 13:257-64.

Hooker, M. L., G.A. Petersen, D. H. Sander, and L.A. Daigger. 1980. Phosphate fractions in calcareous soils as altered by time and amounts of added phosphate. Soil Sci. Soc. Am. J. 44:269-77.

Ibrahim, H. S., and P.F. Pratt. 1982. Effect of rate of application and time on phosphorus sorption by soils. Soil Sci. Soc. Am. J. 46:926-28.

Jackson, T. L., A. D. Halvorson, and B. B. Tucker. 1983. Soil fertility in dryland agriculture. In H.E. Dregne and W.O. Willis (ed) Dryland agriculture. Agron. No. 23, Amer. Soc. Agron. Madison, Wisc.

Khasawneh, F.E., I. Hashimoto and E. C. Sample. 1979. Reactions of ammonium ortho and polyphosphate fertilizers in soil. II. Hydrolysis and reactions with soils. Soil Sci. Soc. Am. J. 43:52-58.

__________, E. C. Sample, and E. J. Kamprath. 1980. The role of phosphorus in agriculture. Amer. Soc. Agron., Madison, Wisc.

Lamaroux, M., and P. Segalen. 1969. Etude comparee des produits ferrugineux dans les sols rouges et bruns mediterraneens du Liban. Soil Sci. 1:63-75.

Matar, A. E., and H. Samman. 1975. Correlation between $NaHCO_3$- extractable P and response to P fertilization in pot tests. Agron. J. 67:616-18.

Mikkelsen, R. L., and W. M. Jarrell. 1987. Application of urea phosphate and sulphate by drip-irrigated tomatoes grown in calcareous soil. Soil Sci. Soc. Am. J. 51:464-68.

Mortvedt, J. J., and J. J. Kelsoe. 1987. Effects of banded acid-type fertilizers on micronutrient levels in soil and uptake by corn. J. Fert. Issues 4:49-55.

O'Neill, M.K., B. I. Gardner, and R. L. Roth. 1979. Orthophosphoric acid as a phosphorus fertilizer in trickle irrigation. Soil Sci. Soc. Am. J. 43:282-86.

Rauschkolb, R. S., D. E. Rolston, R. J. Miller, A. B. Carlton, and R. G. Burau. 1976. Phosphorus fertilization with drip irrigation. Soil Sci. Soc. Am. J. 40:68-72.

Ryan, J. 1982a. A perspective on soil erosion and conservation in Lebanon. FAFS Bull. No. 69. Amer. Univ. Beirut. 70 p.

__________, 1982b. The American University of Beirut's Faculty of Agriculture; a unique Land Grant type institution overseas. J. Agron. Ed. 11:5-9.

__________, 1983a. Phosphorus in soils of arid regions. Geoderma 19:341-54.

__________, 1983b. Civil strife and land management: the case of Lebanon. J. Soil Water Cons. 38(5):404-06.

__________, and J. L. Stroehlein. 1979. Sulfuric acid treatment of calcareous soils: effects on phosphorus solubility, inorganic phosphorus forms, and plant growth. Soil Sci. Soc. Am. J. 43:731-35.

__________, and M.A. Zghard. 1980. Phosphorus transformations with age in a calcareous soil chronosequence. Soil Sci. Soc. Am. J. 44:168-69.

__________, and A. G. Ayubi. 1981. Phosphorus availability indices in calcareous Lebanese soils. Plant Soil 62:141-45.

__________, and S. N. Harik. 1983. Transformation of micronutrient chelates in calcareous as influenced by selected soil properties, temperature and wetting-drying during incubation. Soil Sci. Soc. Am. J. 47:806-10.

__________, and M. Hamze. 1987. Soil fertility studies in Lebanon: a review. Leb. Sci. Bull.

__________, S. Miyamoto, and J. L. Stroehlein. 1974. Solubility of manganese, iron, and zinc as affected by application of sulfuric acid to calcareous soils. Plant Soil 40:139-46.

__________, G. Musharrafieh, and A. Barsumian. 1980. Soil fertility characterization at the Agricultural Research and Education Center of the American University of Beirut, Beirut, Lebanon. FAS-AUB Publ. No. 64.

__________, __________, and M. A. Cheema. 1985a. Significance of iron oxides and calcium carbonate particle size in phosphate sorption by calcareous soils. Soil Sci. Soc. Am. J. 49:74-76.

__________, H. M. Hasan, M. Baasiri, and H.S. Tabbara. 1985b. Availability and transformation of applied phosphorus in calcareous Lebanese soils. Soil Sci. Soc. Am. J. 49:1215-1220.

__________, R. Shwayri, and S. N. Harik. 1985c. Short-term evaluation of non-conventional organic wastes. Agric. Wastes 12:241-49.

__________, M. Hamze, R. Shwayri, and S. N. Harik. 1985d. Behavior of iron-supplying materials in incubated calcareous soils. J. Plant Nutr. 8:425-36.

__________, M. Hamze, S. Barub, and S. N. Harik. 1986. Implications of urea phosphate and iron sources in incubated calcareous soil for micronutrient availability. J. Fert. Issues 3(4):146-50.

__________, M. Hamze, S. N. Harik, and S. Darub. 1988a. Influence of urea phosphate on iron-inefficient soybeans. J. Fert. Issues 5(2):56-60.

__________, E. A. M. Mohamed, H. S. Tabbara, and M. Baasiri. 1988b. Phosphorus movement following water-applied urea phosphate and phosphoric in a calcareous clay soil. J. Fert. Issues 5(3) :

Sayegh, A. H., and A. J. Salib. 1969. Some physical and chemical properties of soils in the Beka'a plain, Lebanon. J. Soil Sci. 20:168-75.

__________, and A. Abdul Majid. 1969. Phosphorus fractionation and retention in alkaline Lebanese soils. Agrochimica 13:265-76.

Shammas, A. 1966. Progress report on soil fertility trials. Inst. Res. Agron. Liban.

Sibbensen, E. 1978. An investigation of the anion exchange resin method for soil phosphate extraction. Plant Soil 50:305-21.

Sleiman, F. T., M. Baassiri, and J. Ryan. 1988. The American University of Beirut's Agricultural Research and Education Center. Agron. Abst. p. 65.

Stumpe, J. M., P. L. G. Vlek, and W. L. Lindsay. 1984. Ammonia volatilization from urea and urea phosphate in calcareous soils. Soil Sci. Soc. Am. J. 48:921-27.

Tabbara, H., J. Ryan and M. Baasiri. 1989. Urea phosphate effects on infiltration and sodium parameters of a calcareous soil. Soil Sci. Soc. Am. J. (in press).

Verheye, W. 1973. Formation, classification, and land evaluation of soils in Mediterranean areas with special reference to southern Lebanon. State University, Ghent. 122 p.

Westfall, D. G., and R. L. Hanson. 1985. Phosphorus, iron, and zinc availability in dual N and P and acid-based fertilizer injection zones. J. Fert. Issues 2:42-46.

# A DESCRIPTIVE MODEL FOR PREDICTION OF RESIDUAL P IN SOIL AFTER PHOSPHATE FERTILIZATION

**A. E. Matar**

International Center for Agricultural Research
in Dry Areas (ICARDA)
P.O. Box 5466, Aleppo, Syria

## ABSTRACT

A descriptive model for prediction of residual P was proposed and tested on three dominant soils in the Mediterranean region: Typic Calciorthid (Breda) and Chromoxerertic Rhodoxeralf (Tel Hadya) and Vertic Chromoxerert (Jindiress). The model requires five components to be known: available soil P, amount of applied P, the relation between applied and available P, rate of P immobilization of the particular soil, and crop P uptake. The rate of P immobilization was determined under field conditions by monitoring the change in available P in soils fertilized with 17.5, 35 and/or 52.5 kg P/ha.

When the model was used, prediction was, in general, satisfactory, except for the soils treated with the highest rate of P during the first season, at both Breda and Tel Hadya. It could be concluded that the model suggested is promising, but the components concerned with the rates of immobilization and the linearity of function of P need to be further verified under more controlled conditions.

## INTRODUCTION

Increasing fertilizer-use efficiency is becoming a crucial factor in improving the productivity of low fertility soils, especially after the big rise in fertilizer price on the world market. The crop utilization of nutrients added by fertilizers is often surprisingly small, especially in the case of P, even in situations in which the fertilizer promotes a large increase in yield. An average uptake of 6% of added P was observed in the low rainfall barley zones and about 10% in the wetter wheat belt (Matar et al., 1988a). Thus, a large amount of residual P is left in the soil after harvest; its consequences for subsequent crops and the fertilizer needs of these crops are important to assess.

Knowledge of those residual effects, and appropriate means of quantifying them, is essential for efficient fertilizer utilization. Phosphate added to soil is subject to chemical transformations into less available forms, but the transformation rate is found to vary with soil types and environmental conditions, e. g., temperature and moisture (Larsen et al., 1965; Barrow, 1974). Larsen et al. (1965) investigated the fate of residual P in soils by following the changes in the levels of labile P in soil P under field conditions after addition of one heavy dressing of superphosphate. They found the L values to decrease exponentially with time at a rate that was expressed as the time in months for half of the applied P to become non-labile or what was designated as the half-life of applied P.

Mechanistic models have been used to predict residual effect of P in soils (Russel, 1977; Barrow and Carter, 1978); but descriptive models based on the chemically extractable P in soils have also been developed (Lins et al., 1985). Expression of the change in a soil test level with time has been shown to provide a reliable and rapid method for assessing the residual value of a nutrient (Mattingly, 1971). The quantities of P extracted by $NaHCO_3$ or by anion exchange resin before sowing were highly correlated with total P removed by cropping (Matar, 1988). The paper presented a descriptive model for prediction on residual P in major calcareous soils under a Mediterranean environment.

## PROCEDURE

### Measurement of P Immobilization Rate

The trial was conducted at three locations representing the major soil types of the northern Syria region; Tel Hadya (Chromoxerertic Rhodoxeralf, long-term average rainfall, 350 mm), Breda (Typic Calciorthid, 275 mm) and Jindiress (Palexerollic Chromoxerert, 470 mm). Metal cylinders (10 cm, 20 cm deep) were pressed into the soil and weighed amounts of triple superphosphate, corresponding to P rates of 17.5; 35 and 52.5 kg/ha, were either banded or incorporated and mixed with the soil down to 15 cm. Sampling took place for ten one-month intervals. At each sampling, the complete bulk of the soil within the cylinders was sampled and carefully mixed prior to analyses. Analyses of soil samples taken just below the base of the cylinder confirmed that the applied P had not leached out of the base of the cylinder. The change in $NaHCO_3$-extractable P with time was monitored and, using the Least Square Method, the best fit for the curvilinear regression was calculated.

**Relation Between $NaHCO_3$-P and Applied P**

The initial levels of $NaHCO_3$-extractable P (P initial) were measured after equilibrating and mixing the soils with the appropriate fertilizer rates in the laboratory. Upon addition of fertilizer, it is assumed that a very rapid sorption or exchange reaction took place first, followed by a slower rate of sorption. After the determination of initial P, the degree of rapid sorption of a P fertilizer by the soil could be calculated. Values for the initial P have been regressed against the amount of fertilizer P added.

## MODEL DEVELOPMENT

The descriptive model chosen is basically similar to the approach adopted by Cox <u>et al</u>. (1981) and Lins <u>et al</u>. (1985). The significant difference is that the change in the extractable-P in soils with time was considered to be related mainly to losses due to crop uptake and immobilization. The change in $NaHCO_3$-P with time could be represented by the following exponential equation.

$$\frac{d\,Pt}{dt} = -k_1 \; (P_t - P_{eq}) - k_2 \cdot Pt \qquad (1)$$

where $P_t$ is extractable P at any one time (kg P/ha);

$P_{eq}$ is extractable P at equilibrium state, which is function of soil properties, climate and cropping systems;

$k_1$ is the loss constant per month$^{-1}$ (P immobilization in soils)

$k_2$ is the rate of P uptake by crops per month$^{-1}$

After integration of equation (1) and assuming that at time zero, $P_O$ is equal to the $NaHCO_3$-P after the addition of fertilizer and the rapid sorption which follows, one would get equation (2)

$$P_t = P_eq + (P_O - P_eq)\exp(-k_1 t) + P_O[1-\exp(-k_2 t)] \ldots (2)$$

But the relationship between the $NaHCO_3$-P at time zero and rate of fertilizer P applied was linear within the range of P applied (0 and 52.5 kg/ha) and of the form as in equation (3)

$$P_tO = A + BF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where A = intercept or the P concentration at pre-sowing or in the check plot;

and

B = slope of the regression lines describing the buffer capacity of soils.

By combining (2) and (3), one could get equation (4)

$$P_t = P_{eq} + [(A+BF) - P_{eq}] \exp(-k_1 t) - k_2 . P_O . \exp(-k_2 t).$$

Since no attempt was made to define a specific plant growth-P uptake model, and only actual P removal from the system is taken into account; the available P in soil at any one time should be lessened by the loss of soil P due to P uptake. It is assumed that P uptake is proportional to the level of available P in soil at any one time t, and that both native P or that added to the soil by fertilization are equally available. Furthermore, it was assumed that there is no replenishment of Olsen-P from the solid-phase P as long as $P_t$ is greater than P at P equilibrium.

Equation (4) could be simplified as follows:

$$P_t = P_{eq} + [(A + BF) - P_{eq}] \exp(-k_1 t) - TPU \qquad (5)$$

where TPU is total P uptake from soil in mg $kg^{-1}$

## Testing of the Model

The predictive model developed was tested with results obtained for two consecutive years at ICARDA experimental sites. The predicted $P_t$ values in soils at Breda, Tel Hadya, and Jindiress were calculated one year after P application to wheat in 1984-85 and 1985-86. Phosphate was applied at three different rates (17.5, 35.0 and 52.5 kg P/ha).

## RESULTS

The changes in levels of soil $NaHCO_3$-P in the cylinders as related to rate and method of applied P and time, were considered as estimates of available P in soils. Levels of P in unfertilized soils remained more or less constant throughout the growing season; these values were subtracted from those found in fertilized soils. The effect of P application method (mean of all levels) on the rate of fertilizer immobilization is shown in Fig. 1. There was little practical difference between the two methods across all three locations, although there was a significant trend

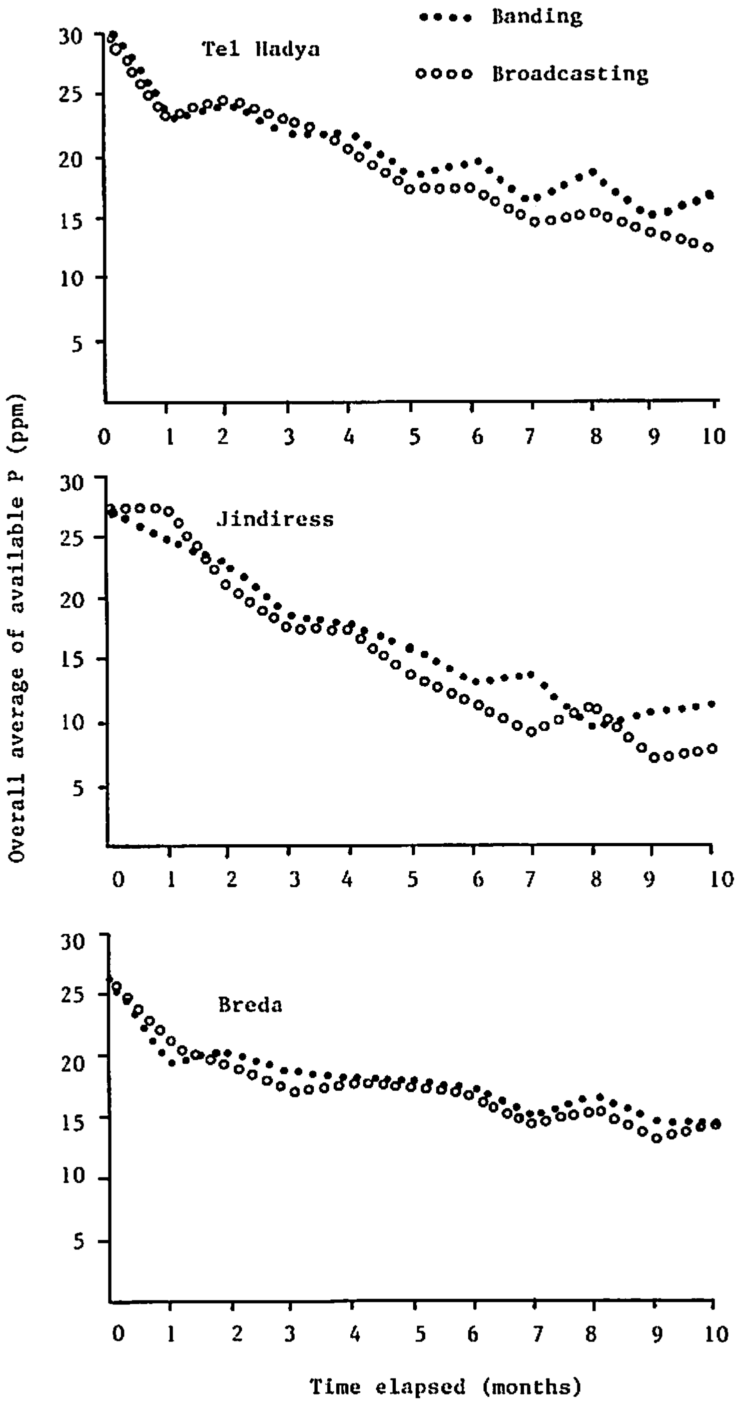



Fig. 1. Effect of banding and broadcasting phosphate fertilizer on the change in its availability (mean of all levels of application).

for broadcast P to be fixed at a slightly greater rate than banded P. It is assumed that P immobilization depends upon fertilizer/soil contact, and that broadcast and incorporated fertilizer may have greater fertilizer/soil contact, and thus be more rapidly immobilized than banded fertilizer. However, detailed examination of the banded fertilizer distribution in the soil showed that, even at 52.5 kg/ha, granules were invariably completely surrounded by soil particles, and only occasionally were they in contact with each other. In practice, there was little difference in fertilizer/soil contact between the two application methods.

The changes in $NaHCO_3$-P with time and at the three different rates of P banded at 5 cm from soil surface were plotted for Breda, Tel Hadya and Jindiress (Fig. 2). The loss constant due to P immobilization ($k_1$) was calculated using equation (1) and averaging the $k_1$ values for all rates of applied P by replacing the values of $P_t$ by the real values observed. It was found that the average values of $k_1$ were equivalent to 0.0693; 0.0715 and 0.127 for Breda, Tel-Hadya, and Jindiress soils, respectively. The corresponding half-lives of applied P (using the relation of $t\ 1/2 = \frac{\ln 2}{k_1}$ would be 10, 9.7 and 5.5 months for Breda, Tel Hadya and Jindiress, respectively. It is clear that the half-life of P applied to these highly calcareous soils with clay to clay loam texture has been far shorter than the values mentioned by other researchers for neutral soils.

The $NaHCO_3$-P values obtained for initial soil P ($P_O$), after application of the various rates of P were measured and the regression equations relating the rates of P fertilizers applied (F) and the initial $P_O$ values were grouped in Table 1. It was clear that the regressions were linear with $r^2$ = 0.99. The intercepts of both regressions showed that the equilibrium P values ($P_eq$) were equivalent to 2.66, 2.92, and 2.52 at Breda, Tel Hadya, and Jindiress, respectively.

Table 1. Regression equations relating the initial soil P ($P_O$) and applied P rates (F).

| Site | Regression equations | |
|---|---|---|
| Breda | $P_O = 2.66 + 0.683\ F$ | $r^2 = 0.99$ |
| Tel Hadya | $P_O = 2.92 + 0.784\ F$ | $r^2 = 0.99$ |
| Jindiress | $P_O = 2.52 + 0.706\ F$ | $r^2 = 0.99$ |

Applied P in kg/ha

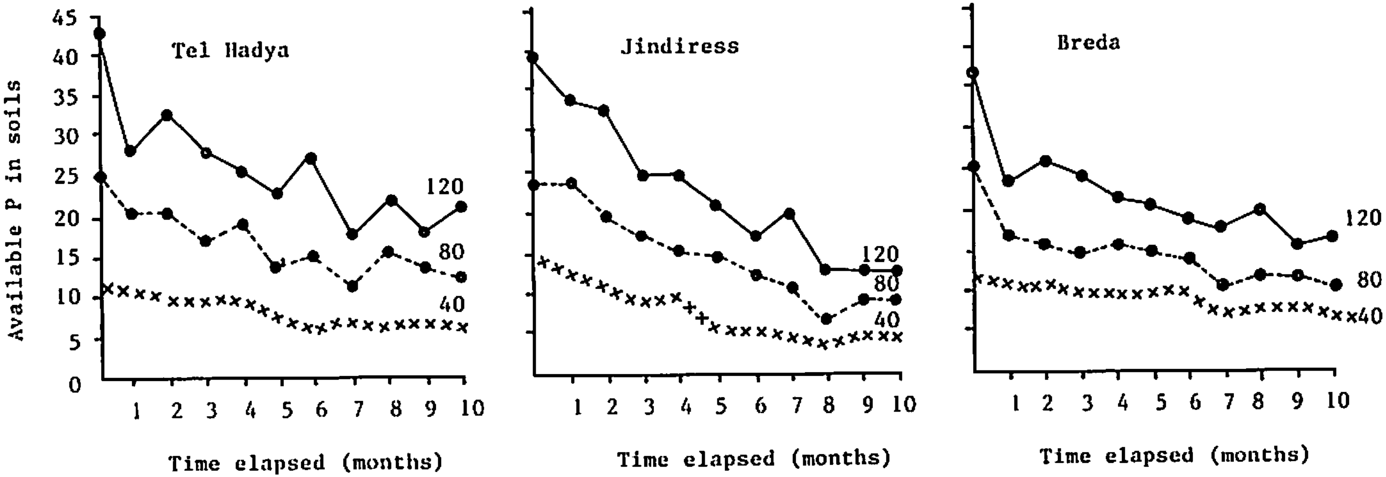



Fig. 2. Change in available banded fertilizer P at three locations in northwestern Syria.

Using equation (1), and replacing the $k_1$ by its average values at Breda, Tel Hadya, and Jindiress, and $P_o$ and $P_{eq}$ by respective values, the predicted and observed values of available soil P in the cylinders in successive months after application of various P rates were compared. It can be observed from Table 2 that the predicted and measured values of available P are very close and highly correlated with the increasing rates of P applied at Tel Hadya (with $r^2$ = 0.89, 0.95, and 0.96, respectively). Similarly, the predicted $P_1$ was very close to that observed for high and medium rates of applied P at Breda. However, smaller predictive P values, as compared to observed P, were noticed with the low rates of P applied. Perhaps averaging the values of $k_1$ for all rates of P applied for one definite site could reduce to some extent the predictive capacity of the model developed.

The predicitive model applied to field trial sites; predicted and observed $P_t$ values in soil which was fertilized with various levels of P applied, a year earlier, to fields grown with wheat, were grouped in Tables 3 and 4 for the two consecutive years, 1984-85 and 1985-86. It is apparent that prediction of Pt values was very satisfactory, except for the first year, 1984-85, with soils treated with high P levels in the previous season. A large part of the differences between predicted and observed Pt values could be due to the standard error in plot sampling of soils which were heavily fertilized in the previous season. The assumption that the rate of P losses is independent of rate of P applied, and more or less stable in spite of environmental variabilities from one year to another, needs to be verified.

It could be concluded from the present work that the descriptive model proposed could be used to predict residual P in soil and reduce soil analyses needed every season for fertilizer recommendations. That would require some information on the P buffer capacity of these soils, the rate of P immobilization with an estimate of P uptake by the crops grown the previous season.

## REFERENCES


Barrow, N. J. 1974. The slow reaction between soil and anions. I. Effect of time, temperature and water content on the decrease in effectiveness of phosphates for plant growth. Soil Sci. 118, 380-386.

Barrow, N. J. and E. D. Carter. 1978. A modified model for evaluating residual phosphate in soil. Aust. J. Agric. Res. 29:1011-1021.

Cox, F. R., E. J. Kamprath and R. E. McCollum. 1981. A descriptive model of soil test nutrient levels following fertilization. Soil Sci. Soc. Am. J. 45: 529-532.

Table 2. Predictive and observed values of average available soil P in cylinders for Breda and Tel Hadya, respectively.

| Time (months) | Breda | | | | | | Tel Hadya | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P kg/ha | | | | | | | | | | | |
| | 17.5 | | 35.0 | | 52.5 | | 17.5 | | 35.0 | | 52.5 | |
| | Obs. | Pred. | Obs. | Pred. | Obs. | Pred. | Obs. | Pred. | Obs. | Pred. | Obs. | Pred. |
| 0 | 17.3 | 17.3 | 29.7 | 29.7 | 41.6 | 41.6 | 18.8 | 18.8 | 32.2 | 32.2 | 48.6 | 48.6 |
| 1 | 15.4 | 13.5 | 23.7 | 25.4 | 30.0 | 36.6 | 14.1 | 14.8 | 24.9 | 17.3 | 35.6 | 42.5 |
| 2 | 16.2 | 12.7 | 20.7 | 23.9 | 30.6 | 34.5 | 14.1 | 13.8 | 24.6 | 25.4 | 40.1 | 39.6 |
| 3 | 13.7 | 11.9 | 19.6 | 22.5 | 28.7 | 32.4 | 13.4 | 12.8 | 21.3 | 23.6 | 37.3 | 36.9 |
| 4 | 14.4 | 11.2 | 20.3 | 21.2 | 27.4 | 30.5 | 12.4 | 11.9 | 20.2 | 22.0 | 35.0 | 34.3 |
| 5 | 15.0 | 10.6 | 20.1 | 19.9 | 25.7 | 28.7 | 12.1 | 11.1 | 17.3 | 20.5 | 28.5 | 32.0 |
| 6 | 14.7 | 9.9 | 19.2 | 18.8 | 24.8 | 27.0 | 10.1 | 10.4 | 18.5 | 19.1 | 31.7 | 29.8 |
| 7 | 13.4 | 9.4 | 16.0 | 17.7 | 22.3 | 25.5 | 11.3 | 9.6 | 14.8 | 17.8 | 28.9 | 27.7 |
| 8 | 13.9 | 8.8 | 17.3 | 16.6 | 24.7 | 24.0 | 10.2 | 9.0 | 16.8 | 16.5 | 28.5 | 25.8 |
| 9 | 13.0 | 8.3 | 16.6 | 15.7 | 19.9 | 22.5 | 9.8 | 8.4 | 12.7 | 15.4 | 24.3 | 22.0 |
| 10 | 12.5 | 7.8 | 16.8 | 14.7 | 20.9 | 21.2 | 8.9 | 7.8 | 14.5 | 14.3 | 24.3 | 22.4 |

Obs. = observed; Pred. = predicted.

Using the descriptive model of Pt=Peq+(P0-Peq) expt-$K_1$ t, when Peq were 2.7, 2.9 and 2.5, and $k_1$, 0.0693 and 0.0715 $month^{-1}$.

Table 3. Predicted versus observed $NaHCO_3$-extractable P one year after application to wheat.

| Applied P | Total P Uptake | Observed | Predicted | Total P Uptake | Observed | Predicted |
|---|---|---|---|---|---|---|
| kg/ha | | mg/kg | | kg/ha | mg/kg | |
| 0 | -2.44 | 4.8 | | 6.26 | 3.4 | |
| 17.5 | -2.87 | 8.0 | 6.7 | 6.81 | 6.6 | 5.9 |
| 35.5 | 3.18 | 10.0 | 11.8 | 6.85 | 11.2 | 11.7 |
| 52.5 | 3.74 | 15.7 | 16.7 | 7.47 | 15.3 | 17.2 |

Data taken in Nov. 1985.

Table 4. Predicted versus observed soil $NaHCO_3$-P one after application to wheat at three descriptive experimental sites using the descriptive model.

| Applied P | P Uptake | $NaHCO_3$-P | | Total P Uptake | $NaHCO_3$-P Obs. | Pred. | Total P Uptake | $NaHCO_3$-P Obs. | Pred. |
|---|---|---|---|---|---|---|---|---|---|
| --------kg/ha | ---------- | mg/kg | | kg/ha | ---- mg/kg | ----- | kg/ha | --mg/kg | ------ |
| 0 | 4.04 | 2.7 | | 10.86 | 2.9 | | 8.15 | 2.46 | |
| 17.5 | 4.77 | 4.4 | 5.9 | 13.39 | 5.0 | 3.2 | 10.24 | 3.51 | 2.52 |
| 35.0 | 5.58 | 9.4 | 10.8 | 13.60 | 7.6 | 7.4 | 11.60 | 4.56 | 3.07 |
| 52.5 | 5.81 | 9.1 | 15.9 | 14.63 | 9.0 | 14.3 | 12.00 | 7.08 | 5.60 |

Assumptions : 1) P uptake from fertilizers as long as $NaHCO_3$-P in soils above P eq.
2) Average value of the loss constants $k_1$ were used,
3) One hectare weight of top 20 cm is equivalent to $2.4 \times 10^6$ kg

Data taken in Nov. 1984 at ICARDA stations.

Larsen, S., D. Gunary, and C. D. Sutton. 1965. The rate of immobilization of applied phosphate in relation to soil properties. J. Soil Sci. 16:141-148.

Lins, I. D. G., F. R. Cox, and J. J. Nicholaides III. 1985. Optimizing fertilization rates for soybeans grown on Oxisols and associated Entisols. Sci. Soc. Am. J. 49:1457-1460.

Matar, A. E., E. Jabbour and K. El Haji. 1988a. Prediction of barley response to fertilizers by means of soil nitrogen and phosphorus tests. P. 12-23. In Matar et al. (editors), Proc. of workshop on soil test calibration in West Asia and North Africa, Ankara, Turkey, 1-6 Sept. 1987. ICARDA, Aleppo, Syria.

Matar, A. E., S. Garabet, S. Riahi, and A. Mazid. 1988b. A comparison of four soil tests for determining available P in calcareous soils in Mediterranean regions. Commun. Soil Sci. Plant Anal. 19(2): 127-141.

Mattingly, C. E. G. 1971. Residual value of P fertilizer on neutral and calcareous soils. p. 1-15. In Residual value of applied nutrients. Tech. Bull. 20. Min. Agric. Fish. Food, London.

Russell, J. S. 1977. Evaluation of residual nutrients in soils. Aust. J. Agric. Res. 28:461-475.

# COMPARISON OF DIFFERENT SOIL TESTING METHODS IN VARIOUS MEDITERRANEAN SOILS


B. Amar and A. Ait Houssa

Institut Mondial des Phosphates (IMPHOS) and
Société Agricole de Services au Maroc (SASMA)
Casablanca, Morocco



## ABSTRACT

This greenhouse study of a wide range of Mediterranean - region soils involved extraction using common procedures for available P and correlation with plant uptake. The $NaHCO_3$ or Olsen procedure and the resin method showed the best relationships with plant growth.


## INTRODUCTION

Several laboratory and field experiments have shown that phosphorus is one of the most limiting nutrients for crop production in Mediterranean soils. Thus, it is necessary to develop techniques that can help farmers of the region to meet demands of plant and soil systems, and therefore increase their production and profit through proper use of P fertilizers. Among various diagnostic methods, soil testing methods are widely used for estimating P availability to plants in developed countries. However, no specific soil extraction method has been developed for the Mediterranean soils. Methods in current use in the region (Table 1) were developed in Europe and in the U.S.A.

Table 1. Methods used for extraction of available phosphorus in various Mediterranean countries.[1]

| | |
|---|---|
| Olsen .... | Turkey, Morocco, Spain, Italy, Tunisia, Greece, Cyprus, Jordan, Syria |
| Bray I ..... | Spain, Turkey, Greece |
| Bray II .... | Turkey |
| Bingham .... | Turkey, Morocco |
| Dyer ....... | Morocco, France |
| Truog ...... | Turkey |
| Morgan ..... | Morocco, France |

[1]Adapted from Ansiaux, 1979, and Kafkafi, 1979

The definition of available P embraces two distinct characteristics : the state of P in the soil and the uptake of P by the plant. The numerical value of each characteristic depends on the methods used for its measurement. Choice of the best soil testing method is usually based on the degree of correlation between the P soil test and plant's response when P is applied (Tisdale and Nelson, 1975). In recent years, much effort has been devoted to soil characteristics in selecting a proper soil testing method (kafkafi et al., 1968; Matar and Samman, 1975; Roche et al., 1980; Varvel et al., 1981). The research presented in this paper is a collaborative effort between IMPHOS and SASMA and aims to evaluate five chemical soil testing methods for measuring available P in various Mediterranean soils.

## MATERIALS AND METHODS

### Soil Samples

A total of 250 soil samples, with a range in available P, were collected from various soil classes in Morocco. These soils are classified as Calcimagnesic, Isohumic, Vertisol, Sesquioxide and Weakly Transformed soils. The general physical and chemical characteristics of the soil samples are grouped in Table 2.

### Pot Trial

The pot trial entailed two treatments: a) complete fertilization (Fc) including N, P, K, Ca, Mg, S, and necessary trace elements, and b) complete fertilization minus phosphorus (Fc-P). During the 11 weeks of growth, three cuts were used to measure dry matter (DM) and P uptake (Pup) of the ryegrass. The Chaminade Index (IC) was used as a biological reference for soil P availability (Chaminade, 1960). The index is expressed as a percentage:

$$IC = \frac{DM\ (Fc-P)}{DM\ (Fc)} \times 100$$

The five different procedures used to measure the available P in soil and their characteristics are grouped in Table 3. Statistical analyses of available P as measured by various soil test methods have been assessed by computing i) the coefficient of correlation among any two soil P-test, and ii) the regression equation between any soil P-test method and the Chaminade Index (IC), which was considered to be the best indicator of P soil availability.

Table 2. Physical and chemical characteristics of the soil samples used for evaluating soil testing methods.

| Soil Type | Sample N° | pH | $CaCO_3$ | O.M. | Clay | P.F.P.[1] |
|---|---|---|---|---|---|---|
| | | | ------------ | % | ------------ | ppm. |
| Total | 250 | 8.1 | 9.9 | 2.5 | 34.9 | 128.4 |
| Calcimagnesic | 66 | 8.1 | 14.4 | 3.0 | 32.5 | 140.0 |
| Isohumic | 71 | 8.2 | 9.2 | 2.6 | 33.8 | 115.5 |
| Sesquioxid | 27 | 7.6 | 2.3 | 2.1 | 29.9 | 99.4 |
| Vertisol | 51 | 8.1 | 8.1 | 2.1 | 47.0 | 157.2 |
| Weakly Transformed | 35 | 8.1 | 11.1 | 2.0 | 28.8 | 113.3 |

[1] P-fixing power

Table 3. Characteristics of soil test procedure used to measure P variability.

| Soil Test Method | Extracting Solution | Ration Soil/ Solution | Shaking[1] Time |
|---|---|---|---|
| Joret-Hebert | Ammonium oxalate (0.2N, pH = 7.0) | 1/25 | 2 h |
| Olsen | Sodium bicarbonate (0.5M, pH = 8.5) | 1/20 | 30 min. |
| Dyer | Citric acid (2 %) | 1/10 | 3 h + 3 h |
| Resin | Dowex 2 x 4 | 1/100 | 48 h |
| P Organic | Sulfuric acid (0.2 N) | 1/25 | 1 h + 1 h |

[1] 3 h non-calcareous, 4 h calcareous soils

## RESULTS AND DISCUSSION

### Soil Analysis of Available P by Various Methods

The analyses of available P in the untreated soils for each of the five different methods are grouped in Table 4. It shows very clearly that i) the values obtained for available P depend on the method of P extraction used and ii) the values present a wide range in ppm, from 2 to 126 (Olsen), 1 - 1476 (Joret-Hebert), 4 - 3515 (Dyer), 5 - 4105 (organic) and 1 - 135 (Resin).

The correlation matrix among the available P in soils determined by various procedures has been grouped in Table 5. The coefficient of correlation between any two of the five different procedures used for determination of available P, ranged from non-significant to highly significant ones. The highest correlation was found between the ammonium lactate extraction procedure (Joret-Hebert) and the citric acid procedure (Dyer), followed closely by the $NaHCO_3$ extraction method and the anion exchange resin method. It was observed that there is a very low relationship between organic P and other soil testing methods.

### Relationship between Available P in Soils and Chaminade Index

In this study, we had considered that the Chaminade Index was the best biological reference to which all chemical soil testing methods were compared. These comparisons were made at two levels : i) for total soils, and ii) for soil class designation. Table 6 shows the comparison of the five different soil P tests to the Chaminade Index. Only correlation coefficients significant at 0.01 level have been reported in this table. It can be concluded that both the P-Olsen and the anion exchange tests are reliable tests for estimation of available P in these

Table 4. Soil analysis of available P by various methods.

| | Olsen | Joret-Hebert | Dyer | Organic | Resin |
|---|---|---|---|---|---|
| Minimum | 1.6 | 1.4 | 4.5 | 5.1 | .9 |
| Maximum | 126.1 | 1476.8 | 3515.8 | 4105.1 | 134.7 |
| Mean | 14.8 | 123.5 | 347.0 | 189.3 | 15.5 |
| Std Dev. | 12.7 | 211.8 | 555.7 | 388.8 | 15.2 |

Table 5. The correlation matrix between any two of the five different procedures used for the determination of available P in soils.

| Soil Test Method | Olsen | Joret-Hebert | Dyer | Organic | Resin |
|---|---|---|---|---|---|
| Olsen | 1.00 | .36 | .28 | - | .79 |
| Joret-Hebert | .36 | 1.00 | .84 | .39 | .50 |
| Dyer | .28 | .84 | 1.00 | .46 | .48 |
| Organic | - | .39 | .46 | 1.00 | .29 |
| Resin | .79 | .50 | .48 | .29 | 1.00 |

Only coefficients significant at .01 level have been tabulated.

Table 6. The correlation between the Chaminade Index and soil P analyses.

| | | | | | | |
|---|---|---|---|---|---|---|
| Olsen | 0.43 | 0.51 | 0.41 | 0.67 | 0.49 | - |
| Jobert-Hebert | 0.28 | - | 0.36 | 0.40 | - | - |
| Dyer | 0.23 | - | 0.32 | - | - | - |
| Organic | - | - | - | - | - | - |
| Resin | 0.43 | 0.43 | 0.44 | 0.70 | 0.46 | - |
| Significant (0.01) | 0.16 | 0.32 | 0.30 | 0.35 | 0.43 | 0.48 |

Table 7. Correlation between the Chaminade Index and log P-Olsen.

| Method | All Soils | Classes | | | | |
|---|---|---|---|---|---|---|
| | | Calcimagnesic | Isohumic | Vertisol | Weakly Transf. | Sesqui-oxide |
| P-Olsen | 0.43 | 0.51 | 0.41 | 0.67 | 0.49 | - |
| Log P-Olsen | 0.61 | 0.59 | 0.54 | 0.73 | 0.54 | 0.64 |

soils. The Joret-Hebert (1955) and Dyer tests are less reliable than the two previous tests. The coefficient of correlation between the Chaminade Index and organic P test was not significant at 0.01 level. These findings are in agreement with previous work in the region conducted either in greenhouse or in field trials (Matar, 1986; Soltanpour et al., 1987; Agbani and El Mejahed, 1983).

However, the correlations between the Chaminade Index and soil P levels test by either test methods were comparatively low when used across all soils. In order to improve the coefficient of correlation, we tried to separate them into five classes: Calcimagnesic, Isohumic, Vertisols, Weakly Transformed and Sesquioxide soils. This grouping system permitted the following conclusions to be made: 1) both the P-Olsen (Olsen et al., 1954) and P resin test methods remain the best soil testing methods, but are not very suitable to Vertisols and not reliable for sesquioxid soils; 2) for P Joret-Hebert, the coefficient of correlation has been improved in case of isohumic and vertisols and become non-significant for Calcimagnesic, Weakly Transformed and Sesquioxid soils; 3) for the organic P, the correlation coefficient remains non-significant for any soils; 4) for Dyer test, a small improvement was observed when used for the isohumic soils. It can be concluded also that this test method is not suitable for the other soil classes.

Another way to improve the correlation coefficient is the transformation of independent variable (P-Olsen) using natural logarithm function (Table 7). This transformation improved the correlation coefficients from 0.43 to 0.61 when considering all soils; whereas, values were changing from 0.51, 0.41, 0.67 and 0.49 to 0.59, 0.54, 0.73 and 0.54, respectively for calcimagnesic isohumic, vertisols and transformed soil classes. For the Sesquioxide soils, this transformation improved the coefficient of determination from non-significant to significant.

These findings are in agreement with results obtained from similar studies (Matar and Samman, 1975; Varvel et al. 1981; Agbani and El Mejahed, 1983). They found that the correlation between $NaHCO_3$-P and response of plants to P levels in pot tests was improved if soils were grouped according to their genetic origin.

## CONCLUSIONS AND RECOMMENDATIONS

This work should not be considered as a final analysis and interpretation of the available data. The above mentioned conclusions showed only some trends of the results which, yet, have to be confirmed and made more precise at the end of the interpretation of the entire data from all Mediterranean soils. This first approach to the interpretation of the available data allows us to draw the following conclusions and recommendations.

The Olsen and anion exchange resin methods appear to be the best extraction procedures for calcareous soils. The correlation coefficients between either of these soil tests and the Chaminade Index were high when compared to those obtained with the other soil tests. The Dyer organic P and Joret-Hebert tests were ill-suited as soil testing methods for assessing P availability. These findings agreed very well with results obtained by Agbani and El Mejahed in Morocco (1983) and by Matar in Syria (1986), who found that anion resin and Olsen methods gave best correlations with P uptake by ryegrass in pots and, as such, were satisfactory for estimating available P over a wide range of soil characteristics. The Olsen extracting method is therefore recommended for determining available P in calcareous soils, because it is both simple and accurate. Although, the anion resin method is also satisfactory, it remains an expensive and more lengthy procedure than the Olsen method.

## REFERENCES


Agbani, M., and K. El Mejahed. 1983. Comparaison des methodes d'analyse du phosphore dans quelques sols marocains. Proc. Third Cong. P Compounds : 249-260. Brussels. Oct. 4-6.

Ansiaux, J. R. 1979. Le niveau de fertilite phosphorique des sols. Phosphore et Agriculture, No. 70:1-11.

Barbre, D., L. Griere, M. Calba, P. Fallavier, and P. Roche. 1980. Comparaison des resultats de determination de carence en phosphore par des tests biologiques et par une methode chimique (extraction par resine) dans les sols tropicaux. C.R. Acad. Agric. Fr. 66:459-465.

Chaminade, R. 1960. Experimentation en vases de vegetation. Ann. Agron. 11.2:121-133.

Joret G., and J. Hebert. 1955. Contribution a la determination du besoin des sols en acide phosphorique. Ann. Agron. :233-299.

Kafkafi, U. 1979. Measurements of available nutrients in the soil for prediction of fertilizer requirements by crops in the Mediterranean region. 14th Coll. Int. Potash Inst. Seville, Spain. May 21-25.

Kafkafi, V., A. Hadas, and J. Hagin. 1968. The effect of soil surface area and time of contact on the extraction of phosphate from superphosphate by soil tests and test plants. Agrochimica 12:231-239.

Matar, A. E., and M. Samman. 1975. Correlation between $NaHCO_3$-P and response to P in pot tests. Agron. J. 67:616-618.

Matar, A. E. 1986. Evaluation of available P in calcareous soils by five different procedures as related to growth and phosphorus uptake by ryegrass on pot experiment. Farming System Program, ICARDA, 20 p.

Olsen, S. R., C. V. Cole, F. S. Watanabe and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate, U.S.D.A. Cir. 939. Washington, D.C.

Roche, P., L. Griere, D. Barbre, H. Calba, and P. Fallavier. 1980. Phosphorus in tropical soils : Assessing deficiency levels and phosphorus requirements. IMPHOS-GERDAT, 40 p.

Soltanpour, P. N., M. El Gharous, A. Azzaoui, and M. Abdel Monem. 1987. Nitrogen and phosphorus soil-test calibration studies in the Chaouia region of Morocco. In A. Matar et al. (ed.) Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey. Sept. 1-6. ICARDA, Aleppo, Syria.

Tisdale, S. and W. Nelson. 1975. Soil fertility and fertilizers. 3rd ed., Macmillan Publ. Co., Inc., New York.

Varvel, G. E., F. N. Anderson, and G. A. Peterson. 1981. Soil test correlation problems with two phosphorus methods on similar soils. Agron. J. 73:516-520.

# RESPONSE OF DRYLAND WHEAT TO NITROGEN AND PHOSPHORUS IN SOME MOROCCAN SOILS

**M. AbdelMonem, A. Azzaoui, M. El Gharous, J. Ryan, and P. Soltanpour**

**Aridoculture Center, Settat, Morocco**

## ABSTRACT

This paper reports the third year's data from the soil test calibration study for spring wheat in farm trials in the semi-arid Chaouia region of Morocco. The specific objectives were to determine the influence of N (0, 40, 80, 120 kg/ha), P (0, 20, 40, 80 kg/ha) and previous crop (wheat, legume, fallow or corn) on N uptake and dry matter yield at anthesis, as well as grain and dry matter yield, of Nesma wheat grown on three representative soils of contrasting depth and productivity: Lithic Rendoll, Calcixeroll, and Chromoxerert. Response data were related to soil $NO_3$ and $NaHCO_3$-P. Seasonal rainfall was above average and well distributed. Grain and dry matter yield were influenced by soil type, previous crop and N fertility, but not by applied P. Higher yields were obtained from the Vertisol and where a legume was grown the previous year. Consequently, the response to applied N following legumes was insignificant, while it was highest after wheat or fallow and intermediate after corn. Responses to N generally were non-significant above 80 kg/ha. The data differed from the previous drier years in not having a P response, but generally coincided with observations on the influence of N and previous crop on wheat.

## INTRODUCTION

As in many developing countries, a major focus of government policy in Morocco has been to increase agricultural output and to satisfy the needs of a rapidly expanding population, and to stem the exodus to the cities. However, the severe drought of the early 1980's has exacerbated the country's dependence on food imports, particularly wheat. The only feasible option is to increase output from dryland areas. As expansion of the cropped land area is limited by rainfall and soil moisture, projected increases have to come from increased yields from each hectare of cropped land.

While limited rainfall in semi-arid areas is the overwhelming constraint to crop production, nutrient deficiency, especially N and to a lesser extent P, is also seen as a limiting factor in many cases (Dregne, 1976). Various field trials in Morocco's semi-arid zone have demonstrated significant responses to additions of fertilizer N and P. Fortunately, most soils of the region are well supplied with the third major element, K. However, due to various socio-economic factors, input of fertilizers in dryland farming in Morocco is perceived to be less than adequate (Primov et al., 1987). In fact, many farmers use no fertilizer at all.

As fertilizer is an expensive input in crop production, it is imperative that conditions where its use will increase yield be identified. For example, in semi-arid areas, the amounts of N required for optimum yield increase as rainfall increases (Jackson et al., 1983). Thus, one would expect fertilizer response to vary from season to season. Similarly, soil moisture is important for P fertilizer use in dry regions (Ryan, 1983); responses to P are relatively higher under drier conditions (Matar, 1977; Krentos and Orphanos, 1979; Harmsen et al., 1983). This series of soil test calibration studies reported here was initiated to establish a rational and economic basis for fertilizer use in dryland farming in Morocco. This effort is part of an overall research project which began in 1980 with the Government of Morocco in collaboration with the Mid America International Agricultural Consortium and funding from the U.S. Agency for International Development. This project encompasses all phases of dryland agricultural development-socio-economic as well as technical - in the regions of Chaouia, Abda and Doukala.

Some factors which impinge on effective fertilizer recommendations are well established, while others, which are site- and location-specific, need to be clarified. That soil types differ in their fertility and moisture-holding capacity, and therefore their productivity, is evident. Thus, one would suspect that deep soils well supplied with organic matter may, under dryland conditions in Morocco, need little or no fertilizer, whereas shallow soils would need such inputs. For example, deep clay soils such as Vertisols, which occur extensively in Morocco, have a high capacity to supply both N and P (Le Mare, 1987). Trials in Morocco and elsewhere have shown that the need for fertilizer is also modified by the crop rotation or previous crop (Soltanpour et al., 1987). Legumes, depending on how they are managed, may reduce the need for addition of N for the subsequent wheat crop. The impact of a legume crop is dependent on its N fixation, which is species-specific, the crop yield, and the extent to which residues are removed. The level of soil $NO_3$ for the subsequent crop is also dictated by the capacity of the soil to mineralize organic matter, i.e, its mineralization potential (Goh and Haynes, 1986).

In contrast to N in soils, P is more stable and less subject to fluctuation in environmental conditions. While soil $NO_3$ is mobile in the profile, P does not move to any significant degree (Sample et al., 1980). Its availability is dependent upon soil factors that are frequently related to soil type. Thus, the objective of this study was to relate the levels of soil $NO_3$ and P to wheat response to N and P fertilization in different soil types and under different crop rotations.

## MATERIALS AND METHODS

This paper reports on the third year of a three-year study of N and P responses to wheat in dryland conditions in central Morocco. Data for the first two years have been reported earlier in this Soil Test Calibration Workshop series (Soltanpour et al., 1986; Soltanpour et al., 1987). As experimental and growing conditions varied from year to year, details for the third year are therefore presented. All three years' trials were researcher-managed on local farms in the vicinity of Settat.

The sites were selected based on productivity and representativeness of major soil types in the region. While only a small proportion of the dryland area is mapped, it is believed that the three soil great groups (Rendoll, Calcixeroll, Chromoxerert) represented as much as 70% of the whole area. Selected data for the three soil great groups of varying depth (30-35, 65, and greater than 65 cm) are given in Table 1, along with values for $NaHCO_3$-P and $NO_3$-N and previous crops in Table 2. The sites were rented from local farmers, who were also paid for supervising the field plots; they also received the grain and straw after harvest.

Table 1. General soil analysis.

| Soils | Depth cm | pH | O.C. | $CaCO_3$ | Clay |
|---|---|---|---|---|---|
| | | % | | | |
| Rendoll | 35-40 | 8.1 | 1.9 | 21.1 | 59 |
| Calcixeroll | 60 | 8.2 | 1.2 | 27.3 | 58 |
| Chromoxerert | <60 | 8.2 | 1.0 | 1.6 | 58 |

Table 2. Nutrient status and previous crops.

| Soils | Previous Crop | $NO_3$-N | $NaHCO_3$-P |
|---|---|---|---|
| | | mg/kg | |
| Rendoll | Barley | 6 | 7 |
| | Fallow | 13 | 6 |
| | Peas | 22 | 6 |
| Calcixeroll | Barley | 7 | 13 |
| | Corn | 6 | 7 |
| Chromoxerert | Wheat | 5 | 10 |
| | Corn | 8 | 9 |
| | Chickpea | 8 | 7 |

As rainfall, and consequently soil moisture, is the dominant constraint to crop production in the region, some statistics are pertinent. Rainfall in the region is sparse and erratically distributed in any one season and from year to year (Watts and El Mourid, 1988). Overall year average is 386 mm/year. However, the early 1980's were characterized by a severe drought for those years, which devastated the area; such intense droughts have a 100 to 300-year occurrence frequency. Rainfall for the previous two years was 300 and 200 mm/year, respectively. Rainfall has a uni-modal pattern from October to April. The third year's distribution pattern is shown in Fig. 1 along with data for cumulative rainfall.

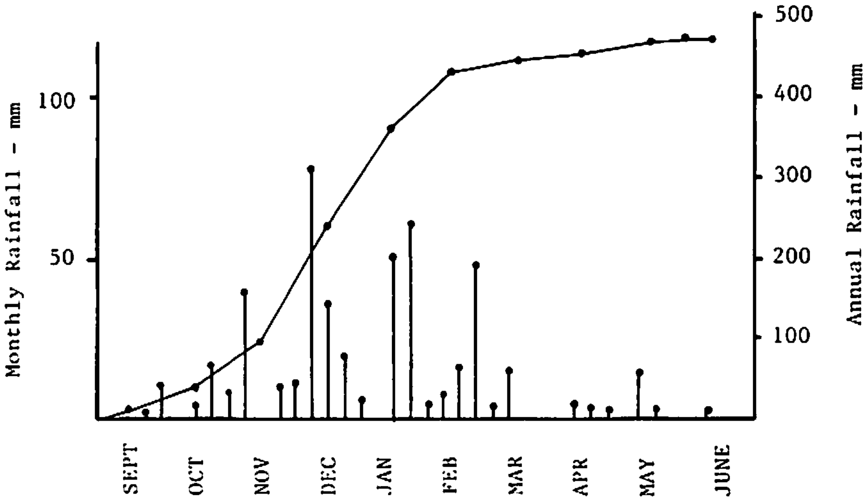



Fig. 1. Monthly and cumulative precipitation at Settat, Morocco, 1987-88

The fertilizer treatments, in factorial combination, were as follows: 1) N-0, 30, 60 and 90 kg/ha for the shallower soils (Rendoll, Calcixeroll) and 0, 40, 80 and 120 kg/ha for the Chromoxerert; and 2) $P_2O_5$ - 0, 20, 40 and 80 kg/ha. The N was applied as ammonium nitrate and $P_2O_5$ as concentrated superphosphate; both were broadcasted by hand and incorporated by a tandem disc ("covercrop"). Subsequently, Nesma wheat was sown by drill at 70 kg/ha. This variety is the most common soft bread wheat in Morocco.

As a major objective was to evaluate wheat response to N and P within commonly used rotations, this N -P trial was conducted at each site on fields that had different crops grown during the previous year (Table 2). The rotations are a function of soil type, i.e., as the shallow soils, fallowing is a common practice to conserve moisture with the ensuing weed crop being fed to animals, while on the deep Vertisols corn is grown as a summer crop, as well as continuous wheat.

The experimental design was a factorial randomized complete block with three replications. Each plot was 1.8 x 10 m with six rows of wheat 30-cm apart. As Hessian fly is a major pest in dryland wheat in Morocco, sometimes completely destroying the crop, the seed was applied with an effective control chemical, Furidan (1.12 kg a.i./ha). For weed control, Certrol-H was sprayed on the plots at the 4-leaf stage at 4 L/ha. In view of the humid conditions favorable for cereal diseases, the crop was sprayed with "Tilt" (0.25 L/ha) for septoria control.

Prior to crop planting, which took place during the second week of November 1987, each experimental site was sampled for $NO_3$-N and $NaHCO_3$-P at 20-cm depth increments, in depth to 1 m where appropriate. During the growing season, the plants were sampled at anthesis for total N uptake and dry matter yield; one meter row length was taken from two central rows in each plot and, after drying for 3 days for $60^{o}C$, the plant material was analyzed for total N by the Kjeldahl method. At harvest, which took place at the end of May, 1988, the plots were sampled by taking two 5-m strips from center rows. The wheat plants were cut by stickle at just above-ground level. The material was subsequently weighed, threshed in a diesel-powered plot mill, and grain weight was recorded. The data were analyzed statistically using analysis of variance.

## RESULTS

The data from this study are presented in terms of: i) rotation and soil effects alone on dry matter yield, grain yield and N uptake, ii) response to N and, iii) response to P for these parameters.

## ROTATION-SOIL EFFECTS

Dry matter and grain yield without fertilization were significantly influenced by soil type and the previous crop (Table 3). As expected, dry matter and grain yield from the deep caly soil, Chromoxerert, were significantly higher than the soils of shallow (Rendoll) and medium depth (Calcixeroll). However, where barley was the previous crop, yields from the Rendoll were higher than from the Calcixeroll, i.e., 40.6 vs. 32.0 qx/ha for dry matter and 16.2 vs. 10.1 qx/ha for grain.

Within each soil type, yield data were significantly influenced by previous crop. In the Rendoll soil, higher yield data were achieved following a legume-pea, while fallowing tended to have less of an effect on wheat than barley. With the Calcixeroll, corn as a previous crop produced higher dry matter and grain yield than barley. While corn was no different from wheat as a previous crop for the Chromoxerert, another legume - chickpea produced a remarkable increase in dry matter and grain yield of wheat. Thus, legumes enhancd the following wheat crop, most probably due to increased $NO_3$ from this N-fixing crop.

Table 3. Dry matter and grain yield of wheat in relation to soil type and rotation

| Soil type | Previous crop | Total dry matter | Grain yield |
|---|---|---|---|
| | | ---------- qx/ha ---------- | |
| Rendoll | Barley | 40.6 | 16.2 |
| | Fallow | 37.2 | 13.0 |
| | Peas | 53.5 | 19.2 |
| Calcixeroll | Barley | 32.0 | 10.1 |
| | Corn | 38.0 | 12.8 |
| Chromoxerert | Wheat | 71.3 | 23.9 |
| | Corn | 70.2 | 22.6 |
| | Chickpea | 101.2 | 35.9 |

Quintal (qx) = 100 kg

The influence of both soil types and previous crop on N uptake of wheat is presented in Fig. 2. The effect of both factors was evident with highest values following legumes and with the deep clay soil, Chromoxerert. However, the N uptake data differed from dry matter and grain yield data in as much as values for the Calcixeroll soil were generally higher than from the Rendoll, while the corn produced an effect equal to chickpea on the Chromoxerert.

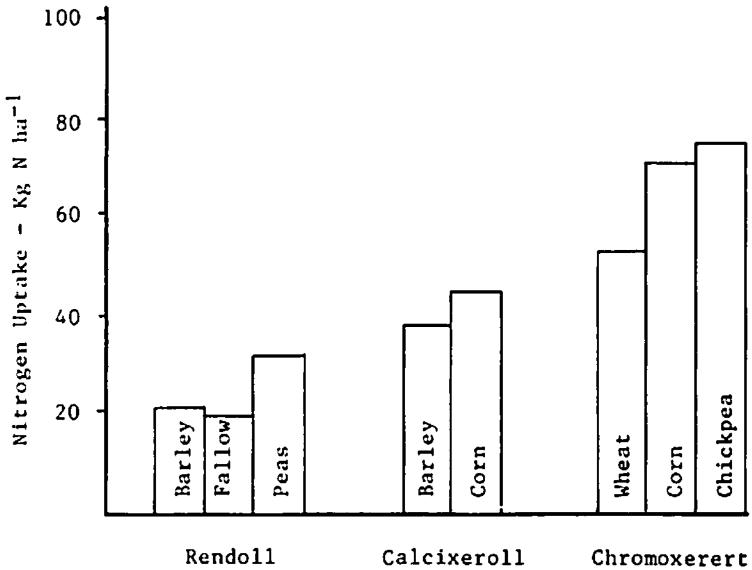



Fig. 2. Nitrogen uptake as influenced by soil type and previous crop.

Relative grain yield (unfertilized controls as a percentage of maximum yield with fertilizer) in relation to available or $NaHCO_3$-P is presented in Fig. 3. As the P level in the soil was above the accepted critical value of 5 ppm P, there was no significant response to P application. The lack of a P response validates the concept of this critical soil P level.

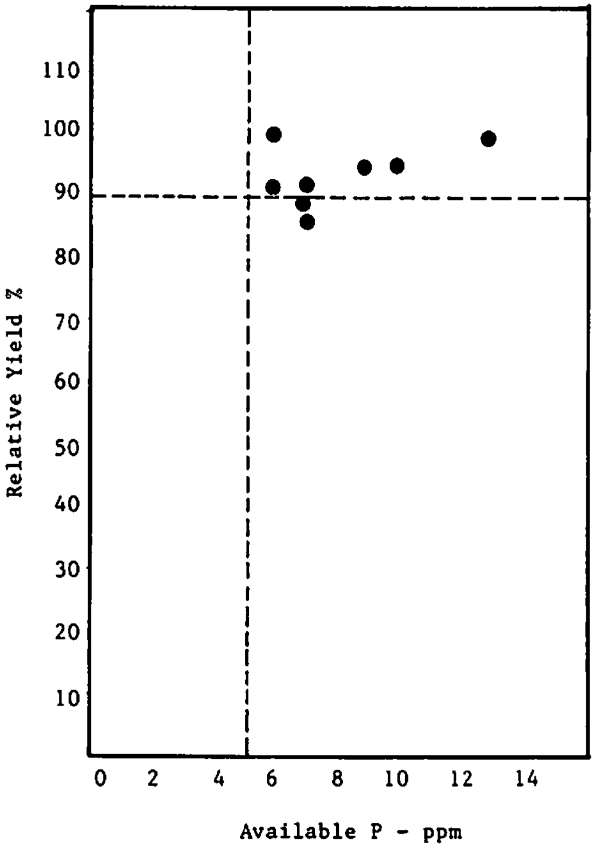



Fig. 3. Relative yield as a function of $NaHCO_3$-P in Rendoll, Calcixeroll and Chromoxerert soils.

## NITROGEN FERTILIZATION

The dry matter yield response to applied N is shown in Table 4. The data consistently increased as the rate of N application increased from 0 to 90 kg/ha; the first increment of 30 kg N produced significant increases in most cases, except where wheat followed legumes and fallow. Indeed, in some cases, i.e., wheat after wheat on the Chromoxerert, each 30 kg increment of N produced a further significant increase in dry matter yield.

Table 4. Dry matter yield of wheat with N fertilization.

| Soil type | Previous crop | N - kg/ha 0 | 30 | 60 | 90 | LSD 5% |
|---|---|---|---|---|---|---|
| | | qx/ha | | | | |
| Rendoll | Barley | 40.6 | 50.8 | 56.4 | 52.9 | 10.3 |
| | Fallow | 37.2 | 45.6 | 53.7 | 57.4 | 9.3 |
| | Peas | 53.5 | 58.3 | 61.9 | 66.9 | 7.5 |
| Calcixeroll | Barley | 32.0 | 45.7 | 48.8 | 56.9 | 6.8 |
| | Corn | 38.0 | 50.7 | 55.8 | 56.8 | 9.5 |
| Chromoxerert | Wheat | 71.3 | 111.8 | 122.2 | 130.5 | 7.6 |
| | Corn | 70.2 | 92.5 | 101.5 | 108.5 | 11.0 |
| | Chickpea | 101.9 | 107.3 | 112.3 | 116.1 | 13.0 |

Rates for Chromoxerert were 0, 40, 80 and 120 kg/ha.

Grain yield showed a similar response to N fertilization with some notable exceptions (Table 5). While grain yield generally increased with applied N, in some cases there was no further response beyond the 60 kg/ha rate. In contrast to dry matter yield, there was no response to N application where a legume had been the previous year's crop, except at the highest N rate on the Rendoll. Under comparable conditions where a cereal was previously grown, the magnitude of the response to N was in the order of Chromoxerert, Calcixeroll and Rendoll.

Table 5. Grain yield of wheat with N fertilization.

| Soil type | Previous crop | N - kg/ha 0 | 30 | 60 | 90 | LSD 5% |
|---|---|---|---|---|---|---|
| | | qx/ha | | | | |
| Rendoll | Barley | 16.2 | 20.3 | 22.5 | 21.2 | 4.1 |
| | Fallow | 13.0 | 15.2 | 17.9 | 18.3 | 3.1 |
| | Peas | 19.2 | 20.4 | 21.1 | 23.3 | 2.6 |
| Calcixeroll | Barley | 10.1 | 15.2 | 17.2 | 19.6 | 2.5 |
| | Corn | 12.8 | 15.1 | 18.8 | 18.0 | 3.9 |
| Chromoxerert | Wheat | 23.9 | 38.7 | 40.8 | 44.0 | 3.2 |
| | Corn | 22.6 | 28.4 | 32.0 | 32.7 | 3.6 |
| | Chickpea | 35.9 | 36.8 | 38.4 | 38.4 | 5.1 |

Rates for Chromoxerert were 0, 40, 80 and 120 kg/ha.

The effect of a previous crop on N response of wheat was clear from these yield data. Here the lack of response where a legume was grown the previous year was evident. Similarly, maximum response was apparent where a cereal - barley or wheat - had been the previous year's crop. The response with corn tended to be intermediate between the cereals and the legumes.

Not surprisingly, the N uptake for wheat (Table 6) followed a pattern similar to dry matter and grain yield in terms of response to N application. Again, uptake tended to increase as the N rate increased. While the highest N rate produced uptake values significantly different from the control, the 30 and 60 kg rates were not always significantly different from the control. The highest actual responses occurred on the Chromoxerert, while in contrast to the dry matter and grain yield data, responses to N where pea or chickpea were grown the previous year were significant.

Table 6. Nitrogen uptake of wheat with N fertilization.

| Soil type | Previous crop | N - kg/ha 0 | 30 | 60 | 90 | LSD 5% |
|---|---|---|---|---|---|---|
| | | qx/ha | | | | |
| Rendoll | Barley | 22.5 | 44.8 | 48.5 | 50.8 | 8.1 |
| | Fallow | 19.8 | 24.6 | 27.6 | 29.7 | 5.6 |
| | Peas | 32.7 | 40.3 | 41.4 | 45.3 | 6.9 |
| Calcixeroll | Barley | 38.7 | 50.8 | 57.1 | 65.0 | 9.3 |
| | Corn | 46.8 | 51.0 | 54.5 | 52.5 | 10.1 |
| Chromoxerert | Wheat | 54.3 | 109.0 | 116.0 | 127.4 | 15.5 |
| | Corn | 71.6 | 82.5 | 90.7 | 103.5 | 15.4 |
| | Chickpea | 75.6 | 100.2 | 100.0 | 126.0 | 17.7 |

Rates for Chromoxerert were 0, 40, 80 and 120 kg/ha

## PHOSPHORUS FERTILIZATION

The relationship between applied $P_2O_5$ and soil type and previous crop is presented in Table 7 for dry matter yield. Since there was no significant interaction between N and P, response data are averaged over all N replicates. In marked contrast to the response to N for dry matter yield, there was no significant effect of applied P at any application rate. Similarly, applied P had no effect on grain yield (Table 8).

Table 7. Dry matter yield of wheat with P fertilization.

| Soil type | Previous crop | P- kg/ha 0 | 30 | 60 | 90 | LSD 5% |
|---|---|---|---|---|---|---|
| | | qx/ha | | | | |
| Rendoll | Barley | 49.1 | 45.1 | 51.2 | 55.2 | 10.2 |
| | Fallow | 45.3 | 49.1 | 48.8 | 50.7 | 7.6 |
| | Peas | 59.5 | 59.0 | 63.5 | 58.6 | 7.2 |
| Calcixeroll | Barley | 44.9 | 47.9 | 45.6 | 45.1 | 6.8 |
| | Corn | 46.5 | 51.9 | 52.4 | 50.4 | 9.5 |
| Chromoxerert | Wheat | 107.3 | 106.4 | 109.7 | 112.4 | 7.6 |
| | Corn | 90.6 | 90.8 | 92.5 | 98.8 | 11.0 |
| | Chickpea | 109.3 | 110.4 | 105.7 | 112.3 | 13.0 |

Table 8. Grain yield of wheat with P fertilization.

| Soil type | Previous crop | P- kg/ha 0 | 30 | 60 | 90 | LSD 5% |
|---|---|---|---|---|---|---|
| | | qx/ha | | | | |
| Rendoll | Barley | 19.7 | 18.1 | 20.5 | 22.1 | 4.2 |
| | Fallow | 15.8 | 16.4 | 16.2 | 16.2 | 2.4 |
| | Peas | 21.1 | 20.4 | 21.9 | 20.5 | 2.6 |
| Calcixeroll | Barley | 15.9 | 15.7 | 15.1 | 15.4 | 2.5 |
| | Corn | 14.4 | 17.0 | 16.6 | 17.5 | 4.0 |
| Chromoxerert | Wheat | 36.3 | 36.1 | 38.0 | 37.0 | 3.2 |
| | Corn | 27.4 | 28.2 | 29.0 | 30.9 | 3.6 |
| | Chickpea | 35.9 | 37.3 | 36.9 | 38.3 | 5.1 |

## DISCUSSION

The third year of a three-year soil test calibration study in Morocco confirmed some observations from the previous two years, having results specific to this above-normal rainfall average. As in previous years, the differences due to soil type within the same rainfall zone were marked. For example, where cereals were the previous crop, thereby eliminating differences due to rotation effects, dry matter and grain yields were almost twice as high on the Chromoxerert than the other two soils. While, in general, there was a relationship between yield and soil depth for the three soils, it is apparent that this relationship with depth would only hold when other soil characteristics are consistent, which is never the case.

As in any area as large as the dryland wheat-growing zone in Morocco, a diversity of soil types is to be found. Though only organic matter-rich soils, Mollisols, and a deep clay soil, Vertisol, were included in this study, other soil orders such as Inceptisols, Entisols, and Aridisols, with a range of characteristics that affect soil fertility and water-holding capacity, are probably of widespread occurrence. Given the dominant influence of soil type, effective transfer of information related to fertilizer needs and response depends on identification of the region's major soil types. Unfortunately, so far, only a small proportion of the soils of the area is identified and mapped.

Wheat growing in central Morocco's dryland area is integrated with livestock farming and other food crops. Consequently, rotations play a key role in maintaining viability of the system as a whole. Traditionally, rotations are believed to conserve soil moisture and sustain or regenerate soil fertility. The particular rotation followed depends on the soil type. Chickpea, lentil, faba bean and pea are the major food legumes grown in rotations with wheat. While wheat following a legume is thought to be better than after another cereal, the effect has not been quantified. The increases in wheat dry matter and grain yield following pea or chickpea were 30 to 50% above those following cereal. Responses of a similar magnitude were also reported for the previous two years.

As moisture was not a limiting factor this season, the enhanced response has to have been due to residual $NO_3$ from the N-fixing legume. Indeed, analyses of $NO_3$ prior to cropping with wheat suggested that this was a likely explanation. Where pea was the previous crop, soil $NO_3$-N values were over three times for barley (i.e., 22 vs. 6 mg/kg). Though values after chickpea were no different from those after corn, an effect of the legume on soil $NO_3$ cannot be discounted, especially if one considers the growth habit of chickpea. During that year this spring-grown crop yielded poorly due to drought; its contribution to soil $NO_3$ may have occurred during the wheat growing season as the legume roots decomposed and released N. The pea crop was grown in winter; as such it yielded well and fixed considerable amounts of N for the succeeding wheat crop. Nevertheless, this year's data raise the question of the relative contribution of any legume species on soil $NO_3$ for the following crop. Future work will focus on growing and managing legumes similarly at any one site in order to quantify such effect.

Fallowing, or leaving land without a crop, has become a controversial issue in view of the increasing demands for crop production. The concept of fallowing in the Middle

East-North Africa region ranges from clean fallow in Syria, where the weeds are plowed under and the soil is kept bare, to weedy fallow in Morocco. In the latter case, the land is intentionally cropped with weeds in order to provide an abundant and reliable source of fodder for livestock. These weedy portions contain variable amounts of Medicago species (Tanji, 1986) and miscellaneous other N-fixing legumes. Though fallow was evaluated at only one site, i.e., shallow Rendoll soil, in our study there was no enhancing effect on subsequent wheat dry matter and grain yield or N uptake. In fact, data after fallow were consistently lower than any other previous crop, including barley. This was in marked contrast to the previous two years (Soltanpour et al., 1986; 1987), where fallow had an effect equal to that of a legume. Positive effects of fallow over barley as a previous crop were also reported from Syria (Jones et al., 1987). The apparent discrepancy without data was probably due to the fact that in the previous year, weed growth was restricted due to the severe drought, thus minimizing any contribution of a leguminous species to soil $NO_3$.

Dryland corn in Morocco is grown as a spring crop as forage primarily and for grain, mainly on deep clay soils. A side-effect of its cultivation is weed control, since the crop is worked several times during the season. Observed beneficial effects on the following crop may be due to conservation of moisture, since the cultivation creates a surface mulch that may reduce evaporative loss. Other factors may include enhanced N mineralization due to cultivation. However, this year's data were not consistent; somewhat higher yield data for the Calcixeroll, but not for the deeper Chromoxerert. However, in the latter soil, N uptake after corn was equal to that after chickpea. However, data of Soltanpour et al. (1987) for the previous year indicated that corn had a greater effect than either wheat or legume as a previous crop. Valid comparisons of the effect of previous crop can only be made when cultural practices are similar, and where yield data are measured as well as soil moisture and $NO_3$ in the profile.

As anticipated, in view of the favorable growing conditions due to the above normal rainfall, addition of N produced a significant yield response. This was highest where a cereal was previously grown and least following a legume. This coincided with data from the previous two years (Soltanpour et al., 1987), which showed no response after legumes, but significant responses after cereals. The respective maximum percentage increases for the Rendoll, Calcixeroll, and Chromoxerert soils after cereals were, respectively, 30, 78, and 83 for dry matter yield, and 31, 94 and 84 for grain yield. In most cases, the increases were significant up to the 60 or 80 kg/ha rate.

The three years' data permit the conclusion that where a productive, well-managed legume crop had been grown the previous year, N fertilization is not necessary for the subsequent wheat crop. On the other hand, with cereals as a previous crop, N fertilization is essential if a reasonable and economic crop yield is expected. While $NO_3$ may theoretically accurately reflect the need for N fertilization, the ephemeral nature of $NO_3$ in soils and the many factors that influence its behaviour tend to obscure the relationship with crop response. The concept of a critical $NO_3$ value is less clearly defined than for P in soils.

A dominant feature of this year's data was the absence of any response to applied P. This coincided to some extent with previous years' data, where a response of only 8% was noted in a comparatively wet year (1986). Yields that year were very low, being restricted by drought. The three years data permit the conclusion that P fertilization is unnecessary where soil $NaHCO_3$-P levels are in excess of about 5 ppm. The no response data this year were recorded on sites with P values from 6 to 13 ppm. In addition, as the season's rainfall was favorable, conditions were such that a P response would even be less likely. Thus, soil testing for available P is a reliable guide for fertilization in dryland areas. From the economic standpoint, it is as important to know when not to apply fertilizer as to know when to do so.

While the dominant influence of rainfall is recognized in semi-arid rainfed areas together with the extreme variation that may exist from season to season, this study has contributed information pertinent to the range of rainfall conditions, as it spanned three years of below normal, normal, and above normal rainfall. Representative wheat grain yields from these years were 8.0, 3.1 and 23.9 qx/ha. Responses to N and P varied with the seasons, while the residual influences of legumes for the following wheat crop were evident in all three years. The study provides a framework for evaluating crop response to fertilizers in general and identifying questions that need answers in the cereal-legume livestock systems in the dryland area of Morocco.

## REFERENCES


Dregne, H.E. 1976. Soils of arid regions. Elsevier Sci. Pub. Co. Amsterdam, 237 p.

Goh, K.M., and R.J. Haynes. 1986. Nitrogen and agronomic practice. p. 379-469. In R.J. Haynes (ed.) Mineral nitrogen in the plant-soil system. Academic Press, Inc.

Harmsen, K., K.D. Sheperd, and A.Y. Allan. 1983. Crop response to nitrogen and phosphorus in rainfed agriculture. p. 223-248. Nutrient balances and the need for fertilizers in semi-arid and arid regions: Proc. 17th colloquim International Potash Institute, held in Rabat and Marrakesh, Morocco.

Jackson, T.L., A.D. Halvorson, and B.B. Tucker. 1983. Soil fertility in dryland agriculture. p. 229-332. In H.E. Oregone and W.O. Willis (ed.) Dryland Agriculture. Agron. 21. Am. Soc. Agron. Madison, Wisc.

Jones, M., A. Matar, and M. Pala. 1987. Farm Resource Management Program. p. 8-41. Annual Report. ICARDA, Aleppo, Syria.

Krentos, V.D., and P.I. Orphanos. 1979. Nitrogen and phosphorus fertilizers for wheat and barley in a semi-arid region. Agric. Sci. 93:711-717.

Le Mare, P.H. 1987. Chemical fertility characteristics of vertisols. p. 125-138. In M. Latham and P. Ahn (ed.). Management of Vertisols under semi-arid conditions. ISBN 947-7614-47-2.

Matar, A.E. 1977. Yields and response of cereal crops to phosphorus fertilization under changing rainfall condition. Agron. 69:874-881.

Primov, G., I. Said, and A. Herzenni. 1987. Crop production in Abda, Morocco. Aridoculture Center report, Settat, Morocco.

Ryan, J. 1983. Phosphorus and its utilization in soils of dry regions. 1983. Geoderma 29:341-354.

Sample, E.C., R.J. Soper, and G.J. Racz. 1980. Reactions of phosphate fertilizer in soils. p. 263-304. In F.E. Khasawneh, E.C. Sample, and E.J. Kamprath (ed.) The role of phosphorus in agriculture. Amer. Soc. Agron., Madison, Wisc.

Soltanpour, P.N., M. El Gharous, and A. Azzaoui. 1986. Nitrogen and phosphorus soil test calibration studies in Morocco. p. 85-95. In P.N. Soltanpour (ed.). Proc. First Regional Soil Test Calibration Workshop, Aleppo, June 23-25. ICARDA, Aleppo, Syria.

Soltanpour, P.N., M. El Gharous, A. Azzaoui, and M. Abdelmonem. 1987. Nitrogen and phosphorus soil test calibration studies in the Ghaouia region of Morocco. p. 67-81. In A. Matar et al. (ed.). Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

Tanji, A. 1986. Inventory of weeds in Ghaouia. Annual Res. Report. p. 140-141. Aridoculture Center, Settat, Morocco.

Watts, D., and M. El Mourid 1988. Rainfall patterns and probabilities in the semi-arid cereal production region of Morocco. Aridoculture Center report, Settat, Morocco.

# WHEAT RESPONSE TO NITROGEN AND PHOSPHORUS FERTILIZERS IN RAINFED AREAS OF PAKISTAN

W. A. Rice, M. E. Akhtar, Y. Rohul Amin, and J. A. Campbell

Barani Agricultural Research and Development (BARD) Project, National Agricultural Research Center (NARC), Islamabad, Pakistan

## ABSTRACT

Four rates of both N (0, 40, 80, 120) and P (0, 80, 60, 120) in kg/ha as urea and single superphosphate alone and in various combinations were applied to wheat crop sown after millet, millet green manure, and fallow at different sites in the rainfed areas of Pakistan. The grain yield was only increased with combined application of N and P fertilizer in case of wheat after fallow, millet, and millet green manure. A marked interaction of fertilizer N and P on grain yield was noted after summer fallow and after millet. Though wheat grain and straw yield responded positively to fertilizers N and P, all the variations observed were not due to soil test values. The polynomial correlation coefficient between $NaHOC_3$-extractable soil P values and grain yield was fairly high, whereas it was difficult to correlate crop response with soil mineral N values. A response surface model was good for prediction (high $R^2$ values) at only two sites.

## INTRODUCTION

Efficient fertilizer use is necessary not only for increasing the agricultural output but also for realizing maximum return from the investment of fertilizer at individual farmer's level. Advice to the farming community on the level of fertilizer to be applied is normally generated from field trials, using different rates of fertilizer nutrients and deriving a mean optimum rate from these trials as general recommendation for the soil test-crop combination in the agro-climatic zones. Such recommendations have the limitation that they do not take into account the large-scale variations in the field fertility levels.

Soil organic matter content and/or total-N is used as a soil test for predicting fertilizer N requirements in Pakistan (Malik et al., 1984). However, the reliability of this method for any crop has not been established. It has been shown that correlation between total soil N and $NH_4$ and $NO_3$ is very poor in soil of rainfed "barani" areas of Pakistan and that the crop response to fertilizer N is greatly affected by the initial levels of soil $NH_4$-N plus $NO_3$-N (Rice et al., 1986). Thus, it has been suggested that soil tests for both $NH_4$ and $NO_3$ are required to develop suitable soil test crop response correlations under "barani" conditions of Pakistan (Rice et al., 1986).

This paper is a preliminary report on soil test calibration involving a collaborative research program with ICARDA aimed at developing site-specific fertilizer recommendations based on soil test values and crop response.

## MATERIALS AND METHODS

The study consisted of four field experiments at two different sites. Three experiments were on the Gujranwala soil series, a silty clay loam soil, at the National Agricultural Research Centre (NARC), Islamabad, and the fourth experiment on the Rajar series, a sandy clay loam in a farmer's field, at Mandra. Some physical and chemical characteristics of these soils are given in Table 1. All the methods used for soil and plant analysis have been described by Winkleman et al., (1986).

Table 1. Some chemical and physical properties of the soils.

| | Series | |
|---|---|---|
| Property | Gujranwala | Rajar |
| Texture | Silty clay loam | Sandy clay loam |
| pH | 7.6 | 7.8 |
| EC - dS $m^{-1}$ | 1.2 | 2.1 |
| Organic matter % | 0.72 | 0.65 |
| $NH_4$ OaC-extractable K -ppm | 79 | 164 |
| Classification | Typic Ustorthent | Typic Torriorthent |

Four levels of fertilizers N and P were used singly as well as in all possible combinations of 0, 40, 80 and 120 kg N/ha, and 0, 30, 60 and 120 kg P/ha as urea and single superphosphate, respectively. The experiment was laid out in a randomized complete block design with four replicates. The fertilizers were broadcast and disked into plots of 1.2 x 10 m prior to seeding of wheat (*Triticum aestivum* L. Cv. Pak-81) on Oct. 20, 1986 at Mandra and Nov. 4, 1986 at NARC.

Values for $PO_4$ at the four sites were 20.7, 10.0, 6.8, and 12.9 kg/ha, respectively. Values for $NH_4$ and $NO_3$ were 16.0 and 11.2 kg/ha at site 1, 6.6 and 35.6 at site 2, 5.2 and 10.7 at site 3, and 17.1 and 21.4 at site 4, respectively.

There was a minimum of six rows in each plot, and only the central four rows, with a plot size of 8 $m^2$, were harvested at maturity. Weeding was done manually during the growing season. The grain and straw samples collected were air-dried and weighed, and finally the straw yield was corrected on an oven-dried weight basis. Grain and straw samples were analyzed for total N by the Kjeldahl method to calculate N uptake.

The data obtained were analyzed by ANOVA with RCBD and factorial arrangements. Response surface curve methodology (multiple regression using a quadratic model) was also adopted to evaluate the response with the equation given below :

$$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP$$

where N and P are nitrogen and phosphorus fertilizers, respectively, Y stands for the yield of the crop, and a and b are unknown constants (Khan _et al_., 1987).

## RESULTS AND DISCUSSION

### Grain and Straw Yield

The statistical analysis indicated that the effect of fertilizers on grain yield was significant only at site 4. However the effect was significant for straw and biomass (grain plus straw) at all four sites. Relatively higher, but not significant, grain yield was obtained with N80 P30 treatment at sites 1, 2 and 3, and in case of site 4, N40 P60 produced more grain weight. The highest rates of combined N and P, i.e., N120 and P120, produced relatively more grain weight, though differences were non-significant compared to some other treatments (Table 2).

Application of fertilizer N alone had a tendency to depress the grain yield in summer fallow - wheat sequence, i.e., sites 2 and 4 plots (Fig. 1). Whereas the application of fertilizer P alone at lower rates showed a positive trend on a yield except at site 1 (Fig. 2), where native extractable P levels were very high, Hobbs _et al_., (1986) have observed that on "Mera" land (soils receiving not much organic manures) N or P fertilizer applied alone did not affect the crop growth and yield under rainfed conditions in Potowan, Pakistan, as compared to control.

The yield data obtained were also analyzed statistically with factorial arrangement. The results given in Table 3 show that N fertilizer application had not affected grain

Table 2. Wheat grain yield response to N and P fertilizer rates at different sites.

| Fertilizer | | Site | | | |
|---|---|---|---|---|---|
| N | P | 1 | 2 | 3 | 4 |
| 0 | 0 | 1.49 | 1.17 | 0.55 | 0.88 |
| 0 | 30 | 1.00 | 1.51 | 1.04 | 1.12 |
| 0 | 60 | 1.12 | 1.36 | 0.67 | 0.98 |
| 0 | 120 | 1.07 | 1.40 | 1.06 | 1.25 |
| 40 | 0 | 1.14 | 1.15 | 1.34 | 0.43 |
| 40 | 30 | 1.24 | 1.38 | 1.15 | 1.91 |
| 40 | 60 | 1.74 | 1.41 | 1.47 | 2.68 |
| 40 | 120 | 1.73 | 1.32 | 1.20 | 2.57 |
| 80 | 0 | 1.62 | 0.95 | 1.25 | 0.48 |
| 80 | 30 | 1.80 | 1.48 | 1.75 | 0.57 |
| 80 | 60 | 1.78 | 1.22 | 1.54 | 2.68 |
| 80 | 120 | 1.79 | 1.28 | 1.39 | 2.83 |
| 120 | 0 | 1.53 | 1.06 | 1.30 | 0.45 |
| 120 | 30 | 1.59 | 1.34 | 1.48 | 2.26 |
| 120 | 60 | 1.71 | 1.24 | 1.19 | 2.90 |
| 120 | 120 | 1.30 | 1.31 | 1.53 | 2.95 |
| LSD (10%) | : | N.S | N.S | 0.51 | 0.89 |

Fertilizer rate = kg/ha; wheat yield = kg/8m$^2$

and straw yields at site 2, i.e., summer fallow-wheat sequence on Gujranwala soil series. Whereas the other plots (sites 1 and 3) of the same soil series but with different cropping sequence at the NARC, i.e., wheat after millet green manuring and after millet harvest, respectively, had shown a marked response to N fertilizer. Response to N fertilizer on another site (No. 4) with summer fallow-wheat sequence, i.e., Rajar series at Mandra, was significant despite

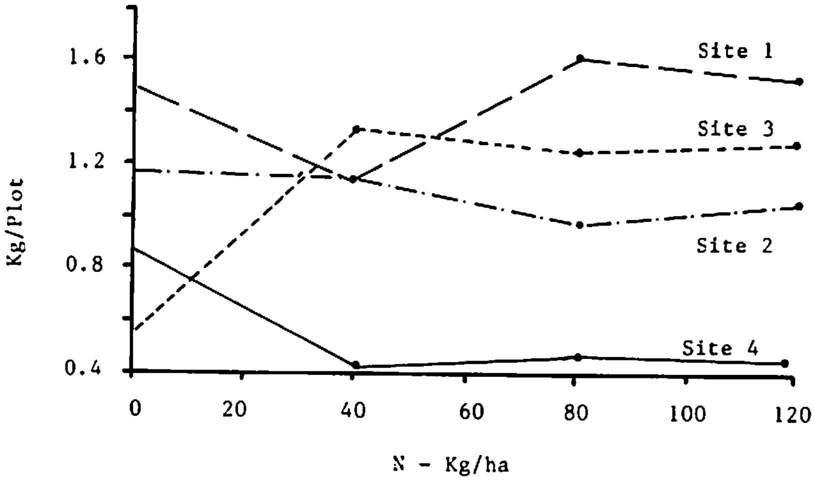



Fig. 1. Effect of nitrogen applied on grain yield of wheat.

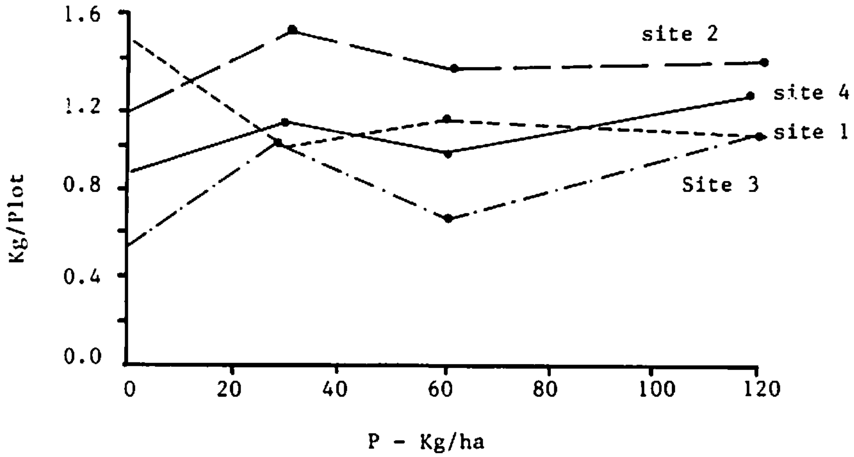



Fig. 2. Effect of phosphate application on grain yield of wheat.

mineral N contents of this site being almost equal to that of site 2, where no response to fertilizer N was observed. Site 4 was, however, relatively uniform in mineral N contents (a small standard deviation) and this could have reduced the experimental error. Rice _et al._, (1980) have also observed high build-up levels of $NO_3$-N+$NH_4$-N in fallow fields of the rainfed area, and wheat response to fertilizer N applied was greatly affected by the initial levels of $NO_3$-N plus $NH_4$-N. The grain and straw yield response to P

Table 4. Response equations for grain and straw yield at different sites.

| Site | | Constant | N | P | $N^2$ | $P^2$ | NP | $R^2$ | Multiple R |
|---|---|---|---|---|---|---|---|---|---|
| 1 | grain | 1322.99 | 1660 | 4.61 | -0.099 | -0.028 | -0.009 | 0.187 | 0.432 |
| | straw | 3981.68 | 23.79 | 1.581 | -0.0153 | -0.035 | 0.040 | 0.354 | |
| 2 | grain | 1523.13 | -2.87 | 8.98 | 0.0103 | -0.061 | 0.0049 | 0.162 | 0.402 |
| | straw | 3512.95 | 6.275 | 2.327 | -0.053 | -0.12 | 0.017 | 0.193 | 0.439 |
| 3 | grain | 872.96 | 19.77 | 5.65 | -0.118 | -0.028 | -0.028 | -0.437 | 0.661 |
| | straw | 3507.8 | 52.77 | 67.65 | -0.276 | -0.042 | 0.061 | 0.545 | 0.789 |
| 4 | grain | 345.56 | 22.68 | 48.46 | -0.164 | -0.239 | -0.15 | 0.736 | 0.859 |
| | straw | 1145.25 | 36.90 | 70.151 | -0.275 | -0.451 | -0.19 | 0.732 | 0.709 |

Table 3. Significance of N and P treatment responses on wheat.

| a) Grain weight | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| N | 4.49** | 1.05 | 18.70 | 19.30 |
| P | 0.49 | 5.98** | 2.51 | 53.52 |
| N X P | 1.07 | 0.28 | 2.15* | 4.82** |
| **b) Straw weight** | **1** | **2** | **3** | **4** |
| N | 13.55** | 0.26 | 25.66** | 15.31 |
| P | 0.25 | 7.65** | 1.23 | 47.93 |
| N x P | 1.71 | 1.27 | 0.53 | 3.31** |

*Significant at 10%; **Significant at 5%.

fertilizer was observed at two sites, i.e., 2 and 4 (Table 4). At sites 2 and 3 (though non-significant) and site 4, all P levels produced similar results but higher than the control (Fig. 2), suggesting that the requirements for vegetative growth and grain production were met with the lowest rate of fertilizer P application.

The levels of extractable P at site 1 were quite high, and these are generally considered adequate for wheat (Olsen and Somers, 1982; Pala and Matar, 1987). Soil extractable P levels at sites 2 and 3 were low. However, a marked response to P fertilizer was observed only at site 2 with no response at site 3, indicating that large heterogeneity occurred in soil and profile characteristics other than soil fertility conditions in the same soil series. A marked interaction of fertilizers N and P was found at sites 3 and 4 for grain yield, and for straw weight only at site 4.

## Nitrogen Uptake

For N uptake, data of only three sites (1, 2 and 3) were used. Nitrogen uptake at all the sites was affected by N application, and P treatment at site 2 only.

## Soil Test Values and Crop Response

An attempt was made to relate soil test values with relative crop yield. The soil extractable P (plant available) levels and grain yield response to p fertilizer followed a typical response pattern; with low levels of soil test values, a large response was observed, and vice versa (Fig. 3-A). However, the response patterns were markedly influenced by the application of varying levels of fertilizer N (Fig. 3b). In contrast to the P response pattern, it was difficult to correlate clearly soil test values of mineral N ($NH_4$-N + $NO_3$-N) with grain yield (Fig. 4a); addition of graded levels of fertilizer P rendered these relationships more intricate (Fig. 4b). Similarly, Pala and Matar (1987) could not develop a relationship between soil test values of mineral N with wheat grain yield which was adequate for prediction.

## Response Surface Equations for Grain

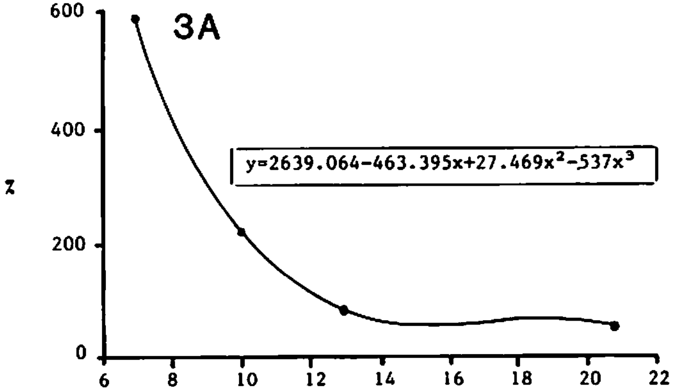
In order to obtain the fertilizer response relationship, the quadratic response surface (multiple regression) method was used. The results of response equations for grain and straw yields at different sites are summarized in Table 4. The characteristics of the multiple regression equations suggest that the predictability of this model is reliable only in the case of site 4 experiment (high $R^2$ value), followed by site 3. In case of sites 1 and 2, the $R^2$ values were too low, and thus of limited use for fertilizer response prediction.

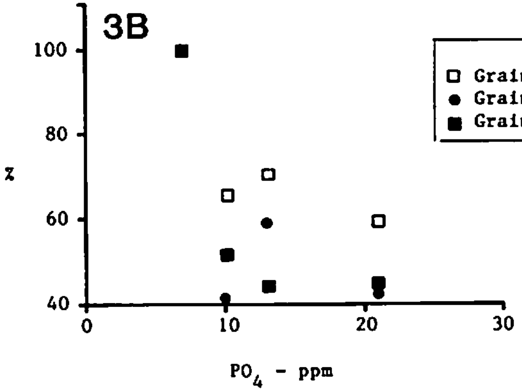
## CONCLUSIONS

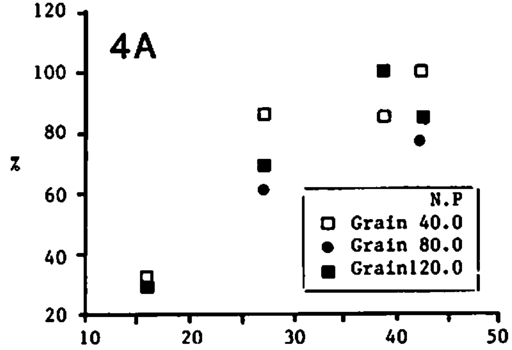
The results are limited as they are based on observations from only four sites with variable cropping history. The wheat grain and straw yield responded positively to fertilizer N and P; however, all the variations observed were not due to soil test levels, and these responses were site-specific. The relationship between P soil test values and grain yield was predictable, whereas it was difficult to correlate mineral N values with grain yield.

## ACKNOWLEDGMENT

We greatly acknowledge the assistance of M. I. Khan and N. A. Khan, Computer and Statistical Section, National Agricultural Research Centre, Islamabad, in making the statistical analysis.



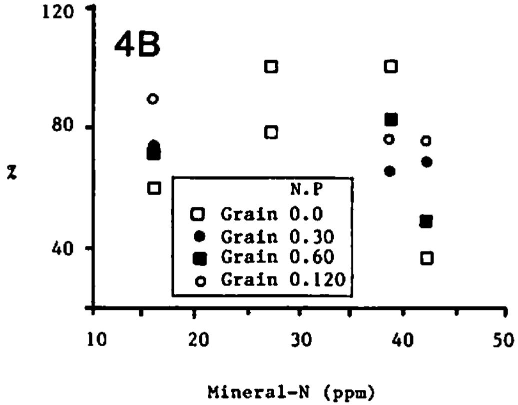




Fig. 3A. Wheat grain yield response (%) as related to extractable P in soil.

Fig. 3B. Wheat grain yield response (%) in relation to extractable-P in soil at various levels of N applied.

Fig. 4A. Wheat grain yield response (%) as related to mineral-N in soils.

Fig. 4B. Wheat grain yield response (%) as related to mineral-N in soils with addition of graded levels of fertilizer P.

REFERENCES

Hobbs, P. R., B. R. Khan, A. Razzaq, B. M. Khan, M. Aslam, N. I. Hashmi, and A. Majid. 1986. Results from agronomic on-farm barani wheat in the high and medium rainfall areas of the northern Punjab for 1983 to 1985. PARC/CIMMYT Wheat Paper No. 86-8; Pak. Agric. Res. Council, Islamabad.

Khan, M. I., M. M. I. Nizami, and N. A. Khan. 1987. Response surface approach to derive economically optimal fertilizer doses for wheat production on two soil families. Occasional Paper; Pak. Agric. Council, Islamabad.

Malik, D. M., M. A. Khan, and T. A. Chaudhary. 1984. Analysis manual for soils, plants and waters. Soil Fertility Survey and Soil Testing Institute, Dept. Agric., Punjab, Lahore, Pakistan.

Olsen, S. R., and L. E. Somers. 1982. Phosphorus: In A. L. Page (ed.) Methods of soil analysis, Agron. 9. Part 2, 2nd Edition. Amer. Soc. Agron., Madison, Wisc., U.S.A.

Pala M., and A. Matar. 1987. Soil test calibration with N and P for wheat under dryland conditions in Syria. p. 55-67. In A. Matar et al. (ed.). Proc. Second Regional Soil Test Calibration Workshop. Ankara, Turkey, Sept 1-6. ICARDA, Aleppo, Syria.

Rice, W. A., M. B. Tahin, R. Amin, and G. E. Winkleman. 1986. Soil test methods for determining the nitrogen fertilizer requirements of rainfed crops in Pakistan. p. 67-85. In P. N. Soltanpour (ed.). First Regional Soil Test Calibration Workshop, ICARDA, Aleppo, Syria.

Winkleman, G. E., R. Amin, W. A. Rice, and M. B. Tahir. 1986. Methods manual : soils laboratory. Pakistan Agric. Res. Council, Islamabad, Pakistan.

# FERTILIZATION RATES FOR CEREALS AND LENTILS IN JORDAN

**N. Abu-Rub and T. Ashab**

**National Center for Agricultural Research and Technology Transfer,**
**Ministry of Agriculture**

**Amman, Jordan**

## ABSTRACT

This paper reports field data from three agricultural experiment stations in Jordan involving N and P trials with wheat, rates and methods of P application for wheat, P rates for barley, and N-P trials with lentils. While N responses were common, P responses occurred only where $NaHCO_3$-P levels were less than 10 ppm.

## INTRODUCTION

Jordan is mainly an agricultural country. Though the area available for agricultural cultivation is only 13% of the total land area and the cultivated area is only about 6%, roughly 40% of the manpower of Jordan is working in agricultural activities. Wheat in Jordan is regarded the most strategic crop due to increasing production, beside the fluctuation of rainfall, domestic wheat output is not sufficient. Because of the big gap between local production (100-150 thousand tons), and consumption (around 500 thousand tons), the Government has made a point of increasing wheat production by all available means. Fertilization is one of the important factors in this effort.

In 1986, Jordan contributed along with other countries in conducting, in cooperation with ICARDA, several studies on fertilization of wheat for higher yields in rainfed areas, i.e., between 200-500 mm/year. In this respect, trials were carried out mainly at two agricultural stations of different locations: Maro Agricultural Station in the north (350-450 mm) and Mushakkar Agricultural Station (300-400 mm). The objectives were a) to determine the wheat requirements for N and P, and b) to study fertilizer application rates and methods of application, i.e., broadcasting and banding. In addition, trials were conducted dealing with lentils at Maro Station and barley at Ramtha Station.

## N AND P FACTORIAL EXPERIMENTS ON WHEAT

Two trials were conducted in 1987-88 to study the NP wheat requirement at two agricultural stations, Maro and

Mushakkar, where the annual rainfall was around 473 mm. The experimental design was a randomized complete block factorial with the wheat variety "Horani Nawawi" planted (Nov. 19-22) with 17-18 cm row spacing at sites previously in fallow. The soil was classified as an Entic Chromoxerert, very fine Montmorillonitic, thermic, with 1% slope. Respective values for soil properties at Maro and Mushakkar were: pH 7.9, 8.1; EC 0.9, 1.4 mmhos; $CaCO_3$ 8.2, 20.4%; Olsen P 10.4, 5.5; $NO_3$-N 22.6, 9.3 mg $kg^{-1}$; and $NH_4$-N 9.7, 6.0 mg kg. Rates of N, as ammonium nitrate, were 0, 40, and 120 kg/ha, while those of $P_2O_5$ were 0, 20, 40 and 80 kg/ha. Harvesting took place on June 13 at Maro and July 10 at Mushakkar.

**Maro Station**

Results

Responses to both N and P are presented separately for both locations; details for Maro are listed under grain yield, 1000-seed weight, and plant height, while only grain yield was presented for Mushakkar.

Grain Yield

Responses to applied N and P in terms of grain yield are shown in Table 1. From the statistical analysis, there were significant effects for N application and the interaction between N and P, but there was no significant response for P. The treatment adding 80 kg N exceeded the control. In terms of interaction, the treatments adding 80 kg N with both 20 and 40 kg $P_2O_5$/ha exceeded the control significantly.

Table 1: Grain Yield at Maro Station with N and P.

| P/N | 0 | 40 | 80 | 120 | Mean |
|---|---|---|---|---|---|
| 0 | 1972 | 2047 | 2232 | 2226 | 2119 |
| 20 | 2003 | 2261 | 2306* | 2234 | 2201 |
| 40 | 2105 | 2255 | 2380* | 2065 | 2201 |
| 80 | 2252 | 2088 | 2025 | 2019 | 2096 |
| Mean | 2083 | 2163 | 2236* | 2136 | 2154 |

All units of fertilizer application and grain yield in kg/ha.
LSD (5%) = 300; Mean LSD (5%) = 150
* significant (5%), CV = 9.6%

1000-Seed Weight

The effect of NP fertilization on the weight of 1000 seeds of wheat is shown in Table 2. From the statistical analysis, it was found that there were no significant effect for N or P or the interaction between N and P on the weight of 1000 seeds of wheat.

Plant Height

The effect of NP on plant height of wheat is shown in Table 3. From the statistical analysis, it was found that there was a significant effect for the N addition at 120 kg N/ha and for the interaction between N and P, i.e., 120 kg. with both 40 and 80 kg $P_2O_5$/ha. But there was no significant response to P application.

Table 2. Effect of N and P fertilizers on 1000-seed weight at Maro Station.

| P/N | 0 | 40 | 80 | 120 | Mean |
|---|---|---|---|---|---|
| | | | g | | |
| 0 | 49.3 | 49.1 | 50.0 | 48.5 | 49.2 |
| 20 | 48.7 | 47.6 | 47.2 | 48.8 | 48.1 |
| 40 | 50.3 | 49.1 | 49.7 | 46.8 | 49.9 |
| 80 | 48.2 | 47.0 | 47.3 | 44.5 | 46.8 |
| Mean | 49.1 | 48.2 | 48.6 | 47.1 | 48.3 |

Units of NP application in kg/ha
LSD (5%) = 3.4 LSD Mean = 1.7 CV= 5.0

Table 3. Effect of N and P fertilizers on plant height at Maro Station.

| P/N | 0 | 40 | 80 | 120 | Mean |
|---|---|---|---|---|---|
| | | | cm | | |
| 0 | 49.3 | 49.1 | 50.0 | 48.5 | 49.2 |
| 20 | 48.7 | 47.6 | 47.2 | 48.8 | 48.1 |
| 40 | 50.3 | 49.1 | 49.7 | 46.8 | 49.9 |
| 80 | 48.2 | 47.0 | 47.3 | 44.5 | 46.8 |
| Mean | 49.1 | 48.2 | 48.6 | 47.1 | 48.3 |

NP application rates in kg/ha
LSD (5%) = 11.9; LSD Mean = 6.0 ; CV = 7.1%

**Mushakkar Station**

Results

Grain Yield

The effect of N and P on wheat grain production is presented in Table 4. From the statistical analysis, there was no significant effect for N application at the 5% level, but there was a mean response to P application at the 1% level for the 20, 40 and 80 kg $P_2O_5$/ha rates and a significant response to the interaction between N and P treatments (40 and 80 kg N/ha + 80 kg $P_2O_5$/ha). The significant response for P application was probably due to the low available P soil content, which was around 5.5 ppm.

Table 4. Grain Production with N and P fertilizers at Mushakkar Station.

| P/N | 0 | 40 | 80 | 120 | Mean |
|---|---|---|---|---|---|
| | | | cm | | |
| 0 | 4025 | 4232 | 4339 | 3901 | 4124 |
| 20 | 4698 | 4614 | 4716 | 4537 | 4641** |
| 40 | 4667 | 4954 | 4948 | 4623 | 4798** |
| 80 | 4904 | 5364** | 5250** | 4704 | 5059** |
| Mean | 4573 | 4797 | 4815 | 4441 | 4656 |

NP application rate and grain yield in kg/ha
LSD (1%) = 981; LSD Mean = 491; CV = 94%
** Significant (1%)

**RATE AND METHOD OF P APPLICATION ON WHEAT**

Two trials were carried out to study the P rate and method of application on wheat production. The experimental details were as for the NP study, except that a standard rate of 60 kg N/ha and an additional increment of $P_2O_5$, i.e., 120 kg were used. The Olsen P at the Maro site was 7.7 ppm compared to 10.4 for the first study with NP.

**Maro Station**

Results

As for the NP study, results are presented in terms of grain yield and 1000-seed weight.

Grain Yield: The effect of P appliation rates and method is presented in Table 5. From the statistical analysis, it was found that there were overall significant effects for the $P_2O_5$ rates of 80 and 120 kg/ha. However, there was no significant difference between method of application or the interaction between P rates and method of application.

<u>1000-Seed Weight</u>: The effect of P rates and method of application on the weight of 1000 seeds is presented in Table 6. From the statistical analysis it was found that there were no significant effects for rates of P, method of P application, or the interaction between P and method of application on the weight of 1000 seeds of wheat.

Table 5. Rate and method of P application for wheat grain yield at Maro Station.

| $P_2O_5$ | Broadcast | Banded | Mean |
|---|---|---|---|
| | kg/ha | | |
| 0 | 1717 | 1661 | 1689 |
| 20 | 1666 | 1871 | 1769 |
| 40 | 1964 | 1917 | 1941 |
| 80 | 2069 | 1957 | 2013* |
| 120 | 2027 | 2047 | 2037* |
| Mean | 1889 | 1991 | 1890 |

* Significant at 5%

Table 6. Rate and method of P application for 1000-seed weight at Maro Station.

| $P_2O_5$ | Broadcast | Banded | Mean |
|---|---|---|---|
| | kg/ha | | |
| 0 | 46.6 | 47.4 | 47.4 |
| 20 | 46.5 | 45.6 | 46.1 |
| 40 | 50.0 | 46.2 | 46.1 |
| 80 | 47.1 | 46.9 | 47.0 |
| 120 | 46.3 | 45.7 | 46.0 |
| Mean | 46.5 | 46.4 | 46.5 |

LSD (5%): For rate means: 24
LSD (5%): For method means: 1.5

## Mushakkar Station

### Results

Grain Yield: The ffect of P rates and P method of application on wheat grain yield is shown in Table 7. From the statistical analysis there were significant effects of P (80, 120, kg $P_2O_5$/ha) at the 1% level and of method of P application, where banding exceeded broadcasting at the 1% level. On the other hand, both rates of banded P (80 and 120) exceeded the same rates broadcast.

Table 7. Effect of banding vs. broadcasting of P on wheat grain yield at Mushakkar Station.

| $P_2O_5$ | Broadcast | Banded | Mean |
|---|---|---|---|
| | kg/ha | | |
| 0 | 3620 | 3838 | 3729 |
| 20 | 3713 | 4299 | 4006 |
| 40 | 4000 | 4459 | 4229 |
| 80 | 4049 | 5236** | 4642** |
| 120 | 4352* | 5347** | 4849** |
| Mean | 3949 | 4636** | 4291 |

LSD (5%); Mean Rate (505); Method Mean (319)
CV = 7%
* Significant (5%)
** Significant (1%)

### FERTILIZER P RATES ON BARLEY

This trial was conducted at the Ramtha Agricultural Experiment Station. With $P_2O_5$ rates of 0, 20, 40, 60, 80, 120 and 160 kg/ha, respective grain yields were 3455, 3355, 3672, 4024*, 4108**, 4105**, and 4299** kg/ha, with the latter yields being significant at the 5 or 1% levels. The level of available soil P was marginal for this site.

### OBSERVATION ON LENTIL FERTILIZATION

A fertilizer trial involving N and P on lentils was also conducted; however, only the Maro Station was involved. Nevertheless, though responses varied widely, there was no apparent effect of either N or P on yield of lentils (Table 8).

## CONCLUSIONS

For these diverse trials at different agricultural experiment stations, a few general conclusions can be made: A significant response to P applications occurs in areas where available P soil is less than 10 ppm (Olsen). Similarly, a response to N application generally occurs, and almost always in high rainfall areas. Banding of P is more efficient than broadcasting in some soils.

Table 8. Response of lentils to N and P fertilization at Maro Station.

| $P_2O_5$ | N applied | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 20 | 40 | 60 | 80 | Mean |
| | kg/ha | | | | | |
| 0 | 3050 | 2134 | 2599 | 2348 | 2972 | 2621 |
| 20 | 1587 | 2423 | 3522 | 2053 | 3041 | 2545 |
| 40 | 2132 | 2282 | 2268 | 3250 | 2972 | 2581 |
| 60 | 2618 | 1811 | 3547 | 3135 | 3090 | 2840 |
| 80 | 2060 | 2339 | 3038 | 2578 | 3328 | 2669 |

Application rates of N and $P_2O_5$ were in kg/ha

## SOIL TEST CALIBRATION WITH PHOSPHORUS FOR WHEAT CROPPED UNDER TUNISIAN RAINFED CONDITIONS

A. Gharbi, L. Ettounsi, and A. Haddad

ESA - Kef and Office des Céréales, Tunisia

### ABSTRACT

The recommendation for systematic application of 100 kg of triple superphosphate per hectare to rainfed wheat without regard to the initial level of soil phosphorus requires re-consideration. Such a practice has led to build-up of P in soils supporting the crops, up to levels exceeding 30 ppm. This study is an attempt to develop a more rational guide to P fertilization of wheat. Twenty on-farm trials were conducted in the main wheat-growing area of Tunisia, located in several "gouvernorats", i.e., Le Kef, Beja, Jendouba, Bizerte, and Zaghouan, under a climate ranging from semi-arid to sub-humid. Fourteen trials were severely damaged by a drought and cricket infestation; only six were in acceptable conditions. The field trials were factorial NP experiments with four ammonium nitrate and four triple superphosphate rates. The experimental design was a randomized complete block with three replicates. Prior to sowing, soil samples were taken from each replication and analyzed for $NaHCO_3$-P which was correlated with crop yields according to the Cate-Nelson graphical method. The critical level, beyond which a response of wheat to P fertilization is unlikely, was 5.2 ppm.

### INTRODUCTION

In Tunisia, the yearly population needs for small grains are estimated to be about two million tons. Part of this amount is produced locally, while the remainder is usually supplemented through imports. Local cereal production varies greatly from year to year. For instance, in the years 1985 and 1987 production was in line with the population needs, whereas, in 1986 it satisfied only one third of the demand. Production of durum wheat (Triticum durum) has for centuries been the main occupation of most farmers in the northern part of the country. The cropping system has been rather traditional until two decades ago, when the first attempts were deployed in efforts to increase crop productivity. The main bases for development have been use of fertilizers, pesticides, and high-yielding cultivars. Despite such efforts, crop yields remain far below their optimum level.

Local fertilizer recommendations formulated for wheat growers by the Ministry of Agriculture (Ministère de l'Agriculture, 1983) consist of the application of 100 kg triple superphosphate (45 % $P_2O_5$) to a hectare of wheat crop regardless of the initial P level in the soil. Such a practice could lead either to nutritional imbalances or to wasteful accumulation of P in the soil supporting the crop, thus incurring higher production costs. Bringing the P rates more in line with the crop demand would rationalize fertilizer use and therefore greatly increase net farm return.

In calcareous soils, phosphates applied undergo reactions of precipitation and fixation as they interact with soil Ca ions, free $CaCO_3$ and with Ca-saturated clays (Cole et al., 1953; Clark and Peech, 1960; Barrow, 1972; Kuo and Lotse, 1972; Tisdale and Nelson, 1975; Holford and Mattingly, 1975). Such an interaction leads to a substantial reduction in P availability for plant growth. Thomas and Peaslee (1973) reported that sodium bicarbonate-extractable P was well correlated with plant response and concluded that this reagent appeared to be more effective than any other extractant for soils with medium-to-high cation exchange capacity, high degrees of base saturation and moderate-to-high amounts of Ca-P and free $CaCO_3$.

Among the various diagnostic techniques developed to determine the plant requirement for nutrients, the critical level approach is most commonly used in crop response studies (Nelson and Anderson, 1975). The critical concentration, which corresponds to the soil test level that produces 90 % of the maximum yield per hectare, separates soils with large probability of response to fertilizers from those with a small probability of response.

Within the framework of the soil test calibration network established by the International Center for Agricultural Research in the Dry Areas (ICARDA) in cooperation with countries in West Asia and North Africa, several scientists have been conducting research to set up guidelines for cereal and legume fertilization. Soltanpour et al. (1987) showed that, in calcareous soils of Morocco, the critical concentration of available P is around 5 ppm. Yurtsever (1988) found that barley grown under central Anatolian conditions of Turkey responded to P up to a concentration of 16.4 ppm in the soil. In contrast, Pala and Matar (1987) reported that the critical level for P with cereals was about 5 ppm in accord with data from Morocco.

This paper aims to assess the P status of soils supporting cereals in Tunisia after two decades of systematic P fertilization, and to determine the biological response of durum wheat to P fertilizer in order to establish guidelines for fertilizer recommendations based on soil tests.

## MATERIALS AND METHODS

### Soil P Status

Two hundred and thirty farm sites were randomly selected within areas producing cereals and legumes under rainfed conditions in the northern and northwestern part of the country; this embraced "gouvernorats" of Bizerte, Beja, Jendouba, le Kef, Siliana, Zaghouan, Ariana, and Nabeul. Farm sizes range from small (less than 5 ha) to large (greater than 50 ha). From each individual farm a composite soil sample was made out of a dozen cores taken in the upper 15-cm segment at different locations in the farm. Soil samples were oven-dried for 24 hours at 105°C, ground to pass through a 2-mm screen, and finally analyzed for available P by colorimetry following P extraction by $NaHCO_3$ according to the Olsen procedure.

### Critical P Level

Twenty on-farm fertilizer trials were conducted at several sites of each cereal production area. Each trial was an N P factorial experiment with four ammonium nitrate rates (0, 40, 80 and 120 kg N/ha, applied alone and in combination with four triple superphosphate rates (0, 20, 40, and 80 kg $P_2O_5$). The experimental design was a randomized complete block replicated thrice. The plot size was 20 $m^2$ (10 m x 2 m). Before fertilizer application, soil samples were taken from each replication to a depth of 0.6 m and divided into three 0.20-m increments. Prior to sowing, each plot received at random a combination of one N and one P level. Fertilizers were tilled into the soil to ensure maximum uptake by plant roots. The experimental sites were planted with the most common durum wheat cultivar ("Karim"). Weeds were controlled chemically as needed.

The very dry conditions during the year in Tunisia as well as the various cricket invasions severely affected the crop development in four experimental sites; only six trials were in acceptable conditions to be considered in this study. At harvesting, grain yield was received on each plot and averaged. The percentage yield value, ratio of the yield at 0-level (check plot) to the maximum yield obtained when all factors are at adequate levels, was computed for each site. The soil P values were averaged so that there was a single percentage yield and one soil test value for each location. Using the Cate-Nelson graphical method the critical level of P for durum wheat was derived (Fig. 1).

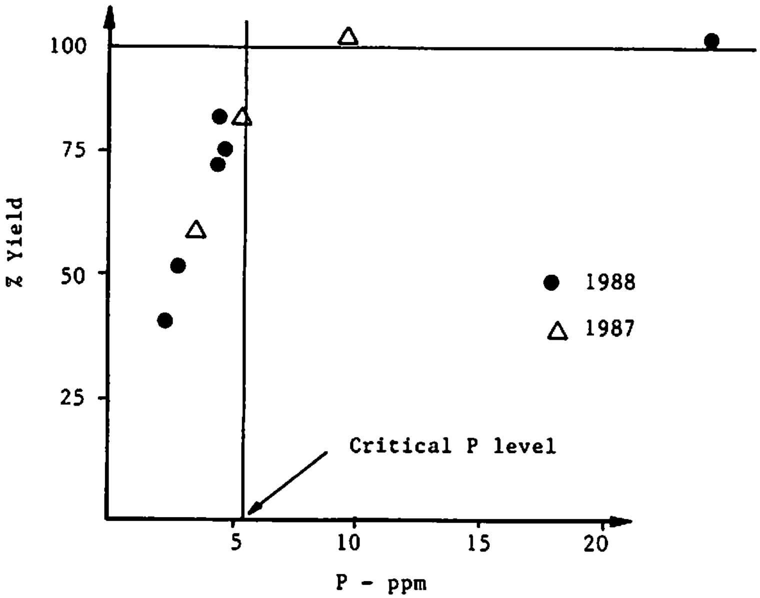



Fig. 1. Scatter diagram of percentage yield vs. extractable soil P.

## RESULTS AND DISCUSSION

### Available P Status

The data (Table 1) showed that only 4 % of the 230 farm sites sampled had an available soil P less than 5 ppm, 12% had Olsen-P value ranging from 5 to 10 ppm, while 84% of the total samples contained an available soil P level greater than 10 ppm. Such data reveal a substantial P accumulation in soils supporting cereal crops. This was probably due to yearly addition of P by cereal growers following fertilizer recommendations made by the Ministry of Agriculture.

### Critical P Level

There was no response of durum wheat to P application when the $NaHCO_3$-P level in the soil was equal to 9.5 mm (Table 2). Similar results were found when the P level was 24 ppm. Data in Table 2 show, on the other hand, that durum wheat was highly responsive to P application when $NaHCO_3$-P

Table 1. Number and percentage of soil site samples in relation to P ranges.

| "Gouvernorats | $NaHCO_3$-P ranges (ppm) < 5 | | 5-10 | | 10-20 | | 20-30 | | > 30 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % |
| Bizerte | 1 | 10.0 | 1 | 10.0 | 1 | 10.0 | 3 | 30.0 | 4 | 40.0 |
| Beja + Jendouba | 2 | 4.2 | 7 | 14.6 | 15 | 31.3 | 14 | 29.1 | 10 | 28.8 |
| Ariana | 0 | 0.0 | 1 | 6.7 | 6 | 40.0 | 2 | 13.3 | 6 | 40.0 |
| Zaghouan | 2 | 15.4 | 5 | 38.5 | 3 | 23.1 | 1 | 7.6 | 2 | 15.4 |
| Siliana | 1 | 1.8 | 5 | 8.9 | 15 | 26.8 | 12 | 21.4 | 23 | 41.1 |
| Le Kef | 4 | 5.3 | 6 | 7.9 | 19 | 25.0 | 26 | 34.2 | 21 | 27.6 |
| Nabeul | 0 | 0.0 | 2 | 16.7 | 6 | 50.0 | 2 | 16.7 | 2 | 16.7 |
| Total | 10 | 4.3 | 27 | 11.7 | 65 | 28.3 | 60 | 26.1 | 68 | 29.6 |

Table 2. Relationship between available P and wheat response.

| Site | Soil Type | Soil-P in Check | 0-Level Yield | Full-Level Yield | Max. Yield |
|---|---|---|---|---|---|
| | | ppm | T/ha | T/ha | % |
| Krib 1 | Alfisol | 4.3 | 1.71 | 2.34 | 73.0 |
| Krib 2 | Alfisol | 24.0 | 1.20 | 1.21 | 99.0 |
| Krib 3 | Vertisol | 4.7 | 1.87 | 2.08 | 85.9 |
| Bouromis | Aridisol | 4.5 | 2.10 | 2.80 | 75.0 |
| Testour 1 | Aridisol | 2.7 | 0.50 | 0.96 | 51.5 |
| Testour 2 | Inceptisol | 2.2 | 0.40 | 1.00 | 40.0 |
| Le Kef 1 | Inceptisol | 9.5 | 4.31 | 4.40 | 98.0 |
| Le Kef 2 | Inceptisol | 5.3 | 3.85 | 4.53 | 85.0 |
| Le Kef 3 | Inceptisol | 3.2 | 2.37 | 4.13 | 57.3 |

Le Kef data taken in 1986-87.

in the soil was low (about 2 ppm). This response diminished as the initial soil P approached values near 4.5 to 5 ppm. The scatter diagram, based on the Cate-Nelson graphical technique, gave a critical soil P level of about 5.2 ppm. Beyond this level, response of durum wheat to P fertilization is very unlikely.

## ACKNOWLEDGMENT

We thank Mr. Sellami Ahmed, Director of the Cereal Production Improvement at the Office des Céréales, who greatly encouraged soil test calibration research work, and Dr. Matar for his untiring efforts to promote the soil test calibration program. In addition, the participation of the technicians in the soil testing laboratory of E.S.A. Kef and of the Office des Cereales is acknowledged.

## REFERENCES

Barrow, N. J. 1972. Influence of solution concentration of calcium on the adsorption of phosphate, sulfate, and molybdate by soils. Soil Sci. 113:175-180.

Clark, J. S., and M. Peech. 1960. Influence of neutral salts on the phosphate ion concentration in the soil solution. Soil Sci. Soc. Am. Proc. 24:346-348.

Cole, C. V., S. R. Olsen, and C. O. Scott. 1953. The nature of phosphate sorption by calcium carbonate. Soil Sci. Sec. Am. Proc. 17:352-356.

Holford, I. C. R., and G. E. G. Mattingly. 1975. The high- and low-energy phosphate adsorbing surface in calcareous soils. J. Soil Sci. 26:407-417.

Kuo, S., and E. G. Lotse. 1972. Kinetics of phosphate adsorption by calcium carbonate and Ca- kaolinite. Soil Sci. Soc. Am. Proc. 36:725-729.

Ministere de l'Agriculture. 1983. La culture du blé. Document technique émanant du service de la vulgarisation, D.E.R.V. Tunisia

Nelson, L. A., and R. L. Anderson. 1975. Partitioning of soil test crop response probability. p. 19-38. In T. R. Peck (ed.) Soil Testing: correlating and interpreting the analytical results. Amer. Soc. Agron., Madison, Wisc. USA. Special Pub. 29.

Pala, M., and A. Matar. 1987. Soil test calibration with N and P for wheat under dryland condition in Syria. p. 55-66. In A. Matar et al., (ed.) Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6, ICARDA, Aleppo, Syria.

Soltanpour; P. N., M. El Gharous, A. Azzaoui, and M. Abdel Monem. 1987. Nitrogen and phosphorus soil test calibration studies in the Chaouia region of Morocco. p. 67-81. In A. Matar et al. (ed.) Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

Thomas, G. W., and D. E. Peaslee. 1973. Testing soils for phosphorus. p. 115-132. In L. M. Walsh, and J. D. Beaton (ed.). Soil testing and plant analysis. Soil Sci. Soc. Amer., Madison, Wisc. USA

Tisdale, S. L., and W. L. Nelson. 1975. Soil fertility and fertilizers. Macmillan, 2nd edition, New York.

Yurtsever, N. 1988. Two soil tests for phosphorus calibrated with barley response to fertilizer in rainfed conditions of Turkey. p. 36-43 In A. Matar et al. (ed.). Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

# WHEAT RESPONSE TO $NaHCO_3$-EXTRACTABLE SOIL P CONTENT IN THE CENTRAL HIGHLANDS OF YEMEN

H. Saad, A. Bamatraf, and A. Haidra

Agricultural Research Authority
P.O. Box 5788, Taiz, Yemen Arab Republic

## ABSTRACT

A field study was conducted to correlate wheat yield with available phosphorus content of a highly calcareous soil in the central highlands of Yemen. Both straw and grain yield increased four times with increasing P applications (0 to 240 $P_2O_5$ kg/ha). The yields tripled when 80 kg/ha of $P_2O_5$ was added, but there were no further significant yield differences with increasing P. Available soil $NaHCO_3$-extractable P increased consistently with added P. Wheat yield was highest when soil P reached an average value of about 13 ppm. Although increasing soil P over this level did not result in significant yield increments, available P removal by wheat was higher as P level in the soil increased.

## INTRODUCTION

The Yemen Arab Republic is characterized by extremely diverse physiography, climate, soils, and agricultural activities. Lack of available soil N and P is a major factor contributing to low crop yields in all agro-ecological regions of the country. Poor management may explain the low soil N content (Bamatraf, 1987). However, the low P availability may be due to P-fixation, as most soils are highly calcareous. In fact, Amer (1985) and Saleh (1986) indicated that soluble P anions were almost fixed as Ca-P, and observed general P deficiency symptoms on wheat and other cultivated crops in the region. Field and laboratory investigations on Yemen soils (King et al., 1983) showed that most soil families contain low-to-medium levels of plant-available P. Detailed soil surveys in the Central Highlands agro-ecological region (Gewaifel et al., 1983) showed that the soils contained, on average, 10.5% $CaCO_3$, with carbonate concretions commonly visible in the soil profile; pH values ranged from 7.3 to 8.3. Available P was generally low, rarely exceeding 6 ppm.

In field trials in the Southern Upland region, Dewan et al. (1978) indicated that a significant response of corn and wheat to P fertilizer was only possible when higher P rates were applied. They concluded that P application should be high enough to satisfy both the soil P fixation capacity and crop nutrient demand. Similarly, trials for four years with N and P fertilizers for wheat, at the Central Highlands Regional Research Station (CHRRS), Dhamar Farm, clearly demonstrated the importance of P application for optimum growth and yield of wheat (ARA, 1984-1987).

The ARA soil fertility research program has mainly dealt with determining optimum fertilizer application rates required to produce maximum yields. Consequently, information such as the use of residual fertilizer P by subsequent crops is, thus far, lacking. The concentration of extractable P sufficient for maximum yield varies with soil properties, especially texture. For example, Novais and Kamprath (1978) reported that critical values on Mehlich-extractable P for clay and sandy Ultisols were 10 and 20 ppm, respectively. Bowman et al. (1978) reported that 10 ppm $NaHCO_3$-extractable P (Olsen-P) was a critical value below which P deficiencies were likely to occur.

Determination of critical values like these is probably important for the utilization of excess P by subsequent crops. Therefore, the objectives of this study were (i) to correlate wheat yield with available P of a highly calcareous soil in the Central Highland of Yemen, and (ii) to identify soil P levels at which additional P fertilizer is not needed.

## MATERIALS AND METHODS

A field experiment with wheat (*Triticum aestivum* L., cv. Pavon) was conducted in the 1986/87 winter season at the CHRRS Dhamar Farm. The soil at the site was clay loam with 36, 48, and 16% sand, silt, and clay, respectively (loamy, mixed calcareous, isothermic, Calcic Ustochrept). It had a well-drained profile that formed on a volcanic parent material (ACSAD, 1987). Some selected physical and chemical properties of the 0-25 cm layer were determined. The soil had a pH of 8.3, 12% $CaCO_3$, 1.2% organic matter, electrical conductivity of 0.44 $dSm^{-1}$ and a cation exchange capacity of 12 meq/100 g. With 0.1% total N, contents of available P and K were 5.5 and 180 ppm, respectively. The site has a frost-free season of more than 200 days, and an annual precipitation of 350 to 400 mm (Bride, 1985).

Wheat was planted dry (Dec. 24, 1986) in east-west oriented rows, 0.25 m apart at a sowing rate of 100 kg/ha. Each of the nine fertilizer treatments had 12 rows in a 3x5 m basin. The wheat basins were irrigated every 14 days from tubewell water. The water was of good quality with an EC of 0.37 dS $m^{-1}$ and a pH of 7.2. Soluble cations were Ca, 1.8; Mg, 0.8; Na, 10 and K, 0.1 meq/L, respectively, while values for soluble anions (meq/L) were Cl, 10; $SO_4$, 0.2; $HCO_3$, 2.3, $NO_3$, 0.27, and $CO_3$, 0, respectively.

Urea 46% N (at 80 kg N/ha) was applied to all basins and one control without P in two split applications : one at planting and the second at tillering. The $P_2O_5$ treatments were 0, 60, 80, 100, 120, 160, 200 and 240 kg/ha, and one control ($N_0$,$P_0$). This was applied as triple superphosphate (46% $P_2O_5$) broadcast before sowing. The nine treatments were arranged in a four-replicate randomized complete block design (RCB). Pest control followed the recommended practice on the farm.

Soil samples were collected from the top 0 to 25 cm of each plot, 35 days after planting and immediately after harvesting. The samples were air-dried and prepared for chemical and physical analyses following standard methods (Black et al., 1965). Soil P was extracted by $NaHCO_3$ (Olsen et al., 1954) and determined spectrophotometrically. On May 25, 1987, the wheat crop was harvested and both grain and straw yields determined and reported.

## RESULTS AND DISCUSSION

Grain and straw yields increased fourfold with increasing fertilizer P rates from 0 to 240 kg $P_2O_5$/ha (Table 1). Wheat yield did not significantly respond to N application at the zero P treatment. However, an application of 60 kg $P_2O_5$/ha increased average grain yield by 132 and 157% compared to average grain yield of wheat that did not receive P with and without N, respectively. Almost similar trends were obtained for straw yield. There was a threefold increase in both grain and straw yields when 80 kg $P_2O_5$ was applied. But, higher application rates did not

Table 1 : Wheat response to increasing P application.

| Applied $P_2O_5$ | Wheat yield | |
|---|---|---|
| | Grain | Straw |
| ----kg/ha----- | ----------tons/ha-------- | |
| 0 | 1.66 | 2.71 |
| 0 | 1.84 | 3.13 |
| 60 | 4.26 | 7.04 |
| 80 | 5.25 | 8.18 |
| 100 | 5.43 | 8.43 |
| 120 | 5.15 | 8.26 |
| 160 | 5.40 | 9.00 |
| 200 | 5.54 | 8.97 |
| 240 | 5.89 | 9.21 |
| L.S.D. 0.05 | 0.76 | 1.66 |
| C.V. % | 11.5 | 15.7 |

significantly further influence yield response. The findings by previous researchers at CHRRS farm (ARA, 1984 to 1987) were in accord with the response in this study. Also, this yield response to P is indicative of the effectiveness of applying 80 kg $P_2O_5$/ha for both wheat yield optimization and proper fertilizer use management under prevailing soil conditions in the Central Highlands.

Available soil P, extracted 35 days after planting increased consistently with increasing P applied (Fig. 1). The regression between applied P and available soil P was linear. The linearity is evidenced by the magnitude of the coefficient of determination; 87% of the variation in available soil P with addition of fertilizer P was accounted for by the equation. Likewise, variation in residual soil P at harvesting with fertilizer P treatments was described by a straight line. The two lines in Fig. 1 depict an increasing trend of P removal by the crop (distance between the two lines) as soil P increases. This trend suggests that wheat plants having normal growth absorb more P when ample supply of the nutrient is available.

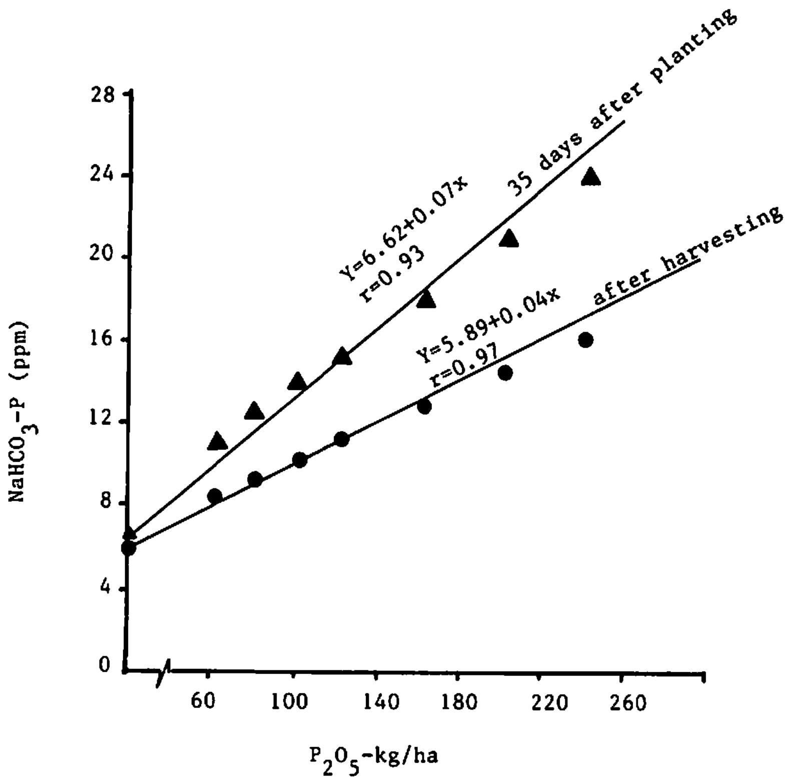



Fig. 1. Relationship between applied P and available soil P.

Yield response to available soil P (35 days after planting) is depicted in Fig. 2. Average wheat yield was lowest when only 6 ppm of soil P were available to the young plants. The grain and straw yields were significantly higher at an available soil P level of 13 ppm than at lower levels, but increasing soil P beyond this critical value did not cause significant yield increase. This influence of soil P content on wheat yield is consistent with results obtained in Texas by Hipp (1986). Also, the relationship in Fig. 2 conformed with the yield response to fertilizer P indicated earlier.

These results show that application of P fertilizer may not be necessary if the initial soil $NaHCO_3$-P level is more than 13 ppm with calcareous soil. Matocha et al. (1970) found that residual P was as available as that applied at the year of cropping. To apply a fertilizer without a response thus leads to a decrease in net profit from any crop production enterprise.

For more efficient and economical use of P in Yemen, these results on the critical soil P value remain to be further assessed for existing P supply, and hence the soils' crop-producing ability.

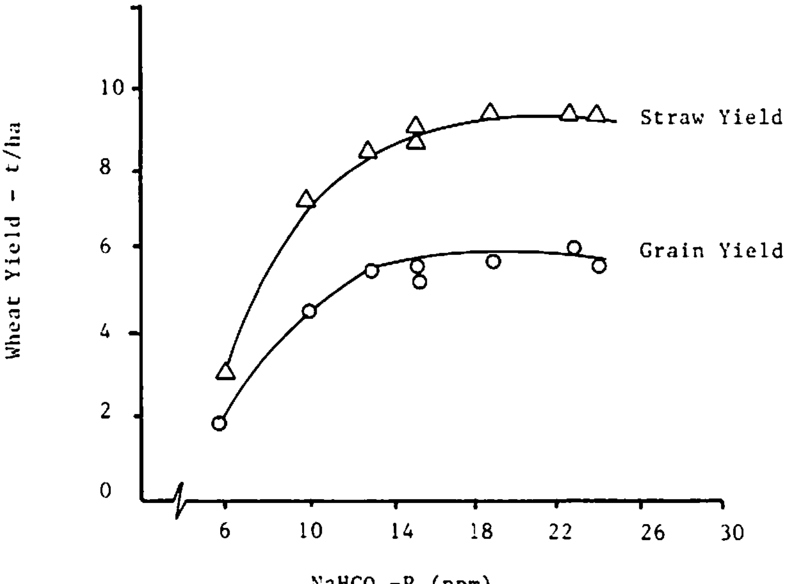



Fig. 2. Influence of available soil P at 35 days from planting on wheat yield.

## CONCLUSIONS

It is concluded that : (i) wheat yield in relation to available soil P is optimum at a soil $NaHCO_3$-P value of 13 ppm under the calcareous soil conditions in the Central Highlands of Yemen; (ii) for more efficient P use, fertilizer application is not necessary when the initial soil P level exceeds this value; and (iii) this critical soil P value remains to be further investigated under different soil conditions in the country.

## REFERENCES

ACSAD. 1987. Tour guide for the Second International Soil Correlation Meeting: Characterization, Classification and Management of Aridosols. Yemen Arab Republic. Jan. 5-15.

Agricultural Research Authority (ARA). Annual Reports. 1984-1987. Min. Agric. and Fisheries. Taiz, Yemen Arab Republic.

Amer, S.A. 1985. Soil fertility research in Yemen. Final report. Min. Agric. and Fisheries, Agric. Res. Authority, Yemen Arab Republic.

Bamatraf, A.M. 1987. Supplemental irrigation in the Yemen Arab Republic. Prepared for ICARDA (International Center for Agricultural Research in the Dry Areas), Aleppo, Syria.

Black, C. A., D. D. Evans, J. L. White, L. E. Ensiminger, and F. E. Clark (ed.). 1965. Methods of soil analysis : Chemical and microbiological properties, Agron. 9, Part 2. Amer. Soc. Agron., Madison, Wisc.

Bowman, R. A., S. R. Olsen, and F. S. Wantanbe. 1978. Greenhouse evaluation of residual phosphate by four phosphorus methods in neutral and calcareous soils. Soil Sci. Soc. Am. J. 42:451-454.

Bride, D. A. 1985. A summary of the meteorological data taken at the RLIP weather stations; 1980-84, Dhamar (Montaine Plains, Yemen Arab Republic), RLIP Commun No. 6.

Dewan, H. C. H. Saad, and A. K. Mabrouk. 1978. Results of fertilizer rate experiments with improved varieties of maize in Southern Uplands of Yemen Arab Republic during 1975-77.

Gewaifel, I., A. Al-thor, and A.A. Saif. 1983. Soil survey and suitability land classification for Dhamar (sample area representing the Central Highlands). MAF, ARDA, Taiz, Yemen Arab Republic.

Hipp, B. W. 1986. Wheat and forage sorghum response to residual phosphorus in Blackland soils. Agron. J. 78:117-120.

King J., T. Forbes, and A. Bughanem. 1983. Soil survey of the Yemen Arab Republic. Dept. Agron., Cornell Univ. Final report for Near East Bureau, Contract No. AID/NE-C 1665. USAID, Washington, D.C.

Matocha, J. E. Lonrad, L. Reves, and G. W. Thomas. 1970 Residual value of phosphorus fertilizer on calcareous soils. Agron. J. 62:572-574.

Novais, R., and E. J. Kamprath. 1978. Phosphorus supplying capacities of previously heavily fertilized soils. Soil Sci. Soc. Am. J. 42:931-934.

Olsen, S. R., D. J. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular No. 939, USDA, Washington, D.C.

Saleh, S. M. 1986. Soil fertility investigations in the Yemen Arab Republic. Mar. 1985 to Dec. 1986. Final report of FAO soil chemist, ARA, Taiz, Yemen Arab Republic.

# USE OF A UNIVERSAL SOIL TEST AND PLANT ANALYSIS FOR DIAGNOSING P DEFICIENCY IN RAINFED WHEAT

A. Rashid, F. Hussain, G. Ahmad, and M. Salim

Land Resources Section,
National Agricultural Research Centre,
Islamabad, Pakistan

## ABSTRACT

Current knowledge about soils of Pakistan indicates widespread deficiency of P in crops. Moreover, there is no reliable fertilizer recommendation system based on sound soil test calibration database. Wheat (*Triticum aestivum* L.), the most important staple food crop in the country, is very sensitive to P deficiency. Seven soil-test crop-response field experiments were conducted during 1986-87 in the rainfed areas of Pakistan (no field experiments could be carried out during 1987-88 due to severe drought). All the experimental fields of 1986-87 were deficient in P to varying degrees, and maximum grain yield increase with P fertilization varied from 31 to 115%. However, maximum grain yield on six sites was obtained with the highest rate of fertilizer (66 kg P/ha), resulting in incomplete response curves and failure to determine critical levels of soil and plant tissue P contents. However, the universal soil test for alkaline soils, ammonium bicarbonate-DPTA (diethylene triamine pentaacetic acid), was effective in separating the soils into deficient and marginal groups. The concentration of P in wheat leaves and mature grains was also helpful for estimating the P fertility status of rainfed soils.

## INTRODUCTION

Wheat, the most important cereal crop grown in Pakistan, is one of the most sensitive species to P deficiency (Rashid *et al*., 1987). Almost all the agricultural soils of Pakistan are alkaline and calcareous to varying degrees (Ahmed, 1986) and hence generally deficient in P (Memon, 1986). According to Bhatti (1973), out of 1110 soil samples taken from 13 districts of the Punjab, 61% contained <3 mg Olsen's P/kg; 24% contained between 3 and 12 mg P/kg, and 5% contained >12 mg P/kg. Hence, wheat growers of rainfed areas of Pakistan generally supply moderate amounts of P in fertilizer form. However, fertilizer applications are not based on any sound fertilizer recommendation program. Rather the fertilizer application rates in the country are based on the past experience with crop response to fertilizer application in a particular region without consideration of the native fertility status of the soils.

In fact, the soil test method (Olsen) used in the country has not been well calibrated against crop response to P fertilizer (Memon, 1986). Therefore, the prevailing fertilizer practices probably indicate injudicious use of a valuable economic input, the fertilizer.

Soltanpour and Schwab (1977) developed the ammonium bicarbonate-DTPA (AB-DTPA) soil test for alkaline soils. This multi-element test is capable of determining the fertility status for macro- and micro-nutrients by a single extraction. Therefore, this soil test is much cheaper, easier, and less time-consuming than the $NaHCO_3$ test now used routinely in Pakistan. Hence the AB-DTPA test could be used for quick, site- and crop-specific recommendations about fertilizer applications to crops grown on alkaline soils of Pakistan. Our preliminary greenhouse and laboratory investigations (Rashid et al., 1987) suggested that the AB-DTPA soil test was very effective for determining P fertility status of soils for growing cereals (including wheat), legumes, and oilseeds. This paper reports the effectiveness of the AB-DTPA soil test and plant analysis for diagnosing P deficiency in rainfed wheat.

## MATERIALS AND METHODS

Four great major soil groups of an important rainfed area in Pakistan, Chekwal district, were selected for the P soil test calibration studies: Typic Cambiorthid, Fluventic Cambiorthid, Typic Ustochrept, and Udorthentic Chromoustert. The soils were sampled to a depth of 60 cm and separated into three 20-cm increments. Locations, and experimental properties of the soils, determined by the methods suggested by Soltanpour and Workman (1981), are given in Tables 1 and 2. No crop was grown at any of the sites during the previous kharif (summer) season.

Wheat response to fertilizer P application was studied at each site. Nitrophos was used to provide four P rates of 0, 22, 44 and 66 kg/ha. One hundred and twenty kg N/ha was applied to all the experimental plots. The balance of N was made up by applying urea. The experimental design was a randomized complete block with three replications. Fertilizers were broadcast on the soil surface by hand and cultivated into the soil prior to planting. Seeds of Pak-81 cultivar of wheat (*Triticum aestivum* L.) were sown in the first week of November, 1986, at a rate of 100 kg/ha, with a row spacing of 30 cm.

Two recently matured leaves (second and third from the top) were sampled from the middle rows at boot stage. At maturity, 1 $m^2$ of each experimental plot was harvested from the central rows during the third week of May, 1987. The crop was threshed with a plot combine thresher. Grain and straw yields were recorded. The leaf samples were washed with distilled water, and leaf and grain samples were oven-dried at 70°C for 2 days and ground in a Wiley mill. Plant material was digested with a nitric perchloric acid mixture (2:1), and P in the digests was determined by the molybdenum blue method (Watanabe and Olsen, 1965). Extractable soil P was determined by the AB-DTPA soil test (Soltanpour and Workman, 1979).

## RESULTS AND DISCUSSION

### Response of Wheat to P Fertilizer

Rainfed wheat responded to P fertilizer application at all the experimental sites of the Chakwal district. Maximum grain yield increase varied from 31% at Balkasar to 115% at Dub (Table 3). Straw yield increase was less than grain; a maximum of 17% at Balkasar and 100% at Dub. Wheat response to P fertilizer was not similar on any one soil type. For example, maximum grain yield increase at three Typic Cambiorthid sites varied from 31 to 73%. Soil P level at the location with 31% yield increase (Balkasar) was 2.68 mg P/kg and 4.1 mg P/kg where yield increase was 73%. Therefore, some other factors besides soil type and soil P status were responsible for crop yields. Wheat is one of the most sensitive crops to P deficiency (Rashid et al., 1987). On a P-deficient soil collected from the rainfed area of Pothowar region in Pakistan, wheat yielded only 19% grain without P fertilizer. The most tolerant species included in the study, chickpea, produced 42% of its maximum on the same P-deficient soil.

AB-DTPA-extractable P in the surface soil layer (0-20 cm depth) varied from 2.68 mg P/kg at Balkasar to 5.63 mg P/kg at Kont (Table 1). Concentrations of extractable P decreased with depth at all locations (Table 1). A decrease in P content with soil depth could be due to crop mining over the years from lower soil layers, accumulation of P on the soil surface due to leaf drop and crop residue, and/or P fertilization of the surface soil (Barber, 1980).

Average annual rainfall in Chakwal district varies from 350 to 500 mm. Annual rainfall during 1986-87 was 373 mm and most of it (258 mm; 69% of the annual) was received during the wheat growing season (Nov., 1986 to May, 1987) (Fig. 1). Enough precipitation with good distribution during the 1986-87 growing season resulted in good crop growth and utilization of the added fertilizer. Adequate moisture also induced vigorous vegetative growth of wheat, resulting in a wide grain to straw ratios (average of all sites, 1:1.49).

Table 1. Locations and soil chemical properties at field experiment sites.

| Soil No. | Location | Soil Depth | P | K | pH(1:1) | EC(1:1) | O.M. | CEC |
|---|---|---|---|---|---|---|---|---|
| | | cm | -- mg/kg -- | | | dSm[1] | % | meq/100g |
| 1 | Balkasar | 0-20 | 2.68 | 50 | 8.0 | 0.18 | 1.11 | 13.6 |
| | | 20-40 | 2.03 | | | | | |
| | | 40-60 | 1.47 | | | | | |
| 2. | Dub | 0-20 | 3.08 | 215 | 7.7 | 0.38 | 0.37 | 16.8 |
| | | 20-40 | 2.66 | | | | | |
| | | 40-60 | 1.89 | | | | | |
| 3. | Murid | 0-20 | 3.89 | 212 | 7.9 | 0.38 | 0.82 | 22.4 |
| | | 20-40 | 3.11 | | | | | |
| | | 40-60 | 2.53 | | | | | |
| 4. | Doultala | 0-20 | 2.92 | 123 | 7.4 | 0.31 | 0.81 | 20.8 |
| | | 20-40 | 1.71 | | | | | |
| | | 40-60 | 1.81 | | | | | |
| 5. | Kont | 0-20 | 5.63 | 202 | 8.1 | 0.43 | 0.96 | 15.2 |
| | | 20-40 | 3.45 | | | | | |
| | | 40-60 | 2.11 | | | | | |
| 6. | Bakhari | 0-20 | 4.10 | 95 | 7.8 | 0.16 | 1.18 | 17.6 |
| | | 20-40 | 2.53 | | | | | |
| | | 40-60 | 1.21 | | | | | |
| 7 | BARI[1] Chakwal | 0-20 | 5.12 | 204 | 7.8 | 0.37 | 1.41 | 20.8 |
| | | 20-40 | 1.58 | | | | | |
| | | 40-60 | 1.31 | | | | | |

[1]Bari (Barani Agricultural Research Institute).

## AB-DTPA Soil Test to Determine P Fertilizer Requirement

Soil analysis is a useful tool for determining fertilizer needs of crops. In the present investigation, AB-DTPA-extractable P contents of surface soil layers (0-20 cm depth) ranged form 2.68 mg P/kg at Balkasar to 5.63 mg P/kg at Kont. A Cate-Nelson graphical plot (Cate and Nelson, 1965) of AB-DTPA-extractable P against percent relative grain yield of wheat separated the soils into two groups at 3.5 mg P/kg soil (Fig. 2). The soils with less than 3.5 mg P/kg were very deficient in P and those with more than this level were marginally deficient in P. None of the soils contained adequate P supplies. As the experiments were conducted only on 7 locations, it is realized that the data set for a scatter diagram are very

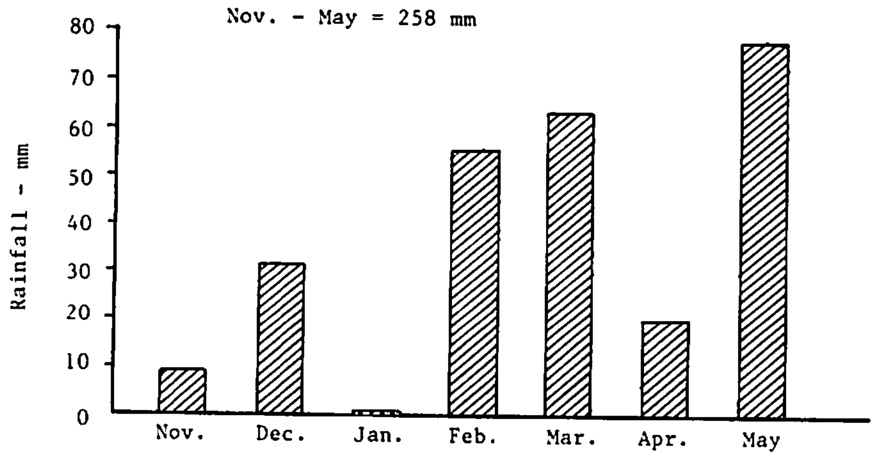



Fig. 1. Rainfall distribution during the 1986-87 growing season in chakwal district of pakistan.

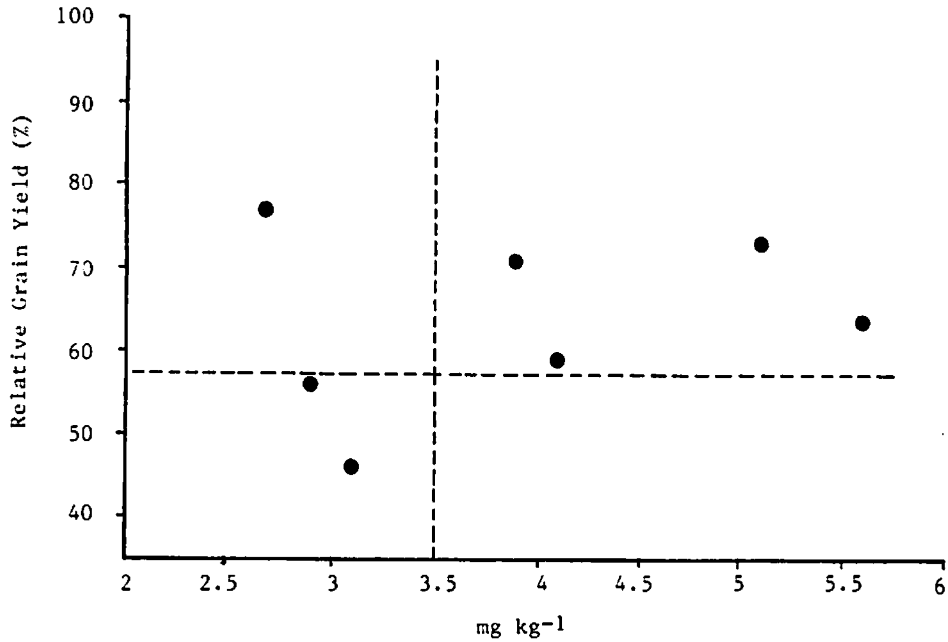



Fig. 2. Scatter diagram of relative grain yield of wheat vs. soil test P by AB - DTPA method.

Table 2. Classification and soil physical properties at field experiment sites.

| Soil No. | Location | Soil Classification: Soil Series | Soil Classification: Great Group | Clay | Silt | Sand | Textural Class |
|---|---|---|---|---|---|---|---|
| 1. | Balkasar | Balkasar | Typic Cambiorthids and Typic Ustochrept | 17 | 73 | 10 | Silt loam |
| 2. | Dub | Chakwal | Fluventic Cambiorthids | 19 | 20 | 61 | Sandy loam |
| 3. | Murid | Missa | Typic Ustochrept, sub-humid | 24 | 65 | 11 | Silt loam |
| 4. | Doultala | Guliana | Typic Ustochrept | 14 | 20 | 66 | Sandy loam |
| 5. | Kont | Balkasar over Rajar | Typic Cambiorthids and Typic Ustochrept | 54 | 34 | 12 | Clay |
| 6. | Bakhari | Balkasar | Typic Cambiorthids and Typic Ustochrept | 24 | 67 | 9 | Silt loam |
| 7. | BARI, Chakwal | Satwal | Udorthentic Chromustert | 27 | 27 | 46 | Sandy loam |

minimal. While reviewing the literature on the use of AB-DTPA soil test for alkaline soils, Soltanpour (1985) suggested 3 mg P/kg soil as deficient for most agricultural crops. AB-DTPA P levels of 4 to 7 mg/kg soil are considered marginal. As wheat is a very sensitive crop to P deficiency, 3.5 mg P/kg may not be an adequate level of soil P. Rather this might be just a partitioning point between highly deficient and marginal soils. Even soils with relatively higher levels of AB-DTPA-extractable P (Fig. 2) were deficient in P, and responded to fertilizer application (Table 3). Therefore, these studies did not help in determining a critical level of AB-DTPA-extractable P in rainfed soils. Further studies are warranted to achieve this objective.

## Use of Plant Analysis for Diagnosing P Deficiency

This study included the evaluation of P concentration in diagnostic leaf tissue and mature wheat grain for diagnosing P deficiency in rainfed wheat. Phosphorus concentration without fertilizer application ranged form 0.10 to 0.25% in leaves and 0.19 to 0.37% in grain. In general, leaves contain a wider nutrient concentration range than mature grain of the same crop species (Rashid, 1986). Therefore, seed is considered a poor indication of the nutritional conditions which grew a crop. But there are many reports contradicting this concept. Seed analyses were shown by some workers as useful for evaluating Mo, N, S and Zn-supplying power of soils (Lavy and Barber, 1963; Pierre et al., 1977a, b; Fox et al., 1977; Rashid, 1986).

Scatter diagrams of percentage grain yield of wheat versus P concentration in diagnostic leaves resulted in two groups partitioned at 0.16% P (Fig. 3). Critical P concentrations in youngest mature wheat leaves reported in the literature are much greater than this. For example, Weir (1986) suggested 0.29% P in youngest mature leaf blades of wheat as the partitioning point between P sufficiency and deficiency. As the fertilizer rates used in this study did not help produce near maximum yields on most soils, the present study failed to determine the critical level of P in leaf tissue.

Partitioning P concentration in mature wheat grain by the Cate-Nelson approach indicated a critical value of 0.3% (Fig. 4). Various researchers (Elliot et al., 1984; Lipsett, 1964) have reported 0.2 to 0.3% P as the critical concentration in mature grain wheat. The use of grain as a diagnostic tissue is potentially advantageous in terms of easier sampling, sample preparation and handling, chemical analysis and less concentration variability of the tissue.

Table 3. Effect of P fertilization on grain and straw yields of wheat grown on rainfed soils of Chakwal district.

| Location | Applied P | Grain Yield | Percent Increase | Straw Yield | Percent Increase |
|---|---|---|---|---|---|
| | ---- kg $ha^{-1}$ ----- | | | ---- kg $ha^{-1}$ ---- | |
| Balkasar | 0 | 2043 | - | 3097 | - |
| | 22 | 2623 | 28 | 3357 | 8 |
| | 44 | 2517 | 23 | 3450 | 11 |
| | 66 | 2670 | 31 | 3630 | 17 |
| Dub | 0 | 1743 C | | 2757 B | - |
| | 22 | 2380 B | 37 | 3550 B | 29 |
| | 44 | 3613 B | 107 | 5320 A | 93 |
| | 66 | 3750 A | 115 | 5517 A | 100 |
| Murid | 0 | 2980 B | - | 3887 | - |
| | 22 | 3817 AB | 28 | 4417 | 14 |
| | 44 | 4127 A | 38 | 4507 | 16 |
| | 66 | 4180 A | 40 | 5153 | 33 |
| Doultala | 0 | 2793 B | - | 4945 B | - |
| | 22 | 3680 AB | 32 | 6277 AB | 27 |
| | 44 | 4530 A | 62 | 7230 A | 46 |
| | 66 | 4973 A | 78 | 7727 A | 56 |
| Kont | 0 | 3117 C | - | 4650 B | - |
| | 22 | 3510 B | 13 | 4890 B | 5 |
| | 44 | 3810 B | 22 | 4890 B | 5 |
| | 66 | 4860 A | 56 | 6407 A | 38 |
| Bakhari | 0 | 2227 B | - | 3207 B | - |
| | 22 | 2370 B | 6 | 3343 B | 4 |
| | 44 | 3007 AB | 35 | 4060 AB | 27 |
| | 66 | 3860 A | 73 | 5180 A | 62 |
| BARI, Chakwal | 0 | 1211 | - | 3233 | - |
| | 22 | 1750 | 45 | 4083 | 26 |
| | 44 | 1700 | 40 | 3866 | 20 |
| | 66 | 1755 | 45 | 4383 | 36 |

Yields of one site followed by different letters are significantly different at the 5% probability level.

Table 4. Correlation coefficients between soil P, wheat yield, and P concentration in plant tissue.

| AB-DTPA P at soil depth | AB-DTPA P at soil depth | | | Yield | | P Concentration | |
|---|---|---|---|---|---|---|---|
| | -------- cm --------- | | | -- kg $ha^{-1}$ -- | | ------- % -------- | |
| | 0-20 | 20-40 | 40-60 | Grain | Straw | Leaves | Grain |
| - cm - | ------------------------ r ---------------------------- | | | | | | |
| 0-20 | - | 0.37 | 0.043 | 0.09 | 0.21 | 0.06 | 0.04 |
| 20-40 | 0.37 | - | 0.67 | 0.62 | 0.18 | -0.22 | -0.45 |
| 40-60 | 0.043 | 0.67 | - | 0.69 | 0.46 | 0.11 | -0.30 |

"r" values > 0.71 are significant at the 5% probability level.

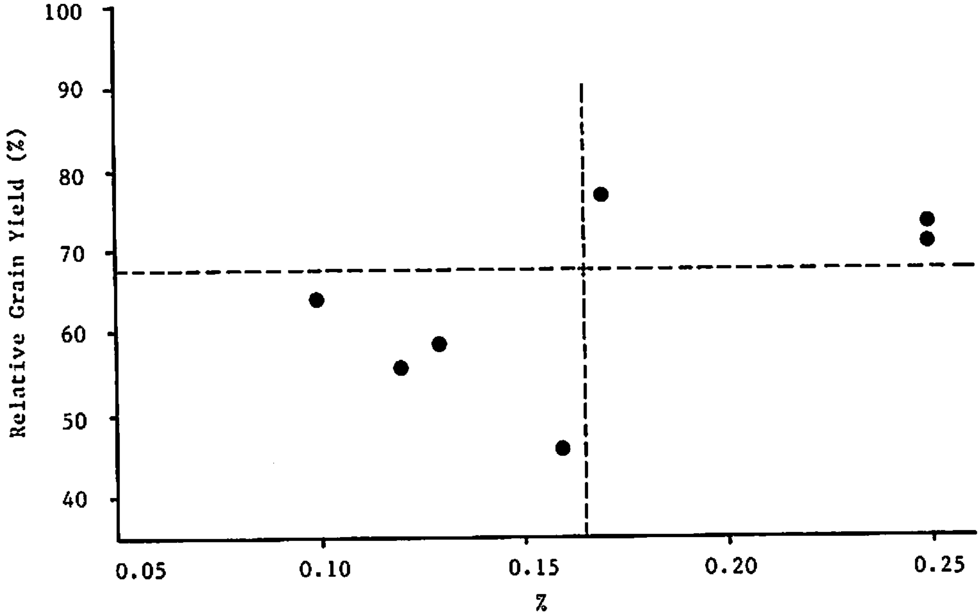



Fig. 3. Scatter diagram of relative grain yield vs. P concentration in diagnostic leaves of wheat.

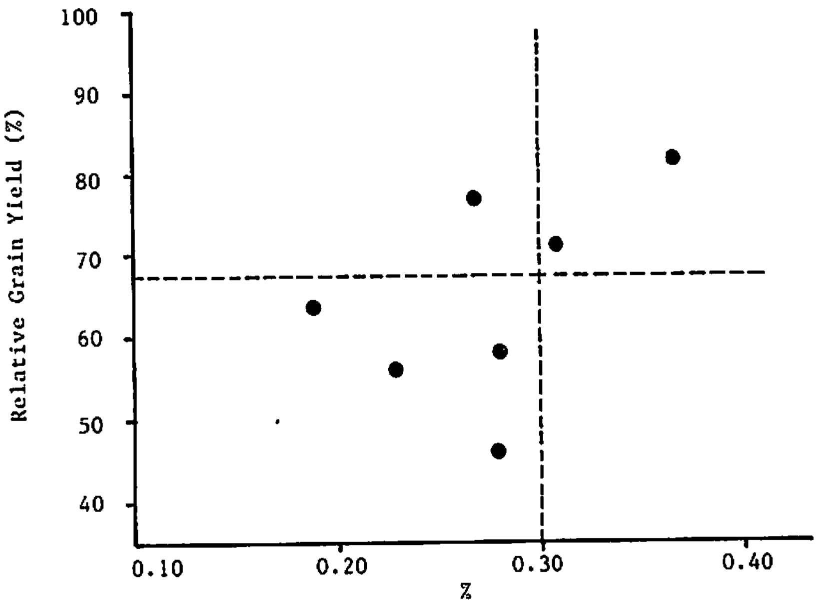



Fig. 4. Scatter diagram of relative grain yield of wheat vs. P concentration in wheat grains.

## CONCLUSIONS

The results reported in this paper are based on only one year's data of a few field experiments and must be interpreted with caution. These experiments were not helpful in determining sufficiency levels of P in soils, leaves or grains. However, the results of the field studies conducted within one geographical district of Pakistan strongly indicate that AB-DTPA soil test may accurately reflect the amount of P available to rainfed wheat crop. Hence, it may be expected that this soil test can be used for predicting fertilizer P requirements. The results presented here hold promise for developing meaningful correlations between the AB-DTPA soil test for P and crop response to fertilizer P, but must be verified and extended to include soil test correlations under various cropping systems on farmers' fields. Future experiments should include soils with a wider range of soil test P values, and the rates of fertilizer should be wide enough to obtain Mitscherlich-type response curves.


## ACKNOWLEDGMENTS

We are grateful to the Soil Survey of Pakistan for assistance in classifying the experimental soils, and to Mr. M. I. Khan of NARC for statistical analysis of the data.


## REFERENCES


Ahmad, M. 1986. Soils of Pakistan. 47-57. In Proc. XII International Forum on Soil Taxonomy and Agrotechnology Transfer, Pakistan. Vol. I : Technical Sessions. Soil Survey of Pakistan and Soil Management Support Services, U.S.A.

Barber, S.A. 1980. Soil-plant interactions in the phosphorus nutrition of plants. p. 591-615. In F. E. Khasawneh et al., (ed.). The role of phosphorus in agriculture. Amer. Soc. Agron., Madison, Wisc., U.S.A.

Bhatti, H. M. 1973. Annual Report, Agricultural Chemist (Soils), 1972-73, Punjab Agric. Res. Inst., Lyallpur.

Cate, R. B., Jr., and L. A. Nelson. 1965. A rapid method for correlation of soil test analyses with plant response data. North Carolina Agric. Exp. Stn., Int. Soil Test Series Techn. Bull. N° 1.

Elliot, D. E., D. J. Reuter, and G. R. Reddy. 1984. Development of a plant test for diagnosing phosphorus deficiency in wheat. Terminal Report (Project DASA 23) for the Wheat Industry Research Council.

Fox, R. L., B. T. Kang, and Nangju. 1977. Sulfur requirements of cowpea and implications for production in the tropics. Agron. J. 69:201-205.

Lavy, T. L., and S. A. Barber. 1963. A relationship between the yield response of soybean to molybdenum content of the seed produced. Agron. J. 55:154-155.

Lipsett, J. 1964. The phosphorus content and yield of grain of different wheat varieties in relation to phosphorus deficiency. Aust. J. Agric. Res. 15:1-8.

Memon, K. S. 1986. Phosphorus requirements of Pakistan soils. p. 105-112. In Proc. XII International Forum on Soil Taxonomy and Agrotechnology Transfer, Pakistan. Vol. II : Technological Sessions. Soil Survey of Pakistan and Soil Management Support Services, U.S.A.

Pierre, W. H., L. Dumenil, V. D. Jolley, J. R. Webb, and W. D. Shrader. 1977a. Relationship between corn yield, expressed as a percentage of maximum, and the N percentage in the grain. I. Various N rate experiments. Agron. J. 69:215-220.

Pierre, W. H., L. Dumenil, and J. Henao. 1977b. Relationship between corn yield, expressed as a percentage of maximum, and the N percentage in the grain. II. Diagnostic use. Agron. J. 69:221-226.

Rashid, A. 1986. Mapping zinc fertility of soils using indicator plants and soil analyses. Ph.D. dissertation. University of Hawaii, Honolulu, U.S.A.

Rashid, A., N. Bughio, and M. Salim. 1987. Calibration of three tests for determining phosphorus fertility of soils to support cereals, legumes, and oilseeds p. 86-93. In A. Matar et al. (ed.) Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6. Aleppo, Syria.

Soltanpour, P. N. 1985. Use of ammonium bicarbonate-DTPA soil test to evaluate elemental availability and toxicity. Commun Soil Sci. Plant Anal. 16:323-338.

Soltanpour, P. N., and A. P. Schwab. 1977. A new soil test for simultaneous extraction of macro and micronutrients in alkaline soils. Commun. Soil Sci. Plant Anal. 8:195-207.

Soltanpour, P. N., and S. Workman. 1979. Modification of the $NH_4HCO_3$-DTPA soil test. Commun Soil Sci. Plant Anal. 10:1411-1420.

Soltanpour, P. N., and S. M. Workman. 1981. Soil testing methods used at Colorado State University Soil Testing Laboratory for the evaluation of fertility, salinity, sodicity and trace element toxicity. Tech. Bull. 142, Colorado State Univ. Exp. Sta., Fort Collins, Colo.

Watanabe, F. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29:677-687.

Weir, R. G. 1986. Dep. Agric., New South Wales, Sydney, Australia. Personal communication. (See Plant Analysis - An Interpretation Manual, D. J. Reuter, and J. B. Robinson (ed.) Inkata Press, Melbourne, 1986).

# A TENTATIVE CALIBRATION FOR THE OLSEN BICARBONATE SOIL TEST WITH WHEAT RESPONSES TO PHOSPHORUS IN RAINFED CONDITIONS OF TURKEY

BY
N. Yurtsever and I. Gedikoglu

Soil and Fertilizer Research Institute, Ankara, Turkey

**ABSTRACT**

A tentative calibration for the Olsen bicarbonate soil test for available Phosphorus and the response of wheat to P fertilizer applications are presented for Turkish rainfed conditions. Using the Mitscherlich-Bray equation, the constants $c_1$ for the soil test value $b_1$ and c for fertilizer rates x were calculated and found to be 0.0143 and 0.0072, respectively. On the bases of these constants, a tentative calibration and P fertilizer application rates for wheat are suggested for the soils of the Central Anatolia Region of Turkey. The same approach was used elsewhere (Matar et al. 1987; Orlando et al. 1982).

## INTRODUCTION

Fertilizer technology and the use of added plant nutrients to restore soil fertility has progressed in the last hundred years. More understanding of soil and plant chemistry has led to improved fertilization and cultural practices. Since arable land is rather limited, the only feasible way to increase production is to increase yield per unit land area. High yields require that correct amounts of fertilizers be applied; this necessitates the use of soil analyses to characterize soil fertility. Proper interpretation of analyses done to make fertilizer recommendations requires that it be based on calibration studies.

Soil analysis has been used in different ways for fertilizer recommendations. Bray (1945, 1958) published ideas about correlation of soil tests with crop responses to added fertilizers and with fertilizer requirements, especially for P and K. Such a procedure was successfully used in illinois, as reported by Arnold (1951, 1953) for P. In Turkey, this is also the case; several correlations, especially between soil P test values and crop responses to fertilizers, have been a subject of major interest in soil fertility work (Yurtsever, 1965, 1986). In Turkey, the extractant usually employed in the determination of soil P in calcareous soils is 0.5 M $NaHCO_3$ cited by Olsen et al. (1954). For the Central Anatolia region the same extractant was also shown to be the most efficient reagent for P extraction.

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) the method of applying the fertilizers and finally; (iv) the crop to be grown. Agronomists are well aware that plant species, and even varieties, differ in their ability to extract soil P.

For wheat, which is one of the principal crops grown under rainfed conditions of the Central Anatolia region of Turkey, P fertilizer recommendations are normally based on calibration generated from field trials conducted in the region between 1960 and 1970 (Yurtsever, 1986). Therefore, fertilizer recommendations have the limitation that they do not take into account the large-scale variations in yield levels between old and new varieties. In fact, continuous research is needed to cope with the challenge of newly introduced crop varieties and change in native soil fertility with management practices.

Therefore, a new research program of soil test calibration was initiated in 1987-88 at the Soil and Fertilizer Research Institute, Ankara, Turkey, with the objective of developing a scientific basis for P fertilizer recommendations based on new field trials with high yielding wheat varieties. Results presented in this paper cover only the first year; it is therefore a tentative calibration for the Olsen bicarbonate-P soil test with three high yielding wheat varieties under Central Anatolian soil and climatic conditions.

## MATERIALS AND METHODS

Sixteen field experiments with three different wheat varieties (Bolal 2973, Haymana 79, and Gerek 79) were sited on varied wheat-growing soils in six locations of the Central Anatolia region of Turkey, in the 1987-88 season. The soils of this region are medium to shallow in depth, moderately sloping, and brown to reddish brown in color. The texture of these soils is silty-clay loam. They are calcareous in nature and low in organic matter, P, and potassium (Table 1). Composite soil samples were collected before seeding from each plot to a depth of 20 cm, and analysed for available P by the Olsen bicarbonate method (1954). The pH was determined on a saturated paste using a glass electrode, and free carbonate was determined by acid neutrilization.

The five basic treatments used were: 0, 30, 60, 90 and 120 $P_2O_5$ per hectare. The experimental design was a randomized block with four replications. Forty kilograms of N per hectare as ammonium sulfate (% 21 N) were broadcast before seeding to all the plots, and P as triple superphosphate (% 42-44 $P_2O_5$) was drill-applied in bands at seeding time. After a growth cycle of approximately 9 months, the plots were harvested and the yields were

Table 1. Some soil physical and chemical properties for 16 experiments, Central Anatolia, Turkey.

| Exp. No. | Texture | pH | C.C.E.[1] | Total Salts | Organic Matter | Available $P_2O_5$ | Available $K_2O$ |
|---|---|---|---|---|---|---|---|
| | | | % | % | % | mg/kg | mg/kg |
| 1 | L | 7.7 | 30.3 | 0.048 | 1.78 | 61.6 | 745 |
| 2 | L | 7.7 | 24.3 | 0.057 | 1.95 | 59.9 | 772 |
| 3 | L | 7.7 | 23.0 | 0.083 | 2.05 | 60.8 | 750 |
| 4 | L | 7.7 | 12.4 | 0.042 | 1.87 | 39.0 | 573 |
| 5 | L | 7.9 | 10.9 | 0.040 | 1.87 | 38.6 | 573 |
| 6 | L | 7.8 | 11.3 | 0.040 | 1.81 | 41.7 | 573 |
| 7 | L | 7.3 | 16.1 | 0.049 | 2.54 | 49.4 | 1793 |
| 8 | L | 7.7 | 11.8 | 0.049 | 2.33 | 58.4 | 1777 |
| 9 | L | 7.7 | 13.4 | 0.048 | 2.07 | 59.2 | 1598 |
| 10 | CL | 7.5 | 24.7 | 0.094 | 1.87 | 31.7 | 1775 |
| 11 | CL | 7.5 | 24.0 | 0.085 | 1.95 | 28.3 | 1483 |
| 12 | CL | 7.7 | 23.4 | 0.094 | 1.87 | 39.8 | 1478 |
| 13 | CL | 7.9 | 10.4 | 0.085 | 1.10 | 43.5 | 2009 |
| 14 | CL | 7.9 | 10.6 | 0.082 | 1.14 | 47.6 | 2167 |
| 15 | CL | 7.9 | 10.8 | 0.089 | 1.27 | 46.9 | 2275 |
| 16 | C | 7.8 | 15.5 | 0.108 | 1.22 | 55.7 | 2408 |

C.C.E. Calcium Carbonate Equivalent.
L = loam; C = clay; CL = clay loam.

weighed. Data from the six middle rows only were used as the estimates of yield. The yields obtained from 0, 30, 60 and 90 kg $P_2O_5$ treatments were then expressed as percentages of those from the corresponding 120 kg $P_2O_5$ plots, i.e., relative yields.

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

$$\log (A-y_0) = \text{Log } A - C_1 b_1 \qquad (1)$$
$$\log (A-y) = \text{Log } A - c_1 b_1 - cx \qquad (2)$$

where:

A = maximum relative yield = 100
$y_0$ = relative yield from check plot
$y$ = 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 $x$

Values of "$C_1$" were calculated from equation (1) for each experiment; a mean value for the constant "$C_1$" and "c" values was calculated from equation (2) for the $P_2O_5$ rates between zero and 120 kg/ha, finally giving a mean value for the constant "c". In some experiments, the yields obtained from 60 and/or 90 kg rates of $P_2O_5$ 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 curve, "c" values calculated from relative yields close to 100 are not reliable (Arnold, 1953). In many cases, the wheat yields from 90 and 120 kg $P_2O_5$/ha were essentially equal, indicating that 90 kg $P_2O_5$/ha rate had corrected the deficiency. Therefore, wheat yields from the 120 kg $P_2O_5$/ha treatments should present a valid "A" for the Mitscherlich equation.

The economic amounts of P fertilizer, as a function of soil P content, were also determined. In other words, the net revenues and rates of return for different levels of fertilizer application were calculated. For these calculations, the theoretical maximum yield "A" of the Mitscherlich-Bray equation was defined by the formula given below:

$$A = \frac{(yk - yo)}{k-1}$$

where:

A = theoretical maximum yield
yo = the yield from the no P-treated plot
y = the 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 theoretical maximum yield "A", and average values of "$C_1$" and "C", total yields and yield increases, obtained with different amounts of P applications for different soil-test values, were calculated, while the sum of the increments for which the last increment still produced an increase in profit was taken as the most economical P fertilizer rate.

Table 2. Wheat response to P fertilization.

| Exp. N° | Experimental Site | Variety | Applied $P_2O_5$ (kg/ha) $x_0$ 0 | $x_1$ 30 | $x_2$ 30 | $x_3$ 90 | $x_4$ 120 |
|---|---|---|---|---|---|---|---|
| | | | Yield (kg/ha) $y_o$ | $y_1$ | $y_2$ | $y_3$ | $y_4$ |
| 1 | Haymana-Sinanli | Haymana | 3352 | 3620 | 3964 | 4533 | 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 | 4973 | 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 | 4881 | 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 | 2774 | 4113 | 4210 |
| 15 | Bala-A. Tepe | Bolal | 2306 | 2675 | 2917 | 3155 | 3300 |
| 16 | Bala-Masat | Bolal | 3250 | 3422 | 3542 | 3696 | 3745 |
| | Average | | 3202 | 3592 | 3828 | 4028 | 4131 |

## RESULTS AND DISCUSSION

The yields obtained from the 16 field trials conducted at six different locations are given in Table 2. Yields of all varieties progressively increased with increasing P application rates. Large differences in wheat yields according to location were obtained, but yield differences among varieties at the same location were not significant. In general, all the varieties responded almost equally to applied P fertilizer (Table 3). Therefore, the results obtained from different varieties were pooled together and used in calibration of the Olsen ($NaHCO_3$) method.

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, per cent 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 4, constants $C_1$ and C were calculated for each experiment. The constant $C_1$ was calculated by using the yield from control plots as yo, and the indicated Olsen soil test values as $b_1$. The constant c was calculated using wheat yields obtained from plots receiving 30, 60 and 90 kg $P_2O_5$ $ha^{-1}$ as Y, the previously calculated $C_1$ value for that field, and the Olsen soil test value $b_1$. Relative yields higher than 96% were not used in calculations of C values.

In most trials, relative yields obtained from 90 kg $P_2O_5$ (in some cases, even from 60 kg) treatments were 96% or more of maximum yield. Therefore, they were not used in calculations of the constant C for x. Average $c_1$ and C values of 0.0143 and 0.0072 were obtained (Table 4). 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 $b_1$ from equation $\log(100-y_0) = \log 100 - 0.0143\, b_1$ and solving it for $y_0$, percent sufficiencies of different soil test values were calculated and given in Table 5 and Fig. 1.

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 was classified as "very low"; if the percent sufficiency is between 50-75% as "low"; between 75-90% as "medium"; between 90-95% as "good"; between 95-98% as "high"; and with soil having percent sufficiency more than 98%, P was classified as "very high". This means that under rainfed conditions of Central Anatolia, any calcareous soil having Olsen soil test value of 90 kg $P_2O_5$ per ha or more will be unresponsive to P fertilization (Fig. 1). That is, in the absence of applied P

Table 3. Average and relative yields of the varieties used in the experiments conducted at six different locations, and average Mitscherlich constants by the varieties used.

| Variety | Applied $P_2O_5$ (kg/ha) | | | | | | | | | | Mitscherlich constants | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | 30 | | 60 | | 90 | | 120 | | $c_1$ for $b_1$ | c for x |
| | Yield Obtained | | | | | | | | | | | |
| | kg/ha | % | kg/ha | % | kg/ha | % | kg/ha | % | kg/ha | % | | |
| Haymana 79 | 3268 | 75.5 | 3612 | 83.9 | 3873 | 89.2 | 4155 | 95.7 | 4320 | 100 | 0.0145 | 0.0065 |
| Gerek 79 | 3512 | 78.0 | 3954 | 87.9 | 4209 | 93.4 | 4436 | 98.5 | 4495 | 100 | 0.0151 | 0.0080 |
| Bolal 2973 | 2889 | 78.0 | 3273 | 88.5 | 3473 | 94.0 | 3583 | 97.5 | 3671 | 100 | 0.0135 | 0.0073 |
| General Average | 3202 | 77.5 | 3592 | 87.0 | 3828 | 92.7 | 4028 | 97.5 | 4131 | 100 | 0.0143 | 0.0073 |

Table 4. Relative yields and Mitscherlich Constants.

| Exp. | Applied $P_2O_5$ (kg/ha) | | | | | Maximum Yield (kg/ha) | | Mitscherlich Constant | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_o$ | $X_1$ | $X_2$ | $X_3$ | $X_4$ | (A) | | | | | |
| | 0 | 30 | 60 | 90 | 120 | | | $c_1$ | c values for | | |
| No. | Obtained Yield (%) | | | | | | | | | | |
| | $Y_o$ | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | Calculated | Obtained | for $b_1$ | $x_1$ | $x_2$ | $x_3$ |
| 1 | 80.8 | 87.2 | 95.5 | 109.2 | 100 | 4378 | 4150 | 0.0116 | 0.0059 | 0.0105 | - |
| 2 | 79.8 | 87.8 | 91.6 | 99.8 | 100 | 5151 | 5055 | 0.0116 | 0.0073 | 0.0063 | - |
| 3 | 81.7 | 93.5 | 97.9 | 98.2 | 100 | 4483 | 4217 | 0.0121 | 0.0150 | - | - |
| 4 | 62.6 | 71.4 | 74.8 | 80.0 | 100 | 3155 | 3524 | 0.0109 | 0.0039 | 0.0029 | 0.0030 |
| 5 | 76.8 | 86.1 | 91.8 | 96.4 | 100 | 3312 | 3255 | 0.0164 | 0.0075 | 0.0075 | - |
| 6 | 68.5 | 79.7 | 84.5 | 95.7 | 100 | 2730 | 2734 | 0.0120 | 0.0063 | 0.0051 | 0.0096 |
| 7 | 74.4 | 86.9 | 91.5 | 99.1 | 100 | 4460 | 4265 | 0.0120 | 0.0097 | 0.0080 | - |
| 8 | 80.4 | 92.0 | 102.1 | 102.6 | 100 | 5324 | 4873 | 0.0121 | 0.0130 | - | - |
| 9 | 79.1 | 85.7 | 89.6 | 93.7 | 100 | 4099 | 4172 | 0.0115 | 0.0055 | 0.0051 | 0.0058 |
| 10 | 77.2 | 82.6 | 91.3 | 95.5 | 100 | 6851 | 6939 | 0.0203 | 0.0039 | 0.007 | 0.0078 |
| 11 | 76.4 | 84.9 | 92.1 | 96.0 | 100 | 5144 | 5083 | 0.0222 | 0.0064 | 0.0079 | - |
| 12 | 81.8 | 99.7 | 108.8 | 103.2 | 100 | 4477 | 3856 | 0.0186 | - | - | - |
| 13 | 82.7 | 91.3 | 92.8 | 94.6 | 100 | 2750 | 2721 | 0.0175 | 0.0100 | 0.0063 | 0.0057 |
| 14 | 76.7 | 88.6 | 89.6 | 97.7 | 100 | 4334 | 4210 | 0.0133 | 0.0103 | 0.0059 | - |
| 15 | 69.9 | 81.1 | 88.4 | 95.6 | 100 | 3346 | 3300 | 0.0111 | 0.0067 | 0.0069 | 0.0093 |
| 16 | 86.8 | 91.4 | 94.6 | 98.7 | 100 | 3763 | 3745 | 0.0158 | 0.0062 | 0.0065 | - |
| | | | | | Average | 4235 | 4131 | 0.0143 | | 0.0072 | |

Table 5. Calculated quantities of phosphorus fertilizer required to attain various per-cent sufficiency level for wheat based on the Olsen soil test.

| Soil Test kg $P_2O_5$/ ha | $P_2O_5$ content (kg/ha) and fertility index | % Sufficiency | Required Fertilizer Rate (kg $P_2O_5$/ha) for relative yields of 90 % | 92% | 94% | 96% | 98% |
|---|---|---|---|---|---|---|---|
| 5 | | 15 | 129.0 | 142.4 | 159.8 | 184.2 | 226.0 |
| 10 | <20 | 28 | 119.0 | 132.5 | 149.8 | 174.3 | 216.1 |
| 15 | (very low) | 39 | 109.1 | 122.5 | 139.9 | 164.3 | 206.2 |
| 20 | | 48 | 99.1 | 112.6 | 129.9 | 154.4 | 196.2 |
| 25 | 20–40 | 56 | 89.2 | 102.7 | 120.0 | 144.5 | 186.3 |
| 30 | | 63 | 79.2 | 92.7 | 110.1 | 134.5 | 176.3 |
| 35 | (low) | 68 | 69.3 | 82.8 | 100.1 | 124.6 | 166.4 |
| 40 | | 73 | 59.4 | 72.8 | 90.2 | 114.6 | 156.5 |
| 45 | | 77 | 49.4 | 62.9 | 80.2 | 104.7 | 146.5 |
| 50 | 40–70 | 81 | 39.5 | 52.9 | 70.3 | 94.8 | 136.6 |
| 55 | (Medium) | 84 | 29.5 | 43.0 | 60.4 | 84.8 | 126.6 |
| 60 | | 86 | 19.6 | 33.1 | 50.4 | 74.9 | 116.7 |
| 65 | | 88 | 9.7 | 23.1 | 40.5 | 64.9 | 106.7 |
| 70 | | 90 | – | 13.2 | 30.5 | 55.0 | 96.8 |
| 75 | | 92 | – | – | 20.6 | 45.0 | 86.9 |
| 80 | 70–90 | 93 | – | – | 10.6 | 35.1 | 76.9 |
| 85 | (Good) | 94 | – | – | – | 25.2 | 67.0 |
| 90 | | 95 | – | – | – | 15.2 | 57.0 |
| 95 | | 96 | – | – | – | 5.3 | 47.1 |
| 100 | 90–120 | 96 | – | – | – | – | 37.1 |
| 110 | (High) | 97 | – | – | – | – | 17.3 |
| 120 | >120 (very high) | 98 | – | – | – | – | – |

fertilizer, the critical level of available $P_2O_5$ in the soil by Olsen is 90 kg per ha. In a previous calibration study with low-yielding wheat varieties, the critical level of Olsen available soil P was 70 kg $P_2O_5$ per ha (Yurtsever, 1986).

Furthermore, equation (2) incorporating 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 $P_2O_5$ in the soil 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 Table 5. This shows, for example, that if the Olsen soil test value of a given soil is 30 kg $P_2O_5$ per ha, the soil produces only 63% of the yield possible with adequate P. To raise the yield to 90% requires 79 kg $P_2O_5$/ha; to raise it to 92, 94, 96 and 98% of maximum yield requires 92, 110, 134 and 176 kg $P_2O_5$/ha, respectively. This part of Table 5 presents a suggested fertilizer guide for wheat for five upper levels of sufficiency, when P fertilizer is applied in bands with seed at seeding time. But such data are not a sufficient

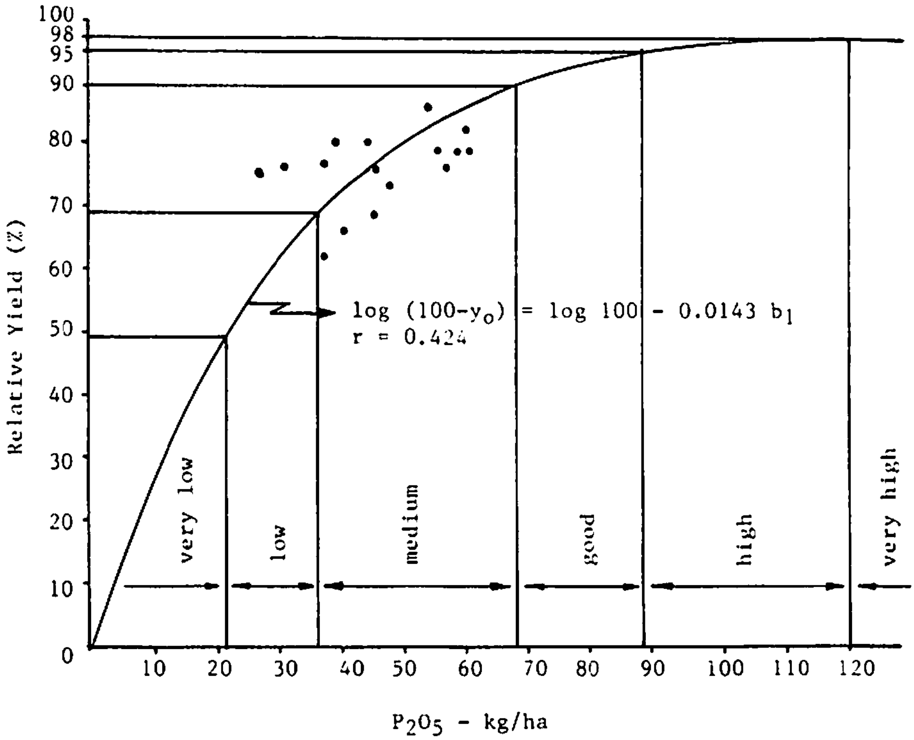



Fig. 1. Relation between levels of (Olsen) soil P and relative wheat yield.

basis for fertilizer recommendations; the calculations must be evaluated economically. In other words, the new revenues and rates of return must be calculated for different levels of fertilizer application.

To conduct such an analysis, parameter A, the theoretical maximum yield of Mitscherlich-Bray equation, must be defined. To calculate theoretical maximum yields for each rate on each field, equation (3) was used. These calculated "A" values for each P rate were averaged and used as the "A" value for that field. The general average was 4235 kg/ha (Table 6). After these calculations, the Mitscherlich-Bray equation can be expressed as the following mathematical function:

$$\text{Log } (4235 - y) = \log 4235 - 0.0143\, b_1 - 0.0072\, x$$

Using this equation, one can calculate the total yields and yield increases obtainable with different $P_2O_5$ applications for different Olsen soil test values.

Table 6. Theoretical maximum yields for different P rates used in the experiments calculated by the formula $A = (yk - y_0) / k-1$

| Exp. n | Applied $P_2O_5$ (kg/ha) | | | | Average |
|---|---|---|---|---|---|
| | 30 | 60 | 90 | 120 | |
| 1 | 4036.2 | 4323.5 | 4875.7 | 4276.5 | 4333.8 |
| 2 | 5066.6 | 4977.2 | 5341.3 | 5217.0 | 5150.5 |
| 3 | 4715.4 | 4531.9 | 4345.0 | 4339.0 | 4482.6 |
| 4 | 3001.2 | 2890.6 | 2995.9 | 3733.0 | 3155.2 |
| 5 | 3275.8 | 3274.4 | 3321.9 | 3374.6 | 3311.7 |
| 6 | 2652.4 | 2567.5 | 2831.3 | 2870.3 | 2730.4 |
| 7 | 4538.4 | 4331.5 | 4531.5 | 4438.1 | 4459.9 |
| 8 | 5363.0 | 5593.4 | 5314.6 | 5024.6 | 5323.9 |
| 9 | 4001.8 | 3998.3 | 4087.0 | 4310.2 | 4099.3 |
| 10 | 6313.5 | 6911.0 | 6991.1 | 7189.4 | 6851.3 |
| 11 | 4982.4 | 5149.8 | 5170.1 | 5272.9 | 5143.8 |
| 12 | 4912.4 | 4809.2 | 4219.7 | 3967.3 | 4477.1 |
| 13 | 2848.7 | 2685.4 | 2669.5 | 2795.8 | 2749.9 |
| 14 | 4506.6 | 4095.1 | 4370.1 | 4365.8 | 4334.1 |
| 15 | 3247.7 | 3275.6 | 3401.4 | 3457.6 | 3345.6 |
| 16 | 3689.0 | 3713.4 | 3825.4 | 3823.4 | 3762.8 |
| | | | | General Average | 4234.7 |

if we consider only the fertilizer cost 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 (Table 7). For example, when soil test value ($b_1$) is 30 kg $P_2O_5$/ha, the first 10 kg $P_2O_5$/ha gives a yield increase of 241 kg/ha of wheat. The gross return is 39689 TL/ha. Each successive 10 kg $P_2O_5$/ha fertilizer gives a smaller yield increase and gross return. The 13th increment, which gives a 33 kg/ha yield increase, valued at 5435 Turkish lira (TL) is the last successive 10 kg $P_2O_5$/ha increment of fertilizer for which the value of the increase yield exceeds the cost of the fertilizer (4641 TL). Therefore, the economically optimal rate of fertilizer is 130 kg $P_2O_5$/ha when the Olsen soil test value ($b_1$) is 30 kg $P_2O_5$/ha, and it is 90 kg $P_2O_5$/ha when soil test value ($b_1$) is 50 kg $P_2O_5$/ha (Table 7). If one compares the economically optimal rates with the quantities of P fertilizer required to attain various sufficiency levels (Table 5), it can be seen that it is not economic to recommend P fertilizers for a yield more than 94% of maximum.

## CONCLUSIONS

A tentative calibration for Olsen bicarbonate soil test values for available P and the response of wheat to P fertilizer applications were presented for Turkish rainfed conditions. 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 and were 0.0143 and 0.0072, respectively. On the basis of these constants, a tentative calibration and P fertilizer application rate for wheat are suggested for these soils of the Central Anatolia region of Turkey. These recommendations apply to average general farming conditions in the region and under current prices of P fertilizer and wheat.

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 the wheat yields for the soil test method employed. A change in the method or growing conditions will change the response data, with a resulting change in the recommendations. Although the growing conditions were selected to represent the general practice in the region, deviations from the average conditions should be expected due to variations in soil and climate especially in the amount and distribution of rain.

Table 7. The calculated total yields, yield changes with successive increments of fertilizer use, and economic optimum fertilizer rates.

| Applied $P_2O_5$ | Increment $P_2O_5$ | Triple superphosphate | $P_2O_5$ Cost | $b_1 = 30$ Total yield | Yield increase | Value-yield increase | $b_1 = 50$ Total yield | Yield increase | Value yield increase | $b_1 = 70$ Total yield | Yield increase | Value yield increase |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 23.8 | - | 2659 | 0 | 0 | 3420 | 0 | 0 | 3813 | 0 | 0 |
| 10 | 10 | 23.8 | 4641 | 2900 | 241 | 39689 | 3544 | 124 | 20529 | 3878 | 64 | 10618 |
| 20 | 10 | 23.8 | 4641 | 3104 | 204 | 33629 | 3650 | 105 | 17394 | 3932 | 55 | 8997 |
| 30 | 10 | 23.8 | 4641 | 3277 | 173 | 28494 | 3739 | 89 | 14738 | 3978 | 46 | 7623 |
| 40 | 10 | 23.8 | 4641 | 3423 | 146 | 24143 | 3815 | 76 | 12488 | 4018 | 39 | 6459 |
| 50 | 10 | 23.8 | 4641 | 3547 | 124 | 20457 | 3879 | 64 | 10581 | 4051 | 33 | 5473 |
| 60 | 10 | 23.8 | 4641 | 3652 | 105 | 17333 | 3933 | 54 | 8965 | 4079 | 28 | 4637 |
| 70 | 10 | 23.8 | 4641 | 3741 | 89 | 14687 | 3979 | 46 | 7596 | 4103 | 24 | 3929 |
| 80 | 10 | 23.8 | 4641 | 3816 | 75 | 12444 | 4018 | 39 | 6437 | 4123 | 20 | 0 |
| 90 | 10 | 23.8 | 4641 | 3880 | 64 | 10544 | 4051 | 33 | 5454 | 4140 | 17 | 0 |
| 100 | 10 | 23.8 | 4641 | 3934 | 54 | 8934 | 4079 | 28 | 4621 | 4154 | 14 | 0 |
| 110 | 10 | 23.8 | 4641 | 3980 | 46 | 7570 | 4103 | 24 | 0 | 4167 | 12 | 0 |
| 120 | 10 | 23.8 | 4641 | 4019 | 39 | 6414 | 4123 | 20 | 0 | 4177 | 10 | 0 |
| 130 | 10 | 23.8 | 4641 | 4052 | 33 | 5435 | 4140 | 17 | 0 | 4186 | 9 | 0 |
| 140 | 10 | 23.8 | 4641 | 4080 | 28 | 4605 | 4155 | 14 | 0 | 4193 | 7 | 0 |
| 150 | 10 | 23.8 | 4641 | 4104 | 24 | 0 | 4167 | 12 | 0 | 4200 | 6 | 0 |
| 160 | 10 | 23.8 | 4641 | 4124 | 20 | 0 | 4177 | 10 | 0 | 4205 | 5 | 0 |
| 170 | 10 | 23.8 | 4641 | 4141 | 17 | 0 | 4186 | 9 | 0 | 4210 | 5 | 0 |
| 180 | 10 | 23.8 | 4641 | 4155 | 14 | 0 | 4194 | 7 | 0 | 4213 | 4 | 0 |

- Prices used for calculation were 195 TL. per kg triple superphosphate and 165 TL. per kg of wheat (1988).
- Fertilizer application in kg/ha; Yield in kg/ha; crop value in TL/ha
- $b_1$ values in kg $P_2O_5$/ha
- $\log 4235 - 0.0143\, b_1 - 0.0072\, C$ used to calculate economic response.

2. In calculating the economically optimal P recommendations, the current prices prevailing in 1988 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.

**REFERENCES**


Arnold, C.Y. and W.A. Schmidt. 1951. Soil tests as a measure of phosphorus availability to tomatoes on heavy soils. Soil Sci. 71: 105-115.

Arnold, C.Y. 1953. The phosphorus requirements of transplanted tomatoes on heavy soils. Soil Sci. 76: 405-419.

Bray, R.H. 1945. Soil-plant relations: II. Balanced fertilizer use through soil tests for potassium and phosphorus. Soil Sci. 60: 463-473.

Bray, R.H. 1958. The correlation of a phosphorus soil test with the response of wheat through a modified Mitscherlich equation. Soil Sci. Soc. Amer. Proc. 22: 314-317.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dept. of Agr. Cir 939, Washington, D.C.

Yurtsever, N.M. Atesalp, and S.W. Melsted. 1965. A tentative correlation for the Olsen bicarbonate phosphorus soil test with wheat responses under Turkish soil conditions. Soil Sci. 100: 163-167.

Yurtsever, N. 1986. A study on calibration for the Olsen phosphorus soil test with wheat responses under Turkish soil conditions. p. 99-144. First Regional Soil Test Calibration Workshop. ICARDA, Aleppo, Syria, 23-25 June 1986.

# NITROGEN RESPONSES OF BARLEY GRAIN AND BARLEY FORAGE GROWN CONTINUALLY OR AFTER FALLOW

P.I. Orphanos and Chr. Metochis,

Agricultural Research Institute, Nicosia, Cyprus

## ABSTRACT

In a long-term experiment, barley was grown for grain and straw (grain barley) or was cut at the milk stage of grain for hay production (forage barley). Grain barley was grown continually and drilled either with a conventional seeder, or with a special seeder in the uncultivated stubble, or was grown in rotation with forage barley or cultivated fallow. Forage barley was grown continually and also drilled either with a conventional seeder, or a special seeder in the uncultivated stubble of the previous forage barley crop, or was grown in rotation with grain barley and conventionally sown. In all cases, three N rates (0, 30, 60 kg N/ha) and two P rates (0, 20 kg P/ha) were applied in factorial combination. The experimental field was exceptional in having been used for irrigated cropping and fertilized rather liberally. As a result, at the initiation of the experiment the soil contained 50 ppm Olsen P, 400 ppm exchangeable K and 50 ppm $NO_3$-N in the plough layer.

Over the 8-year experimental period (1980-88) rainfall was mostly below average and yields were low. In only three years was a significant amount of water conserved (70 mm) in the fallowed soil. In contrast, substantial amounts of mineralized N accumulated in fallowed soil, particularly when there was rainfall between the time the previous crop was harvested and the new crop was sown (up to 70 ppm $NO_3$-N in the top 45-cm layer). As a result grain yield after fallow was mostly slightly depressed relative to continual growing. Forage barley gave more stable yields. In particular, in the very dry 1985-86 season (180 mm rainfall) in which grain was not produced, 4 t/ha hay was produced.

As expected, P application did not influence yield, Nitrogen tended to decrease grain yield but to increase hay yield. It also invariably increased N concentration in grain, straw and hay, and K concentration in straw and hay. The amount of N removed by a ton of grain + straw or hay was about 15 kg. The amounts of N in the grain + straw and the hay produced on unfertilized plots under continual growing over the 8-year period were very close to each other. The amount of N removed annually from the unfertilized plots in the grain + straw

ranged between zero and 99 kg/ha and that removed in the hay between 62 and 85 kg/ha.

It is proposed that N fertilizer recommendations must be based on: yield potential, rotation (including fallow), rainfall during the preceding season, and N fertilizing during the preceding season. Soil $NO_3$-N at sowing time is also certainly useful but it may not be practically possible to determine. Quantification of the relative importance of these and possibly other factors must be the scope of future work.

## INTRODUCTION

In most of the winter cereal-growing area of Cyprus (central plain), rainfall is not only low (average 300 mm) but also erratic in distribution, with the result that the crops may suffer water stress at any time of their growth cycle. However, such stress is predominantly experienced in March-April during the grain-filling period. Almost 40% of the total rainfall occurs in Dec.-Jan. At Athalassa (the test site), on the central plain, in five out of 10 years, annual rainfall is less than 330 mm and in two of these years it is even less than 290 mm. On the other hand, in two out of 10 years it is higher than 375 mm (Metochis, 1979). No grain yield can be expected when rainfall is below 100 mm (Hadjichristodoulou et al., 1977).

Because barley grows better than wheat in cold weather, it matures 2-3 weeks earlier and thereby escapes late drought to a considerable extent. It produces higher and more stable yields (Hadjichristodoulou, 1974), evidently because its water requirement is about 300 mm (Orphanos and Metochis, unpublished), i.e., it closely matches the average rainfall. It is also highly versatile with regard to water stress and has been observed in Cyprus to regrow well following serious drought early in season. Lawlor et al. (1981) have shown that barley adapts to drought through production of fewer tillers and smaller leaves, the photosynthetic rate of which is not impaired unless they senesce earlier.

Since barley produces more stable yields, and wheat grain is available on the international market at reasonable prices, barley growing has been expanding in recent years and presently occupies almost 95% of the cereal area. It is grown, firstly, for the production of grain (used only as livestock feed) and straw, secondly, for the production of hay, and thirdly, for grazing. Hay produced by cutting at the milk stage of grain has been shown to provide slightly more digestible dry matter than that contained in the grain and straw that will be harvested at full maturity (Droushiotis, 1984).

Barley grain production in Cyprus presently ranges between 30,000 and 150,000 tons per year, whereas the grain requirement for the livestock industry is 400,000 tons; the balance is met by imports of barley, sorghum and corn grain. This state of affairs has prompted the intensification of barley growing and the significant reduction of fallowed land, which now stands at just under 20% of the cereal area (Dep. Stat. Res., 1987). Such continual growing of barley, combined with improved management (machine drilling, weed control), demands more fertilizer than under the barley-fallow rotation.

All Plain soils in Cyprus are inherently low in N (total soil N around 0.1%) and bicarbonate-extractable P (1-5 ppm), but are adequately supplied with exchangeable K (higher than 250 ppm). Therefore, N and P, but not K, fertilizers are regularly applied. Despite the fact that rainfall is insufficient, N and P but not water may be the factors most limiting yield, a fact recognized long ago by Littlejohn (1946). However, response to P is known to be more pronounced in years of low rainfall (Matar, 1977; Krentos and Orphanos, 1979a; Harmsen et al., 1983), which may explain why Loizides (1958) reported consistent responses to N by wheat but less consistent responses to P. Krentos and Orphanos (1979a) reported 6 ppm $HCO_3$-P in the plough layer as the threshold value above which response to P would not be obtained, even in dry years. They concluded that, because rainfall is unpredictable, adequate N and P must be applied in order to make best use of whatever rainfall occurs. They also showed that fertilizer N not taken up because of drought remains in the soil available to the following crop. They recommended 40 kg N/ha for barley grown after fallow.

The purpose of the present experiment was to monitor the N relationships of barley grown continuously or after fallow on the same field over a number of years.

## MATERIALS AND METHODS

A long-term experiment was established at Athalassa Farm (E 033.24, N 035.08, Altitude 150 m) in 1979 to test the effects of three N rates (0, 30, 60 kg N/ha) and two P rates (0, 20 kg P/ha), combined factorially, on yield of barley (cultivar Athenais) cut at the milk stage of grain for making hay (hereafter referred to as forage barley) or allowed to mature and be harvested as grain and straw (hereafter referred to as grain barley). The fertilizer treatments occupied the sub-plots of a number of single- or two-course rotations (main-plot treatments) indicated below.

Grain barley followed:

1) grain barley (continual barley growing); all crops were sown in cultivated soil using the conventional drill.
2) grain barley, but the crops were sown in the stubble (direct drilling in uncultivated soil),
3) forage barley conventionally drilled, and
4) cultivated fallow

Forage barley followed:
1) forage barley and was drilled as in 1) above
2) forage barley and was drilled as in 2) above
3) grain barley conventionally drilled (companion leg of 3 above)

The 'diret drilling' treatment was introduced in 1984 for grain barley and in 1985 for forage barley, and replaced legume-barley treatments, in which the legume (vetch, forage peas) did not grow well due to infestation by volunteer barley and attack by blight. The drilling was done with a John Deere machine, but the fertilizer was applied broadcast even though the machine could drill it in with the seed. In years in which there was early rainfall, and as a result the field was weedy at sowing time, a paraquat spray was applied to kill weeds before sowing. Sowing with this drill disturbs most of the soil surface and forms little furrows above the seed rows. The rows were spaced with this drill, as well as with the conventional drill, at 17.5 cm.

The seed rate was 106 kg/ha for grain barley and 185 kg/ha for forage barley. The P fertilizer (triple superphosphate) was broadcast just prior to sowing, together with half the N (as ammonium nitrate), and cultivated into the soil. The other half of the N was topdressed at the end of tillering (early Feb). However, starting with the 1983-84 season, all N was applied together with the P at the sowing time.

A sub-plot measured 5.5 x 6.0 m, and six sub-plots (fertilizer treatment plots) made a main plot. Each main-plot treatment (rotation) was replicated three times. The yield from the central 1.5 x 5.5 m area of each sub-plot was recorded. Forage barley was cut with a mower and grain was combine-harvested.

Over the period 1964-1979, the experimental field had been used by the Agronomy Section for various trials, and had also grown lucerne and sudax under irrigation. As a result of liberal NP and occasionally K fertilizer application, the plough layer was very high in Olsen P (50 ppm), sufficiently high in exchangeable K (400 ppm), and rather high in $NO_3$-N (40 ppm). Partly due to irrigation, the composition of exchangeable cations was as follows: Na+4, Mg++ 6 and Ca++ 10 meq/100 g soil. The soil was a sandy loam and contained about 30% $CaCO_3$ throughout the profile, and 1% organic matter in the top

30-cm layer decreasing with depth. The field was rather variable in all of the above parameters, but was the only one available for a long-term experiment. In dividing it into blocks (replications) slope and stoniness were the factors considered most.

When there was rainfall in Oct.-Nov. the soil was cultivated soon afterwards. Otherwise it was only tine cultivated dry just before sowing in early Dec. Fallowed plots were rotavated mostly twice in spring, as the wetness of the soil permitted, to control weeds in order to have a clean fallow. This, however, was not always feasible. Forage barley plots were cultivated as soon as possible after the plants were cut in mid April.

The period over which the experiment spanned was rather dry; extremely dry spells occurred in Jan., 1982, Feb., 1985, and Jan., 1987. To salvage the crop, 50 mm of water was applied by sprinklers on 25 Jan., 1982, 19 Mar., 1985, and 24 Feb., 1987. Rainfall over the period Nov.-Apr. (including the irrigation given) is presented in Table 1 together with the long-term average rainfall. The earliest emergence was on 2 Dec., 1983, and the latest on 12 Jan. 1981, normally with tillering in January, flowering in late March-early April, and harvesting in May.

## RESULTS AND DISCUSSION

As expected from the high soil P, P fertilizing had no effect on yields. Therefore all the results presented are averages over the two P treatments. Because of the high variability of the field, the differences due to the treatments were not always statistically significant (Table 2). However, trends were clear and consistent. Grain yield was virtually nil in 1986 (even though this was not the driest year in terms of total Nov.-Apr. rainfall), and highest (3.5 t $ha^{-1}$) in 1988 (Table 1). It could have been even higher in 1988 had the period 20 Mar. - 30 Apr. not been practically rainless.

Another striking result is that grain yield in 1983 was twice as high as in 1985 even though rainfall in 1983 was only one half that in 1985. This is because in 1985 one third of the rainfall occurred too early, i.e., Nov., and the Feb.-Apr. period was dry, which necessitated applying a 50 mm irrigation on 19 March. These results portray the well-known (Hadjichristodoulou, 1982) vagaries of the rainfall-yield relationship in the Mediterranean region.

In contrast to grain yield, hay yield at the milk stage of grain was much less reduced in the dry years. For example, in 1986 no grain was harvested, but 4t/ha hay was produced (Table 1). This, and also the fact that even in a normal year the total dry matter as well as the digestible

Table 1. Rainfall, and barley grain and forage yields under the different rotations over the period 1981-88.

| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
| Rainfall* (mm) | 296 | 242 | 156 | 258 | 302 | 187 | 316 | 274 |
| Rotation | | | Barley grain (t ha$^{-1}$) | | | | | |
| G.B-G.B. (C) | 2.29 | 3.29 | 1.64 | 1.38 | 0.43 | - | 1.76 | 3.41 |
| G.B.-G.B. (D) | | | 1.57 | 1.49 | 1.28 | - | 1.68 | 3.42 |
| F.B.-G.B. (C) | 2.44 | 3.18 | 1.82 | 1.18 | 0.66 | - | 1.75 | 3.60 |
| F. -G.B. (C) | 2.15 | 2.66 | 1.90 | 1.09 | 0.56 | - | 1.89 | 2.91 |
| | | | Barley forage DM (t ha$^{-1}$) | | | | | |
| F.B.-F.B. (C) | 6.64 | 7.70 | 4.51 | 3.79 | 3.56 | 3.79 | 4.33 | 6.08 |
| F.B.-F.B. (D) | | | | | 3.97 | 4.33 | 3.27 | 5.76 |
| G.B.-F.B. (C) | 6.83 | 6.84 | 4.84 | 4.23 | 3.79 | 3.78 | 4.59 | 6.20 |

* Long-term average for November-April = 240 mm

G.B. = Grain barley; F.B. = Forage barley; F. = Fallow
C. = Conventional drilling; D = Drilling in the stubble.

Table 2. Summary of statistical significance of rotations and N fertilizing on barley grain and forage.

| Year | Rotation | | N | | Rotation x N | |
|---|---|---|---|---|---|---|
| | Sig. | SE | Sig. | SE | Sig. | SE |
| Barley grain | | | | | | |
| 1981 | NS | 0.12 | ** | 0.05 | NS | 0.09 |
| 1982 | ** | 0.06 | NS | 0.10 | NS | 0.17 |
| 1983 | NS | 0.14 | * | 0.08 | NS | 0.16 |
| 1984 | NS | 0.12 | NS | 0.08 | NS | 0.16 |
| 1985 | * | 0.12 | * | 0.06 | NS | 0.12 |
| 1986 | Not harvested due to drought | | | | | |
| 1987 | NS | 0.16 | NS | 0.08 | NS | 0.15 |
| 1988 | * | 0.09 | ** | 0.07 | NS | 0.13 |
| Barley forage | | | | | | |
| 1981 | NS | 0.38 | NS | 0.16 | NS | 0.22 |
| 1982 | NS | 0.35 | * | 0.37 | NS | 0.52 |
| 1983 | NS | 0.43 | NS | 0.18 | NS | 0.25 |
| 1984 | NS | 0.43 | NS | 0.16 | ** | 0.22 |
| 1985 | NS | 0.18 | NS | 0.12 | NS | 0.21 |
| 1986 | NS | 0.26 | NS | 0.17 | NS | 0.30 |
| 1987 | NS | 0.27 | * | 0.18 | NS | 0.32 |
| 1988 | NS | 0.20 | NS | 0.31 | NS | 0.53 |

SE = t ha$^{-1}$; Sig. = Significance level.

dry matter contained in the hay is even slightly more than that in the grain and straw (Droushiotis, 1984), suggests that production of hay instead of grain and straw must be considered at least in areas where rainfall is low and/or erratic.

Grain yield was highest with continual cropping irrespective of drilling method whether conventional or direct drilling (Table 1). This indicates that direct drilling merits further testing in the region. In the very dry 1984-85 season, direct drilling gave higher yield than conventional drilling probably because following the relatively high Nov. rainfall, lack of soil disturbance in the direct drilling treatment conserved more water relative to the cultivated soil. Contrary to expectation, grain yield after fallow was mostly similar to or less than that with continual cropping.

This was apparently the result of the combination of low rainfall (low yield potential) and excessively high accumulation of mineralized N after fallow (Table 3). In only three years was water conserved during fallow (about 70 mm in the 0-90 cm profile) (Table 5). Two of the crops that followed (1983, 1987) gave higher yields than under continual cropping. In contrast, the 1981 crop did not benefit from the water stored during the preceding fallow period, apparently because there was sufficient rainfall in the later part of the season.

The lack of a direct relationship between total rainfall and water conserved during fallow (Table 5) is due, among other factors, to the timeliness or the lack of it of weed control by cultivation. On the other hand, the plough layer dries to almost the same extent in both non-fallowed and fallowed soil (Table 5) and unless there is sufficient rainfall in the early part of the season to wet the profile down to the layer where the conserved water is, this stored water will not be utilized because the roots will not have grown that deep. It should also be emphasized that fallowing every other year reduces the number of crops grown by one half. The present data clearly show that if land is short, as is the case in Cyprus, continual barley growing can be unreservedly recommended.

In common with barley grain, yield of barley forage was the same after forage barley or after grain barley, whether drilling was in cultivated soil or directly in the uncultivated stubble. Nitrogen tended to decrease grain yield particularly after fallow, presumably as a result of accumulation of excessive amounts of mineralized N. In contrast, 30 kg N/ha in most cases increased barley forage yield even though this was not always statistically significant (Table 2). Obviously, maximum vegetative growth is required for forage, but not for grain production.

Table 3. Nitrate concentration in the 0-45 cm soil layer of unfertilized plots.

| Rotation | 1980 | 1982 | 1983 | 1984 | 1987 |
|---|---|---|---|---|---|
| | NO$_3$-N, ppm | | | | |
| Grain barley-Grain barley | 7 | 2 | 10 | 40 | 13 |
| Grain barley-Grain barley (stubble-drilled) | | | 14 | 37 | 15 |
| Forage barley-Grain barley | 10 | 8 | 10 | 37 | 16 |
| Fallow-Grain barley | 36 | 51 | 33 | 68 | 51 |
| Forage barley-Forage barley | 12 | 9 | 25 | 23 | 21 |
| Grain barley-Forage barley | 10 | 5 | 16 | 24 | 20 |

1 ppm N = 0.13 kg $ha^{-1}$ $cm^{-1}$, assuming bulk density = 1.3 t $m^{-3}$
Sampled in late November of the indicated year just before the underlined crop was sown (data from only one replication).
In 1987, the 0-60 layer was sampled.

Table 4. Nitrate concentration in the 0-60 cm soil layer in late Nov., 1987, under different rotations and N rates.

| Rotation | | N rate (kg/ha) | | |
|---|---|---|---|---|
| 1986-87 | 1987-88 | 0 | 30 | 60 |
| | | NO$_3$-N, ppm | | |
| Grain barley-Grain barley | | 13 | 16 | 27 |
| Grain barley-Grain barley (stubble-drilled) | | 15 | 20 | 41 |
| Forage barley-Grain barley | | 16 | 28 | 33 |
| Fallow - Grain barley | | 51 | 64 | 63 |
| Forage barley-Forage barley | | 21 | 31 | 32 |
| Grain barley-Forage barley | | 20 | 19 | 28 |

Data from a single replication.

Table 5. Annual rainfall and water content of the 0-30 and 0-90 cm soil layers in late November.

| Year | Rainfall (mm) | 0-30 cm | 0-90 cm | 0-30 cm | 0-90 cm |
|---|---|---|---|---|---|
| | | mm | | | |
| 1979-80 | 317 | 40 | 140 | 50 | 215 |
| 1980-81 | 350 | 32 | 190 | 40 | 210 |
| 1981-82 | 230 | 40 | 145 | 65 | 220 |
| 1982-83 | 302 | 55 | 170 | 50 | 160 |
| 1983-84 | 368 | 75 | 200 | 75 | 205 |
| 1984-85 | 260 | 50 | 180 | 55 | 185 |
| 1985-86 | 349 | 50 | 150 | 75 | 220 |
| 1986-87 | 300 | 50 | 170 | 65 | 180 |

Measurements taken after grain barley or fallow (water content of the 0-90 cm layer at field capacity was 350 mm, and at wilting percentage, 165 mm).

Nitrogen application almost invariably increased the N concentration in hay, grain and, particularly, straw (Fig. 1). Irrespective of applied N, straw after fallow contained more N, reflecting the accumulation of soil mineralized N under this sequence (Table 3). It must be pointed out that the 'straw' analyzed consisted of the stem + leaves of plants sampled just prior to harvesting. Under commercial conditions, however, a substantial part of the leaf material would be lost during harvesting, and consequently N concentration in the straw would be lower than shown here.

In agreement with Orphanos and Krentos (1980), increasing N supply due to mineralization or fertilizing also increased K concentration in hay and straw (data not presented). This could be the result of increased K uptake, reduction of K translocation to the roots during crop maturation or both. In any case, the fact remains that under high N conditions more K is removed with the harvested matter, which is wasteful if such high N does not proportionately increase yield.

The soil data for $NO_3$-N (Tables 3,4), though limited, indicate some clear trends, the most important of which is the accumulation of mineralized N during the fallow phase. The markedly high values for 1984 (Table 3) are apparently the result of more intense mineralization caused by high rainfall in Apr. (91 mm) and Nov. (62 mm). This clearly shows that, in any advisory scheme for N fertilizing, rainfall will need to be thoroughly considered. As expected, N fertilizer application increased soil $NO_3$-N relatively more under continual cropping (Table 4).

The amount of N removed with the harvested matter (grain + straw or hay) over the 8-year period increased linearly with applied fertilizer N (Table 6). If the 1986 harvest is excluded (only hay was harvested), then the two values are very close to each other. Assuming that N removed in the hay from unfertilized plots (574 kg N) came from mineralized soil organic matter, 24% of the organic matter of the top 45 cm layer would have been mineralized.

The present experiment illustrates more some types of results which can be obtained rather than providing widely applicable recommendations. The experimental field was unique in that it had for long years in the past been intensively managed and heavily fertilized, as a result of which it was at a high 'fertility level'. However, under rainfed conditions organic matter will not accumulate even if legumes are grown (Papastylianou and Samios, 1987). If rainfall and the other conditions favour high yields, fertilizer N will have to be added. It is well documented that soil fertility is built up gradually, as clearly shown here. Fertilizer application over the years raises soil fertility to a considerably higher level

Table 6. Amount of N removed with harvested parts of barley (grain, straw, forage) over the 8-year period.

| | | Grain | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|
| Year | N rate (kg/ha) | Continually grown | After forage barley | After fallow | Continually grown | After forage barley | After fallow | Forage |
| | | -------- | -------- | -------- | kg $ha^{-1}$ | -------- | -------- | |
| 1981 | 0 | 44 | 56 | | 33 | 54 | | 85 |
| | 30 | 49 | 54 | | 54 | 48 | | 96 |
| | 60 | 41 | 51 | | 44 | 50 | | 105 |
| 1982 | 0 | 56 | 60 | | 21 | 22 | | 79 |
| | 30 | 75 | 92 | | 27 | 36 | | 101 |
| | 60 | 85 | 73 | | 33 | 32 | | 111 |
| 1983 | 0 | 37 | 52 | 61 | 23 | 20 | 48 | 62 |
| | 30 | 43 | 57 | 58 | 22 | 39 | 75 | 71 |
| | 60 | 49 | 49 | 51 | 31 | 38 | 61 | 85 |
| 1984 | 0 | 34 | 39 | 36 | 19 | 33 | 35 | 68 |
| | 30 | 39 | 39 | 32 | 28 | 37 | 30 | 84 |
| | 60 | 46 | 36 | 47 | 33 | 36 | 36 | 103 |
| 1985 | 0 | 25 | 22 | 22 | 23 | 18 | 18 | 84 |
| | 30 | 22 | 18 | 14 | 16 | 15 | 11 | 90 |
| | 60 | 26 | 17 | 15 | 25 | 20 | 16 | 92 |
| 1987 | 0 | 42 | 52 | 66 | 23 | 34 | 50 | 72 |
| | 30 | 47 | 54 | 61 | 32 | 44 | 49 | 89 |
| | 60 | 49 | 52 | 51 | 42 | 40 | 45 | 99 |
| 1988 | 0 | 68 | 81 | 88 | 24 | 31 | 61 | 57 |
| | 30 | 81 | 91 | 72 | 29 | 35 | 55 | 81 |
| | 60 | 79 | 83 | 80 | 29 | 32 | 55 | 80 |
| 1981-88 | 0 | 306 | 362 | | 161 | 212 | | 574 |
| | 30 | 356 | 405 | | 208 | 254 | | 705 |
| | 60 | 375 | 361 | | 237 | 248 | | 786 |

The figures for the forage are average over all rotations. Straw yield was calculated from grain yield considering a grain to straw ratio of 40:60.

Due to drought only forage was obtained for 1986, i.e. 67, 93 and 111.

than can be achieved even with a generous single application (Krentos and Orphanos, 1979b).

Soil $NO_3$-N at sowing was superior to 'paddock history' (cropping sequence) in predicting responses to added N (Taylor et al. 1978). Yet, however useful the soil $NO_3$-N analysis may be, it may not be feasible in practice. Perhaps a scheme could be divided to test for $NO_3$-N on an area basis and advise the farmers accordingly. Such testing should perhaps be carried out under the predominant rotations of the area, including fallow, and take into account the rainfall. Low rainfall during the growing period of the previous crop limits growth and thereby the amount of N used. Such unused N remains available for the next crop (Krentos and Orphanos, 1979a). On the other hand,

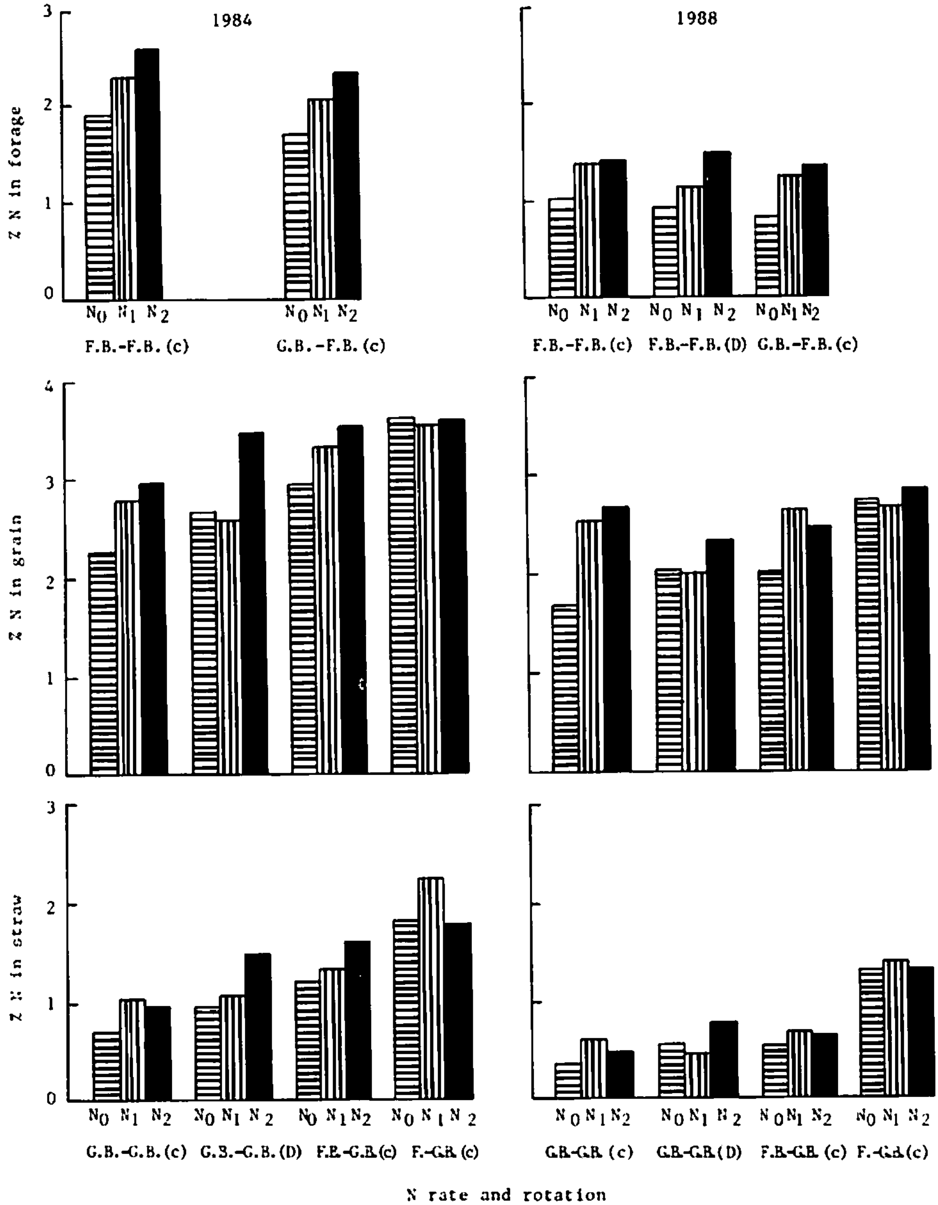



Fig. 1. Concentration of N in barley forage (hay), grain and straw under the different rotations and N rates in 1984 and 1988 (means over the P rates from one replicate; see Table 1 for explanation of rotations; $N_0, N_1, N_2$ = 0, 30, 60 kg N/ha).

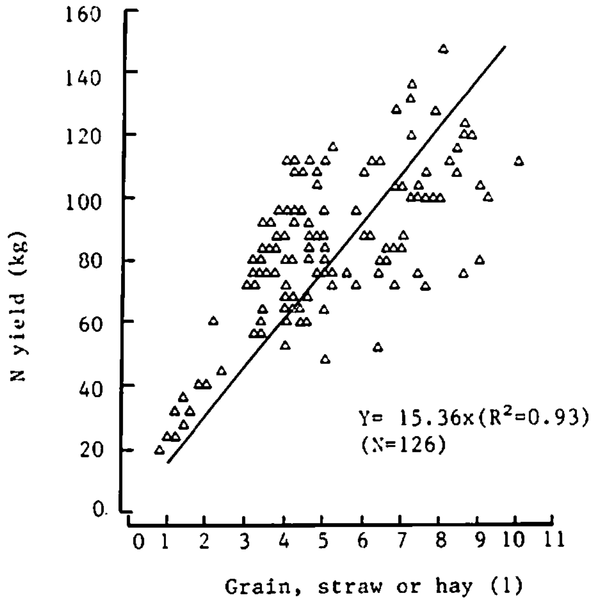



Fig. 2. Amount of N removed with the harvested matter of grain barley (grain + straw) and forage barley (hay).

rainfall occurring between the time the previous crop is harvested and the sowing of the new crop will enhance mineralization of soil N. Potential yield will also have to be considered. Since one ton of grain + straw, or hay, removed 15 kg N (Fig. 2), a rough calculation can be made of the amount of N required.

## REFERENCES

Dept. Stat. Res. 1987. Agric. Statistics. Min. Finance, Nicosia, Cyprus.

Droushiotis, D. 1984. Effect of grazing simulation on forage, hay and grain yields of spring barley in a low rainfall environment. J. Agric. Sci. (Camb.). 103:587-594.

Hadjichristodoulou, A. 1974. Comparative studies of yield and quality of grain cereals under rainfed conditions. Tech. Bull. 15. Agric. Res. Inst., Nicosia, Cyprus. 12 p.

Hadjichristodoulou, A. 1982. The effects of annual precipitation and its distribution on grain yield of dryland cereals. J. Agric. Sci. (Camb.), 99:261-270.

Hadjichristodoulou, A., A. Della, and C. Josephides. 1977. A new durum wheat variety, Aronas. Tech. Bull. 22. Agr. Res. Inst. Nicosia, Cyprus. 14 p.

Harmsen, K., K.D. Shepherd, and A.Y. Allan. 1983. Crop response to nitrogen and phosphorus in rainfed agriculture. In nutrient balances and the need for fertilizers in semi-arid and arid regions. Proc. 17th Colloquium Int. Potash Inst., Morocco. Worblaufen-Bern, Switzerland.

Krentos, V.D., and P.I. Orphanos. 1979a. Nitrogen and phosphorus fertilizers for wheat and barley in a semi-arid region. J. Agric. Sci. (Camb.), 93:711-717.

Krentos, V.D., and P.I. Orphanos, 1979b. Nitrogen, phosphorus and potassium fertilizers for potatoes in Cyprus. J. Agric. Sci. (Camb.), 92:645-661.

Lawlor, D.W., W. Day, A.E. Johnston, D.J. Legg, and K.J. Parkinson. 1981. Growth of spring barley under drought: crop development, phtosynthesis, dry-matter accumulation and nutrient content. J. Agric. Sci. (Camb.). 96:167-186.

Littlejohn, L. 1946. Some aspects of soil fertility in Cyprus, Empire J. Exp. Agric., 14:123-134.

Loizides, P.A. 1958. Fertilizer experiments in Cyprus. II. Cereals. Empire J. Exp. Agric. 26:25-33.

Matar, A.E. 1977. Yields and response of cereal crops to phosphorus fertilization under changing rainfall conditions. Agron. J., 69:879-881.

Metochis, Chr. 1979. The agroclimatology of Athalassa Farm. Tech. Paper 17. Agric. Res. Inst., Nicosia, Cyprus, 6p.

Orphanos, P.I., and V.D. Krentos. 1980. Concentration of N, P and K in leaves, straw and grain of wheat and barley as influenced by N and P fertilizers under semi-arid conditions. J. Agric. Sci. (Camb.), 94: 551-556.

Papastylianou, I., and Th. Samios. 1987. Comparison of rotations in which barley for grain follows woolypod vetch or forage barley. J. Agric. Sci. (Camb.), 108:609-615.

Taylor, A.C., R.R. Storrier, and A.R. Gilmour. 1978. Nitrogen needs of wheat. 2. Grain yield response to nitrogenous fertilizer. Aust. J. Agric. An. Husb., 18: 118-128.

# EFFECT OF RATE AND METHOD OF PHOSPHATE PLACEMENT ON WHEAT PRODUCTION IN SYRIA

M. Pala and A. Matar

International Center for Agricultural Research
in the Dry Areas (ICARDA)
P.O. BOX 5466, Aleppo, Syria

**ABSTRACT**

On-farm wheat experiments were conducted in the 1986/87 and 1987/88 growing seasons at four farmers' fields and two ICARDA experimental stations (Tel Hadya and Jindiress) in Syria. Trials consisted of four levels of P (0, 20, 40 and 80 kg $P_2O_5$/ha) with two replications in 1986/87 and five levels of P (0, 20, 40, 80 and 120 kg $P_2O_5$/ha), with three replications in 1987/88 and three methods of P placement: (1) banding P with the seeds, (2) broadcasting P and incorporating and drilling the seeds, and (3) broadcasting P with the seeds on ridges and then splitting the ridges to cover them (farmers' practice). A rainfall gauge was installed at each site, and precipitation recorded daily. Before planting, $NaHOC_3$-extractable P, determined in the 0-20 cm soil layer, ranged from 2.1 to 7.7 ppm. The soils were similar in texture (clay > 60%), lime content (20-34%), and pH (7.9 - 8.1).

In 1986/87, grain yield responded significantly to method of P placement at all sites. Although there was no significant differences between the Methods 1 and 2 for grain yields, Method 1 gave consistently higher yield than Method 2. Both methods of placement were superior to Method 3. Mean percent increases in grain over farmers' practice (Method 3) at all sites were 25% and 21% from Methods 1 and 2, respectively. Grain response to P was positive and significant only at Atareb with the lowest level of Olsen-available P being 3.5 ppm. In 1987/88, the effect of methods of P application on grain yield was significant at all sites, similar to the first season. Grain yield was significantly increased with P fertilization only in Afes and Jindiress, where the initial available soil P was inadequate for optimum growth.

## INTRODUCTION

Most rainfed wheat of West Asia and North Africa is grown on predominantly calcareous soils under winter rainfall ranging from 300 to 600 mm. Twenty years ago, about 70% of all wheat soils had less than 6 ppm Olsen-P, and wheat yields responded well to P-fertilizer, but since then wheat responses to P have declined; a recent survey showed that only 25% of wheat-growing soils now have less than 6 ppm Olsen-P because most wheat in the wetter zone routinely receives fertilizers. The presence of a few very high values implies that some farmers have been using excessive rates of fertilizers (Jones et al., 1987).

The priority is to optimize the use of P fertilizer and improve the efficiency of applied P in order to achieve these objectives; the question of how best to apply P has to be studied. ICARDA wheat experiments for three seasons have compared banded and broadcast plus incorporated P at three or four application rates. At tillering, it was found that total dry matter (TDM) and total P uptake (TPU) increased linearly with the rate of P applied (Table 1 and Fig. 1). A rate of 40 kg $P_2O_5$/ha banded with the seeds was as effective as 120 kg $P_2O_5$/ha broadcast and incorporated for increasing TDM and TPU. The early advantage of banding remained significant, but it dropped to an overall increase of 13% by harvest (Table 2).

In the light of these experiments (Matar et al., 1988), similar trials were conducted, mostly in farmers' fields to test the adaptability of these methods, comparing with common farmers' method of sowing which is broadcasting P fertilizer and seeds on the ridged land, then splitting the ridges to cover them.

## MATERIALS AND METHODS

On-farm wheat experiments were conducted in the 1986/87 and 1987/88 growing seasons at four farmers' fields and two experimental stations (Tel Hadya and Jindiress) of ICARDA, Syria. Some physical and chemical analyses of surface soils, and seasonal rainfall at the experimental sites, are given in Table 3. The soils of all the sites are similar both in texture (clay > 60%), lime content (20-34%), and pH (7.9-8.1). The available P concentrations at sowing ranged between 2.1 and 7.7 ppm.

The trials consisted of two replicates of a factorial experiment with four levels of $P_2O_5$ (0, 20, 40 and 80 kg/ha) in 1986/87, and three replicates of a factorial experiment with five levels of $P_2O_5$ (0, 20, 40, 80 and 120 kg/ha) in

Table 1. Dry matter of durum wheat at various growth stages at three locations as affected by rate and method of P application, 1985-87.

| | | Dry Matter (kg/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Breda | | | Tel Hadya | | | Jindiress | | |
| $P_2O_5$ | Method | Tillering | Anthesis | Maturity | Tillering | Anthesis | Maturity | Tillering | Anthesis | Maturity |
| kg/ha | | kg/ha | | | | | | | | |
| 0 | | 213 | 2525 | 3363 | 235 | 5813 | 7211 | 271 | 3831 | 7150 |
| 17.5 | banded | 480 | 3979 | 4269 | 451 | 7234 | 8732 | 688 | 6711 | 9876 |
| | broadcast | 321 | 3397 | 3716 | 333 | 6588 | 8504 | 448 | 6089 | 8080 |
| 35.0 | banded | 652 | 4556 | 4811 | 542 | 8203 | 9369 | 860 | 7366 | 10223 |
| | broadcast | 375 | 3719 | 4325 | 373 | 7056 | 8006 | 558 | 6690 | 9445 |
| L.S.D. (.05) | | | | | | | | | | |
| Rate | | 60 | 419 | 601 | 69 | 755 | 1144 | 85 | 949 | 1021 |
| Method | | 49 | 342 | 490 | 56 | 616 | 943 | 70 | 775 | 833 |

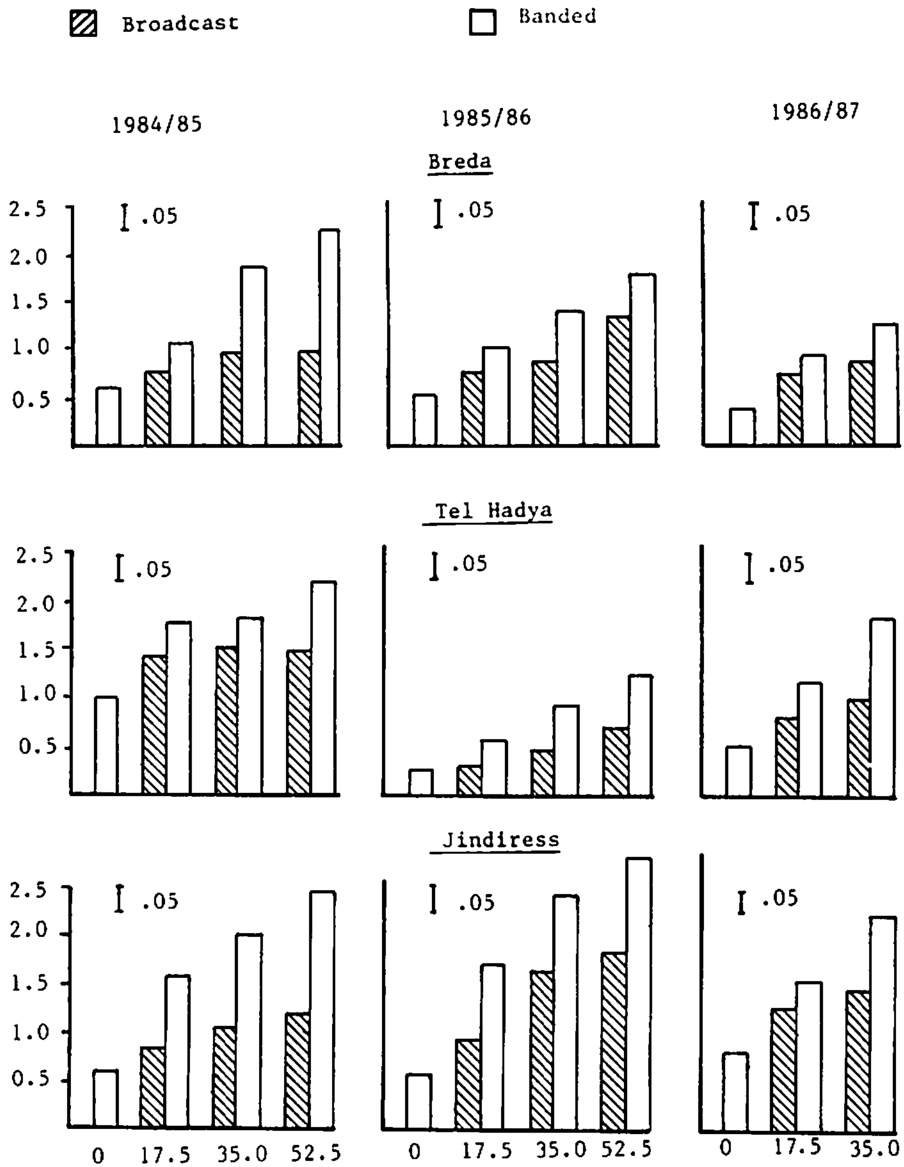



Fig. 1. Total phosphorus uptake of durum wheat at tillering in all sites and seasons as related to rate of P applied and method of placement.

Table 2. Effect of rate and method of P application on durum wheat grain yield at the three locations in Syria, 1985-87.

| Applied P kg/ha | Placement Method | Grain Yield (kg/ha) Breda 1985 | Breda 1986 | Breda 1987 | Tel Hadya 1985 | Tel Hadya 1986 | Tel Hadya 1987 | Jindiress 1985 | Jindiress 1986 | Jindiress 1987 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 1665 | 859 | 814 | 3352 | 2038 | 2421 | 2689 | 1713 | 2551 |
| 17.5 | Banded | 2054 | 1338 | 1007 | 3512 | 2239 | 2535 | 3476 | 2854 | 3488 |
| - | Broadcast | 2085 | 823 | 819 | 3998 | 1931 | 2361 | 3190 | 1806 | 3334 |
| 35 | Banded | 2389 | 1064 | 1026 | 3797 | 2304 | 2516 | 3439 | 2678 | 4023 |
| - | Broadcast | 1917 | 984 | 733 | 3566 | 2126 | 2468 | 3626 | 2252 | 3374 |
| 52.5 | Banded | 2532 | 1051 | - | 4377 | 2310 | - | 3762 | 2671 | - |
| - | Broadcast | 1895 | 1172 | - | 3459 | 2241 | - | 3749 | 2936 | - |
| L.S.D. (0.05) | | | | | | | | | | |
| Among any 2 means | | 393 | 269 | 229 | 501 | 243 | NS | 495 | 844 | 489 |

the 1987/88 season along with three methods of placement (1) banding P with seeds, (2) broadcasting P and drilling seeds, and (3) broadcasting P and seeds. Phosphorus was applied as triple superphosphate (45% $P_2O_5$). The P was either banded by drilling with the seed after cultivation (Method 1), broadcast and rotavated into about 10-12 cm surface layer just before sowing by drill (Method 2), or broadcast on the ridged land together with the seed and the ridges where they split to cover them (Method 3).

Plots under Methods 1 and 2 were sown with 120 kg/ha certified seed of the released ICARDA durum wheat cultivar, Sham 1, with a row spacing of 17.5 cm. Plots under Method 3 were sown with 150 kg/ha in rows 47.5 cm apart. Fertilizer N was applied uniformly across all treatments (40 kg N/ha at sowing and 40 kg N/ha top-dressed at tillering as ammonium nitrate). Weeds were controlled by a single application of bromoxynil plus diclopmethyl (0.5 kg ai/ha + 1.0 kg ai/ha) at the time of 4-leaf stage.

## RESULTS AND DISCUSSION

In the first season (1986/87), total rainfall was around the long-term average at all sites (Table 3), but there was a drought spell of about 40 days from mid-November to the end of December after emergence was completed. However, grain yield responded significantly to method of P placement at all sites (Table 4). Although there was no significant differences between banding (Method 1) and broadcasting plus incorporating (Method 2) for grain yield, banding gave consistently higher yields. Both methods were superior to the method of broadcasting fertilizer and seeds over the ridges and splitting the ridges to cover them (Method 3). Mean percent increases in grain over farmers' practice (Method 3) at all sites were 25 and 23 % from banding and broadcasting plus incorporating, respectively. Response of grain to P was positive and significant ($p<0.05$) only at Atareb which had the lowest level of Olsen P (3.51 ppm). Significant N x P interaction was found also in this location, where banding gave significantly higher yield than broadcasting plus incorporating at low level of applied P in contrast to the highest P level.

In the second season (1987/88), all sites received high rainfall compared with the long-term average (Table 3). Therefore grain yield level was 106 % higher than that of the first season. The effect of rate and method of P application on grain yield of durum wheat in 1987/88 is shown in Table 4. Interaction between method and rate of P application was not significant; therefore only main effects were presented. Grain yields were significantly increased ($p<0.01$) with P fertilization at Afes and Jindiress, where the initial available soil P was considered to be inadequate for optimum growth. However, at Afes, the yield increase

Table 3. Soil physical and chemical properties of the 0-20 cm layer at seven experimental sites.

| Experimental Site/Season | Rainfall | pH | $CaCO_3$ | O.C. | Sand | Silt | Clay | Total N | Olsen P at sowing |
|---|---|---|---|---|---|---|---|---|---|
| 1986/87 | mm | | (%) | | | | | (ppm) | |
| Tel Hadya | 340.5 | 7.9 | 24.4 | 0.99 | 9.6 | 26.7 | 63.7 | 660 | 5.1 |
| Afes | 309.3 | 7.9 | 33.5 | 0.67 | 4.5 | 26.6 | 68.9 | 461 | 4.0 |
| Atareb | 408.6 | 7.9 | 21.3 | 0.83 | 3.6 | 20.9 | 75.5 | 559 | 3.5 |
| 1987/88 | | | | | | | | | |
| Tel Hadya | 499.2 | 7.9 | - | 1.04 | - | - | - | 7.7 | 712 |
| Afes | 478.2 | 8.1 | - | 1.04 | 6.4 | 25.9 | 67.7 | 2.9 | - |
| Taoum | 396.5 | 8.2 | - | 0.73 | - | - | - | 3.8 | 582 |
| Jindiress | 686.5 | 7.9 | - | 1.29 | - | - | - | 2.1 | 744 |

Soil classification at Taoum, Tel Hadya, Afes, and Atareb = Typic Chromoxerert; Jindiress = Vertic Chromoxerert.

Table 4. Effect of rate and method of P application on durum wheat grain yield in farmers' fields and at seven sites in northwest Syria, for two seasons.

| $P_2O_5$ | Grain Yield (kg/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1986/87 | | | | 1987/88 | | | | |
| kg/ha | Tel Hadya | Afes | Atareb | Mean | Tel Hadya | Afes | Taoum | Jindiress | Mean |
| | | | * | ** | NS | ** | NS | NS | ** |
| 0 | 2323 | 1608 | 3742 | 2558 | 4611 | 4013 | 4055 | 2687 | 3842 |
| 20 | 2358 | 1586 | 4170 | 2704 | 4756 | 4022 | 4125 | 3037 | 3985 |
| 40 | 2404 | 1649 | 4028 | 2694 | 4612 | 4433 | 4203 | 3521 | 4192 |
| 80 | 2477 | 1666 | 4240 | 2794 | 4932 | 4436 | 4588 | 4314 | 4568 |
| 120 | - | - | - | - | 4956 | 4528 | 4579 | 4438 | 4623 |
| LSD (0.05) | - | - | 248 | 104 | - | 318 | - | 339 | 174 |
| Method | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| 1 | 2572 | 1700 | 4458 | 2910 | 4864 | 4527 | 4743 | 4165 | 4575 |
| 2 | 2480 | 1678 | 4302 | 2820 | 5016 | 4422 | 4456 | 3865 | 4440 |
| 3 | 2121 | 1503 | 3375 | 2333 | 4440 | 3907 | 3731 | 2768 | 3711 |
| LSD (0.05) | 136 | 63 | 215 | 90 | 266 | 246 | 293 | 263 | 135 |

** $p < 0.01$; * $p < 0.05$.

obtained from applying 40 to 120 kg $P_2O_5$/ha compared with 0 to 20 kg $P_2O_5$/ha was not sufficiently high. At Jindiress, where special fertilizer management was applied in previous years, P application resulted in 13, 31, 61 and 65 % grain yield increases relative to the control with $P_2O_5$ rates of 20, 40, 80 and 120 kg/ha, respectively.

The effects of method of P application on grain yield were significant at all sites in 1987/88 (Table 4). These results were similar to the first season where Method 1 and 2 were not significantly different from each other, but both were superior to Method 3, which is the common farmers' practice in Syria. Compared with Method 3, Methods 1 and 2 provided 10 and 13 % yield increases at Tel Hadya, 16 and 13 % at Afes, 27 and 19 % at Taoum, and 50 and 40 % at Jindiress, respectively.

These results have shown that drill use in Methods 1 and 2 has a more pronounced effect on yield than P placement, because the narrower row spacing by drill provides more uniform seed depth, better crop establishment and increased crop canopy for more efficient water use. In Method 3, sowing was applied by broadcasting fertilizer and seed on ridged land and then splitting the ridges to cover them at row spacing of 47.5 cm. By this way of sowing, seeds were distributed at variable depths from 0 to 12 cm with non-uniform stand establishment and lower crop canopy, resulting in lower yield at harvest. Although interactions between rates and methods of P application were insignificant, it can be seen from Fig. 2 that Methods 1 and 2 constitute a group significantly different from Method 3 at all sites.

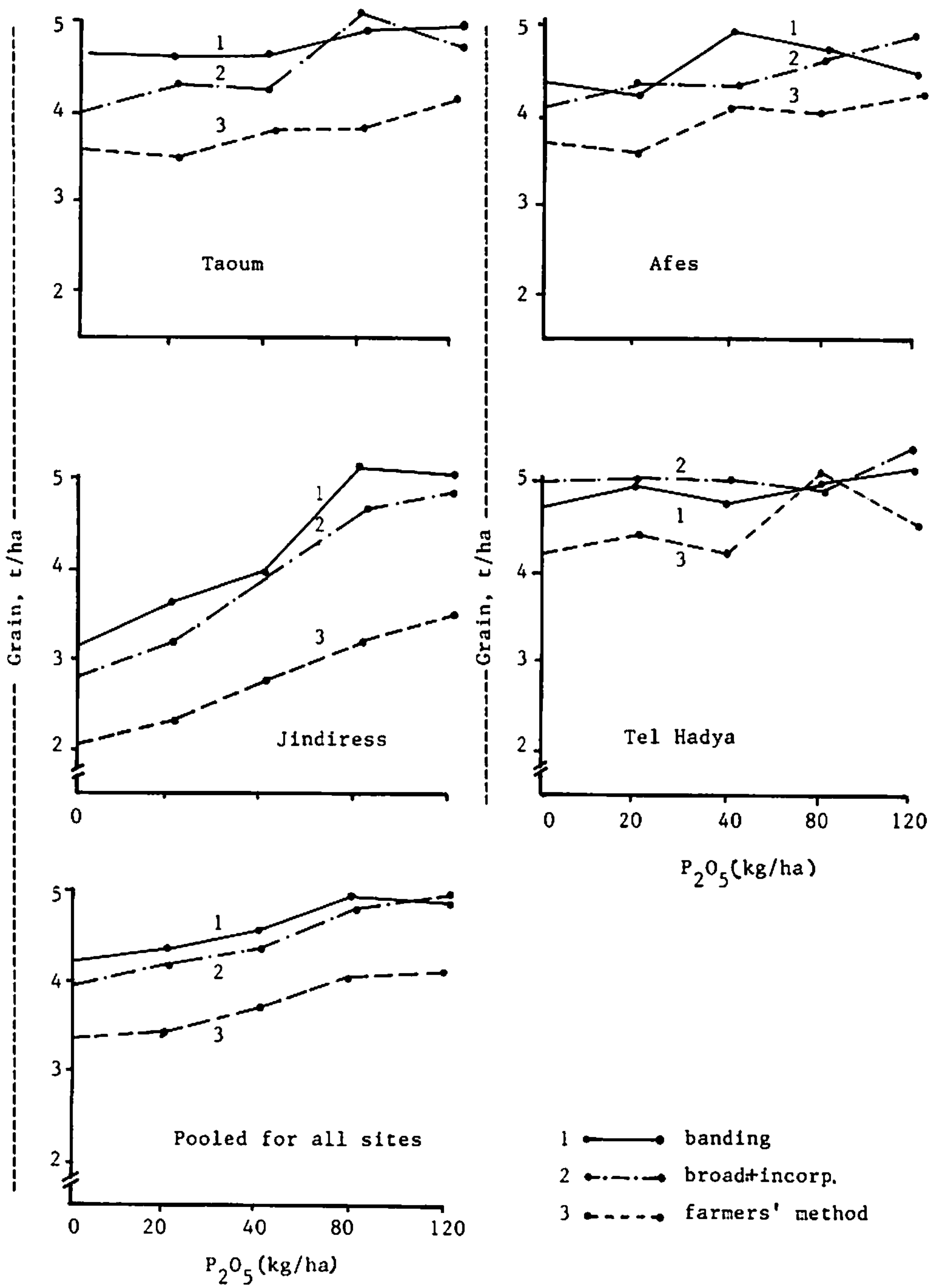



Fig. 2: Effect of rate and method of P application on grain yield of durum wheat at four locations in NW Syria, 1987/88.

## CONCLUSIONS

1) The frequent and regular application of P by farmers to soils of the wetter areas has led to a P fertility build-up. Therefore, a lower response to P application was observed. Regular responses to P have been observed only at sites with low or no P applied.

2) Banding of P with the seeds, compared to broadcasting and incorporating, was superior in soils with low available P, and where response to P application was significant.

3) Whenever P is needed, banding P with the seed seems more economical than broadcasting plus incorporating P when using the drill in both cases.

4) The common farmers' practice of broadcasting fertilizer and seeds in ridged land and then splitting the ridges to cover them is responsible for low yields. Therefore, it is strongly recommended that this method of sowing be replaced by drill use, which provides more efficient use of fertilizer.

## REFERENCES

Jones, M., A.E. Matar, and M. Pala. 1987. A strategy for fertilizer research in variable rainfed environments: Cereals in Syria, a case study. Farm Resource Management Program, p. 8-81. ICARDA Annual Report, Aleppo, Syria.

Matar, A.E., S.C. Brown, and S. Masri. 1988. Effect of rate and method of phosphate placement on productivity of durum wheat in Mediterranean environments: I. Crop yields and P uptake. II. Root distribution and P dynamics. Fertilizer research 20: 75-88.

# FERTILIZER PLACEMENT FOR DRYLAND WHEAT IN CENTRAL MOROCCO

M. Abdel Monem, A. Azzaoui, M. El Gharous,
J. Ryan, and P. Soltanpour

Aridoculture Center, Settat, Morocco

## ABSTRACT

While fertilizer banding, especially P, is more efficient than traditional broadcast application, such an advantage depends on factors such as the level of soil nutrients, soil type, and relative crop yield. The second year's data from a 2-year placement study of N and P for wheat are reported. The trial was at three sites featuring deep (Chromoxerert), moderately deep (Calcixeroll), and shallow (Rendoll) soils previously cropped with wheat. The respective $NaHCO_3$-P values were 10, 13, and 7 ppm. The P rates were 0, 20, 40 and 80 kg $P_2O_5$ $ha^{-1}$ banded and broadcast, while N was applied banded or broadcast at 80 kg $ha^{-1}$. Measurements were taken of N uptake at tillering and anthesis along with grain and dry matter yield. Rainfall was above average at 471 mm and well distributed. The primary response was to applied N. Though other treatment effects were not significant, some consistent trends were observed. Yield and N uptake data were higher in all cases where N was banded than where broadcast. Such data were consistently higher with banded P than with broadcast on all except the deep soil, where available P levels were highest. Benefits of banding P for dryland wheat are accentuated in drier years and at P values less than 5 ppm. In recommending fertilizer banding over broadcasting, a careful assessment has to be made of cultural practices and socio-economic circumstances.

## INTRODUCTION

An important concept in fertilizer use is efficiency, i.e., the impact or effect of any given quantity of fertilizer in increasing crop yield. Scarcity of supply and high fertilizer prices underline the importance of application methods that increase fertilizer efficiency. The earliest research on chemical fertilizers has shown that banding, i.e., placing rows of fertilizer to the side and slightly below the seed, was more efficient than broadcasting, i.e., spreading on the soil surface followed by mechanical incorporation (Engelstad and Terman, 1980). Banding tended to be consistently more effective than broadcasting for P than in the case of N. The advantage of banding is particularly evident in soils low in available P and in soils with a high "P-fixation" capacity.

Numerous studies have addressed the topic of P placement. The recent review of P and K placement (Randall and Hoeft, 1988) attests to the importance of this topical subject. The findings of Rudd and Barrow (1973) that band-applied superphosphate was about twice as effective as that broadcast at seeding is typical of many such studies. At low application rates, Welch et al. (1966) showed the same efficiency rates for banding of P with row crops. However, they and others, such as Ham et al. (1973) and Barber (1958), showed that banding alone on low-P soils was not adequate for maximum yield; this was obtained by a combination of banding and broadcasting. Banded P at low application rates generally gives maximum return on fertilizer investment, while broadcast P usually gives maximum return per hectare (Engelstad and Terman, 1980).

Following a critical examination of the literature relating to the efficiency of banded vs. broadcast P, Peterson et al. (1981) concluded that the relative effectiveness of banding changed with changing soil test P level; at low test level, the ratio was about 3:1, while medium tests had ratios of 1:1. This generally coincided with earlier findings of Barber (1958) that response to banded P decreased with rising P levels.

The physical basis for the efficiency of banding over broadcasting was examined in a pot experiment by Sleight et al. (1984). They concluded that the early beneficial effects of banding are due mainly to placing the fertilizer where contact with active roots is likely, rather than from any increase in availability that may be due to decreased soil-fertilizer contact associated with banding. In considering the influence of placement depth, McConnell et al. (1986) found the optimum to be about 10 cm, but that this varied with location. The increasing use of liquid fertilizers provided the rationale for study using banded liquid ammonium polyphosphate. The efficiency of banding was related to droplet size and factors such as traveling speed; where droplets formed a continuous band, root fertilizer contact and uptake was more effectively promoted.

It is pertinent to refer to studies of P application methods in the Middle East-North Africa region -- an area characterized by low soil P levels, low yields and low fertilizer inputs. Where fertilizer is used, it is most frequently applied broadcast by hand in the absence of appropriate drills for banding fertilizer. Data from

Morocco showed contrasting findings. One study by Soltanpour et al. (1986) found no difference between banded or broadcast P nor any response to P, the soil having a P test level of 8 ppm. The following year, using a shallow rendoll soil with 4.5 ppm P, Soltanpour et al. (1987) showed that the response to banded $P_2O_5$ leveled off at 80 kg $ha^{-1}$, whereas broadcast $P_2O_5$ leveled off at 20 kg $ha^{-1}$. Studies from Syria showed that banding produced greater P uptake and wheat yield as well as increased fertilizer efficiency compared to broadcasting (Matar, 1986). Similarly, Ryan et al. (1980) cited several early studies in Lebanon where banded P was more efficient than broadcast. However, other studies from Syria (Pala and Matar, 1987) and Jordan (Abu Rub and Al-Ashhab, 1987) found only slight increases from banding P fertilizers.

As N is normally mobile as $NO_3$, placement has generally little advantage over broadcasting, except to reduce gaseous loss of $NH_3$ where ammoniacal fertilizers are surface-applied under warm moist conditions in calcareous soils (Nelson, 1982). It seems that depth of N placement in soils is not a limiting factor as long as moisture is adequate (Daigger and Sander, 1976). However, with the development of new N-P fertilizers and the widespread use of drills for fertilizer and grain application, new interest has arisen in the interaction between N and P when hand-placed. Dual placement of N in a band with P has generally led to increased P availability and fertilizer efficiency (Raun et al., 1987). Thus, in view of the potential significance of N and P fertilizers in dryland agriculture in Morocco, the objective of the foregoing study was to compare N and P applied alone and together in terms of nutrient uptake, and dry matter and grain yield.

## MATERIALS AND METHODS

This one-year field experiment was designed to compare the effectiveness of banding of N and P fertilizers as opposed to broadcast application. The experiment was conducted in conjunction with the on-going soil test calibration study at three sites in the Settat area, representing three major soil great groups in the dryland area of central Morocco. These were shallow (Rendoll), moderately deep (Calcixeroll), and deep (Chromoxerert) soils. Selected properties are shown in Table 1 along with pertinent values for $NO_3$ and $NaHCO_3$-P. In order to eliminate any residual influence of different previous crops, the previous crop at each of the three sites chosen was a cereal. The trial was on-farm and researcher-managed. However, the farm owner served as "guardian" for the plots at each site and provided paid assistance in the planting, sampling and harvest operations. While average rainfall for the area was 380 mm/year (Watts and El Mourid, 1988), rainfall for this experiment was 471 mm as measured in rain

Table 1. Soil depth and nutrient status.

| Soil Type | Soil Depth cm | $NO_3$ | P |
|---|---|---|---|
| | | ------ mg $kg^{-1}$ | ------- |
| Rendoll | 35-40 | 6 | 7 |
| Calcixeroll | 60 | 7 | 13 |
| Chromoxerert | < 60 | 5 | 10 |

gauges placed at each site. The previous two years had 300 and 200 mm, respectively. This year's rains were not only favorable, but well distributed.

The fertilizer treatments were 0 and 80 kg $ha^{-1}$ N as ammonium nitrate, and 0, 20, 40 and 80 kg $ha^{-1}$ $P_2O_5$ as concentrated triple superphosphate. The fertilizers were applied in the conventional manner, i.e., broadcast by hand followed by soil incorporation using a tandem disc called a "covercrop" and banded, i.e., by applying in a row 4 cm from the seed at a depth of 10 cm using a tractor-drawn grain drill. The $P_2O_5$ rates were applied at 0 and 80 kg N $ha^{-1}$ with both methods of application. The experimental design was a factorial randomized complete block with three replications. Each individual plot was 1.8 x 10 m, with six rows of wheat 30 cm apart in each. The wheat variety Nesma, a common bread wheat in Morocco, was planted in late November at 70 kg $ha^{-1}$. In view of the susceptibility of wheat to Hessian fly attack, Furidan at 1.12 kg $ha^{-1}$ was applied with the seed for its control. Weeds were controlled by spraying Certrol-H at the 4-leaf stage using 4 L $ha^{-1}$.

Prior to planting, the experimental sites were sampled to 20 cm for $NO_3$ and $NaHCO_3$-P. Subsequently, plants were sampled at tillering and anthesis (two rows of 1 m in the center of each plot) for N uptake. At harvest in late May 1988, two 5-m rows in each plot were hand-cut by sickle at just aboveground level. Subsequently, the harvested dry matter was measured, and after threshing, grain yield was recorded. Statistically, treatment effects were measured by analysis of variance.

## RESULTS

The data are arranged in terms of the effects of banded vs. broadcast application of N and P on; i) total dry matter yield of wheat, ii) grain yield, iii) N uptake at tillering, and iv) N uptake at anthesis.

## Dry Matter Yield

Dry matter yield data for wheat grown on the three great soil groups and fertilized by varying rates of $P_2O_5$ (0, 20, 40, 80 kg $ha^{-1}$) banded or broadcast, together with 80 kg N banded or broadcast, are presented in Table 2 along with LSD values to identify treatment differences. As might be expected, yields were highest on the chromoxerert soil, and there was an apparent relationship with soil depth when the three soils were considered. The main feature of these data was that there was no consistent response to P application when N was also applied either banded or broadcast; a few significant responses to P occurred, but no trend was evident. These erratic data may be explained by comparably high c.v. values for the harvest data. The most consistent observation was a response to N rather than to P.

Table 2. Dry matter of wheat with fertilizer application methods.

| N | $P_2O_5$ | Chromoxerert | Calcixeroll | Rendoll |
|---|---|---|---|---|
| | | Soil | | |
| --- kg $ha^{-1}$ --- | | Dry Matter qx $ha^{-1}$ | | |
| Broadcast | | | | |
| 0 | 0 | 83.8 | 30.4 | 33.3 |
| 80 | 0 | 103.3 | 31.1 | 41.2 |
| " | 20 B | 109.2 | 29.8 | 29.8 |
| " | 20 | 117.3 | 24.6 | 36.6 |
| " | 40 B | 105.5 | 54.1 | 42.4 |
| " | 40 | 104.3 | 36.6 | 42.7 |
| " | 80 B | 116.5 | 47.5 | 62.5 |
| " | 80 | 126.9 | 32.1 | 39.9 |
| Banded | | | | |
| 0 | 0 | 76.4 | 22.9 | 31.3 |
| 80 | 0 | 108.5 | 39.5 | 52.0 |
| " | 20 B | 114.9 | 37.6 | 57.6 |
| " | 20 | 113.5 | 40.0 | 44.8 |
| " | 40 B | 102.0 | 44.7 | 43.3 |
| " | 40 | 114.6 | 46.3 | 54.2 |
| " | 80 B | 115.6 | 45.9 | 50.4 |
| " | 80 | 119.4 | 36.1 | 36.3 |
| B = Banding; L.S.D. = 5% | | 23.8 | 20.3 | 23.1 |

qx = quintal (100 kg).

In order to identify possible overall effects of banding or broadcasting, the mean values of Table 2 were arranged to give overall means in Table 3. This time some trends were evident. On each soil, mean values for banded N were consistently higher than where N was broadcast. The overall effect of banding P was higher than with broadcasting, i.e., 67.1 and 64.8 qx $ha^{-1}$. In two out of the three soils, i.e., Rendoll and Calcixeroll, banded P was consistently higher than broadcast, whether N was banded or broadcast.

### Grain Yield

On the unfertilized controls, differences in grain yield between soils (Table 4) paralleled those for dry matter yield. Likewise, as with dry matter yield, there was no consistent effect of applied P or of broadcasting or banding. In most cases the response was due to added N, but the effect was not significant. In view of the variability of the data, the treatments were averaged to detect any consistent trend. Again, as with dry matter yield, the overall effect of banding N on each soil was better than broadcasting (Table 5), with values averaged over the P application methods. However, in contrast to dry matter yield, there was no overall difference between banded or broadcast P.

Table 3. Dry matter yield of wheat - overall averages of treatment means.

| | P Application | | | |
|---|---|---|---|---|
| N application | Banded | Broadcast | Mean | Soil |
| | Dry Matter -------- qx $ha^{-1}$ ------- | | | |
| Broadcast | 110.4 | 116.2 | 113.3 | Chromoxerert |
| Banded | 110.6 | 115.8 | 113.2 | |
| Broadcast | 44.9 | 39.7 | 42.3 | Calcixeroll |
| Banded | 50.4 | 45.1 | 47.8 | |
| Broadcast | 43.8 | 31.1 | 37.5 | Rendoll |
| Banded | 42.7 | 40.8 | 41.8 | |
| | 67.1 | 64.8 | | |

N = 80 kg $ha^{-1}$, $P_2O_5$ = 0, 20, 40 and 80 kg $ha^{-1}$.

Table 4. Grain yield of wheat with fertilizer application methods.

| N | $P_2O_5$ | Soil: Chromoxerert | Soil: Calcixeroll | Soil: Rendoll |
|---|---|---|---|---|
| | | Grain Yield | | |
| ---- kg ha$^{-1}$ -------- | | ------------ qx ha$^{-1}$ | ------------- | |
| Broadcast | | | | |
| 0 | 0 | 30.4 | 11.6 | 9.4 |
| 80 | 0 | 33.6 | 14.7 | 8.9 |
| " | 20 | 38.5 | 10.0 | 8.2 |
| " | 20 B | 42.8 | 12.2 | 7.1 |
| " | 40 | 37.7 | 15.5 | 16.5 |
| " | 40 B | 30.3 | 20.5 | 11.5 |
| " | 80 | 37.0 | 23.9 | 13.3 |
| " | 80 B | 45.7 | 13.8 | 10.1 |
| Banded | | | | |
| 0 | 0 | 26.5 | 11.0 | 6.8 |
| 80 | 0 | 36.0 | 18.1 | 11.1 |
| " | 20 B | 39.8 | 21.4 | 10.7 |
| " | 20 | 41.5 | 14.1 | 13.3 |
| " | 40 B | 35.9 | 15.8 | 14.6 |
| " | 40 | 41.7 | 17.5 | 13.9 |
| " | 80 B | 40.8 | 19.9 | 9.7 |
| " | 80 | 41.6 | 15.1 | 14.0 |
| B = Banding; L.S.D. = 5% | | 8.5 | 9.2 | 7.1 |

Table 5. Grain yield of wheat showing overall averages of treatment means.

| N application | P Application: Banded | P Application: Broadcast | Mean | Soil |
|---|---|---|---|---|
| | ---- kg ha$^{-1}$ | ------- | | |
| Broadcast | 37.7 | 39.6 | 38.7 | Chromoxerert |
| Banded | 38.8 | 41.6 | 40.2 | |
| Broadcast | 16.5 | 15.5 | 16.2 | Calcixeroll |
| Banded | 19.0 | 15.6 | 17.3 | |
| Broadcast | 12.7 | 9.6 | 11.2 | Rendoll |
| Banded | 11.7 | 13.7 | 12.7 | |
| | 22.7 | 22.6 | | |

N = 80 kg ha$^{-1}$; $P_2O_5$ = 0, 20, 40, 80 kg ha$^{-1}$.

### Tillering - N Uptake

As with yield parameters, N uptake was more influenced by N application and no effect of P application was apparent. This is consistent with the observation that P had no effect on dry matter yield or grain yield (Table 6). The random significant effects of P on N uptake were unrelated to P application rate or method. Despite these seemingly erratic data, averaging the mean responses again revealed expected and explainable trends (Table 7). Though there was no basis for comparing these overall averages statistically, the superiority of banded vs. broadcast N was evident for each of the three soils. As with dry matter and grain yield, the overall effect of banded P was greater than broadcast, with the exception being on the Chromoxerert soil.

Table 6. Nitrogen uptake of wheat at tillering with fertilizer application methods.

| | | Soil | | |
|---|---|---|---|---|
| N | $P_2O_5$ | Chromoxerert | Calcixeroll | Rendoll |
| --- kg ha$^{-1}$ ---- | | ------------ kg ha$^{-1}$ --------------- | | |
| Broadcast | | | | |
| 0 | 0 | 57.4 | 8.6 | 7.8 |
| 80 | 0 | 65.3 | 10.2 | 12.7 |
| " | 20 B | 98.0 | 11.3 | 16.6 |
| " | 20 | 83.6 | 21.5 | 22.0 |
| " | 40 B | 94.4 | 25.6 | 24.2 |
| " | 40 | 83.7 | 22.6 | 19.9 |
| " | 80 B | 58.0 | 48.4 | 24.7 |
| " | 80 | 74.1 | 26.8 | 17.8 |
| Banded | | | | |
| 0 | 0 | 34.3 | 4.5 | 8.0 |
| 80 | 0 | 84.0 | 22.0 | 19.7 |
| " | 20 B | 92.6 | 30.7 | 16.8 |
| " | 20 | 81.0 | 20.7 | 23.0 |
| " | 40 B | 72.2 | 27.7 | 23.2 |
| " | 40 | 78.0 | 19.6 | 18.3 |
| " | 80 B | 80.0 | 42.3 | 28.6 |
| " | 80 | 94.0 | 18.5 | 14.8 |
| B = Banding; | | | | |
| L.S.D. = 5% | | 29.8 | 14.1 | 9.9 |

Table 7. Nitrogen uptake of wheat at tillering showing overall averages of treatment means.

| N Application | P Application: Banded | P Application: Broadcast | Mean | Soil |
|---|---|---|---|---|
| | --- kg $ha^{-1}$ ------ | | | |
| Broadcast | 83.0 | 80.5 | 81.8 | Chromoxerert |
| Banded | 81.6 | 84.3 | 83.0 | |
| Broadcast | 28.4 | 23.6 | 26.0 | Calcixeroll |
| Banded | 33.7 | 19.6 | 26.7 | |
| Broadcast | 21.8 | 19.9 | 20.9 | Rendoll |
| Banded | 22.9 | 18.7 | 20.8 | |
| | 45.2 | 41.1 | | |

N = 80 kg $ha^{-1}$; $P_2O_5$ = 0, 20, 40, 80 kg $ha^{-1}$

**Anthesis - N Uptake**

Details of N uptake at anthesis as a function of N and P treatment on the three soils are presented in Table 8. As might be expected, uptake was substantially higher than at tillering and markedly higher on the deep clay soil, Chromoxerert, than on the shallower Calcixeroll and Rendoll soils. Thus, a relationship with soil depth was apparent, with N uptake being greater with depth. As with yield and N uptake at tillering, no consistent effect of P was apparent for the individual means of treatment effects. The only apparent observation was a response to applied N. While some P effects were significant, they were random and permit no valid conclusion to be made regarding P rate or application method.

When arranged over all other treatments (Table 9) banding of N produced higher uptake values on all except the shallow Rendoll soil -- an observation noted for all other measurements, i.e., dry matter and grain yield, and N uptake at tillering.

**DISCUSSION**

Despite variability and inconsistency in response to individual rates of P application , an overall effect of banding both N and P was apparent. Though the magnitude of

Table 8. Nitrogen uptake of wheat at anthesis with fertilizer application methods.

| | | Soil | | |
|---|---|---|---|---|
| N | $P_2O_5$ | Chromoxerert | Calcixeroll | Rendoll |
| | | | Nitrogen Uptake | |
| -- kg ha$^{-1}$ ---- | | ------------------ | kg ha$^{-1}$ | ----------- |
| Broadcast | | | | |
| 0 | 0 | 75.0 | 32.0 | 18.9 |
| 80 | 0 | 80.0 | 34.2 | 23.8 |
| " | 20 B | 88.3 | 29.6 | 38.7 |
| " | 20 | 73.7 | 35.5 | 38.5 |
| " | 40 B | 107.4 | 48.8 | 53.8 |
| " | 40 | 74.4 | 38.4 | 25.3 |
| " | 80 B | 101.1 | 68.7 | 52.3 |
| " | 80 | 107.2 | 49.1 | 48.2 |
| Banded | | | | |
| 0 | 0 | 81.3 | 34.1 | 15.4 |
| 80 | 0 | 119.8 | 52.0 | 29.1 |
| " | 20 B | 105.7 | 55.3 | 26.9 |
| " | 20 | 82.7 | 42.1 | 31.8 |
| " | 40 B | 94.5 | 41.9 | 28.7 |
| " | 40 | 74.3 | 45.5 | 34.6 |
| " | 80 B | 93.9 | 46.5 | 48.7 |
| " | 80 | 98.3 | 35.2 | 45.9 |

B = Banding;
L.S.D. = 5% 22.9 23.9 19.1

such increases tended to be small, it was nevertheless consistent. The higher values for banded N, averaged over all P treatments, can only be explained by considering possible loss of efficiency which would occur with broadcasting. In recent years it has been recognized that surface-applied $NH_4$ compounds, especially urea, to calcareous soils cause volatile loss of $NH_3$ to the atmosphere unless the fertilizer is quickly incorporated in the soil (Fenn and Kissel, 1976). Ammonium nitrate or ammonium sulfate may be susceptible to considerable $NH_3$ loss (Ryan et al., 1981). Part of the effect here may have been due to banding eliminating some $NH_3$ loss which may have occurred with surface broadcast application.

The increased efficiency of banded N may also be due to less mineralization by incorporated surface plant residues, since Tomer and Soper (1981) showed that the positive effect of banding was greatest when straw residues were added to the soil to stimulate immobilization of fertilizer

Table 9. Nitrogen uptake of wheat at anthesis; overall averages of treatment means.

| | P Application | | | |
|---|---|---|---|---|
| N application | Banded | Broadcast | Mean | Soil |
| | ---- kg $ha^{-1}$ ----- | | | |
| Broadcast | 98.9 | 85.1 | 92.0 | Chromoxerert |
| Banded | 98.0 | 85.1 | 91.6 | |
| Broadcast | 48.7 | 41.0 | 44.9 | Calcixeroll |
| Banded | 47.9 | 40.9 | 44.4 | |
| Broadcast | 54.7 | 37.3 | 46.0 | Rendoll |
| Banded | 34.8 | 37.4 | 36.1 | |
| | 63.8 | 54.5 | | |

N = 80 kg $ha^{-1}$; $P_2O_5$ = 0, 20, 40, 80 kg $ha^{-1}$.

and soil mineral N. The significance of the possible effects for dryland farming in Morocco remains to be established in future research. Similarly, though the observed improvement of banded N over broadcast may be due to an enhancing effect on P uptake (Raun _et al._, 1987), and therefore dry matter and grain yield, this could not be established as there was no response to applied P.

The evaluation of banded vs. broadcast P in the study was limited by the general absence of a response to applied P. This coincided with results of a soil test calibration study this year at the same sites (Abdelmonem _et al._, 1988) where no response to P was observed. This follows from the fact that the available P levels for these sites ranged from 6 to 13 ppm - all in excess of the 5 ppm level considered by Soltanpour _et al._ (1987) as a critical value beyond which no P response could be expected. Indeed, the favorable moisture during the year made a response to applied P even more unlikely. The absence of any effect of banding P at such levels of available P coincides with research elsewhere (Welch _et al._, 1966). Nevertheless, there were some apparent trends in this study. Banding P did increase overall dry matter yield compared to broadcasting, but had no apparent effect on grain yield. However, N uptake at tillering and anthesis tended to be higher with banded P than with broadcast.

This study permitted only the most tentative conclusions and some speculation regarding banding of fertilizers for dryland wheat. Valid comparisons should only be made where soil test levels of $NaHCO_3$-P are less than 5 ppm, preferably at the lower end of that range. Such comparison should span both wet and dry years in view of the dominant influence of moisture on P response. While research may show a clear advantage of banded P in the dryland area of Morocco, any recommendation for banding to be adopted here should consider current practices, the extent of fertilizer use, and the availability of drilling equipment. Hand broadcasting of seed or fertilizer is a time-honored practice that allows flexibility for the farmer to apply fertilizer later depending on season's rainfall.

## REFERENCES


Abdelmonem, M., A. Azzaoui, M. El Gharous, J. Ryan, and P.N. Soltanpour. 1988. Response of dryland wheat to nitrogen and phosphorus in some Moroccan soils. In J. Ryan and A. Matar (ed.) Proc. Third Soil Test Calibration Workshop, Amman, Jordan, Sept 2-9. ICARDA, Aleppo, Syria (this edition).

Abu-Rub, N., and T. Al-Ashhab. 1987. Response of wheat to nitrogen and phosphorus in rainfed areas of Jordan. p. 82-86. In A. Matar et al. (ed). Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, Sept. 1-6, 1987. ICARDA, Aleppo, Syria.

Barber, S.A. 1958. Relation of fertilizer placement to nutrient uptake and crop yield. I. Interaction of row phosphorus and the soil level of phosphorus. Agron. J. 50:535-539.

Daigger, L.A. and D.H. Sander. 1976. Nitrogen availability to wheat as affected by depth of nitrogen placement. Agron. J. 68:524-526.

Engelstad, O.P. and G.L. Terman. 1980. Agronomic effectiveness of phosphate fertilizers, p. 311-332. In F.E. Khasawneh, E.C. Sample, and E.J. Kamprath (ed.). The role of phosphorus in agriculture. Soil Sci. Soc. Am. Madison, Wis.

Fenn, L.B., and D.E. Kissel. 1976. The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. Soil Sci. Soc. Am. J. 40:394-398.

Ham, G.E., W.W. Nelson, S.D. Evans, and R.O. Frazier. 1973. Influence of fertilizer placement on yield response of soybeans. Agron. J. 65:81-84.

Matar, A. 1986. Evaluation of available phosphorus in calcareous soils as determined by five different procedures as related to growth and uptake by ryegrass in pots. Research Report No. 17. Farming Systems Program. ICARDA, Aleppo, Syria.

McConnell, S.G., D.H. Sander, and G.A. Peterson. 1986. Effect of fertilizer phosphorus placement depth on winter wheat yield. Soil Sci. Soc. Am. J. 50:148-157.

Nelson, D. 1982. Gaseous loss of nitrogen other than through denitrification. p. 327-364. In F.H. Stevenson (ed.) Nitrogen in agricultural soils. Agron. 22. Amer. Soc. Agron. Madison, Wisc.

Pala, M., and A. Matar. 1987. Soil test calibration with N and P for wheat under dryland conditions in Syria, p. 55-67. In A. Matar et al. Proc. Second Regional Soil Test Calibration Workshop. Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

Peterson, G.A., D.H. Sander, P.H. Grabowski, and M.L. Hooker. 1981. A new look at broadcast phosphate recommendations for winter wheat. Agron. J. 73:13-17.

Randall, G.W., and R.G. Hoeft. 1988. Placement methods for improved efficiency of P and K fertilizers. J. Prod. Agric. 1:70-78.

Raun, W.R., D.H. Sander, and R.A. Olson. 1987. Phosphorus fertilizer carriers and their placement for minimum till corn under sprinkler irrigation. Soil Sci. Soc. Am. J. 51:1055-1062.

Rudd, C.L., and N.J. Barrow. 1973. The effectiveness of several methods of applying superphosphate on yield response by wheat. Aust. J. Exp. Agric. Anim. Husb. 13:430-433.

Ryan, J., G. Musharrafieh and A. Barsumian. 1980. Soil fertility characterization at the Agricultural Research and Education Center of the American University of Beirut, Beirut, Lebanon. Fac. Agric. Publ. No. 62.

Ryan, J., D. Curtin, and I. Safi. 1981. Ammonia volatilization as influenced by calcium carbonate particle size and iron oxides. Soil Sci. Soc. Am. J. 45:338-344.

Sleight, D.M., D.H. Sander, and G.A. Peterson. 1984. Effect of fertilizer phosphorus placement on the availability of phosphorus. Soil Sci. Soc. Am. J. 48:338-340.

Soltanpour, P.N., M. El Gharous, and A. Azzaoui. 1986. Phosphorus and nitrogen placement study. Annual Research Report. p. 85-86. Aridoculture Center, Settat, Morocco.

Soltanpour, P.N., M. El Gharous, A. Azzaoui, and M. Abdel Monem. 1987. Nitrogen and phosphorus soil test calibration studies in the Chaouia region of Morocco. p. 86-81. In A. Matar et al ed.) Proc. Soil Test Calibration Workshop. Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

Tomer, J.S., and R.J. Soper. 1981. Fate of tagged urea in the field with different methods of N and organic matter placement. Agron. J. 73, 991-995.

Watts, D., and M. El Mourid. 1988. Rainfall patterns and probabilities in the semi-arid cereal production region of Morocco. Aridoculture Center report, Settat, Morocco.

Welch, L.F., D.L. Mulvaney, L.V. Boone, G.E. McKibben, and J.W. Pendleton. 1966. Relative efficiency of broadcast versus banded phosphorus for corn. Agron. J. 58:283-287.

# RESIDUAL NITROGEN AND PHOSPHORUS FOR DRYLAND WHEAT IN CENTRAL MOROCCO

M. Abdel Monem, A. Azzaoui, M. El Gharous
J. Ryan, and P. Soltanpour

Aridoculture Center, Settat, Morocco

## ABSTRACT

An important aspect of fertilizer use is the extent to which succeeding crops benefit from current year's application and how this influences subsequent fertilizer recommendations. This is especially true for rainfed areas where fertilizer responses are limited by soil moisture. A three-year study was conducted with urea (0, 30, 60, 90 and 120 kg $ha^{-1}$) and concentrated superphosphate (0, 20, 40 and 80 kg P $ha^{-1}$) for wheat grown on a heavy clay soil (vertic calcixeroll, 6 ppm P). Initially, all plots received fertilizers, while in the next two years fertilizer was applied to only half of each plot. In the first year, which had average rainfall (300 mm), there was no response to either N or P. Response to both elements in the second year was limited by drought (200 mm). In the third year, which had favorable rains (471 mm), there was a response to both applied and residual N, but not to P. However, soil P levels increased with increasing application rates. Residual N studies should consider the soil's mineralization potential, while residual P should be evaluated in P-deficient soils.

## INTRODUCTION

Since the beginning of the era of widespread chemical fertilizer use, attention has focused on the immediate or current year effects of fertilization on crop growth and on economic return from fertilizer use. However, with continued fertilizer use and increasing application rates, concern was widened to consider the residual or carry-over effect of fertilizer to the second and subsequent years. However, while both N and P fertilizers do have a residual effect, their behavior is distinct and merits separate consideration.

Because N fertilizers are readily converted to $NO_3$, which is mobile and can be rapidly taken up by growing plants, there is normally little carry-over of fertilizer N under conditions of high rainfall. However, in arid regions, $NO_3$ remains in the profile if not taken up by plants. After a year where yields were low due to drought, considerable amounts of $NO_3$ were available (Jackson et al., 1983). Depending on conditions of mineralization, organic matter may contribute to the pool of soil $NO_3$. The residual effect of fertilizer N may be marked by contributions from leguminous crops (Keeney, 1982) and from previous soil addition of crop residues (Power, 1981). While the residual influence of N fertilizers can be detected by use of $N^{15}$ in dryland agriculture (Abdelmonem et al., 1987), the effect can more easily be measured where a cereal crop has been used and where crop residue addition is not a variable factor.

Under conditions similar to those in the dryland wheat growing area of Morocco, studies reported by Jackson et al. (1983) showed that residual $NO_3$ accumulated to a depth of 120 to 180 cm following modest N applications of 34 to 67 kg N $ha^{-1}$. Under re-crop conditions with wheat, 35 kg N $ha^{-1}$ was considered a common level of carry-over N. In other studies, considerable build-up of $NO_3$ was shown in the Southern Great Plains (Tucker, 1977) and in wheat producing areas of Oregon (Jackson et al., 1983). The levels of soil $NO_3$ dictate the response to N fertilizer as exemplified by data of Olson et al. (1976); when $NO_3$ levels were less than 45 kg $ha^{-1}$, wheat yield increased sharply with fertilizer N up to 67 kg $ha^{-1}$. However, where residual $NO_3$ was greater than 135 kg $ha^{-1}$, grain yield was decreased by fertilizer N addition.

Fertilizer P undergoes complex reactions with inorganic soil constituents which greatly reduce solubility and P fertilizer efficiency. Initial reactions are followed by slower ones, all of which reduce availability of P fertilizer residues (Barrow, 1980). However, with repeated use of P fertilizers, numerous studies have shown that response decreases while $NaHCO_3$-P levels tend to increase (Halvorson and Black, 1985). The latter study showed that P fertilization may persist for several crop years in dryland conditions, but adequate N was necessary to make effective use of the residual P. Indeed, Tucker (1977) observed marked build-up of both P and N, a condition where fertilization could be omitted, at least temporarily. Alessi and Power (1980) showed that residual P could accumulate from both broadcast and banded P with respect to winter wheat yield.

Despite less intensive use of P fertilizers in the Middle East - North Africa region, the issue of residual P in soils has been addressed. In Lebanon, laboratory studies (Ryan et al., 1985) showed that P reactions and residual P were largely related to soil type. In field trials, Ryan et al. (1980) showed that P accumulates in the top 5 cm with continued P use, thus reducing or eliminating the need for fertilizer P in the current year. In Syria, a significant response to residual P for barley was obtained at two drier sites, but not at the wetter sites, indicating the significance of soil moisture for P response (ICARDA, 1982). In Cyprus, Orphanos (1987) incorporated a comparison of a residual P in a long-term fertilizer trial with barley. Therefore, in view of the importance of residual N and P and the diversity of soil types and cropping systems in the dryland wheat growing area of Morocco, a three-year study was initiated to examine the carry-over effect of both N and P in an agriculturally important soil type in the region.

## MATERIALS AND METHODS

Both experiments, which were conducted simultaneously for three years, were established at the Sidi El Aydi experimental station in the Berechid plain about 10 km from Settat. The soil at both locations was similar. The soil was classified as a Vertic Calcixeroll; the respective values for clay, $CaCO_3$, pH and organic matter were 38, 17.8, 8.1, and 1.9 %. Exchangeable K was high at 341 mg $kg^{-1}$. At the site of the N study, the previous crop was fallow and the levels of $NO_3$ and $NaHCO_3$-P at the beginning of the study were 6.8 and 6.3 ppm, respectively. At the P site the previous crop was also fallow, with the respective values for $NO_3$ and P similar to those of the N site.

The experiment was designed and established at adjacent sites in 1985 for three years with continuous wheat, variety Nesma, each year. For the N study, the rates of application were 0, 30, 60, 90 and 120 kg $ha^{-1}$ each year with four replications. For the P study, the P application rates were 0, 20, 40 and 80 kg $ha^{-1}$. In this case, a blanket dressing of 60 kg N was applied each year. Thus, the N study involved five treatments with four replications in a randomized complete block design. The P study had four treatments with four replications in a Latin Square design. However, the treatment schedule for both experiments was the same.

Individual plots were 3.6 m wide by 10 m long, with 12 rows of wheat 30 cm apart. In 1985 all plots received the appropriate rates of either N as urea or $P_2O_5$ as concentrated superphosphate. However, in 1986 the plots were split with one half (1.8 m x 10 m) receiving the usual rate of either N or P and the other receiving no fertilizer. In 1987, fertilizer was again applied to the first half-plot and none to the second half. Therefore, in essence, the residual effect of one application in 1985 was being compared with yearly applications of N and $P_2O_5$.

Cultural practices for both locations each year were essentially similar. In the fall, the land was plowed with a moldboard plow, fertilizer was broadcast by hand and incorporated by an offset disc called a "covercrop". Wheat was drilled at 70 kg seed $ha^{-1}$ with Furidan at 1.12 kg a.i.

$ha^{-1}$ to control Hessian fly, a devastating endemic pest of wheat in the dryland area of Morocco. As weeds can also decimate a wheat crop in dryland areas, the plants were sprayed with Certrol-H at 4 l $ha^{-1}$ at the 4-leaf stage. Where septoria appeared to be a problem, the plants were sprayed with "Tilt" at 0.25 kg $ha^{-1}$.

The plots were designed to be sampled at anthesis (2 x 1 m length in central rows) for N and P uptake, while total dry matter and grain yield were recorded at harvest (2 x 5 m rows from central rows). However, only dry matter and grain yield were recorded the first year, and N uptake in addition to dry matter and grain yield were recorded for the other years. As no consistent differences due to treatment were apparent for tissue P concentrations, uptake data for P were not considered. All data were analyzed statistically using analysis of variance. At the end of each growing season, the plots were sampled for $NO_3$ and $NaHCO_3$-P.

## RESULTS

As both residual studies of N and P were conducted separately, it is appropriate to deal with each individually.

### Residual P

Grain yield data for the three years are shown in Table 1. This shows the response to P fertilization in 1985 and the residual effect of that addition in 1986 and 1987, together with accumulated current year treatment in 1986 and 1987. In the initial year of the study, Soltanpour et al. (1986) reported that addition of P had no effect on grain

Table 1. Grain yield of wheat with P fertilization.

| P kg $ha^{-1}$ | 1986 Residual | 1986 Cumulative | 1987 Residual | 1987 Cumulative |
|---|---|---|---|---|
| | Grain Yield qx $ha^{-1}$ | | | |
| 0 | 4.5 | 4.5 | 17.9 | 20.3 |
| 20 | 4.3 | 5.0 | 18.2 | 21.7 |
| 40 | 4.8 | 5.1 | 19.6 | 18.5 |
| 80 | 4.4 | 6.4 | 19.6 | 22.5 |
| LSD (5%) | 1.5 | | 5.0 | |

yield. In the second year, which was characterized by extremely low yields due to drought (200 mm), there was no residual response to P nor to currently added P except at the highest rate, i.e., 80 kg P $ha^{-1}$. In 1987, which was a most favorable year there was no response to residual or cumulatively added P.

Dry matter yield data are reported in Table 2. While Soltanpour et al. (1986) did not refer to dry matter yield data for the 1985 season, it is reasonable to assume that there was no response to P in terms of dry matter, since grain yield was not affected by P addition. There was no significant response to residual or currently added cumulative P, neither during the second nor the third year. However, there was a tendency for the two highest rates, i.e., 40 and 80 kg P, to be consistently higher than the control.

Despite the absence of a response in terms of dry matter and grain yield to applied P, fertilization did influence P availability in the soil as measured by $NaHCO_3$ extraction. Data for the three years at depths of 0 to 10 cm and 0 to 20 cm are shown in Fig. 1. In the first year, increasing P application rates consistently increased available P in the top 10 cm, but had virtually no effect on the 0 to 20 cm sample. Soil P values increased with each year as yearly additions of P were made. For the second and third years, P fertilization enriched the 0 to 20 cm zone, but to a lesser extent than the 0 to 10 cm zone.

It is of interest to consider changes in soil P from P additions in 1985, (Fig. 2). After harvest that year, as the P rate increased (0, 20, 40 and 80 kg $ha^{-1}$), the respective P values in the top 0 to 10 cm layer were 7.5, 10.0, 17.6, and 21.9 ppm. With succeeding years, soil P test levels

Table 2. Dry matter yield of wheat with P fertilization.

| P kg $ha^{-1}$ | 1986 Residual | 1986 Cumulative | 1987 Residual | 1987 Cumulative |
|---|---|---|---|---|
| | Dry Matter Yield | | | |
| | qx $ha^{-1}$ | | | |
| 0 | 13.7 | 15.0 | 49.1 | 52.1 |
| 20 | 13.2 | 14.7 | 50.9 | 50.0 |
| 40 | 14.0 | 15.5 | 51.0 | 54.4 |
| 80 | 14.3 | 16.1 | 54.8 | 59.1 |
| LSD 5% | 2.5 | | 9.4 | |

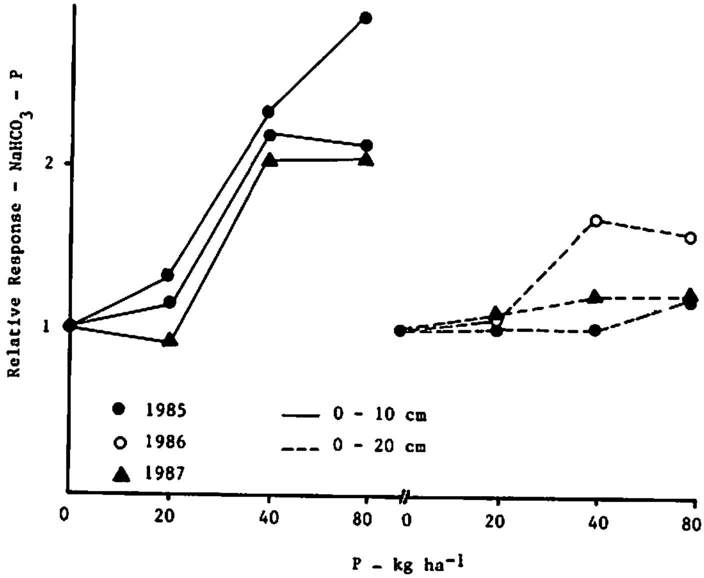



Fig. 1. Relative change in extractable P in surface soil layers with yearly P addition.

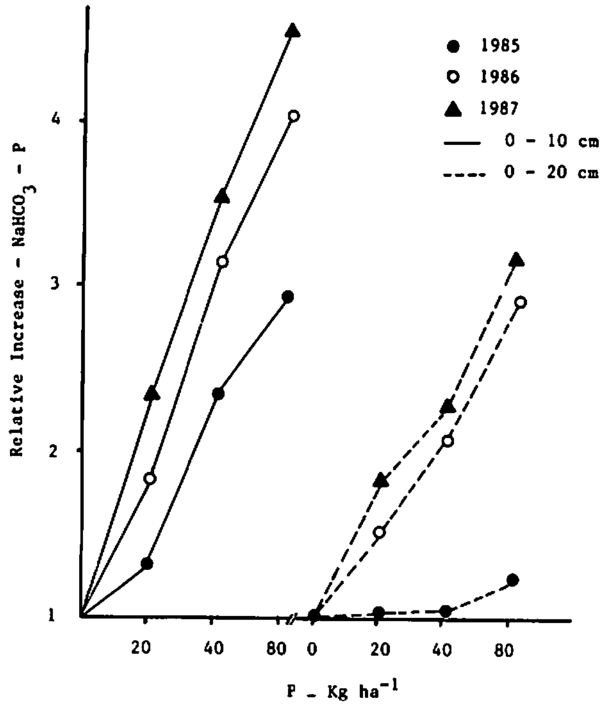



Fig. 2. Relative change in extractable P in surface soil layers following P fertilization in 1985.

decreased; however, after the third year, the residual value of 40 and 80 kg $ha^{-1}$ was over twice that of the control. Such a consistent decreasing trend with time was not readily apparent by test values from the 0 to 20 cm layer. While the lower P rate, i.e., 20 kg P had no effect on P values, the changes in the two higher rates with time were inconsistent; the second year's data tended to be higher than the third, though the magnitude of the effect was small.

**Residual N**

Grain yield data for the residual N study are presented in Table 3. Though yield data for 1985 are not shown, Soltanpour and El Gharous (1986) reported that there was no significant response to applied N during the first year of the study, i.e., 1985. Neither residual nor currently applied N had a significant effect in the second growing season, i.e., 1986. However, it must be borne in mind that yields were extremely low that year, being limited by a severe drought in which the annual rainfall was only 200 mm. In the third season, yields from the residual N, applied in 1985, were higher than the control, but were only significant at the 120 kg $ha^{-1}$ rate of application. In that same year, the 60, 80, and 120 kg $ha^{-1}$ rates of currently applied cumulative N were significant. However, the highest rates from the cumulative and residual N were not significantly different from each other.

Dry matter yield response to residual and currently applied cumulative N (Table 4) followed a similar pattern to that of grain yield. For reasons given in the previous paragraph, dry matter yield data are not presented.

Table 3. Grain yield of wheat with N fertilization.

| N | 1986 | | 1987 | |
|---|---|---|---|---|
| kg $ha^{-1}$ | Residual | Cumulative | Residual | Cumulative |
| | Grain Yield (qx $ha^{-1}$) | | | |
| 0 | 3.5 | 3.4 | 7.9 | 7.9 |
| 30 | 3.1 | 3.7 | 8.1 | 9.7 |
| 60 | 3.3 | 3.4 | 9.9 | 17.7 |
| 90 | 3.7 | 2.9 | 8.7 | 14.3 |
| 120 | 3.3 | 2.4 | 11.6 | 12.8 |
| LSD (5%) | 1.1 | | 3.6 | |

Table 4. Dry matter yield of wheat with N fertilization.

| N kg $ha^{-1}$ | 1986 Residual | 1986 Cumulative | 1987 Residual | 1987 Cumulative |
|---|---|---|---|---|
| | Dry Matter qx $ha^{-1}$ | | | |
| 0 | 11.8 | 11.8 | 17.7 | 17.7 |
| 30 | 12.2 | 13.2 | 19.3 | 26.6 |
| 60 | 11.6 | 13.7 | 21.8 | 40.0 |
| 90 | 12.5 | 12.8 | 22.9 | 43.6 |
| 120 | 13.0 | 11.9 | 29.9 | 38.0 |
| LSD (5%) | 2.7 | | 9.0 | |

However, it is reasonable to conclude from the lack of response of grain to applied N that dry matter yield similarly would not be influenced. Data for 1986, a year in which growth was severely limited by drought, reflected no significant or consistent response to N application rates. In contrast, there was a significant effect of residual N at the 120 kg $ha^{-1}$ rate in 1987, while all currently added and cumulative N rates significantly increased dry matter yield in comparison with the control; however, there was no further significant increase beyond the 60 kg $ha^{-1}$ rate.

Residual and cumulative N uptake data are presented in Table 5. As no N analysis was done for the plant tissue in 1985, uptake data could not be calculated. However, as there was no significant increase in grain or dry matter yield that year, it is reasonable to assume that uptake would have increased as the rate of application increased. In the second season there was slightly significant effect of residual N, i.e., 90 and 120 kg $ha^{-1}$ rates, while the 60, 90 and 120 kg/ $ha^{-1}$ rate of currently applied N were higher than the control. Responses to currently applied N were generally higher than residual N, but differences generally were not significant. In the 1987 season, residual N produced yields higher than the control, but was erratic; only the highest rate was significant. In contrast, currently applied and cumulative N produced a significant increase with each increment of added N up to the highest rate.

## DISCUSSION

Interest in residual value of fertilizers stems from economic considerations, i.e., reduced application costs and from changes in tillage systems, i.e., from conventional to

Table 5. Nitrogen uptake of wheat with N fertilization.

| N kg $ha^{-1}$ | 1986 Residual | 1986 Cumulative | 1987 Residual | 1987 Cumulative |
|---|---|---|---|---|
| | Nitrogen Uptake qx $ha^{-1}$ | | | |
| 0 | 22.5 | 22.5 | 17.3 | 17.3 |
| 30 | 23.3 | 22.0 | 19.5 | 22.1 |
| 60 | 20.8 | 27.2 | 23.8 | 36.0 |
| 90 | 25.5 | 30.9 | 21.3 | 53.6 |
| 120 | 25.2 | 27.0 | 28.4 | 60.4 |
| LSD (5%) | 2.7 | | 9.0 | |

minimum or reduced cultivation. Though single applications of P may sustain crops for several years (Halvorson and Black, 1985), the amount applied, the soil type and the cropping system are factors that determine the longevity of fertilizer residues in soil. Minimum tillage is not practiced in Morocco, and is only in the conceptual stage. However, P fertilizer is expensive and, where used, sparse amounts are applied. Having a residual benefit the following year, especially if drought devastates the crop during the year of application, would add to the economic argument for using N or P fertilizers and reduce the investment risk involved.

The study attempted to answer this question about fertilizer use on a major soil type in the region. However, though conducted over a three year period, Barrow's (1980) criteria for evaluating residual P, i.e., a measurable response, did not fully apply to the study. With a level of 6.3 ppm in the soil prior to P addition, a growth and yield response could reasonably have been expected. Indeed, Halvorson and Black's (1985) long-term study on a soil with a similar P level gave a consistent yield increase with increasing P application rate. However, our study was initiated at a time when a soil test calibration study was established to identify a critical available soil P level. That three-year study (Abdelmonem et al., 1988) indicated that no response would be likely with P values above 6 ppm. The experiment had another limitation; deep clay soils such as the one at the experimental site apparently can supply adequate P to crops even at relatively low levels of available P (Le Mare, 1982).

Nevertheless, this residual effect of P did affect levels of $NaHCO_3$-P in the soil. Repeated yearly P addition further raised this level. Though residual P gradually declines in availability with time (Hooker et al., 1980, Ryan et al., 1985), there was relatively little difference between extractable P values with the year of application, 1985, and in subsequent years, allowing for some decrease due to crop removal over that period. This would suggest that this particular soil had a slow immobilization rate. It again emphasized the importance of soil properties, and therefore soil type, on aspects such as response, and evaluation of banding vs. broadcasting, and residual P.

The study of residual N was beset by similar limitations as those for residual P in as much as the response in terms of dry matter and grain yield varied from none in the first and second years to a significant but inconsistent response in the third year. Though initial $NO_3$ levels were marginal - 6.8 ppm, one would expect a response based on data of Olson et al. (1976) who related crop response to soil $NO_3$. As soil $NO_3$ is mobile and dependent on soil moisture regime, and fluctuates with biological processes of mobilization-immobilization, etc., its use as a guide for N fertilization will never be as reliable as the $NaHCO_3$ test for P. However, subsequent guidelines (Soltanpour et al., 1987; Pala and Matar, 1987; Matar et al., 1987) would indicate that this critical $NO_3$ level may have been adequate.

The lack of a response the first year was attributed by Soltanpour and El Gharous (1986) to fallow with weeds which may have included forage legumes. This lack of response raises the question of the soil's mineralization potential or its capacity to release N over the longer term to the growing crop. The relatively high organic matter content of 1.9% would suggest a reservoir of organic N available for mineralization. As the diverse soil types in the dryland region of Morocco vary widely in organic matter, future studies involving residual N should focus on representative soil groups showing a range of organic matter contents and therefore mineralization potentials.

## REFERENCES

Abdelmonem, M., K. Harmsen, W.L. Lindsay, and P.G. Vlek. 1987. Fate of nitrogen-tagged urea applied to wheat in the arid Mediterranean region. p. 103-110. In A. Matar et al. (ed.). Proc. Second Soil Test Calibration Workshop, Ankara, Turkey, Sept 1-6, ICARDA, Aleppo, Syria.

Abdelmonem, M., A. Azzaoui, M. El Gharous, J. Ryan, and P.N. Soltanpour. 1988. Response of dryland wheat to nitrogen and phosphorus in some Moroccan soils. In J. Ryan and A. Matar (ed.). Proc. Third Soil Test Calibration Workshop. Amman, Jordan, Sept. 2-9. ICARDA, Aleppo, Syria.

Alessi, J., and J.F. Power. 1980. Effects of banded and residual fertilizer phosphorus on dryland spring wheat yield in the northern plains. Soil Sci. Soc. Am. J. 44:792-796.

Barrow, N.J. 1980. Evaluation and utilization of residual phosphorus in soils. p. 333-355. In F.E. Khasawneh, E.C. Sample, and E.J. Kamprath (ed.). The role of phosphorus in agriculture. Am. Soc. Agron. Madison, Wisc.

Halvorson, A.D., and A.L. Black. 1985. Long-term dryland crop responses to residual phosphorus fertilizer. Soil Sci. Soc. Am. J. 49:924-933.

Hooker, M.L., G.A. Peterson, D.H. Sander, and L.A. Daigger. 1980. Phosphate fractions in calcareous soils as altered by time and amounts of added phosphate. Soil Sci. Soc. Am. J. 44:269-277.

ICARDA. 1982. Farming system program. p. 3-57. ICARDA Annual Report. ICARDA, Aleppo, Syria.

Jackson, T.L., A.D. Halvorson, and B.B. Tucker. 1983. Soil fertility in dryland agriculture. p. 299-326. In H.E. Dregne and W.O. Willis (ed.). Dryland agriculture, Agron. 23. Am. Soc. Agron. Madison, Wisc.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. p. 605-607. In F.J. Stevenson (ed.). Nitrogen in agricultural soils. Am. Soc. Agron., Madison, Wisc.

Le Mare, P.H. 1982. Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Columbia and Brazil, and comparisons with soils of southern Nigeria. Soil Sci. 33:691-707.

Matar, A., E. Jabbour, and K. El Hajj. 1987. Prediction of barley response to fertilizers by means of soil nitrogen and phosphorus tests. p. 12-22. In A. Matar et al. (ed.). Proc. Second Soil Test Calibration Workshop. Ankara, Turkey. Sept. 1-6. ICARDA, Aleppo, Syria.

Olson, R.A., K.D. Frank, E.J. Deiber, A.F. Dreier, D.H. Sander, and V.A. Johnson. 1976. Impact of residual mineral N in soil on grain yields of winter wheat and corn. Agron. J. 68, 769-772.

Orphanos, P.I. 1987. Direct and residual effect of fertilizer phosphorus on barley in Cyprus. p. 44-49. In A. Matar et al. (ed.). Proc. Second Soil Test Calibration Workshop. Ankara, Turkey. Sept. 1-6. ICARDA, Aleppo, Syria.

Pala, M., and A. Matar. 1987. Soil test calibration with N and P for wheat under dryland conditions in Syria. In A. Matar et al. (ed.). Proc. Second Soil Test Calibration Workshop. Ankara, Turkey. Sept. 1-6. ICARDA, Aleppo, Syria. p. 55-66.

Power, J.F. 1981. Nitrogen in the cultivated ecosystem. p. 529-546. In F.E. Clark and T. Rasswall (ed.). Terrestrial nitrogen cycles: processes, ecosystem strategies and managements. Ecol. Bull. Stockholm, Sweden.

Ryan J., G. Musharrafeh and A. Barsumian. 1980. Soil fertility characterization at the Agricultural Research and Education Center of the Amer. Univ. Beirut. Fac. Agric. and Food Sci. Publ. No 64. Beirut, Lebanon.

Ryan, J., H. M. Hassan, M. Baasiri, and H.S. Tabbara. 1985. Availability and transformation of applied phosphorus in calcareous Lebanese soils. Soil Sci. Soc. Am. J. 49:1215-1220.

Soltanpour, P.N., and M. El Gharous. 1986. Residual effect of urea on wheat. p. 108. Annual Report, 1985-86. Aridoculture Center, Settat, Morocco.

Soltanpour, P.N., A. Azzaoui, and M. El Gharous. 1986. Residual effect of concentrated superphosphate on wheat. p. 97. Annual Report. Aridoculture Center, Settat, Morocco.

Soltanpour, P.N., A. Azzaoui, M. El Gharous, and M. Abdel Monem. 1987. Nitrogen and phosphorus soil test calibration studies in the Chaouia region of Morocco. p. 67-81. In A. Matar et al. (ed.). Proc. Second Soil Test Calibration Workshop. Ankara, Turkey, Sept. 1-6. ICARDA, Aleppo, Syria.

Tucker, B.B. (ed.). 1977. Oklahoma soil fertility handbook. Coop. Ext. Serv. Oklahoma State Univ., and Oklahoma Plant Food Educ. Soc., Inc. Stillwater, Ok.

# NITROGEN FORMS IN CALCAREOUS SOILS AND THEIR CORRELATION TO NITROGEN-INDICES OF WHEAT

**F.C. Aziz, B. I. Mohammad, and H. M. Salih**

Dept. of Soil and Land Reclamation,
Scientific Research Council,
Baghdad, P.O. Box 2416, Iraq

## ABSTRACT

Changes that occur in N forms were monitored after urea application at a recommended rate on eight different calcareous soils cropped to wheat. Measurements taken were: total N, inorganic N, $NO_3$-N, mineralized N and non-exchangeable $NH_4$ in relation to N-indices of wheat plant, namely; dry matter yield, N uptake and % N in grain. The results showed that the range of inorganic N losses (one month after planting) over all the soils was from 22.0 - 65.0% of the N applied. The estimation of soil mineralized N (2 weeks incubation) gave higher correlation coefficients with N indices than other N forms. However, the relationships were improved by adding $NO_3$-N fraction to mineralized N. The contribution of non-exchangeable $NH_4$ to plant N requirement varied, and ranged from 2.6 to 21.9 mg $kg^{-1}$ soil. The results also indicate that the different forms of N in the native soils gave the best correlation with N indices.

## INTRODUCTION

Arid and semi-arid regions need to be exploited to the fullest extent in crop production. This may be achieved through a better understanding of the various components of such ecosystems and their interactions (Vlek et al., 1981). Nitrogen is an important input in these ecosystems. Various soil N forms play a significant role in the chemical and microbiological processes responsible for the various reversible and irreversible N transformation in soils (Selim and Iskandar, 1981). The nature of the N transformation processes is complex and requires an understanding of the various reactions associated with specific N forms. In the soils of humid regions, if the variability in soil N availability is not taken into account, most N fertilizer recommendations would be inaccurate. However, in dry areas, where leaching and denitrification are likely to be minimal, balance data for N availability are more reliable (Broadbent, 1981).

The prediction of N availability in Iraqi soils using soil tests appears to have some promise. El-Aggory et al. (1980) concluded that initial $NO_3$ may be useful in predicting N fertilizer in soil with low organic matter. Aziz et al. (1986) found a significant correlation between N uptake by wheat and soil inorganic N when they used different N fertilizer sources. In 12 Iraqi soils, mineralizable N during the growing season of wheat was well correlated with N uptake (Aziz et al., 1988). In a recent investigation, Berigari et al. (1987) found a considerable amount of non-exchangeable $NH_4$ in six soils representing most of the soils in Iraq. The question of non-exchangeable $NH_4$ contribution to plant uptake under local conditions needs to be answered.

The objectives of this investigation was to follow up the change occurring in some N forms in soils after urea applications at successive periods of plant growth, and to evaluate various N forms as an N index by correlating soil N tests with yield and N uptake of wheat grown in a greenhouse on eight calcareous soils of widely varying properties.

## MATERIALS AND METHODS

Soil samples from the ploughing layer of selected locations representing the major soils under cultivation in Iraq were collected, air-dried, and passed through a 2-mm sieve. Nine kilograms of each were packed uniformly in Mitscherlich pots. Some of the relevant chemical and physical properties of these soils were determined (Table 1) following the common methods (Page, 1982). The soils belong to three great groups; Calciorthids, Xerorthents and Torrifluvents. All soils were calcareous, low in organic matter, and varied in N content. Total and inorganic N in these soils ranged from 0.021 to 0.145%, and from 9.2 to 69.0 ppm, respectively. The dominant form of available N in all soils was $NO_3$-N. These soils contain relatively large quantities of non-exchangeable $NH_4$. Barigari et al. (1987) reported comparable quantities of non-exchangeable $NH_4$ in several other calcareous soils of Iraq.

A basal application involved 36 mg N as urea, 18 mg P as triple superphosphate and 7 mg K as potassium sulfate for each kg soil and mixed with soil from the upper 5 cm of the soil profile. Each treatment was replicated thrice. Ten seeds of Maxipak wheat (Triticum aestivum L.) were sown in each pot. Soil moisture was kept at half of the saturation percentage by weighing. After seed emergence, the seedlings were thinned to eight per pot. Soil samples along the soil column were taken during the growing season at three times by a Hoffer auger of 2 cm diameter. Sample holes were filled with the same native soil.

Table 1. Physical and chemical properties of major soils in Iraq.

| Soil N° | Location | Great Group | Clay | Texture | E.C. | $CaCO_3$ | O.M. | Total N | Inorganic N | $NO_3$-N | Non-exchangeable $NH_4$ | Mineralized N | C/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % | | $dSm^{-1}$ | % | % | % | mg/kg | mg/kg | mg/kg | mg/kg | |
| 1 | Aski-kalak | Calciorthid | 41.6 | SiC | 0.19 | 37.5 | 0.51 | 0.084 | 17.6 | 14.0 | 151 | 15.8 | 6.1 |
| 2 | Hammam Al-Alil | Xerorthent | 9.9 | SL | 0.21 | 16.0 | 0.47 | 0.054 | 9.2 | 7.5 | 161 | 17.4 | 8.7 |
| 3 | Akra | Calciorthid | 22.9 | L | 0.23 | 22.2 | 1.49 | 0.145 | 15.6 | 10.6 | 206 | 30.9 | 10.3 |
| 4 | Alton Kopri | Calciorthid | 29.9 | SiCL | 0.69 | 24.0 | 0.77 | 0.103 | 69.0 | 62.7 | 193 | 43.4 | 7.5 |
| 5 | Abi Ghraib | Torrifluvent | 28.9 | SiCL | 1.49 | 23.4 | 0.64 | 0.059 | 30.9 | 25.0 | 161 | 8.6 | 10.9 |
| 6 | Ishaki | Torrifluvent | 2.6 | SiL | 2.39 | 22.7 | 0.23 | 0.021 | 16.7 | 9.2 | 245 | 6.4 | 11.0 |
| 7 | Fudhailiyah | Torrifluvent | 35.5 | SiCL | 3.19 | 32.3 | 0.63 | 0.051 | 45.8 | 34.6 | 245 | 9.5 | 12.4 |
| 8 | Basrah | Torrifluvent | 32.5 | SiCL | 4.89 | 30.0 | 1.00 | 0.085 | 34.1 | 27.7 | 196 | 16.9 | 11.8 |

Inorganic N and $NO_3$ were determined by direct extraction of fresh sample with 100 ml 2N KCL followed by distillation (Bremner and Keeney, 1966). Mineralizable N was measured using short-term incubation. It involved determination of N produced when a 10 gm soil sample was mixed with 30 gm of 30-60 mesh quartz sand, moistened with 6 ml distilled water and incubated at 39 °C for 2 weeks. Non-exchangeable $NH_4$ was measured according to Silva and Bremner (1965). Total N was analyzed by micro-Kjeldahl digestion with sulfuric and salicylic acids. All soil analyses were carried out in duplicate.

Plant shoots were taken simultaneously with the soil samples for N analysis. At harvest, roots were separated from soil particles by flotation (Al-Khafaf et al., 1977) and oven-dried at 65 °C for 24 hr. Straw, roots and grain were weighed and ground separately and their N content determined by a modified micro-Kjeldahl digestion procedure using salicylic acid and sodium thiosulfate.

## RESULTS AND DISCUSSION

Mineralizable N from a short-term 2-week incubation ranged from 6.4 to 43.4 ppm. Since the change in total N during the growing season was expected to be small, it was not determined in subsequent soil samplings. Inorganic soil N as function of time is presented in Table 2. An average recommended N rate (36 ppm) was added to the native inorganic N and presented in first column of Table 2. It was noticed that the different soils had lost inorganic N during the two months from planting. However, inorganic N losses varied with different soils. One month after planting, inorganic N decreased significantly in all soils. Because of the limited root system at the beginning of growth, it was assumed that the differences in organic N after one month from N application resulted mainly from the different forms of N loss. Usually measurements of N loss are reported as a percentage of the applied N, but it seems more realistic to base it on added N plus initially N present in the soil.

Therefore, the supposed percentage losses in inorganic N one month after planting ranged from 22.8 to 65.0%. These results are in accordance with those of El-Shakweer et al. (1973), and could be explained throughout $NH_3$ volatilization and immobilization of $NH_4$ or $NO_3$-N, and to a lesser degree, leaching and denitrification (Vlek et al., 1981). The input of N mineralization in the beginning period has a limiting value. Two months after planting, inorganic N sharply

Table 2. Inorganic N as a function of time in the experimental soils.

| Soil Source | Inorganic N | | | | |
|---|---|---|---|---|---|
| | Native Applied | After one month | After two months | At harvest | Supposed N loss [1] |
| | mg/kg | | | | % |
| Aski-Kalak | 53.6 | 41.4 | 11.5 | 13.2 | 22.8 |
| Hammam Alil | 45.2 | 19.5 | 13.6 | 13.4 | 56.9 |
| Akra | 51.6 | 23.8 | 21.5 | 17.6 | 54.0 |
| Alton Kopri | 105.0 | 36.8 | 20.1 | 14.6 | 65.0 |
| Abu-Ghraib | 66.9 | 29.2 | 4.9 | 12.4 | 56.4 |
| Ishaki | 52.7 | 40.2 | 5.6 | 14.3 | 23.7 |
| Fudhailyiah | 76.8 | 41.3 | 20.0 | 27.8 | 46.2 |
| Basrah | 70.1 | 28.4 | 11.4 | 14.0 | 59.5 |

[1]one month after planting.

decreased in all the soils. This decrease was associated with increased plant nutrient absorption, as well as N losses. On the other hand, these inorganic N values are probably overestimated, and might be much less when the mineralizable N is taken into consideration. Thus, the estimation of N balance at this phase is probably erratic.

At harvest, the inorganic N values in different soils fluctuated in comparison with their values two months after planting. The increases in organic N in the Aski-Kalak, Abu-Ghraib, Ishaki, Fudhailyiah and Basrah soils at harvest were probably due to the remobilization of N assimilated biologically at N fertilizer application (Herbst et al., 1987) and/or the nature of their organic matter content.

The soil mineralizable N as a function of time at different soils is presented in Table 3. The Akra and Ishaki soils showed the highest and the lowest mineralizable N in their native soils, which may be attributed to the relatively higher and lower total N content, respectively (Aziz et al., 1988). Incubation of soil samples taken one month after planting resulted in different values of inorganic N, which ranged between -20 to +10 ppm. The minus values, however, might be explained by immobilization of inorganic N in these soils, which exceeded the quantity of N mineralized. It can also be noted that the soils that gave negative values of mineralizable N (sampled one month after

Table 3. Mineralizable N as a function of time.

| Soil Source | Mineralizable N | | | |
|---|---|---|---|---|
| | Native | After one month | After two months | Harvest |
| | mg $kg^{-1}$ | | | |
| Aski-Kalak | 15.8 | -8.5 | 11.4 | 13.0 |
| Hammam Al-Alil | 17.4 | 1.8 | 7.5 | 14.4 |
| Akra | 30.9 | 9.8 | 15.3 | 17.4 |
| Alton Kopri | 43.4 | 7.3 | 19.7 | 24.2 |
| Abu-Ghraib | 8.6 | -11.0 | 18.0 | 9.0 |
| Ishaki | 6.4 | -20.0 | 5.2 | 0.8 |
| Fudhailyiah | 9.8 | -20.3 | 3.0 | 10.4 |
| Basrah | 16.9 | -5.5 | 6.2 | 5.6 |

planting showed higher inorganic N values (Table 2) at harvest than two months after planting. This might be explained by mobilization of inorganic N in the later period. However, the quality of the organic matter and the grade of decomposition might be of direct effect on the variation of mineralization. Generally, mineralizable N in most soil samples was more at harvest than two months after planting. This was probably related to the nature of organic matter and/or to the raising of soil temperature at harvest time.

The changes in non-exchangeable $NH_4$ during the growing season are presented in Table 4. Generally, in all soils, there were gradual decreases in non-exchangeable $NH_4$ at different periods of the growing season. However, one soil (Hammam Al-Alil) showed an increase in the amount of non-exchangeable $NH_4$ one month after planting, which may be due to relatively high capacity of this soil to fix applied N (Berigari *et al.*, 1987). The low content of native inorganic N support such an assumption (Kowalenko and Cameron, 1978). However, the considerable loss in non-exchangeable $NH_4$ during the growing season suggested that non-exchangeable $NH_4$ has a contribution in supplying plants with part of their N requirement (Mengel and Scherer, 1981; Saha *et al.*, 1982; Baethgen and Alley, 1987). The decreases in non-exchangeable $NH_4$ were higher in the soils of low native inorganic N. This may be due to the ability of the plants to obtain part of their N requirements from non-exchangeable $NH_4$ when N was limiting.

These are consistent with the findings that the release of clay fixed $NH_4$ occurs when soluble and exchangeable $NH_4$ are depleted by the nitrification process and/or by the plant's uptake (Saha *et al.*, 1982). Two months after

**Table 4 : Non-exhangeable $NH_4$ as a function of time and the supposed contribution in the experimental soils.**

| Soil source | Mineralizable $NH_4$ | | | | |
|---|---|---|---|---|---|
| | Native | After one month | After two months | At harvest | Supposed contribution |
| | mg kg$^{-1}$ | | | | |
| Aski-Kalak | 150.5 | 146.1 | 129.5 | 128.6 | 21.9 |
| Hammam Al-Alil | 161.0 | 169.8 | 150.5 | 150.5 | 10.5 |
| Akra | 205.5 | 196.9 | 190.8 | 187.3 | 18.2 |
| Alton Kopri | 192.5 | 189.5 | 181.1 | 187.3 | 5.2 |
| Abu-Ghraib | 161.0 | 151.0 | 140.0 | 140.0 | 21.0 |
| Ishaki | 245.0 | 241.5 | 222.3 | 224.9 | 20.1 |
| Fudhailyiah | 245.0 | 238.9 | 224.9 | 242.4 | 2.6 |
| Basrah | 196.0 | 190.8 | 183.8 | 186.4 | 9.6 |

planting, all soils showed the highest decreases in non-exchangeable $NH_4$, consistent with increasing plant capability to absorb N. However, the native non-exchangeable $NH_4$ may not necessarily be the sole source of non-exchangeable $NH_4$ during the growing season. The other source could be the recently fixed $NH_4$ from added N and/or $NH_4$ produced through mineralization of native organic soil N (Saha et al., 1982; Berigari et al., 1987). It has been assumed that the difference between native non-exchangeable soil $NH_4$ and that at harvest was the contribution of non-exchangeable $NH_4$ to plant requirement. These values ranged from 2.6 to 21.6 ppm. However, these values are underestimated since they are not included, the non-exchangeable $NH_4$ that comes from N fertilizer and from N mineralization during the growing season.

It seems that calculating the contribution of non-exchangeable $NH_4$ to plant uptake by the difference between the higher non-exchangeable $NH_4$ and the lower one for each soil during the growing season is more reliable in the study. On the basis of the latter principle, the new calculated values of non-exchangeable $NH_4$ contribution to plant N requirement in different soils ranged from 11.4 to 22.7 ppm. Mengel and Scherer (1981) reported 40 ppm net loss in non-exchangeable $NH_4$ from 90 cm depth of the soil.

Data for total dry matter, grain yield and N uptake by grain or whole plant material are presented in Table 5. The

Table 5 . Yield and N uptake of wheat dry matter and grain.

| Soil Source | Total Dry Matter Yield | Grain Yield | Total N Uptake | Grain N Uptake |
|---|---|---|---|---|
| | -------- g/pot | --------- | ------- mg/pot | ------ |
| Aski-Kalak | 23.9 | 8.6 | 238.1 | 170.3 |
| Hammam Alil | 32.8 | 13.2 | 269.6 | 190.1 |
| Akra | 30.7 | 13.3 | 347.6 | 264.7 |
| Alton Kopri | 46.4 | 19.2 | 603.6 | 434.6 |
| Abu-Ghraib | 40.1 | 16.2 | 312.0 | 222.9 |
| Ishaki | 18.0 | 6.4 | 121.9 | 90.5 |
| Fudhailyiah | 18.3 | 7.8 | 231.1 | 173.0 |
| Basrah | 34.8 | 13.5 | 363.6 | 250.3 |

variation in dry matter, grain yield and their N content reflects variation in soil physico-chemical and, probably, biological properties. The grain yield in different soils ranged from 36 to 43% of total dry matter yield (shoot + root + grain), while grain N uptake ranged from 69 to 76% of total N uptake. The latter results are consistent with those reported on a balance study with labeled N. It is worth mentioning that the influence of different N forms on yield and N uptake varies in these different soils, and the soil with high N test does not necessarily give the highest yield, and vice versa. However, the correlation coefficients between the different N forms and wheat yield and its components should clarify this ambiguity.

The relationships between the different forms of native soil N and N indices, namely, grain yield, dry matter yield, grain N uptake and total N uptake are summarized in Table 6. Soil N forms were more correlated with total and grain N uptake than with grain and dry matter yields. However, the mineralized N and native $NO_3$-N showed the highest

Table 6. Correlation coefficients between native N forms and N indices for wheat.

| | Yield | | Uptake | |
|---|---|---|---|---|
| Index | Grain | Dry Matter | Grain N | Total |
| | "r" | | | |
| Total | 0.507 | 0.448 | 0.661 | 0.632 |
| Inorganic | 0.554 | 0.514 | 0.767* | 0.770* |
| Nitrate | 0.615 | 0.583 | 0.815** | 0.820** |
| Mineralized | 0.688* | 0.644 | 0.898** | 0.878** |
| Mineralized $NO_3$ | 0.443 | 0.394 | 0.722* | 0.693* |
| Fixed $NH_4$ | -0.485 | -0.513 | -0.342 | -0.286 |
| Inorganic N + Mineralized N | 0.684* | 0.638 | 0.926** | 0.919** |
| Nitrate + Mineralized N | 0.718* | 0.678 | 0.947** | 0.942** |
| Nitrate + Mineralized $NO_3$ | 0.639 | 0.582 | 0.914** | 0.905** |
| Mineralized $NO_3$ + Inorganic N | 0.610 | 0.558 | 0.854** | 0.887** |

*, ** Significant at 5% and 1%, respectively.

correlation coefficients with N uptake, which indicated the importance of mineralized N in supplying plants with part of their N requirements in the soils of semi-arid regions (Aziz et al., 1988). Inorganic N form also showed a significant correlation with yield and N uptake in contrast to total N and non-exchangeable $NH_4$.

Correlations of different combinations among the N forms (soil N test) in native soils, on one hand, and N indices of wheat on the other hand were calculated. Adding mineralized N or $NO_3$-N (native soil) to the initial inorganic N or $NO_3$-N improved the correlations. Such improvement was clear with the native $NO_3$-N form plus mineralized N. However, El Aggori et al. (1980) found that the N indices in some Iraqi soils were highly correlated with initial $NO_3$, but no significant improvement was obtained in these correlations by adding mineralized N. This could be attributed to the low efficiency of the incubation method they used (10 gm soil in a covered conical flask without quartz sand).

The sequence of the best correlation obtained between N indices and different N in the soils at successive periods of growing season is shown in Table 7. The different N forms in the samples taken from native soils gave the best correlation with N indices. Combining the native $NO_3$-N with mineralized N in the native soils improved the correlation with N indices. Combining the mineralized N in the samples taken two months after planting with native inorganic N also has a highly significant correlation, especially with grain and dry matter yields. This means that the availability of N for plant uptake two months after planting was of great importance to yield development.

This investigation has highlighted the importance of mineralizable N in calcareous soils of semi-arid regions. Soil sampling before planting gives a satisfactory indication of N status and consequently plant development during the growth season. The $NO_3$-N fraction in soils plus that expected to be mineralized during the growing season can be used to predict the yield and fertilizer recommendation. The results indicate also that the calcareous soils contained relatively large amounts of non-exchangeable $NH_4$. However, this non-exchangeable form can be partially utilized by plants, especially when there is limited N available to the plant. Application of this study in field experiments must be the next step.

Table 7. Correlation sequence between N indices and soil N forms.

| N Index | 1 | 2 | 3 |
|---|---|---|---|
| Grain Yield | Mineralized $NO_3$ | Inorganic N plus mineralized N after 2 months | Mineralized N after 2 months |
| | 0.904 | 0.787 | 0.786 |
| Dry Matter | Mineralized N | Mineralized $NO_3$ after 2 months | Inorganic N + Mineralized $NO_3$ after 2 months |
| | 0.897 | 0.779 | 0.709 |
| Grain N Uptake | Mineralized N+$NO_3$ | Mineralized N | Mineralized N + Inorganic N |
| | 0.912 | 0.906 | 0.882 |
| Total N Uptake | Mineralized N+$NO_3$ | Mineralized N + inorganic N | Mineralized $NO_3$-$NO_3$ |
| | 0.942 | 0.919 | 0.905 |

## REFERENCES


Al-Khafaf, S., P.J. Wierenga, and B.O. Williams. 1977. A flotation method for determining root mass in soil, Agron. J. 69.

Aziz, F. G., H. M. Salih, B. I. Mohammad, and A. M. Abdul-Raheem. 1986. Efficiency of urea added with different materials to soil in terms of inorganic N,N-recovery and wheat yield. Proc. 4th Soil Conf., SRC, Baghdad.

Aziz, F. C., H. M. Salih, and B. I. Mohammad. 1988. Nitrogen mineralization in some calcareous soils of Iraq. Biol. Fert. Soil. (submitted).

Baethgen, W. E., and M. M. Alley. 1987. Non-exchangeable ammonium nitrogen contribution to plant available nitrogen. Soil Sci. Soc. Am. J. 51:110-115.

Berigari, M. S., F. M. S. Al-any, M.A. Umran, and L. H. Ibrahim. 1987. Ammonium fixation in relation to characteristics of some entisols and aridisols of Iraq. J. Agric. Water Resources Res. 6 (3):65-81.

Bremner, J. M., and D. R. Keeney. 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soil : 3. Exchangeable ammonium, itrate, nitrite by extraction-distillation methods. Soil Sci. Soc. Am. Proc. 30:577-582.

Broadbent, F. E. 1981. Methodology for nitrogen transformation and balance in soil. Plant Soil 58:383-399.

El-Aggory, E., N. A. K. Hassan, T. Hussain, S. Askar, and E. Haban. 1980. Nitrogen availability in Iraqi soils. Agric. Res. Review 58:259-276.

El-Shakweer, M. H. A., A. S. Abdel-Ghaffar, and M. A. Barakat. 1973. Nitrogen balance studies for different Egyptian soils cropped with corn. Plant Soil, 39: 341-349.

Herbst, F., F. G. Aziz, J. Garz. 1987. Stickstoffumsetzungen im Boden nach Zugabe von $^{15}$N-markierter Guelle. Arch. Acker-Pflanzenbau-Bodenkd. Berlin 31, 160-165.

Keeney, D. R., and J. M. Bremner. 1969. Characterization of mineralizable nitrogen in soil. Soil Sci. Soc. Am. Proc. 30:714:718.

Kowalenko, C. G., and D. R. Cameron. 1978. Nitrogen transformation in soil plant system in three years of field experiments using tracer and non-tracer methods on an ammonium fixing soil. Can. J. Soil Sci. 58:195-208.

Mengel, K. H., and W. Scherer. 1981. Release of non-exchangeable (fixed) soil ammonium nitrogen under field condition during the growing season. Soil Sci. 131:226-232.

Page, A. L. 1982. Methods of soil analysis, Agon. 9. Part 2. Amer. Soc. Agron., Madison, Wisc.

Saha, D., R. Mukherjee, and K. Mukhopadhyah. 1982. Availability of fixed $NH_4$ to crops. 1. Native fixed form. Plant Soil 65:345-349.

Selim, H. M., and I. K. Iskandar. 1981. Modeling nitrogen transport and transformations in soils, 1. Theoretical consideration. Soil Sci. 131, (4) : 233-241.

Silva, J. A., J. M. Bremner. 1965. Nitrogen-Inorganic forms. In C. A. Black et al. (ed). Methods of soil analysis. Agron. 9, Part 2. Madison, Wisc. USA.

Vlek, P. L. G., I. R. P. Fillery, and J. R. Burford. 1981. Accession, transformation and loss of nitrogen in soils of the arid regions. Plant Soil 58:133-175.

# NITROGEN MINERALIZATION POTENTIAL OF SOME SEMI-ARID SOILS OF MOROCCO

**M. El Gharous, R.L. Westerman, and P.N. Soltanpour**

Aridoculture Center, Settat, Morocco

## ABSTRACT

The rate of N mineralization or mineral N supplied by soil as a function of time is often needed to predict N fertilizer requirements of crops. The objective of this study was to determine the ability of different soils in the Chaouia region of Morocco to mineralize organic N. Soil samples were incubated for 16 weeks under optimum moisture and temperature, and N mineralization (No) and rate constants (k) are determined for each soil. Soils of the region had $N_0$'s ranging from 120 to 240 $\mu g\ g^{-1}$ and k values ranging from 0.06 to 0.274 $week^{-1}$. The lowest average $N_0$ value for different soils was shown to occur in Palexerolls, which are shallow soils (35 cm) that have received very low N input. Despite differences in soil preparation, rate constants did not differ between the soils.

## INTRODUCTION

The intensification of agriculture in the arid and semi-arid regions of Morocco requires the use of N fertilizer or at least more efficient use of the N mineralized by the soil. Soltanpour et al. (1986) reported increases in grain yield in the region ranging from 14 to 190% due to N fertilizer application. The climate in the arid and semi-arid region of Morocco is characterized by winter rainfall with high soil moisture and low temperatures, but the distribution and occurrence of rain varies from year to year. Light rainfall that generally occurs after summer drought may lead to enhanced mineralization of organic N which increases soil mineral N content (Chiang et al., 1983). The nitrogen mineralization potential ($N_0$) is defined as the quantity of soil organic N that is susceptible to mineralization. In some instances, $N_0$ has been used successfully to predict amounts of N mineralized under field conditions (Smith et al., 1977). However, $N_0$ is affected by many complex factors such as moisture, aeration, temperature, nature and quantity of organic matter, nature and quantity of the previous crop residue, and other soil physical, chemical, and biotic properties.

The effect of moisture on N mineralization has been investigated by many researchers. Miller and Johnson (1964) reported the optimum moisture to vary from 0.015 to 0.05 MPa; it was also found to vary from 0.010 to 0.033 MPa by Stanford and Epstein (1974). However, Cassman and Munns (1980) found that moisture tension of 0.03 MPa gave the maximum mineralization rate. Similar results were found by others (Chiang et al., 1983; Myers et al., 1982). Soil N mineralization rate is affected profoundly by temperature within the range that is normally encountered under field conditions. Cassman and Munns (1980) reported the optimum temperature for N mineralization to be from 30 to 35 C. Using a temperature coefficient of approximately 2 "$Q_{10}$", Stanford et al. (1973) found a similar mineralization rate in different soils for each temperature studied in the 5 to 35°C range.

Nitrogen mineralization rate is also affected by the nature of the organic matter. Stanford (1968) reported the existence of two general pools of organic N. The first pool is relatively easily decomposable through microbial action. However, the second pool is somewhat resistant to further rapid decomposition, and contributes only a small proportion of N mineralization during a short-term incubation or even within a cropping season. The objective of this research was to determine the N mineralization potential ($N_O$) and rate constant (k) of different soil types of the Chaouia region of Morocco.

## MATERIALS AND METHODS

Fourteen soil types were selected for this study, which represented five of the six orders mapped in the Chaouia region of Morocco. Surface soil (0 to 20 or 30 cm) was sampled and air-dried without delay. Methods of analysis used were Kjeldahl for total N (Bremner, 1965), and Walkey and Black for organic carbon (Allison, 1965). The pH values were measured using a 1/1 (w/v) soil-water suspension ratio. The classification and certain chemical and physical characteristics of the 14 soils are shown in Table 1.

The N mineralization procedure followed the method used by Stanford and Smith (1972). Triplicate samples of 30 g of soil plus 5 g of vermiculite were mixed thoroughly. Soil samples were then transferred to 50-ml leaching tubes and moistened using a fine spray of distilled water. Soil was retained in 50-ml leaching tubes by means of a glass wool pad. The pad was placed over the soil to avoid dispersing the soil when solutions were poured into the tubes.

Table 1. Classification, chemical and physical properties of the soils at the Chaouia region of Morocco.

| No. | Soil Classification | pH | Organic Carbon | Total Nitrogen | $CaCO_3$ | Clay Content | CEC |
|---|---|---|---|---|---|---|---|
| | | | g $kg^{-1}$ | | | | Cmol(+) $kg^{-1}$ |
| 1. | Orthent-1 | 8.2 | 13.0 | 1.1 | 15 | 180 | 10.2 |
| 2. | Orthent-2 | 8.0 | 6.4 | 0.9 | 20 | 420 | 18.2 |
| 3. | Chromoxerert-1 | 8.0 | 13.0 | 1.0 | 30 | 510 | 42.0 |
| 4. | Chromoxerert-2 | 8.1 | 12.7 | 1.1 | 30 | 640 | 69.1 |
| 5. | Palexeroll-1 | 8.0 | 22.7 | 2.0 | 170 | 330 | 42.0 |
| 6. | Palexeroll-2 | 8.3 | 24.0 | 1.9 | 70 | 390 | 43.7 |
| 7. | Palexeroll-3 | 8.2 | 16.7 | 1.4 | 110 | 420 | 39.9 |
| 8. | Palexeroll-4 | 8.2 | 18.7 | 1.7 | 15 | 450 | 49.0 |
| 9. | Palexeroll-5 | 8.0 | 18.4 | 1.4 | 107 | 350 | 35.1 |
| 10. | Calcixeroll | 8.4 | 12.5 | 1.4 | 94 | 370 | 44.7 |
| 11. | Xeralf-1 | 7.1 | 11.1 | 1.2 | 0 | 340 | 28.5 |
| 12. | Xeralf-2 | 7.6 | 13.8 | 1.4 | 5 | 330 | 23.5 |
| 13. | Xeralf-3 | 7.3 | 16.6 | 1.1 | 3 | 160 | 18.0 |
| 14. | Xeralf-4 | 7.1 | 17.2 | 1.4 | 0 | 440 | 28.9 |

Mineral N initially present was removed by leaching with 100 ml of M $CaCl_2$ in 5 to 10 ml aliquots, followed by 25 ml of a nutrient solution of N (2.0 mM $CaSO_4$; 2.0 mM $MgSO_4$; 5.0 mM $Ca(H_2)_2.H_2O$; and 2.5 mM $K_2SO_4$). Excess water was removed under vacuum (0.02 MPa). The tubes were then incubated at 32 + 1°C. After two weeks, mineral N was recovered by leaching with 100 ml of 10 mM $CaCl_2$ and 25 ml of "minus-N" solution followed by applying suction as described above. Tubes were returned to the incubator for periods of 2, 4, 6, 8, 19, 12, 14 and 16 weeks cumulative, with intermittent extraction of mineral N. Optimal soil water content was maintained at about 0.02 MPa throughout the incubations. Twenty ml of the leachate was used to determine ammonium ($NH_4$-N) and nitrate ($NO_3$-N) using MgO and Devarda's alloy. Ammonium and nitrate were determined by acid titration using 0.10 M $H_2SO_4$ after distillation into boric acid.

## Calculations

Two models were used to describe the data of this study. The first one was proposed by Stanford and Smith (1972) :

$$N = N_O.(1 - \exp(-kt))$$

Where N is mineralized N in time t, and $N_O$ and k are the N mineralization potential and rate constant. This equation was applied to the data using the non-linear Least Squares fitting. The second model used was the one proposed by Juma et al. (1984) :

$$N = N_O./(T_C + t)$$

Where $T_C$ is the half time for mineralization and other terms are as described above. A Systat non-linear program was used to evaluate $N_O$ and k in soil (Wilkinson, 1986).

## RESULTS AND DISCUSSION

The time course of N mineralization obtained from the incubation experiment with intermittent leaching using the method of Stanford and Smith (1972) is shown in Fig. 1. All soils exhibited the same general trend of cumulative net N mineralization. The rate of mineralization for all soils was rapid at first and then declined with the length of incubation period. The lowest quantity of mineral N produced during the incubation period was observed in the Palexerolls. However, the highest quantity (191 $\mu g\ g^{-1}$) was produced by Xeralfs. Mineral N produced by all soils ranged from 120 to 241 $\mu g\ g^{-1}$ of soil.

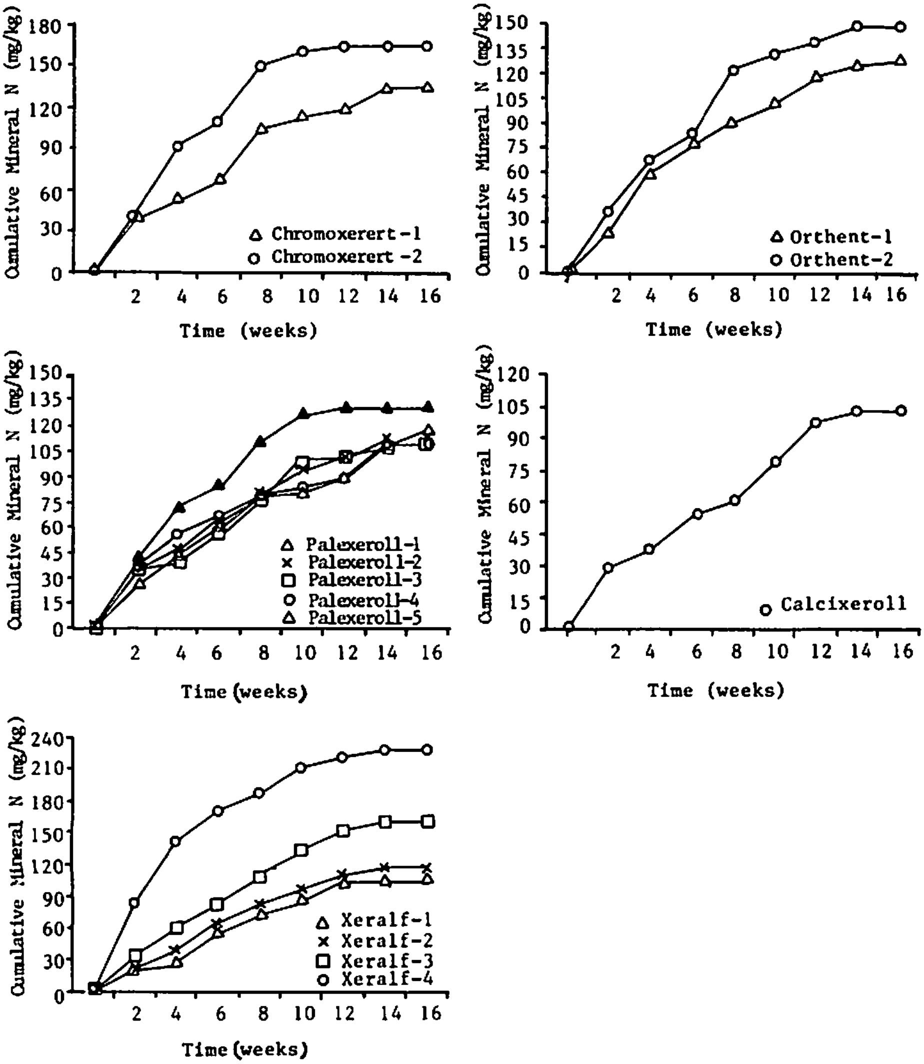



Fig. 1. The time course of N mineralization from incubation experiments with intermittent leaching.

## Nitrogen Mineralization Potential ($N_O$)

The N mineralization potential values ($N_O$) obtained by both models (Table 2) were within the range that Stanford and Smith (1972) reported in their study of 39 soils. Except for Palexeroll-3 and Xeralf-3, all soils had about the same $N_O$. The highest $N_O$ occurred in Xeralf-3, presumably because the soil sampled had not been cultivated for many years. However, the lowest $N_O$ observed in Palexeroll-3 was attributed to loss of topsoil by erosion. It is worth noting that Palexerolls, which have depths varying from 15 to 35 cm, have low $N_O$ compared to the others. These soils are also stony and hard to cultivate. Thus, they have a low production potential in spite of their high organic matter content.

## Rate constant (k)

The rate constant (k) values of the different soils (Table 2) estimated with the exponential model were considerably higher than those obtained by Stanford and Smith (1972) or Campbell et al. (1981). However, they generally agreed with those of Smith et al. (1980). The hyperbolic model rate constant (k) estimates were lower than the ones estimated by the exponential model. The means of the k values were found to be equal to 0.119 and 0.015, and 0.063 and 0.008 week$^{-1}$ for the exponential and the hyperbolic models, respectively. In general, the values obtained in this study from the exponential equation are in or above the upper limit of the range obtained by Juma et al. (1984) and in or below the lower limit of the range obtained by Beauchamp et al. (1986). However, those estimated with the hyperbolic equation are within the range of Stanford and Smith (1972).

Providing an overall mean of k might be ambiguous. However, a mean for each soil order shows that the K value is about the same in all great soil groups studied, except for the Calcixeroll, where it was low (0.07 week$^{-1}$). Excluding the uncultivated soil, the k values were also low for Xeralfs. The weeks of incubation required to mineralize 50% of $N_O$ were determined by both equations (Table 3). As a general observation, Tc determined by the hyperbolic model was about two times the values determined by the exponential model. The half-life did not show any consistent changes with soil types. But, generally, the exponential equation showed that 50% of $N_O$ in the soils studied occurred within 10 weeks, whereas 20 weeks were calculated to be required if the hyperbolic equation was used.

Table 2. Nitrogen mineralization potentials ($N_0$) and rate constant (k) of the soils at the Chaouia region of Morocco.

| Soil | Exponential Model | | | | Hyperbolic Model | | | |
|---|---|---|---|---|---|---|---|---|
| | $N_0$ | Std. Error | k | Std. Error | $N_0$ | Std. Error | k | Std. Error |
| | $\mu g\ g^{-1}$ | | $week^{-1}$ | | $\mu g\ g^{-1}$ | | $week^{-1}$ | |
| 1. | 157 | 6.8 | 0.109 | 0.009 | 235 | 18.2 | 0.054 | 0.008 |
| 2. | 178 | 35.1 | 0.123 | 0.086 | 262 | 23.2 | 0.063 | 0.005 |
| 3. | 174 | 6.6 | 0.100 | 0.007 | 264 | 25.6 | 0.09 | 0.008 |
| 4. | 184 | 5.5 | 0.168 | 0.013 | 255 | 14.6 | 0.095 | 0.013 |
| 5. | 145 | 4.0 | 0.164 | 0.012 | 199 | 9.7 | 0.099 | 0.012 |
| 6. | 144 | 4.8 | 0.127 | 0.009 | 208 | 11.1 | 0.068 | 0.007 |
| 7. | 120 | 6.7 | 0.139 | 0.017 | 164 | 10.3 | 0.083 | 0.010 |
| 8. | 169 | 15.4 | 0.073 | 0.010 | 266 | 8.7 | 0.034 | 0.006 |
| 9. | 145 | 11.7 | 0.095 | 0.014 | 223 | 22.4 | 0.046 | 0.009 |
| 10. | 164 | 12.5 | 0.068 | 0.008 | 266 | 40.8 | 0.030 | 0.006 |
| 11. | 184 | 17.8 | 0.060 | 0.008 | 317 | 62.4 | 0.024 | 0.007 |
| 12. | 165 | 9.1 | 0.082 | 0.007 | 266 | 23.1 | 0.037 | 0.009 |
| 13. | 241 | 14.4 | 0.076 | 0.007 | 391 | 31.9 | 0.035 | 0.008 |
| 14. | 172 | 1.7 | 0.274 | 0.004 | 210 | 3.5 | 0.212 | 0.016 |
| LSD (0.05) | 17 | | 0.019 | | 36 | | 0.014 | |

Table 3. Time required to mineralize half of $N_0$, and percent active N in Moroccan soils.

| Soil | Half Time | | | | Active N Fraction | |
|---|---|---|---|---|---|---|
| | Exponential | Std. Error | Hyperbolic | Std. Error | Exponential | Hyperbolic |
| | weeks | | | | % | |
| 1. | 6.39 | 0.58 | 12.85 | 1.84 | 14.23 | 21.38 |
| 2. | 5.70 | 0.62 | 11.13 | 1.91 | 19.75 | 29.15 |
| 3. | 6.94 | 0.90 | 14.21 | 2.43 | 17.39 | 26.41 |
| 4. | 4.13 | 0.34 | 7.28 | 0.97 | 16.77 | 23.22 |
| 5. | 4.13 | 0.29 | 7.03 | 0.82 | 7.26 | 9.93 |
| 6. | 5.46 | 0.39 | 10.25 | 1.11 | 7.57 | 10.92 |
| 7. | 5.06 | 0.65 | 8.45 | 1.08 | 8.54 | 11.72 |
| 8. | 9.62 | 1.30 | 20.62 | 1.13 | 9.93 | 15.67 |
| 9. | 7.23 | 0.98 | 15.02 | 2.59 | 10.36 | 15.91 |
| 10. | 10.40 | 1.80 | 23.04 | 5.29 | 11.74 | 19.00 |
| 11. | 11.64 | 3.66 | 28.41 | 7.90 | 15.29 | 26.31 |
| 12. | 8.69 | 0.93 | 18.97 | 2.72 | 11.80 | 19.03 |
| 13. | 8.92 | 1.29 | 20.76 | 2.61 | 21.87 | 35.52 |
| 14. | 2.53 | 0.18 | 3.28 | 0.19 | 12.27 | 14.97 |
| LSD (0.05) | 1.56 | | 4.39 | | 3.27 | 5.55 |

## The Active Fraction

The active fraction of total N ($N_0$/Nt) where Nt is total N content, was found to vary from 7 to 21% (Table 3). These values are of the same order as those reported in other countries (Stanford and Smith, 1972; Feingin et al., 1974; Herlihy, 1979; Campbell and Souster, 1982). Soils studied were divided into two groups according to their active N fraction: the first group with an active N fraction less than 10%, and the second group with an active N fraction ranging from 10 to 20%. A linear relationship between total N and the inverse of the active N fraction was found in this group of soils. The slope and the intercept were found to be equal to 0.725 and -0.015, respectively, with a coefficient of determination ($R^2$) of 0.90 (Fig. 2). This relationship was probably due in part to the previous management of the Palexerolls. These are shallow soils with the lowest active N fraction and the highest organic C levels and are fallowed in alternate years during which animals graze the weeds. These soils receive little or no fertilizer N during the cereal phase of the fallow-cereal rotation.

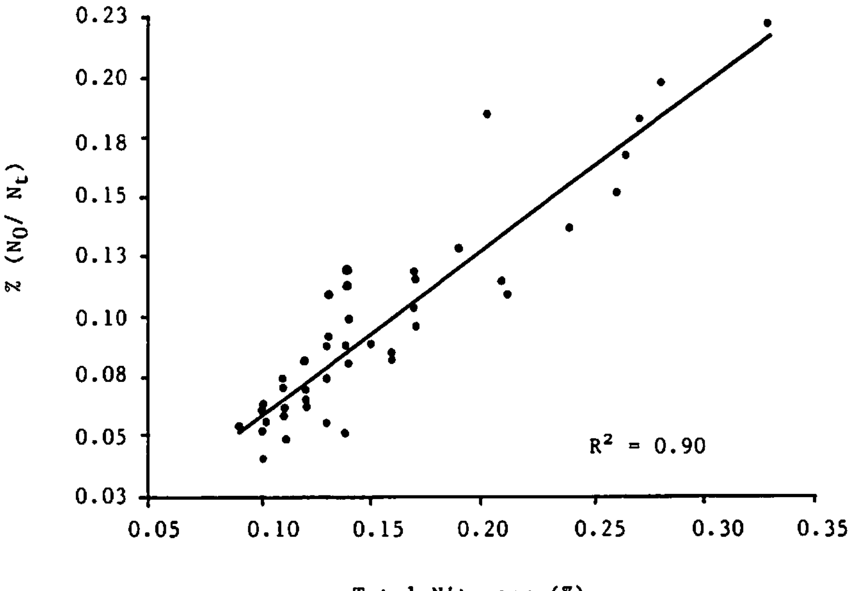



Fig. 2. Relationship between total N and the inverse of the active N fraction in Moroccan soils.

## Exponential vs. Hyperbolic Model

The parameters estimated by the hyperbolic model were always higher than those estimated by the exponential model, except for k, where the values were lower than the ones estimated by the exponential model. However, the parameters estimated by both equations were highly correlated. For instance, the correlation coefficient (r) for $N_0$ was 0.025 and that of k was 0.989. These high r values confirm the earlier findings that both models can be used successfully to estimate $N_0$ and k using a non-linear Least Square fitting technique (Juma et al., 1984).

## CONCLUSIONS

It was assumed that Palexerolls in the Chaouia region of Morocco had low $N_0$ values due to the management they had received as detected by their shallow depth (35 cm). However, other soils now showing the same $N_0$ can have different N mineralization potentials in the future if the farmers of the region change their practices and start applying enough N fertilizer to build their soil fertility levels. This study supported earlier findings that a single exponential model as well as a hyperbolic model can be used to estimate reliable $N_0$ and k values in soils if a non-linear Least Square fitting technique is used.

## REFERENCES

Allison, L. E. 1965. Organic carbon. p. 1367-1378. In C. A. Black et al. (eds.). Methods of soil analysis, Agron. 9, Part 2. Am. Soc. Agron., Madison, WI.

Beauchamp, E. G., W. D. Reynolds, D. Brasche-Villenneuve, and K. Kirby. 1986. Nitrogen mineralization kinetics with different soil pretreatments and cropping histories. Soil Sci. Soc. Am. J. 50:1478-1483.

Bremner, J. M. 1965. Total nitrogen. p. 1149-1176. In C. A. Black et al. (ed.). Methods of soil analysis, Agron. 9, Part 2. Am. Soc. Agron., Madison, WI.

Campbell, L. A., and W. Souster. 1982. Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-656.

Campbell, C. A., R. J. K. Myers, and K. L. Weier. 1981. Nitrogen mineralization potential, decomposition rates, and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-332.

Cassman, K. G., and D. N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44:1233-1237.

Chiang, C., B. Soudi, and A. Moreno. 1983. Soil nitrogen mineralization and nitrification under Moroccan conditions. p. 129-140. In Proc. 17th Coll. Int. Potash Institute, Bern, Switzerland.

Feingin, A., D. H. Kohl, G. Shearer, and B. Commoner. 1974. Variation in natural nitrogen-15 abundance in nitrate mineralized during incubation of several Illinois soils. Soil Sci. Soc. Am. Proc. 38:90-95.

Herlihy, M. 1979. Nitrogen mineralization in soils of varying texture, moisture, and organic matter. I. Potential and experimental values in fallow soils. Plant Soil. 53:255-267.

Juma, N. G., E. A. Paul, and B. Mary. 1984. Kinetic analysis of net nitrogen mineralization in soil. Soil Sci. Soc. Am. J. 48:753-757.

Miller, R. D., and D. D. Johnson. 1964. The effect of soil moisture tension on carbon dioxide evolution, nitrification, and nitrogen mineralization. Soil Sci. Soc. Am. Proc. 28:644-647.

Myers, R. J. K., C. A. Campbell, and K. L. Weier. 1982. Quantitative relationship between net nitrogen mineralization and moisture content of soils. Can. J. Soil Sci. 62:111-124.

Smith, S. J., R. R. Schanbel, B. L. McNeal, and G. S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 44:996-1000.

Smith, S. J., L. B. Young, and G. E. Miller. 1977. Evaluation of soil nitrogen mineralization potentials under modified conditions. Soil Sci. Soc. Am. J. 41:74-76.

Soltanpour, P. N., M. El Gharous, A. Azzaoui, and M. Abdel Monem. 1986. N and P soil test calibration study. p. 119-120. Ann. Report, INRA-MIAC Project, Settat, Morocco.

Stanford, G. 1968. Effect of partial removal of soil organic N with sodium pyrophosphate in sulfuric acid solution on subsequent mineralization of nitrogen. Soil Sci. Soc. Am. Proc. 32:679-682.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization water relation in soils. Soil Sci. Soc. Am. J. 38:103-106.

Stanford, G., and S. J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., M. H. Frere, and D. H. Schwaninger. 1973. Temperature coefficient of soil N mineralization. Soil Sci. 115:321-323.

Wilkinson, L. S. 1986. The system for statistics. Evanston, Systat, Inc., Ill.

# USE OF THE FREUNDLICH SORPTION EQUATION FOR EVALUATING THE PHOSPHATE REQUIREMENTS OF ARID ZONE SOILS

S. Berigari

Scientific Research Council Baghdad, Iraq

## ABSTRACT

Simple, quick and verified laboratory test bear some obvious merits over long-range and expensive field trials to assess phosphate requirements of soils. Samples from typical soils of Iraq were equilibrated with a wide range of P concentrations (0-30 mg $L^{-1}$) at 1:20 soil : solution ratio. Phosphate in the supernatant solution was measured photometrically in order to determine by difference the quantity of soil adsorbed P. The data conformed to the linear plots of the Freundlich, Langmuir and Temkin equations with highly significant positive correlations. Superior fit of the data, however, was observed with the Freundlich equation, Which is simple in form and subject to rigorous derivation with more realistic assumptions. The estimated P requirements of most soils ranged between 32-52 mg P/kg soil when obtained from normal isotherms, which agreed closely with values obtained from application of the Freundlich equation. Thus, to estimate P requirement of a given soil for optimum crop production, only two-point sorption data are needed where a linear Freundlich plot can be applied.

## INTRODUCTION

Field trials are still practiced to determine the P requirements of soils for optimum crop production. These are slow and laborious, and their results pertain only to local application (Onken et al., 1980). For these reasons, many laboratory tests have been developed and the results correlated with plant yields and P uptake. A value of 0.2 ppm, P in solution has been suggested as one at which most plants attain near maximum growth (Beckwith, 1964; Fox and Kamprath, 1970). In soils, a value of 0.3 ppm P has been used as a standard value for estimating fertilizer rates for wheat (Ozanne and Shaw, 1968). However, it is known that the value varies with soil moisture, since soil moisture influences P diffusion to roots (Olsen and Watanabe, 1963, 1966). Evidence exists that P moves to the roots of plant by diffusion.

During the past two decades advanced studies have been made on the soil parameters which play major roles in P flux to plant roots. These include the intensity (I), quantity (Q), capacity ( $\Delta Q/\Delta I$) and mobility factors (Dalal and Hallsworth, 1976; Williams, 1967). Intensity refers to P concentration in the soil solution, quantity to the total exchangeable P, capacity to the soil P buffering capacity and mobility, which includes a number of rate factors involved in the dissolution of soil P, transport of P to roots, and P uptake by plants.

The quantitative description of Q to I relationship is important for predicting the P fertilizer requirement of soils (Fox and Kamprath, 1970; Holford, 1976; Ozanne and Shaw, 1967). Such relations for P in soil systems have been described by the familiar Langmuir, Freundlich and Temkin equations. The Langmuir model, despite its limitations for soils, enjoyed aaceptance because of the physical significance attached to the two constants for bonding energy and maximum P sorption. On the other hand, the Freundlich isotherm did not receive such acceptance for a long time because of its assumed empirical character. However, it was recently shown to have a rigorous theoretical derivation (Sposito, 1980). Also, the Freundlich equation is in greater harmony with the process of p sorption by soils (Barrow, 1978). Generally, the choice among equations is often based on the goodness of fit achieved in a given case along with its simplicity in form (Polyzopoulos et al., 1985), which only recently gave the Freundlich model such merits (Berigari et al., 1985; Polyzopoulos et al., 1985).

The purpose of the present work was to determine the P requirements of some typical soils of Iraq by means of sorption isotherms for best fitted equations. This is to be used subsequently as a standard procedure where two-point sorption data can be fitted to the linear plot of the selected model.

## MATERIALS AND METHODS

Soil samples were taken from the surface (0-30 cm) at six different locations in Iraq. The soils were characterized as described elsewhere (Berigari et al., 1985) and in Table 1, which shows some physical and chemical properties. Except for the Calciorthid soil from Sulaymania, the soils are Typical Torrifluvents of the Mesopotamian Plain, which, to a certain extent, represent the most abundant alluvial soils of the country known to have developed under arid-conditions.

Adsorption of O-phosphate as $KH_2PO_4$ was evaluated by adding 40 ml of 0.01 M NaCl solution containing the specified levels of P for ten points (0-30 ppm) to 2-g of air-dried soil samples in 70 ml

Table 1. Physical and chemical properties of some soil in Iraq.

| Soil Source | pH | Clay | Silt | $CaCO_3$ | O.M. | EC mmhas cm | Gypsum meq/100 | CEC gsoil | EDTA-P | Anion-P g/g | Total P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sulaymania | 7.8 | 40.0 | 40.4 | 47.4 | 3.42 | 0.50 | 0.23 | 31.9 | 51.2 | 142.9 | 1095 |
| 7-Nissan | 6.2 | 38.3 | 57.6 | 32.0 | 0.37 | 1.34 | 1.13 | 18.4 | 2.2 | 4.6 | 512 |
| Fudhaylia | 8.0 | 47.4 | 46.0 | 31.0 | 0.79 | 8.48 | 4.00 | 19.2 | 1.3 | 12.0 | 570 |
| Al-Wehda I | 7.8 | 40.5 | 54.7 | 29.4 | 0.75 | 18.1 | 4.93 | 19.8 | 3.0 | 4.7 | 479 |
| Al-Wehda II | 8.1 | 48.9 | 48.0 | 31.3 | 0.33 | 3.54 | 1.88 | 23.2 | 3.2 | 13.8 | 572 |
| Qalat-Seker | 7.9 | 43.8 | 53.3 | 8.2 | 1.72 | 0.55 | 0.13 | 45.1 | 0.8 | 9.8 | 694 |

pH = 1:2.5 soil: solution; Al-Wehda-I unreclaimed saline soil; Al-Wehda-II was reclaimed from salinity.

polycarbonate centrifuge tubes, in triplicate. A few drops of chloroform were added to each tube to inhibit microbial growth. Then it was stoppered with well-fitted screw cap. The tubes were equilibrated at 25 ± 1 °C with shaking on a wrist-type shaker for 48 hr., a time which seems necessary to achieve the equilibrium state according to Ryden and Syers (1975). The covers were removed and the suspensions centrifuged at 25°C and 1859 g, using a high speed centrifuge until clear supernatant solutions could be separated. The solution was passed through Whatman No. 42 filter paper to ensure removal of floating particles. Each tube, with and without wet soil sediment, was weighted to obtain the volume of the retained solution after decantation of the bulk solution. Phosphorus which disappeared from the equilibrated solution was considered to have been sorbed.

For P desorption, sufficient NaCl solution was added to each tube containing the wet soil sediment to adjust the ratio of soil: solutin to 1:10 (w/v). The suspension was equilibrated and the supernatant solution was separated the same way as the adsorption was carried out. The inorganic P in the soil extracts was measured photometrically at =882 m using the John method (1970). Phosphorus, which was released from the previously sorbed P and appeared in solution, was taken as equal to quantity desorbed from the soils samples.

Sorption isotherms were constructed manually and by means of an HP 9830 mini-computer with an HP 9830 plotter using Basic language. Adsorption data for the soils were fitted to the linear forms of the Freundlich, Langmuir, and Tamkin equations as described below:

1. Freundlich equation. This may be written as :
   $K = A\ C^B$ (1)
   or in a linear form as:
   $Log\ X = Log\ A + B\ Log\ c$ (2)
   Where X = quantity of sorbate/unit weight of adsorbent,
   C = equilibrium solution concentration of the adsorbate, and
   A and B are constants characteristics of the system.

2. Langmuir equation:
   $K = K\ M\ C\ /\ 1 + K\ C$ (3)
   Where K = sorption constant related to binding energy
   M = maximum monolayer adsorption, X and C have the usual meaning.
   The constants can be obtained from the linear form as:
   $C\ /\ X = C\ /\ M + 1\ /\ K\ M$ (4)

3. Temkin equation. Its simplest form is:
   $K = A + B\ log\ C$ (5)
   where A and B are constants, and X and C have their usual meaning.

## RESULTS AND DISCUSSION

The sorption data, with and without including native adsorbed P (anion resin-extractable), conformed to the linear plots of the Freundlich, Langmuir, and Temkin models with highly significant positive correlations (P<0.01) as shown by linear regression (Table 2). However, visual inspection of the isotherms revealed that the data can best be described by the Freundlich model, whereas the Temkin model

Table 2. Use of three mathematical models to describe phosphate sorption isotherms of six soils expressed in terms of a linear correlation coefficient.

| Soil Source | Freundlich Adsorption +NAP | -NAP | Desorption +NAP | Langmuir Adsorption +NAP | -NAP | Desorption +NAP | Temkin Adsorption +NAP | -NAP | Desorption +NAP |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | r | | | | |
| Sulaymania | 0.997 | 0.981 | 0.986 | 0.999 | 0.996 | 0.999 | 0.996 | 0.396 | 0.987 |
| 7-Nissan | 0.998 | 0.999 | 0.993 | 0.984 | 0.980 | 0.952 | 0.947 | 0.947 | 0.933 |
| Fudhaylia | 0.996 | 0.992 | 0.978 | 0.995 | 0.996 | 0.995 | 0.980 | 0.980 | 0.990 |
| Al-Wehda I | 0.993 | 0.991 | 0.976 | 0.990 | 0.997 | 0.991 | 0.969 | 0.967 | 0.874 |
| Al-Wehda II | 0.998 | 0.996 | 0.997 | 0.975 | 0.991 | 0.972 | 0.955 | 0.955 | 0.990 |
| Qalat-Seker | 0.996 | 0.996 | 0.995 | 0.987 | 0.990 | 0.988 | 0.964 | 0.964 | 0.960 |

Native adsorbed P included = +NAP and excluded = -NAP.
The values (n=10) are highly significant ($P<0.01$) when $r = 0.735$.

showed obvious curvature for the six soils (Figs. 1-3). Also, deviation of the data from the linear Langmuir equation was observed for most soils. Similar observations were reported recently (Berigari et al., 1985; Ozanne and Shaw, 1968).

Inclusion of the native adsorbed P in the sorption isotherms, in general, did not improve the shape of the curves, but shifted the position of the intercepts (Table 2, Fig. 4). Also, desorption of the adsorbed P conformed to the linear plot of the Freundlich equation, for

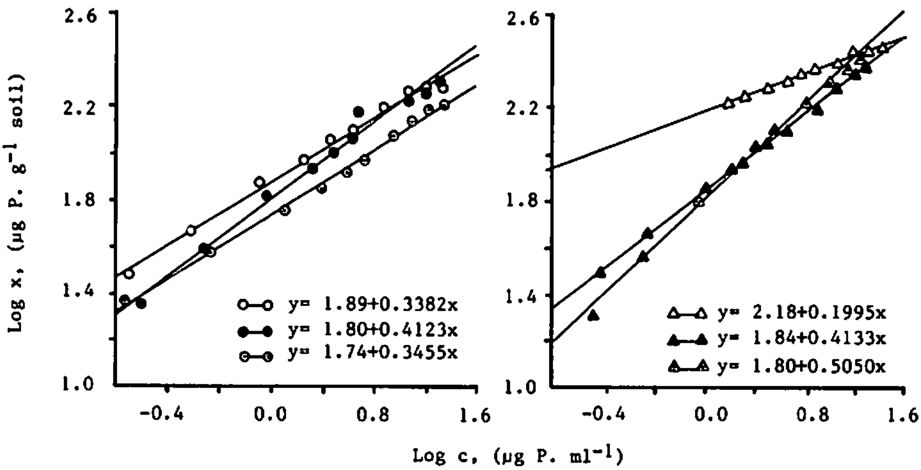



Fig. 1. Phosphate sorption data, including native adsorbed P, of six soils plotted according to the linear form of the Freundlich equation.

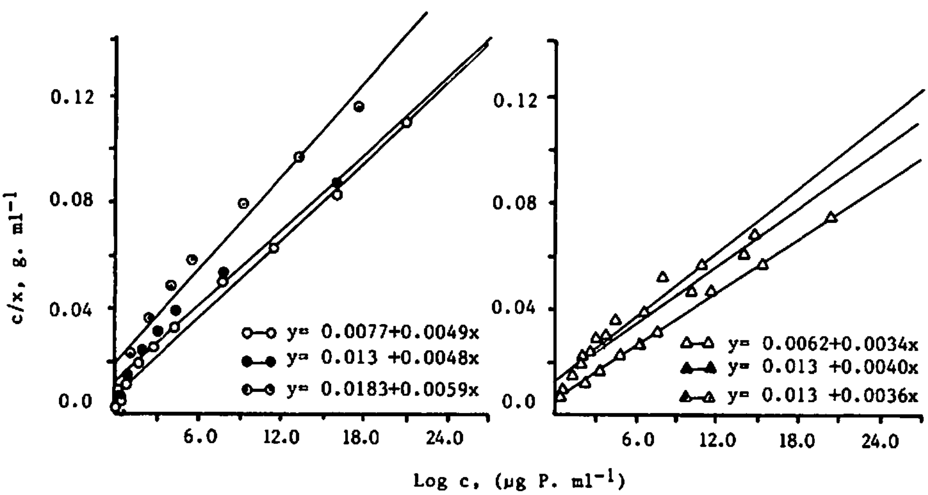



Fig. 2. Phosphate sorption data, including native adsorbed P, of six soils plotted according to the linear form of the Langmuir equation.

which typical isotherms are shown (Fig. 5). The extent of reversibility of the process can be measured by the magnitude of reproducibility of the constants for each equation during adsorption and desorption. Tables 3 and 4 show the values of the constants obtained for the Langmuir and Freundlich equations. Again, the values of the constants for the Freundlich equation are in better agreement than those for the Langmuir equation.

Although the Freundlich equation is emperical in origin, it is simple in form, and can be derived theoretically with more realistic assumptions. As it now stands, from theoretical and experimental bases,

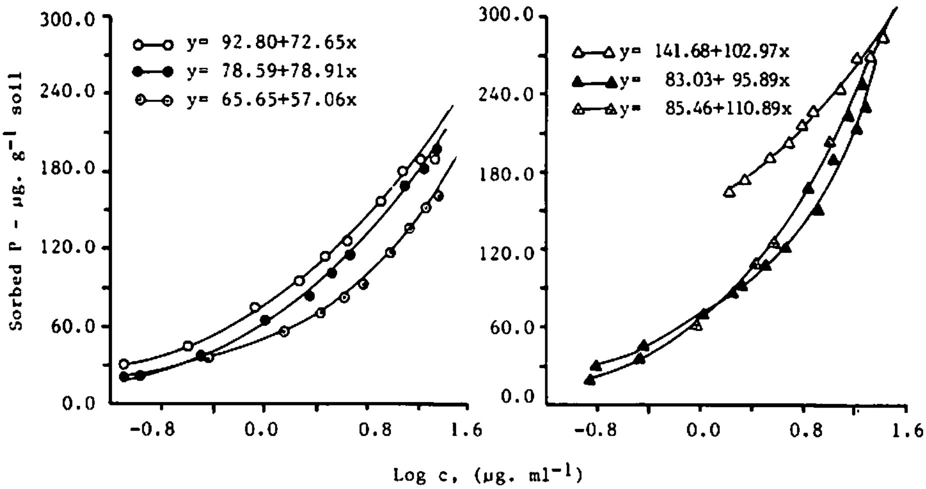



Fig. 3. Phosphate sorption data, including native adsorbed P, of six soils plotted according to the linear form of the Temkin equation.

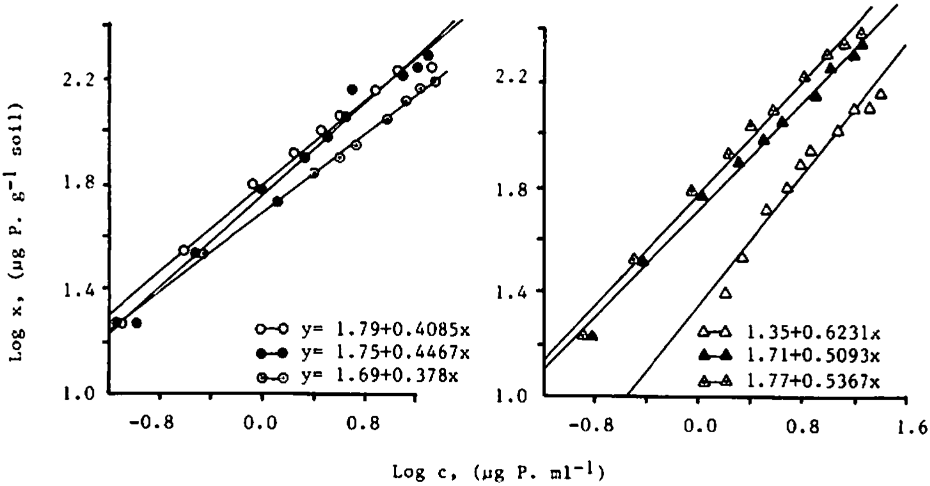



Fig. 4. Phosphate sorption data, excluding native adsorbed P, of six soils plotted according to the linear form of the Freundlich equation.

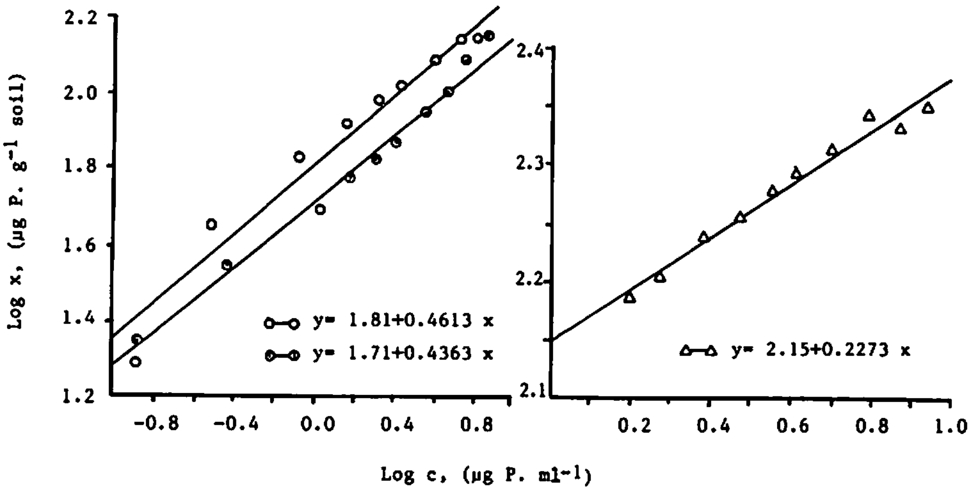



Fig. 5. Phosphate desorption data, including native adsorbed P, of soils plotted according to the linear form of the Freundlich equation.

Table 3. Constants of Langmuir plots of phosphate sorption data for six soils.

| Soil Source | Adsorption | | | Desorption | | |
|---|---|---|---|---|---|---|
| | K | M | KM | K | M | KM |
| Sulaymania | 0.55 | 294 | 162 | 0.95 | 250 | 237 |
| 7-Nissan | 0.32 | 196 | 62.7 | 0.47 | 137 | 64.4 |
| Fudhaylia | 0.64 | 204 | 130 | 0.94 | 156 | 174 |
| Al-Wehda I | 0.37 | 208 | 77.0 | 0.88 | 196 | 172 |
| Al-Wehda II | 0.31 | 250 | 77.5 | 1.12 | 156 | 175 |
| Qalat-Seker | 8.28 | 270 | 77.6 | 0.92 | 116 | 107 |

Table 4. Constants of Freundlich plots of P sorption data for six soils.

| Soil source | Asorption | | | Desorption | | |
|---|---|---|---|---|---|---|
| | A | B | AB | A | B | AB |
| Sulaymania | 2.81 | 0.20 | 0.44 | 2.15 | 0.23 | 0.39 |
| 7-Nissan | 1.74 | 0.34 | 0.59 | 1.71 | 0.44 | 0.75 |
| Fudhaylia | 1.89 | 0.34 | 0.64 | 1.81 | 0.64 | 0.83 |
| Al-Wehda I | 1.80 | 0.41 | 0.74 | 1.93 | 0.38 | 0.73 |
| Al-Wehda II | 1.89 | 0.41 | 0.77 | 1.83 | 0.42 | 0.77 |
| Qalat-Seker | 1.80 | 0.51 | 0.92 | 1.77 | 0.57 | 1.01 |

the Freundlich equation offers the best choice among the three equations commonly used in fitting P sorption data of soils.

The quantitative description of Q/I in the form of isotherms is important for predicting P fertilizer requirements of soils (Holford, 1976; Ozanne and Shaw, 1967). A value of 0.2 ppm P in soil solution in equilibrium with the sorbed soil P has been used as a standard value required for most plants to attain near maximum growth (Beckwith, 1964; Dick and Tabatabai, 1980), whereas 0.3 ppm P in the soil solution has been used as a standard value for assessing fertilizer rates for wheat (Ozanne and Shaw, 1968). The adsorbed P (µ/g soil in equilibrium with 0.2 or 0.3 P/ml in solution) obtained directly from normal isotherms (Fig. 6) agreed quite well with the values computed from the Freundlich equation (Table 5). Moreover, the sorbed P corresponding to either 0.20 or 0.30 µ P/ml in the equilibrium solution could not be measured accurately from the normal sorption isotherm for the soil with very high native sorbed P (Sulaymania), but it was easily obtained from application of the Freundlich equation (Table 5).

Thus, to estimate the P requirement of a given soil, a sorption isotherm from two-point Q/I data is all that is needed within the range where the Freundlich equation can be applied. The required P is considered equal to that adsorbed at a soil: solution ratio of 1:20 (w/v) corresponding to the equilibrium solution concentration of 0.3 ppm P for wheat and 0.2 ppm P for most crops. When the native sorbed P is determined and subtracted from the required P, then the amount of fertilizer needed is obtained. Table 5 shows the values of fertilizer P required for the soils investigated, which range between 0 and 39.3 µg/g soil.

The values of sorbed P (µg/g soil at 0.3 µg/ml equilibrium solution concentration) correlated highly significantly µg/g (P > 0.01) with ETA-extractable P (see Helyar and Spencer, 1977), anion exchangeable P (see Sibbesen, 1978), total P (see Dick and Tabatabai,

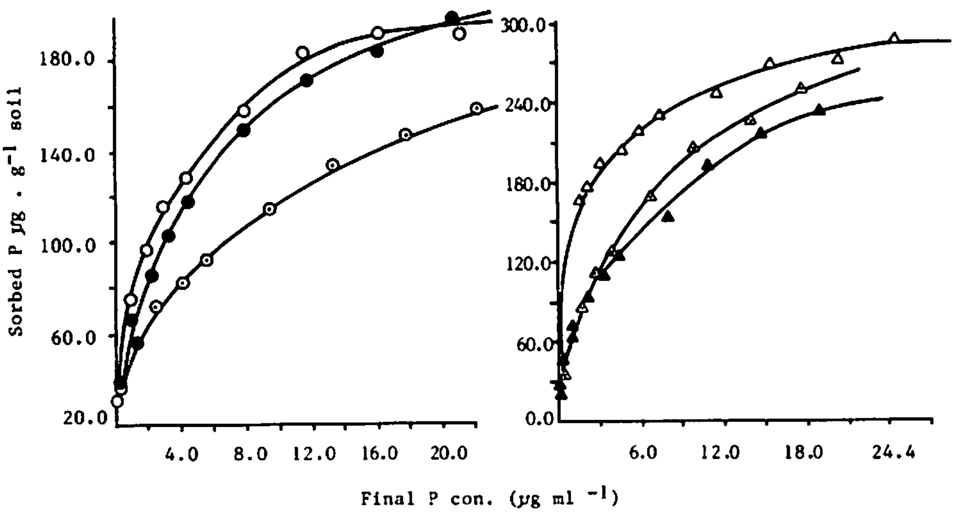



Fig. 6. Phosphate sorption data, including native adsorbed P, of six soils plotted as normal isotherms.

1980) and the maximum buffering capacity (se Helyar and Spencer, 1977), as shown in Table 6. These parameters have been shown by numerous workers to correlate significantly with plant growth.

Table 5. Required P corresponding to two P solution concentrations, 0.30 and 0.20 obtained by different isotherms.

| Soil Source | Normal | | Freundlich | | Langmuir | | Temkin | | Fertilizer[1] |
|---|---|---|---|---|---|---|---|---|---|
| | 0.30 | 0.20 | 0.30 | 0.20 | 0.30 | 0.20 | 0.30 | 0.20 | P needed |
| | g/g soil | | | | | | | | |
| Sulaymania | - | - | 120.0 | 110.9 | 41.5 | 29.1 | 87.8 | 69.7 | 0.0 |
| 7-Nissan | 32.2 | 31.0 | 35.8 | 31.2 | 17.3 | 11.9 | 35.8 | 25.8 | 31.2 |
| Fudhaylia | 51.5 | 44.0 | 51.3 | 44.7 | 32.7 | 23.0 | 54.8 | 42.0 | 39.3 |
| Al-Wehda I | 38.0 | 32.0 | 38.5 | 37.2 | 20.8 | 14.3 | 37.3 | 23.4 | 33.8 |
| Al-Wehda II | 43.0 | 35.5 | 42.0 | 35.5 | 21.2 | 14.5 | 32.9 | 16.0 | 28.2 |
| Qalat-Seker | 35.5 | 28.0 | 34.5 | 28.3 | 21.7 | 14.9 | 27.5 | 7.9 | 24.7 |

[1] Value obtained by difference between column 4 of this table and anion-exchangeable P from Table 1.

Table 6. Linear correlation coefficient between the listed parameters and soil P requirements at a P solution concentration of 0.3 g/ml.

| Parameter | "r" | Linear Regression Eq. |
|---|---|---|
| EDTA-extractable P | 0.982** | y = 23.81 + 0.428 x |
| Anion-exchangeable P | 0.988** | y = 61.95 + 1.711 x |
| Total P | 0.932** | y = 322.8 + 4.362 x |
| Freundlich constant A | 0.995** | y = 21.06 + 1.099 x |
| Freundlich constant B | -0.864* | y = 0.514 + 0.003 x |
| Maximum buffer capacity | 0.874** | y = 39.02 = 1.068 x |

* p = < 0.05; ** p = < 0.001; Number of cases = 6.

## REFERENCES


Barrow, N. J. 1978. The description of phosphate adsorption curves. J. Soil Sci. 29: 447-462.

Beckwith, R.S. 1964. Sorbed phosphate at standard supernatant concentration as an estimate of the phosphate needs of soils. Aust. J. Exp. and An. Husb. 5:52-58.

Berigari, M.S., M.J. Raihan, and M.A. Umran. 1985. Phosphate sorption isotherms for assessing phosphorus requirements of soils in Iraq. J. Agr. and Water Resources. 4:97-117.

Dalal, R.C., and E.G. Hallsworth. 1976. Evaluation of the parameters of soil phosphorus availability factors in predicting yield responses and phosphorus uptake. Soil Sci. J. 40:541-546.

Dick, W.A., and A. Tabatabai. 1980. An alkaline oxidation method for determination of total phosphorus in soils. Soil Sci. Soc. Amer. J. 41:511-514.

Fox, R.L., and E.J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Sci. Soc. Amer. Proc. 34:902-907.

Helyar, K.R., and K. Spencer. 1977. Sodium bicarbonate soil test values and the phosphate buffering capacity of soils. Aust. J. Soil Res. 15:263-273.

Holford, I.C.R. 1976. Effects of phosphate buffer capacity of soil on the phosphate requirements of plants. Plant Soil, 433-444.

John, M.K. 1970. Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. Soil Sci. 109:214-220.

Olsen, S.R., and F.S. Watanabe. 1963. Diffusion of phosphorus as related to soil texture and plant uptake. Soil Sci. Soc. Amer. Proc. 27:648-653.

Olsen, S.R., and F.S. Watanabe. 1966. Effective volume of soil around plant roots determined from phosphorus diffusion. Soil Sci. Soc. Amer. Proc. 30:598-602.

Onken, A.B., K. Matheson, and E.J. Williams. 1980. Evaluation of EDTA-extractable phosphorus as a soil test procedure. Soil Sci. Soc. Amer. J. 44:783-786.

Ozanne, P.G., and R.C. Shaw. 1967. Phosphate sorption by soil as a measure of the phosphate requirement for pasture growth. Aust. J. Agric. Res. 18:601-612.

Ozanne, T.G., and T.C. Shaw. 1968. Advantages of the recently developed phosphate sorption test over the older extractant methods for soil phosphate. Int. Cong. Soil Sci. Trans. 9th (adeliade, Aust.) 2:273-280.

Polyzopoulos, N.A., V.Z. Keramidas, and H. Kiosse. 1985. Phosphate sorption by some alfisols of Greece as described by commonly used isotherms. Soil Sci. Soc. Amer. J. 49:81-84.

Ryden, J.C., and Syers. 1975. Rationalization of ionic strength and cation effects on phosphate sorption by soils. J. Soil Sci. 26:395-406.

Sibbesen, E. 1978. An investigation of the anion-exchange resin method for soil phosphate extraction. Plant Soil. 50:305-321.

Sposito, G. 1980. Derivation of the Freundlich equation for ion exchange reactions in soils. Soil Sci. Soc. Amer. J. 44:652-654.

Williams, E.G. 1967. The intensity and quality aspects of soil phosphate status as measured by laboratory extraction values. Anal. Edafol. Agrobiol. 26:525-545.

# A NOTE ON THE EFFECT OF REGULAR FERTILIZER USE WITHIN DIFFERENT TWO-YEAR CROPPING ROTATIONS ON SOIL PHOSPHATE AND ORGANIC MATTER STATUS

M.J. Jones and A. Matar

ICARDA, P.O. Box 5466, Aleppo, Syria

## INTRODUCTION

Most of our attention at this workshop is directed towards crop response to fertilizer in relation to the current nutrient status of the soil and, in some cases, to the nature of the previous crop. In this, our concern is with short-term effects. However, regular fertilizer application and the employment of particular crop sequences will usually build up longer-term effects on soil properties, on crop responses to fertilizer, and on the maintenance of yield levels. Some of these will be evident within a few years, e.g., increases in soil available P status from the regular use of P fertilizer. Others will take much longer to appear, but may ultimately have important implications for sustained and profitable long-term cropping.

To date, in the West Asia-North Africa (WANA) region, there have been few long-term trials or long-term studies of changes in soil properties under different types of management. Our research priorities are usually more immediate. However, when and where we can, we should seek to monitor the cumulative effects of cropping and fertilizer use on our soil and to take account of these findings in our short-term trials and in the recommendations we make from them to farmers.

This short paper summarizes certain soil analytical data from three rotation trials which were sampled five or six years after their initiation. These trials compared three rotations; barley-fallow (B-F), barley-legume (B-L) and barley-barley (B-B), each under several different fertilizer regimes. Crop data show clear fertilizer and rotation effects on productivity; viz. (i) yields are generally increased by fertilizer, with N being of special importance in B-B rotations; (ii) barley yields most after fallow, but B-F is the least productive rotation because of the barren fallow year; and (iii) B-L is the most productive rotation, both absolutely and per unit of fertilizer applied (Jones, 1988). However, the question here is : what is the concurrent effect of the rotations and fertilizer regimes on the soil itself?

## EXPERIMENTAL DETAILS

The three trials were : New Rotations (NR) established in 1982-83 at Tel Hayda and Breda, and an Old Rotation (OR) established at Breda in 1980-81. Each NR trial comprised three replicates of both phases of an incomplete factorial combination of six two-year rotations and six fertilizer regimes (Table 1). The OR trial was similar, but had only five fertilizer regimes and fewer combinations. Other similarities and differences to note between NR and OR trials were :

i) Fertilizer regimes : NR I, III and VI = OR I, III, and V, respectively; but the remainder do not correspond.

ii) Four of the six rotations were common. These were barley/barley, barley/fallow, barley/vetch and barley/peas. The remainder do not correspond.

iii) The barley variety was Arabic Aswad in the new, and Beecher in the old rotation.

Management was similar in the OR and NR trials. The crops, which were all local landraces, except Beecher

Table 1. Rotation trials : definition of treatments.

| Fert. Regime No. | $N:P_2O_5$ in phase 1 | phase 2 | Rotation (NEW) Phase 1. / Phase 2. A B-P | B B/P+B | C B-V | D B/V+B | E B-F | F B-B |
|---|---|---|---|---|---|---|---|---|
| I | 20:60 | 60 | | | | | | 19 |
| II | 0:0 | 20:60 | | | | | | 22 |
| III | 20:60 | 0:0 | 1 | 2 | 3 | 4 | 18 | 20 |
| IV | 20:30 | 0:30 | 5 | 6 | 7 | 8 | | |
| V | 20:0 | 0:60 | 9 | 10 | 11 | 12 | | |
| VI | 0:0 | 0:0 | 13 | 14 | 15 | 16 | 17 | 21 |

| Fert. Regime No. | $N:P_2O_5$ in phase 1 | phase 2 | Rotation (OLD) Phase 1. / Phase 2. A B-V | B B-P | C B-L | D B-P | E B-F | F B-B |
|---|---|---|---|---|---|---|---|---|
| I | 20:60 | 20:60 | | | | | | 2 |
| II | 0:0 | 0:60 | 6 | | 9 | 10 | | |
| III | 20:60 | 0:0 | 8 | | | | 4 | |
| IV | 0:0 | 0:60 | 7 | | | | | |
| V | 0:0 | 0:0 | 5 | 11 | | | 3 | 1 |

- Treatments 9, 10 and 11 were not consistent for all years and are therefore omitted in the present analysis.
- Numbers refer to particular treatment combination of rotation and fertilizer regimes.
- Crop rotation : B = barley; P = peas; l = lentil, v = vetch; f = fallow - Lathyrus replaced peas in 1986-87.

barley, were drilled at 17.5 cm row-spacing in 6.5 x 12.5 m plots at the following seed rates (kg/ha) : barley, 90; peas, 200; vetch, 150; peas + barley, 185 + 15; vetch + barley, 135 + 15; lathyrus + barley, 135 + 15. All legumes were inoculated with appropriate rhizobia. Fertilizers, as ammonium nitrate and triple superphosphate, were drilled with the seed, but at Tel Hadya half the N was held back and top-dressed at the start of stem extension; 20 and 40 kg N/ha were applied at Breda and Tel Hedya, respectively. Weeds were controlled with herbicides or, in mixed crops and bare fallow, by hand. Vetch, peas and lathyrus (and their mixtures with barley) were harvested at the hay stage (early pod set) every year in the OR trial and until 1985-86 in the NR trials, when they were allowed to continue to maturity. Barley, when cropped alone, was harvested at maturity.

The soil was sampled in all plots of the OR trials in Oct./Nov. 1986, 6 years after the start of the trials, and in the NR trials in the same period in 1987, 5 years after the start. Three cores per plot were taken from a depth of 0-20 cm. In the laboratory, soil samples ground to pass a 2-mm sieve were analyzed for available P using the Olsen sodium bicarbonate extraction method. Total N was determined by a semi-micro Kjeldahl procedure using concentrated sulfuric acid and a potassium sulfate/copper-sulfate/selenium catalyst, and oxidizable organic carbon by the Walkely-Black method.

## RESULTS

### Soil Available Phosphate Status

In unfertilized soils, available P was fairly constant at around 2-3 ppm (Figs. 1 and 2). Values tended to be lowest in the B-B rotation, especially at Breda, and highest in the B-F rotation at Tel Hadya only. This may possibly indicate a rotation effect, but differences were not statistically significant.

Bi-annual P fertilization increased soil available P to around 6-9 ppm at both Breda and Tel Hadya; but a higher value, 12-16 ppm, from annual fertilization at Breda was not matched at Tel Hadya (6 ppm). In fact, at Tel Hadya, soil available P in the annually fertilized B-B rotation was appreciably lower than in the bi-annually fertilized B-F rotation. Part, at least, of these differences may arise from the greater total crop productivity, and therefore P uptake, in B-B compared with the B-F rotation, and at Tel Hadya compared with the lower rainfall at Breda.

### Soil Organic Carbon and Total Nitrogen Status

The large differences in soil available P status due to P fertilization were expected. But treatment differences in

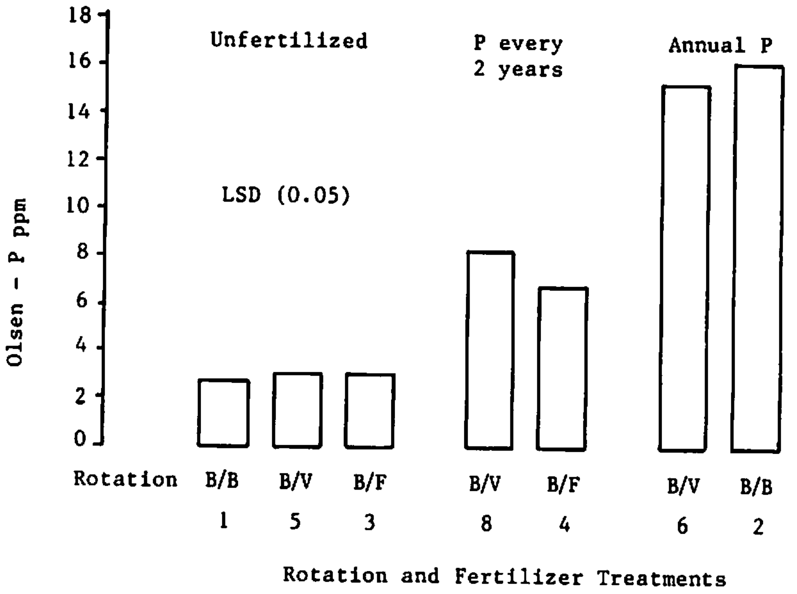



Fig. 1. Effect of fertilizer regime on top soil available-P content after six years in the Old Rotation trial at Breda.

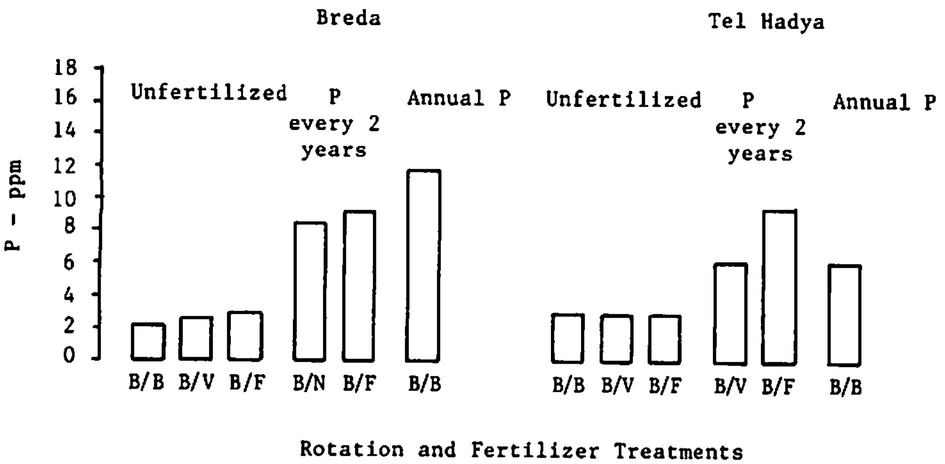



Fig. 2. Effect of fertilizer regime on topsoil available P content after five years in the New Rotation trials at Breda and Tel Hadya.

soil organic carbon and total N contents are likely to develop only slowly. Initial inspection of the data suggested that five or six years had not been sufficient for any such effects to become visible. In each of the three trials, analysis of variance across all treatments indicated no differences significant at the 5 % level. However, a graphical plot of the carbon values for the individual treatments in the two NR trials showed a considerable degree of correspondence between sites (Fig. 3). In most cases, a high (or low) treatment value at one site was matched by a high (or low) value at the other site, with a significant correlation coefficient over all treatments of 0.730 ($P<0.01$). Since this could hardly have been a chance occurrence, a closer look at the data seemed justified.

## New Rotation Trials

Largest differences - none exceeded 10 % in relative magnitude - appeared to be between rotations. For example, soils in B-F rotation tended to have less organic carbon and/or total N than soils in a B-L rotation, although these differences were statistically significant only in the absence of applied fertilizer (Table 2). Amounts of carbon and N in B-B rotation soil were generally similar to those in B-L rotation soil. Also, within the fertilized B-L rotation, the organic carbon values, though not the total N values, were higher where the legume phase comprised a legume/barley mixture rather than a pure forage legume, the effect being significant at Breda.

## Old Rotation Trials

The general pattern of soil organic carbon and total N in these trials was similar to that in the NR trials. At

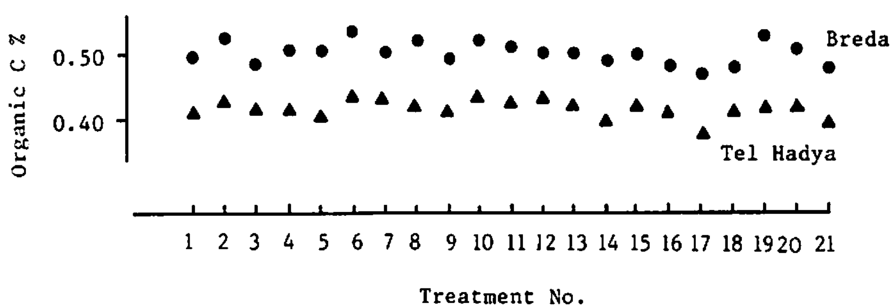



Fig. 3. Effect of fertilizer and rotation treatment on top soil organic C content after five years, in the New Rotation trials at Breda and Tel Hadya.

Table 2. Comparison of B-L and B-F rotations in new rotation trials in respect of their topsoil organic carbon and total nitrogen contents.

| | | Treatments | | Breda | | | Tel Hadya | | |
|---|---|---|---|---|---|---|---|---|---|
| | | B-L | B-F | Means | | F | Means | | F |
| | | | | ---- % ----- | | | --- % ---- | | |
| Organic C: | | | | | | | | | |
| | a | 1-4 | v. 18 | 0.508 | 0.488 | 2.54ns | 0.419 | 0.415 | 0.22ns |
| | b | 13-16 | v. 17 | 0.504 | 0.478 | 4.44* | 0.423 | 0.395 | 9.44** |
| Organic N: | | | | ---- ppm --- | | | -- ppm --- | | |
| | a | 1-4 | v. 18 | 732 | 707 | 1.94ns | 673 | 649 | 1.36ns |
| | b | 13-16 | v. 17 | 709 | 710 | 0.00ns | 675 | 620 | 7.26** |

Treatment numbers, see Table 1.
a: Fertilized rotations; b: unfertilized rotations.
*, ** Significant at 5 and 1%, respectively.

comparable fertilizer rates, values tended to be lower in B-F than in B-V and B-B rotations (Table 3); but few, if any, differences were statistically significant. Similarly, fertilizer effects were not significant. Fertilizer, particularly N, apparently led to higher soil carbon and N contents. However, the only significant differences were between "low" and "high" fertilization treatments in the B-V rotation; with "low" fertilization (0:0 and 0:60) average organic carbon and total N values were 0.526 % and 745 ppm, respectively. The corresponding values for the "high" fertilization treatment (20:60 and 20:120) were 0.573 % and 799 ppm.

## DISCUSSION

Results from the Breda trials showed a very significant accumulation of available P. Application rates averaging 30 kg $P_2O_5$/ha over 5 or 6 years have been adequate to meet crop requirement and to increase Olsen-P values from 3 to around 8 ppm. And, as previous results have shown, little response to further P fertilizer can be expected when Olsen-P values exceed 8 ppm (Matar et al., 1987). However, the accumulation of available P was smaller, or slower, at Tel Hadya, especially in the annually fertilized B-B treatment. This can probably be attributed to the higher rainfall at Tel Hadya, which promotes greater crop growth and, therefore, greater uptake of the applied P than is the case at Breda.

The amounts of organic matter and N in a well-drained soil are primarily a function of climate, land use, and vegetative cover. Under stable conditions, these amounts remain approximately constant from year to year but they usually decline when previously unploughed land is brought into cultivation. New equilibria are eventually reached at levels which reflect the management employed. Fertilization and the return of organic residues can have a large part to play. There are many examples in the literature. For instance, Warren (1956) reported total N contents in the top 23 cm of the Broadbalk continuous wheat field at Rothamsted, U.K. to range between 1886 and 1944; with no fertilization N content was basically unchanged, i.e., 0.105 and 0.106 %, while with annual NPK fertilization, the respective values were 0.117 and 0.121 % higher, but unchanged with time. The 1944 figures approximate to the equilibrium values for their respective managements.

However, data from a wheat-fallow cropping sequence in Oregon, USA, (Rasmussen et al., 1980) relate to a situation in which total N values appear to be still diverging according to treatment and, except for the manured treatment, still to be declining almost linearly after 45 years. Beginning in 1931, the N from several treatments (wheat straw burned, wheat straw returned to the soil, wheat straw returned with fertilizer N) decreased from 0.093 % to

Table 3. Mean soil organic carbon and total nitrogen values of topsoil in the old rotation trial, as affected by rotation and fertilizer treatments.

| Fert./2-yr. rotation | | | Organic C | | | Total N | | |
|---|---|---|---|---|---|---|---|---|
| N | $P_2O_5$ | | B-V | B-F | B-B | B-V | B-F | B-B |
| kg ha$^{-1}$ | | | ---------- % ---------- | | | ---------- ppm ---------- | | |
| 0 | 0 | | 0.543 | 0.527 | 0.566 | 762 | 731 | 778 |
| 0 | 60 | | 0.509 | | | 729 | | |
| 20 | 60 | | 0.563 | 0.547 | | 794 | 753 | |
| 20 | 120 | | 0.583 | | | 804 | | |
| 40 | 120 | SE (±) | | 0.0173 | 0.550 | | 25.6 | 805 |

Rotations : B-V = barley, vetch; B-F barley, fallow; B-B barley, barley.

0.073, 0.080, and 0.084 %, respectively, in 1976. Where straw was returned with the manure, the value was 0.103 % N.

As yet, our data from Syria show only small treatment effects, but there are indications that significant differences are beginning to emerge. Annual cropping, barley-legume, and barley-barley, seem to be leading to higher soil contents of both carbon and N relative to those in a barley-fallow rotation, and, less distinctly, NP fertilization also seems to have positive effects. This is broadly what would be expected, both on theoretical grounds and from experience elsewhere. The greater the crop production (either from frequent cropping or fertilization or both), the greater the return of residues to the soil (mainly roots, but also some stubble). In proportion to this return, soil organic matter content is increased or its rate of decline is decreased, until a new equilibrium level is eventually reached.

## CONCLUSIONS

Regular P fertilizer additions to a crop rotation - even additions only in alternate years - tend to increase the "native" P availability, even of soils known to be "P-fixing". One implication of this is that rates of P fertilization can probably be reduced to a "maintenance" level after a few years. On the present limited evidence, these levels will likely have to be higher where rainfall is higher.

The crop rotation and fertilizer regime employed can influence soil organic matter content, but the effect is slow. In general, the new equilibrium level to which that content will evolve is determined by the rate of return of organic materials to the soil; this will usually reflect cropping intensity and individual crop productivity, as well as residue management (graze, burn, or plough in). In contrast to the situation with P, the use of N fertilizer has little or no direct long-term effect on either soil total N or available N. Any effect it may have on either parameter is an indirect one, acting through crop productivity and the return of residues.

## REFERENCES

Jones, M. J. 1988. Barley rotation trials at Tel Hadya and Breda stations : a summary of biological yield data, 1981-87. ICARDA publication (in preparation), Aleppo, Syria.

Matar, A. E., E. Jabbour, and K. El Hajj. 1987. Prediction of barley response to fertilizers by means of soil nitrogen and phosphorus tests. In A. Matar et al. (eds).

Proc. Second Regional Soil Test Calibration Workshop, Ankara, Turkey, 1-6 Sept, 1986. ICARDA, Aleppo, Syria.

Rasmussen, P. E., R.R. Allmaras, R.C. Rohde, and N. C. Roaper. 1980. Crop residue influence on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. 44:596-600.

Warren, R. G. 1956. NPK residues from fertilizers and farmyard manure in long-term experiments at Rothamsted. Proc. Fertilizer Society (U.K.), n° 37, quoted by Cooke, G. W. in "The control of soil fertility". 1987. Hafner, USA.

# FERTILIZER USE ON BARLEY IN NORTHERN SYRIA: THE VALUE OF SOIL NUTRIENT INFORMATION

**Kutlu Somel, Abdallah Matar and Khazaa El-Hajj** [1]

## I. INTRODUCTION

Multiple season and multiple location, researcher managed on-farm trials have been conducted in Northern Syria for four seasons (1984-87) as part of the Syrian MAAR Soils Directorate - ICARDA FRMP collaborative research project on Fertilizer Use on Barley. The history and the details of the project have been described in annual progress reports and FRMP and ICARDA annual reports (e.g., SAR-MAAR-SD/ICARDA 1985, 1986, 1987, 1988).

In Syria, barley is produced predominantly at the drier range of the spectrum of rainfed agriculture as part of the barley-livestock (small ruminants) systems, typical of these areas. Barley is more adapted to dry conditions than bread and durum wheat and its integration with livestock production has made the barley-livestock system a time tested option for the dry areas. However, the system is forcing the boundaries of long term viability and sustainability. The increased demand for livestock products implies increased derived demand for barley as well as other sources of feed. Historically, the response to this increased demand has been a gradual shift from fallowing to continuous barley and expansion of cultivation, particularly into marginal areas with fragile ecological conditions.

Furthermore, barley production takes place with a minimum input technology which is extremely exploitative of the environment - almost a mining operation. Fertilizer use is minimal and concentrated in a higher rainfall area. Hand harvesting in some areas and the widespread grazing of the stubbles do not allow adequate organic matter to be returned to soils. A survey of barley production in northern Syria in 1981/82 found that available phosphorus (P-Olsen) in the top soil (0-20 cm) averaged 5.84 ppm and 71 per cent of the sampled barley fields had less than 6 ppm of P-Olsen (Somel et al., 1984). Organic matter in the current trial plots average less than 1 percent in the top soil (0-20 cm).

---

1) Economist and Soil Chemist, Farm Resource Management Program ICARDA, and Head of Soil Fertility, Soils Directorate, Syria, respectively.

Despite the low fertility status of the barley soils, fertilizer allocation to barley was restricted by policy. Part of the reason could be attributed to the relative neglect of barley in research, typical of West Asia and North Africa (WANA). This neglect is generally compounded by preconceived ideas that fertilizer will not give a profitable crop response in dry areas. Again, part of the reason for the policy of restricting fertilizer allocation to barley could have been consideration of risk factors. Rainfed agriculture, particularly in the drier areas, is characterized by extreme variability of environmental conditions in space but more importantly in time. This variability is a cause of uncertainty for both farmers and policy makers because crop failure is inevitable under extreme drought conditions. The risk of loss of working capital invested in fertilizer when the crop fails may be perceived as too high and unacceptable by both farmers and policy makers even if fertilizer use is profitable in terms of long term averages.

The current project aims to develop fertilizer recommendations for rainfed barley and attempts to treat these preconceived ideas as testable hypotheses. For example, the on-farm venue for the trials is an attempt to get closer to farmers' conditions. Even then, we observe substantial differences between farmers' yields and the trial check plots with no fertilizer. In other words, there is potential for yield increases through other management factors as well.

The project tries to give extensive consideration to environmental variability by conducting the trials in a wide range of environmental conditions in multiple season, multiple location trials. Furthermore, some of these environmental factors are monitored and recorded in order to be able to incorporate them in analysis.

Research at ICARDA has focused on optimizing the use of the scarcest factor in rainfed agriculture: water. Research has indicated that fertilizer use increases water use efficiency (Cooper, 1984). Through enhanced vigour in early crop growth which provides an early and adequate crop cover, fertilizer use increases the proportion of water used by the plant and reduces losses that occur through evaporation from the soil surface. In particular, phosphate fertilizer advances maturity to reduce the effects of moisture stress that invariably occurs towards the end of the season. Concern for the effects of environmental variability and farmer circumstances has also influenced the acceptance of on-farm multiple season and multiple location trials as the appropriate experimental venue. Various options for analysing the information have been discussed in Somel (1987). One option is the pooled regression analysis used for example in Ryan and Perrin (1974) and used experimentally in Somel (1984). The method of pooled regressions allows the environmental factors to be explicitly included in analysis. Further manipulations allow predicted response surfaces to be identified for different environmental conditions. Technical and economic optima can be calculated for such response surfaces. The sensitivity of the optimum conditions to changes in economic parameters (e.g., relative prices) can be assessed. The performance of optimum fertilizer recommendations under different environmental conditions can be assessed by using probability or frequency distributions of the environmental factors. This last point is particularly important in assessing the influences of variability and uncertainty. Finally, the value of collecting environmental information can be calculated by assessing the precision they impart to measurement and optimum recommendations.

Ryan and Perrin (1974: 341) focus on this point as well. They indicate that "if soil tests were not made, producers ... rely upon a blanket recommendation for all soil types." They find the average value of soil information for potatoes in Peru to be $94/ha and to vary from $1 to $430/ha. Similar principles were used in analysing corn response in Brazil and finds that the value of soil test information is between $6 and $31/ha depending on the model chosen.

This note demonstrates the use of a pooled analysis to arrive at predicted response surfaces. The objective is to assess and compare optimum input levels which can form the basis of fertilizer recommendations targeted to different classifications based on soil nutrient and rainfall levels. We also attempt to provide an estimate for the value of the soil nutrient information. This should only be used as an indication and not interpreted as conclusive. The same warning applies to interpreting optimal fertilizer levels as recommendations. The results should be interpreted as an exercise in the demonstration of a method. We anticipate a refinement of the results with data from the fourth year of the trials.

## II. MODEL SPECIFICATION

The independent variable is taken as barley grain yields. Barley straw also has economic value and it is possible to convert it into a barley equivalent. This can be done by using a factor of 0.35, the ratio of the value of straw to grain, as an average. However, it cannot be claimed that this average factor is a stable one as it may change depending on the season. For the purposes of the present study, only barley grain is considered.

Four environmental factors are considered. These are soil nutrient levels of nitrogen and phosphorus and rainfall at two stages of plant growth. This overlooks other environmental factors related to both soils (e.g., depth, other chemical and physical properties) and climate (e.g., temperature). While a large number of soil parameters have been determined, rainfall is the only climate factor that has been monitored in the SD/FRMP trials.

The experimental factors are applied nitrogen and phosphate fertilizers. All trials have a 4x4 randomized complete block with two replicates. Other standard treatments are described in Somel (1987). Finally, the analysis is confined to 37 sites with the fallow-barley crop sequence. This was done to avoid the possible confounding problems that could be posed by including the continuous barley trials. Two sites with abnormally high soil mineral-N were excluded as well.

The basic variables are then defined as follows:

y: barley grain yields, kg/ha

N: applied nitrogen fertilizer, kg N/ha (0, 20, 40, 60).

P: applied phosphate fertilizer, kg $P_2O_5$/ha (0, 30, 60, 90).

R1: rainfall influencing emergence and vegetative growth up to tillering (mm).

RX: rainfall from tillering to maturity (mm).

NA: soil mineral-N ppm (in soil layer 0-40 cm).

PA: soil available phosphorus, ppm P-Olsen (in soil layer 0-20 cm).

Interactions among these variables are indicated in variables defined as the joint notation of basic variables, e.g., NP, R1N, NAP, etc. Second order terms are indicated in the usual was as $N^2$, $P^2$. Interactions involving second order terms are defined following the same procedures, e.g., $R1N^2$, $NAP^2$, etc.

The basic model is a second order polynomial with interaction. This is a standard Taylor series expansion approximation to a non-linear response surface. It is written as:

$$y = a + bN + cP + dNP + eN^2 + fP^2 + u \qquad (1)$$

where u is error term normally distributed with mean 0 and variance $^2$.

Environmental factors vary to cause this response surface to change and shift. A complete model would be specified by including all the environmental factors under consideration directly and in interaction with the experimental factors as well as each other. Such a general model would look as follows:

$$
\begin{aligned}
y = a &+ bN + cP + dNP + eN^2 + fP^2 \\
&+ R1\,(a_1 + b_1N + c_1P + d_1NP + e_1N^2 + f_1P^2) \\
&+ RX\,(a_2 + b_2N + c_2P + d_2NP + e_2N^2 + f_2P^2) \\
&+ NA\,(a_3 + b_3N + c_3P + d_3NP + e_3N^2 + f_3P^2) \\
&+ PA\,(a_4 + b_4N + c_4P + d_4NP + e_4N^2 + f_4P^2) \\
&+ gR1RX + kR1NA + lR1PA \\
&+ nRXNA + oRXPA + rNAPA + u \qquad (2)
\end{aligned}
$$

It is possible to estimate, interpret and use for predictive purposes such a model with 36 coefficients. However, in the first instance certain statistical problems would beset this estimation. In particular, the environmental variables on rainfall have one value per experiment and soil variables have one value per replicate. This relative constancy by itself and when it enters interaction variables causes a high degree of correlation between the variables in (2). This results in the usual problems of multicollinearity such as the difficulty of precisely estimating individual coefficients. Furthermore, not all the interactions in (2) can be claimed to be biologically meaningful.

There are two approaches to choosing the variables to be included in estimating a general model. One is to use a priori scientific criteria to choose the meaningful variables. The second is to use the mechanistic statistical method of stepwise regression.

An intermediate approach is also feasible where the correlation matrix among the variables is studied to determine a subset of variables which are not highly correlated amongst themselves but each of which is correlated with an independent set of variables. Each such variable in the subset would then be representing the effects of the variables it is correlated with. This approach is not used as it would have entailed scrutinizing 35 x 34 = 1190 correlation coefficients. This approach would still not have eliminated multicollinearity arising from correlation among linear combinations of variables. Other multivariate methods are possible but have not been utilized.

A somewhat a priori specification is used here. This specification is based on two principal and not unreasonable expectations: first, the response to applied fertilizer is influenced by soil nutrient levels and second, the response to applied fertilizer is influenced by the magnitude and distribution of rainfall. The assumptions of the model specified are as follows:

a. Autumn rainfall influences primarily the crop response to applied phosphate (P).

b. Spring rainfall influences primarily the crop response to applied nitrogen (N).

c. Soil nutrients influence the response to applied fertilizer. This is simplified as NA influencing response to N only and PA influencing P only.

d. In order to avoid increased multicollinearity, the effects in a-c are assumed to be manifested in the linear terms only.

e. The four environmental variables have direct effects influencing average yields.

The model specified is then:

$$\begin{aligned} y = {} & a + bN + cP = dNP + eN^2 + fP^2 \\ & + R1 + R1P + RX + RXN \\ & + NA + NAN + PA + PAP + u \end{aligned} \qquad (3)$$

Ordinary least squares (OLS) estimation of the regression yields the following:

$$\begin{aligned} y = {} & \underset{a}{-912} + 2.04N + \underset{a}{8.61P} + \underset{a}{0.054NP} - \underset{c}{0.061N^2} - \underset{a}{0.047P^2} \\ & + \underset{a}{5.67R1} + 0.016R1P + \underset{a}{12.43RX} + \underset{a}{0.059RXN} \\ & + \underset{b}{8.94NA} - \underset{a}{0.269NAN} + \underset{a}{47.92PA} - \underset{a}{0.648PAP} \end{aligned}$$

$$\text{Adjusted } R^2 = 0.59 \qquad n = 1184 \qquad (4)$$

Significance levels of the coefficients (used throughout the text) are indicated as follows; $a: p \le 0.01$, $b: 0.01 < p \le 0.05$, $c: 0.05 < p \le 0.1$.

The estimated regression in (4), pooling data from three seasons and 37 sites with the fallow-barley crop sequence accounts for nearly 60 percent of the variation in grain yields. The regression appears to provide acceptable estimates in that:

a. The responses to N and P appear to behave well within reasonable ranges of the environmental variables, i.e., first order partial derivatives are positive and second order partial derivatives are negative.

b. The effects of increased rainfall are positive.

c. The effects of soil nutrients are positive at low levels of fertilizers but become negative at higher levels due to "e" below.

d. Interactions between rainfall and applied fertilizer are positive.

e. Interactions between applied and soil available nutrients are negative.

The model in (4) is useful in so far as it is used to make predictions. Such a pooled regression, using information from a wide range of environmental variable values, increases the statistical efficiency of the estimates. It can be used for predictive purposes for given values of the environmental values. Below, some exercises will be presented for this approach. For a given environment, represented by average or hypothetical values of the environmental variables, these values will be substituted into (4) to obtain predicted response surfaces of the specification in (1). The significance of the coefficients in the predicted response surfaces is determined through tests on the linear combinations of coefficients in (4).

## III. Predicted Response Surfaces for Different Soil Nutrient Levels

A possible grouping is based on soil nutrient levels of NA and PA. Matar, et al. (1988) indicate that beyond critical levels of NA or PA, response to applied N or P, respectively, is quite flat. Hence, it is worthwhile to assess response surfaces with data sets partitioned along different values of soil nutrients.

The grouping used in this study is as follows in parts per million:

| | | PA (ppm) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 |
| | 5 | 1 | 4 | 7 | 10 | 13 |
| NA (ppm) | 10 | 2 | 5 | 8 | 11 | 14 |
| | 15 | 3 | 6 | 9 | 12 | 15 |

The number in each cell indicates the soil nutrient level group number. For each group predicted response surfaces are derived from (4) for two sets of rainfall variables as follows:

| | R1 (mm) | RX (mm) |
|---|---|---|
| High Rainfall: | 140 | 115 |
| Low Rainfall: | 117 | 91 |

Syria is divided into agricultural stability zones according to the amount and distribution of rainfall. The definitions can be found in SAR (1980). There is an approximate correspondence between the high rainfall values of R1 and RX and the average values of those variables observed in the trials in the agricultural stability Zone 2. Similarly, there is a correspondence between the low rainfall values and Zone 3.

Hence, 30 predicted response surfaces are derived. For each response surface, optimum N (OPN) and $P_2O_5$ (OPP) levels are calculated in kg/ha for the relative price set of (3,3). In other words the price of each fertilizer is three times that of barley grain. These optimum input levels are illustrated in Table 1. In this table, the following are also indicated:

YIELD: Predicted barley grain yield at the optimum (kg/ha)

Δ YIELD: Predicted yield difference between the optimum and the no fertilizer level (kg/ha)

Δ NR: Increase in net revenue due to yield increase with fertilizer, expressed in barley grain equivalents (kg/ha)

COST: Cost of optimum fertilizer input levels,

TABLE 1 Characteristics of optima in different soil nutrient groups

| Group | OPN | OPP | YIELD | ΔYIELD | ΔNR | COST | MBC |
|---|---|---|---|---|---|---|---|
| HIGH RAINFALL | | | | | | | |
| 1 | 90 | 121 | 2682 | 1232 | 476 | 632 | 75 |
| 2 | 75 | 112 | 2546 | 1050 | 382 | 563 | 68 |
| 3 | 61 | 104 | 2529 | 889 | 308 | 493 | 62 |
| 4 | 82 | 102 | 2555 | 1008 | 354 | 554 | 64 |
| 5 | 67 | 94 | 2429 | 838 | 270 | 484 | 56 |
| 6 | 52 | 86 | 2324 | 688 | 204 | 414 | 49 |
| 7 | 74 | 84 | 2451 | 809 | 253 | 475 | 53 |
| 8 | 59 | 76 | 2336 | 649 | 179 | 405 | 44 |
| 9 | 45 | 67 | 2242 | 510 | 123 | 336 | 37 |
| 10 | 66 | 66 | 2371 | 633 | 174 | 396 | 44 |
| 11 | 51 | 57 | 2267 | 484 | 110 | 326 | 34 |
| 12 | 36 | 49 | 2183 | 356 | 63 | 257 | 25 |
| 13 | 58 | 48 | 2314 | 481 | 115 | 317 | 36 |
| 14 | 43 | 39 | 2222 | 343 | 61 | 247 | 25 |
| 15 | 28 | 31 | 2148 | 225 | 25 | 178 | 14 |
| LOW RAINFALL | | | | | | | |
| 1 | 72 | 106 | 2000 | 978 | 344 | 467 | 61 |
| 2 | 58 | 98 | 1999 | 821 | 272 | 398 | 58 |
| 3 | 43 | 90 | 1795 | 684 | 218 | 458 | 55 |
| 4 | 64 | 88 | 1891 | 773 | 238 | 388 | 52 |
| 5 | 50 | 80 | 1789 | 627 | 176 | 317 | 45 |
| 6 | 35 | 71 | 1708 | 500 | 132 | 379 | 41 |
| 7 | 56 | 70 | 1805 | 592 | 154 | 309 | 41 |
| 8 | 41 | 62 | 1715 | 456 | 101 | 240 | 33 |
| 9 | 27 | 53 | 1644 | 341 | 67 | 300 | 28 |
| 10 | 48 | 52 | 1744 | 434 | 91 | 230 | 30 |
| 11 | 33 | 43 | 1664 | 309 | 48 | 161 | 21 |
| 12 | 19 | 35 | 1604 | 205 | 24 | 221 | 15 |
| 13 | 40 | 34 | 1705 | 300 | 49 | 151 | 22 |
| 14 | 25 | 25 | 1636 | 186 | 16 | 82 | 11 |
| 15 | 11 | 17 | 1587 | 92 | 1 | | 2 |
| HIGH RAINFALL | 56 | 84 | 2339 | 694 | 204 | 421 | 48 |
| LOW RAINFALL | 40 | 72 | 1725 | 519 | 134 | 333 | 40 |

OPN=Optima N; OPP=Optima P;
Yieldl=Predicted barley grain at the optimum (kg/ha);
ΔYield=Predicted yield difference between optimum and control (kg/ha);
ΔNR=Increase in net revenue (kg barley/ha)Cost=Cost of optimum fertilizer input levels (in barley grain,kg/ha)
MBC=Marginal benefit cost ratio $\left(\frac{\Delta NR}{Cost}\right) \times 100$

expressed in barley grain equivalents (kg/ha)

MBC: The marginal benefit cost ratio, i.e. (NR/COST) x 100, expressed as percentage.

According to the specification, as soil nutrient levels increase, optimum input levels, increases in yield and net revenue due to fertilizer as well as marginal benefit cost ratios decrease. In fact, given risk factors, at high levels of soil nutrients, the rates of return may not be adequate to justify fertilizer use.

In order to assess the value of soil information we shall go through a counterfactual exercise. First, we assume that the model estimated in (4) is as accurate a representation of response relations with the given data. If a second model is estimated without soil nutrients, we obtain

$$y = -\underset{a}{637} - 1.27N + \underset{a}{6.29P} + \underset{a}{0.054NP} - 0.061N^2 - \underset{a}{0.047P^2}$$

$$+ \underset{a}{5.98R1} + 0.012R1P + \underset{a}{12.56RX} + \underset{a}{0.057RXN}$$

$$\text{Adjusted } R^2 = 0.59 \qquad n = 1184 \quad (5)$$

The implicit optimality conditions are then constant for each soil nutrient group and are presented at the bottom of Table 1 for average rainfall conditions. What would happen if these latter input levels are recommended is given in Table 2. In other words, we substitute the optimum input levels for the high and low rainfall levels into the predicted surface for each soil nutrient group based on the estimation in (4).

The last two columns in Table 2 provide an estimate of the yield and net revenue losses per hectare (in barley equivalents) that arise due to using average recommendations instead of recommendations specific to each soil nutrient group. The net revenue losses vary from 1 to 116 kg/ha of barley in Zone 2 and from less than 1 to 39 kg/ha in Zone 3.

The next step is to generalize for Zones 2 and 3. For this, a distribution of soil nutrients is necessary for barley areas. This is not readily available, hence we shall use the distribution observed in the trial. This is apparently not too bad an approximation, but one should remember that it is just that. Comparing the results with respect to soil phosphorus only, we use the data from Somel, _et al_. (1984). The two distributions are given in Table 3 which indicates that there are deviations between the two but the patterns are similar.

TABLE 2 Predictions based on average rainfall values and without soil nutrient information

| GROUP | OPN | OPP | YIELD | ΔYIELD | ΔNR | COST | MBC | YIELD LOSS | NET REVENUE LOSS |
|---|---|---|---|---|---|---|---|---|---|
| HIGH RAINFALL | | | | | | | | | |
| 1 | 56 | 84 | 2402 | 952 | 437 | 420 | 104 | 280 | 39 |
| 2 | 56 | 84 | 2372 | 876 | 369 | 420 | 88 | 174 | 13 |
| 3 | 56 | 74 | 2343 | 801 | 301 | 420 | 71 | 88 | 6 |
| 4 | 56 | 84 | 2389 | 843 | 339 | 420 | 82 | 165 | 15 |
| 5 | 56 | 74 | 2359 | 767 | 271 | 420 | 64 | 71 | 1 |
| 6 | 56 | 84 | 2328 | 692 | 203 | 420 | 47 | -6 | 1 |
| 7 | 56 | 84 | 2377 | 734 | 241 | 420 | 57 | 75 | 12 |
| 8 | 56 | 84 | 2346 | 659 | 173 | 420 | 41 | -10 | 6 |
| 9 | 56 | 84 | 2315 | 583 | 105 | 420 | 25 | -73 | 18 |
| 10 | 56 | 84 | 2364 | 625 | 143 | 420 | 34 | 8 | 31 |
| 11 | 56 | 84 | 2333 | 550 | 75 | 420 | 18 | -66 | 35 |
| 12 | 56 | 84 | 2302 | 474 | 7 | 420 | 02 | -118 | 56 |
| 13 | 56 | 84 | 2351 | 517 | 45 | 420 | 11 | -36 | 70 |
| 14 | 56 | 84 | 2316 | 441 | -23 | 420 | -5 | -98 | 84 |
| 15 | 56 | 84 | 2289 | 366 | -91 | 420 | -22 | -139 | 116 |
| LOW RAINFALL | | | | | | | | | |
| 1 | 40 | 72 | 1740 | 717 | 310 | 336 | 92 | 260 | 8 |
| 2 | 40 | 72 | 1730 | 664 | 261 | 336 | 78 | 158 | 11 |
| 3 | 40 | 82 | 1721 | 610 | 213 | 336 | 63 | 74 | 5 |
| 4 | 40 | 72 | 1742 | 624 | 226 | 336 | 67 | 149 | 12 |
| 5 | 40 | 72 | 1733 | 570 | 176 | 336 | 53 | 56 | 0 |
| 6 | 40 | 72 | 1724 | 516 | 129 | 336 | 38 | -25 | 3 |
| 7 | 40 | 72 | 1745 | 531 | 142 | 336 | 42 | 81 | 12 |
| 8 | 40 | 72 | 1736 | 477 | 93 | 336 | 28 | -21 | 5 |
| 9 | 40 | 72 | 1726 | 423 | 45 | 336 | 13 | -82 | 22 |
| 10 | 40 | 72 | 1747 | 438 | 58 | 336 | 17 | -3 | 33 |
| 11 | 40 | 72 | 1738 | 324 | 9 | 336 | 3 | -74 | 39 |
| 12 | 40 | 72 | 1729 | 330 | -39 | 336 | -12 | -125 | 36 |
| 13 | 40 | 72 | 1750 | 344 | -26 | 336 | -8 | -45 | 57 |
| 14 | 40 | 72 | 1741 | 291 | -74 | 336 | -22 | -105 | 38 |
| 15 | 40 | 72 | 1732 | 237 | -123 | 336 | -37 | -855 | 38 |

Using the percentage distribution in the low rainfall group for Zone 3 and the high rainfall group for Zone 2, the average net revenue loss equals 19 kg/ha of barley in Zone 2 and 9 kg/ha of barley in Zone 3. While these figures are small on a per hectare basis they add up to a considerable amount. Between 1979-82, the average rainfed barley land in Zone 2 was around 310 th.ha and in Zone 3 around 290 th.ha. This would imply a total of 5.9 th.tons in Zone 2 and 2.6 th.tons in Zone 3 adding to around 8.5 th.tons in net revenue loss for both zones. The net revenue loss is defined as the loss due using the average blanket fertilizer recommendations instead of recommendations based on soil nutrient groups. Using a conservative estimate of around $150/ton c.i.f. in the elevated price environment of today, the net revenue loss would equal $1.3 million of value added per year.

## IV. CONCLUSIONS

This study has demonstrated the use of pooled analysis to produce predicted response surfaces. This approach, which uses each site/season as a "state of the environment" allows pooling the data which leads to more efficient use of the information statistically.

Based on this approach, the value of soil information was tentatively estimated to be worth $1.3 million per year for Zones 2 and 3.

TABLE 3 Percentage distribution of soil phosphorus groups (P-Olsen, ppm)

| | Soil Phosphorus Groups (P-Olsen, ppm) | | | | |
|---|---|---|---|---|---|
| | 1-3 | 3-5 | 5-7 | 7-9 | 9+ |
| <u>Zone 2</u> | | | | | |
| Present Study | | 21 | 47 | 18 | 69 |
| Somel, et al. | 25 | 27 | 25 | 8 | 15 |
| <u>Zone 3</u> | | | | | |
| Present Study | 24 | 45 | 25 | 0 | 0 |
| Somel, et al. | 10 | 49 | 27 | 4 | 10 |
| <u>Total</u> | | | | | |
| Present Study | 23 | 46 | 24 | 3 | 4 |
| Somel, et al. | 18 | 38 | 26 | 6 | 12 |

Sources: SAR-MAAR-SD/ICARDA-FRMP (1985, 1986, 1987), Somel, et al. (1984).

The results once again demonstrate in an unequivocal way that fertilizer use on rainfed barley is a profitable option for farmers as well as the national program which can meet its increasing feed demand from increased domestic barley production. Further study is warranted, using pooled analysis with calendar interval rainfall data, to produce yield and profit probability distributions based on optimum input levels and rainfall probability distributions. This would allow an assessment of risk both for the farmer and the country. Risk is a critical factor in fertilizer use on barley due to high variability of rainfall, and pooled models can be used in analysing risk for example with the stochastic dominance approach.

**ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the contribution of E. Jabbour, A.K. Joumaa, P. Cooper, D. Keatinge, M. Jones, H. Harris, A. Mazid, A. Wahbi and many research associates in the SAR-MAAR-SD/ICARDA-FRMP Collaborative Project on Fertilizer Use on Barley in Northern Syria. Secretarial assistance of Ms. K. Artinian and computational assistance of Ms. M. Erskine are also gratefully acknowledged. The views presented in this paper belong only to the authors and do not implicate any person or organization.

**REFERENCES**

Cooper, P.J.M. (1984). The Effect of Fertilizer on Water Use and Water Use Efficiency of Barley in Dryland Regions, in SAR-MAAR-SD/ICARDA (1984), 193-204.

Matar, A.E., E. Jabbour and K. El-Hajj (1988). Prediction of Barley Response to Fertilizers by Means of Soil Nitrogen and Phosphorus Tests. In: Matar et al (Editors). Second Regional Workshop on Soil Test Calibration Proc.: p 12-23. Ankara 1-6 September 1987, Turkey.

Ryan, J.G. and R.K. Perrin (1974). Fertilizer Response Information and Income Gains: The Case of Potatoes in Peru. AJAE, May 1974, 337-343.

SAR - Syrian Arab Republic (1980). Statistical Abstract, 1980. Damascus.

SAR-MAAR-SD/ICARDA-FRMP (1985) (1986) (1987) (1988). Annual Report on Cooperative Research on Fertilizer Use on Barley in N. Syria. Aleppo, Syria.

Somel, K. (1987). Analytical Options for the Soils Directorate/FRMP Multiple Season On-Farm Trials on Fertilizer Use on Rainfed Barley in Northern Syria. ICARDA/FRMP, Aleppo.

Somel, K. (1984). Environmental Variability and Multiple Site-Multiple Season Trials. ICARDA/FSP Discussion Paper No. 12, Aleppo.

Somel, K., A. Mazid and M. Hallajian (1984). Survey of Barley Producers, Northern Syria, 1981/1982. Volume II, Descriptive Statistics, FSP Research Report 12-II, ICARDA, Aleppo.

# PROTOCOL FOR COOPERATIVE SOIL TEST CALIBRATION IN LIMITED RAINFALL ZONES

**A. Matar, ICARDA, Syria; and J. Ryan, MIAC, Morocco**

This paper is written as a guideline for a regional soil test calibration study in limited winter rainfall areas (200-500 mm) of West Asia and North Africa. In arid and semi-arid regions, nitrogen and phosphorus are usually the main nutrients limiting crop yields; here we concentrate on these two nutrients. The strategy of researchers in limited rainfall areas should be to maximize yield per unit of precipitation. Research results show that using optimum rates of fertilizers increases yields and water-use efficiency and, consequently, income of farmers. To establish the optimum rate, one can conduct soil tests and calibrate them with crop responses; such studies require a team of scientists with laboratory and field experience, and an adequate budget. For this, regional cooperation is essential.

## SITE SELECTION

In soil test calibration, researchers interpret results of soil tests and fertilizer trials, and use them for predicting fertilizer requirements of crops. The objective is to transfer results from the experimental sites to farmers' fields. To increase the probability of success, they must seek maximum variation among sites and minimum variation within sites; they must select:

(i) On-farm sites with soil types that are extensive and agriculturally important.

(ii) Rainfall zones representative of important agroecological areas in the region.

(iii) Soils with a wide range of the nutrients under study.

(iv) Rotations commonly used by farmers, and

(v) Accessible locations for trials.

Researchers should also cooperate with soil taxonomists and request classification of soils at the family level. The new U.S. system for soil Taxonomy should be used to classify soils, if not countrywide, at least for the experimental soils. Taxonomic names should also be given in other systems, if available. The U.S. system integrates information on soil organization (horizons), soil physical and chemical properties, and soil climate (moisture and temperature). Therefore, its use increases the probability of success for the transfer of results from the experimental site to farms with the same soil type.

The best way to ensure uniformity within a site is to inspect crop growing on it: height, density, and appearance. By use of simple colormetric tests for $NO_3$ and P, researchers can determine a soil test level to ensure a wide range of nutrient availability between sites and nutrient homogeneity within each site. The on-field tests expedite site selection.

## EXPERIMENTAL TREATMENTS AND DESIGN

Three types of experiments are recommended for the 200-500 mm rainfall zone: single nutrient experiments for calibrating N and P soil tests and placement experiments for comparing the efficiency of banding and broadcasting P. In many countries of this region farmers cannot band fertilizers because they do not have seed drills. Therefore, for recommendations on rate and time of fertilization with P, one needs calibration data for both methods of P application.

## PHOSPHORUS TRIALS ON WHEAT, BARLEY OR FOOD LEGUMES

### OBJECTIVE

To determine field responses of the common local varieties of wheat, barley or food legume crops to P fertilizer in relation to measured environmental conditions (rainfall, soil type, depth, and fertility level) as a basis for calibrating soil P tests.

### SOIL TYPE

The experimental sites should include at least one common soil type with a high yield potential (deep soil) representative of a large agricultural area. The soil profile should be described for each soil type used, or, if, possible, for each experimental site. If possible, trial sites should also include (i) a soil of medium depth and (ii) a soil of shallow depth. Experiments should be sited on land under at least two different rotations, for instance, wheat following cereals, legumes, fallow, or summer crops. The level of P, tested by the Olsen method, should be less than 7 ppm at a majority of sites. Few sites, if any, should have high P (i.e., more than 10 ppm).

## FERTILIZERS

Suggested rates in all areas of 0, 20, 40, and 80 kg $P_2O_5$/ha and a blanket application of 60 kg N/ha for cereals and 20 kg N/ha for food legumes were used. Ammonium nitrate and concentrated superphosphate are recommended. Nitrogen should be broadcast and incorporated. Phosphorus should be banded or broadcast with incorporation. The placement method should reflect the local practice in each area. All fertilizers should be applied before or at planting time.

## EXPERIMENTAL DESIGN

Different rates of P should be distributed in a randomized complete block design with three to four replications.

# NITROGEN TRIALS ON WHEAT OR BARLEY

## OBJECTIVE

To determine the field responses of common local wheat and barley varieties to N fertilizer in relation to measured environmental conditions (rainfall, soil type and depth, and fertility level), as a basis for calibration of soil tests for N.

## SOIL TYPE

The experimental sites should include at least one common soil type with a high yield potential (deep soil), representative of a large agricultural area. The soil profile should be described for each soil type used or, if possible, for each experimental site. If possible, the sites should also include (i) a soil of medium depth and (ii) a soil of shallow depth. Experiments should be sited on land under at least two different rotations, for instance, wheat following cereals, legumes, fallow, or summer crops.

## FERTILIZERS

Suggested rates in areas where rainfall is more than 300 mm are 0, 40, 80 and 120 kg N/ha, applied as ammonium nitrate, and in areas where rainfall is less than 300 mm are 0, 20, 40 and 60 kg. A blanket application of 60 kg $P_2O_5$/ha is applied in all areas as triple superphosphate. Nitrogen should be broadcast and incorporated. The placement method should reflect the local practice in each area. All fertilizers should be applied before or at planting time.

**EXPERIMENTAL DESIGN**

Different rates of N should be distributed in a randomized complete block design with three to four replications.

## PHOSPHORUS RATE AND APPLICATION METHOD FOR WHEAT OR BARLEY

**OBJECTIVE**

To compare the response of wheat (or barley) to banded and broadcast P fertilizer, using the most common local wheat (or barley) variety where, at present, farmers do not band P fertilizers.

**SOIL P TESTS**

The sites should have low available P, preferably less than 5 ppm when tested by the Olsen method. They should include important soil types in the area.

**FERTILIZERS**

Five levels of $P_2O_5$ are recommended: 0, 20, 40, 80 and 120 kg, with a blanket rate of 60 kg N/ha. Concentrated superphosphate and ammonium nitrate are recommended. Banding is to be compared with broadcasting followed by incorporation as methods of placement. Fertilizers should be applied before or at planting time, with the times of application being as close as possible for the two placement methods.

**EXPERIMENTAL DESIGN**

A complete factorial combination is recommended with P rates and placement methods in a randomized complete block design with four replications.

## PHOSPHORUS TRIAL ON FOOD LEGUMES (OPTIONAL)

A similar experiment could be carried out on food legumes in countries that have the resources. The only modification would be in the blanket N rate of 20 kg, rather than 60 kg N/ha. Four levels of P are recommended; 0, 40, 80 and 120 kg $P_2O_5$/ha with at least three replicates. This should be broadcast and incorporated before planting or drilled with the seed. The experimental design would be a complete randomized block.

## EXPERIMENTAL PROCEDURES

### FIELD OPERATIONS AND PLOT SIZE

Seedbeds should be carefully prepared to facilitate uniform seedling emergence, using whatever implements are available locally. Plot size is at the discretion of the scientists, but there are risks of edge effects if unplanted spaces are left between plots, or if plots are very narrow and the implements used throw or drag fertilized soil across plot boundaries. A minimum width of 2 m or six rows, whichever is wider, is suggested. Seeding rate should be about 100-150 kg/ha at a row spacing common locally.

For the broadcast treatment, fertilizers should be applied to the soil surface and then incorporated. During incorporation care must be taken to prevent plot-to-plot contamination. This can be accomplished by disking at low speed across the treatment plots. Seed should be drilled and, in the banded treatment, the P fertilizer drilled with the seed. Measures to control insects, diseases, and weeds should be taken so that results do not become confounded.

### SOIL SAMPLING AND ANALYSIS

Rainfall measurements should be taken on a daily or weekly basis. If possible, soil moisture in the profile (0-120 cm) should be measured at least three times during the season, once before planting, once at flowering, and once after harvest. For testing for available soil P and N, soil samples must be taken before fertilizer application and planting, preferably before the first rains of the season. Four soil cores to a depth of 120 cm (if possible) or at least 60 cm should be divided into 20-cm increments by depth. If subsoil is moist, they should be placed in sealed plastic bags in an ice chest and transported to the laboratory. Soils should then be spread on brown paper, air dried, and subsequently analyzed for pH, organic matter (OM), cation exchange capacity (CEC), P, K, $NO_3$-N, $NH_4$-N, lime, and texture.

For pH, EC, K, lime, and texture measurements, we suggest samples be bulked to one per field replicate for each depth. For $NO_3$-N determination, use a water-$CaCl_2$ extract. For $NH_4$-N, use 2 M KCL. For P, use the Olsen method. Make other determinations according to standard methods: pH of saturated paste, OM by the Walkley-Black method, EC of the saturated extract, K by IN-$NH_4$ AC, lime by the acid-neutralization method and texture by the hydrometric method. These methods, except acid neutralization, are given in Methods of Soil Analysis (Agron. 9 1965 or 1982 Amer. Soc. Madison, Wisc.)

## PLANT SAMPLING AND ANALYSIS

Grain and straw yields at maturity are essential; measurements of 1000-grain weight and of grain and straw N and P contents are highly recommended. Other, optional measurements are:

1. At the end of tillering, but before jointing, plant samples from 1 m of two middle rows: dry each sample at 65-70°C and determine its dry weight and N and P composition.

2. At anthesis, the same sampling as at tillering.

3. At maturity, determine the number of heads per unit area; separate samples (at least 20 heads per plot) are needed to determine the number of grains per head.

4. Dates of emergence, tillering, heading and physiologic maturity should be recorded.

## INTERPRETATION

Analysis of variance and regression analysis will be used for the data. Initially, the Cate-Nelson graphical method is used for P; Mistcherlich, and quadratic methods will be used for estimates of critical levels. For N, models will be developed to relate fertilizer requirement to yield, inorganic N in the profile, N mineralization potential of OM, and previous crop. Soil N and P availability will also be determined by extrapolation of the linear part of N and P uptake at anthesis (or at maturity if anthesis samples were not obtained) vs. fertilizer rates and inorganic N in the check plots to the x axis.

## SAMPLE STANDARDIZATION

## SOIL SAMPLING STUDIES

Soils from farms should be sampled on a grid system to determine sampling distribution of organic matter, $NO_3$, P, etc. Based on the results of this kind of study, strategies for sampling should be devised. We suggest first that the soil test data from N and P trial sites be analyzed.

## QUALITY CONTROL FOR LABORATORIES

We suggest that at least two plant and two soil samples from each participating country be sent to other laboratories within this group for analysis and comparison of results. ICARDA will coordinate the transfer of soil and plant samples to various laboratories in the region.

## ANNUAL MEETINGS

At the end of each experimental season, data will be analyzed by scientists who conducted the experiments. Every year a soil test calibration workshop will be held in a different country in the region to compare results and to develop recommendations. As more information is obtained, the recommendations will be updated until a reasonable degree of accuracy is achieved. Papers submitted for presentation at each workshop will be edited and published by ICARDA prior to the subsequent meeting.

## List of Participants

| | |
|---|---|
| **Jordan** | |
| Dr. Fayez Kasawneh | Faculty of Agriculture, Dean<br>University of Science and Technology, (JUST)<br>Irbid |
| Dr. Zahir Rawajfeh | " " " |
| Dr. Sudki Kader | Department of Soil and Irrigation<br>Faculty of Agriculture, University of<br>Jordan, Amman |
| Dr. Sayed Kattari | " " " |
| Dr. Ibrahim Ghawi | " " " |
| Dr. Butros Hattar | " " " |
| Dr. Taleb Abu Sharar | " " " |
| Mr. Naji Haddadin | National Center for Agricultural Research<br>and Technology Transfer (NCARTT),<br>P.O. Box 226, Amman |
| Mr. Nazeem Abu Rub | " " " |
| Mr. Talal El-Ashhab | " " " |
| Dr. Kareem El-Rabadi | " " " |
| Dr. Samir Salti | " " " |
| Mr. Zakaria El-Wadi | " " " |
| Mr. Abdel Nabi Fardous | " " " |
| Mr. Rajib Shammout | " " " |
| Miss. Iman Husseini | " " " |
| Miss. Rima Khammash | " " " |
| Miss. Sawsan Al Fayez | " " " |
| **Turkey** | |
| Dr. Necdet Yurtsever | Soil and Fertilizer Research Institute<br>P.O. Box 54, Yenimahalle, Ankara |
| **Cyprus** | |
| Dr. Panayotis I. Orphanos | Agricultural Research Institute, Nicosia |
| **Morocco** | |
| Dr. John Ryan | Aridoculture Center, (MIAC)<br>Mid America International and Agricultural<br>Consortium, BP 290, Settat |
| Dr. Mohamed Abdel Monem | " " " |
| Mr. Mohamed El-Gharous | " " " |
| Mr. Amar Boujomaa | World Phosphate Institute,<br>Angle Route d'el Jadida et Blvd de la<br>Grande Ceinture, B.P. Maarif 5196<br>Casablanca |
| **Pakistan** | |
| Dr. Abdul Rashid | Land Resources Section,<br>National Agricultural Research Center,<br>Park Road, Islamabad |
| Dr. Rohul Amin | Barani Agric. Research and Development |

| | |
|---|---|
| | Project (BARD), Park Road, NARC, Islamabad |
| **Yemen Arab Republic** | |
| Dr. Hadi Said Saaed | Soil and Water Department, Agric. Res. Authorities, ARA, P.O. Box 5788, Taiz |
| **Tunisia** | |
| Dr. Tounsi Laroussi | Office des Cereales, 30 rue Alain Savary, Tunis |
| Dr. Gharbi Azaiez | Ecole Superieure d'Agriculture du Kef, 15 Rue 6486, Cite Romana Medjerda, Le Bardo 2000, Tunis |
| **Iraq** | |
| Dr. Mohammed Said Berigari | Soil and Land Reclamation Dept., Scientific Research Council, P.O. Box 2416, Baghdad |
| **Syria** | |
| Dr. Khaldoun El-Dermoush | Faculty of Agriculture, University of Aleppo, Aleppo |
| Mr. Khazza El-Hajj | Soils Directorate, Ministry of Agriculture and Land Reform Damascus |
| **ICARDA** | |
| Dr. Abdallah Matar | P.O. Box 5466, Aleppo |
| Dr. Mustafa Pala | " " " |
| Dr. Michael Jones | " " " |
| Dr. Ammar Wahbi | " " " |
| Ms. Sonia Garabet | " " " |

المركز الدولي للبحوث الزراعية في المناطق الجافة
ايكاردا
ص. ب. 5466 ، حلب ، سورية

INTERNATIONAL CENTER FOR AGRICULTURAL
RESEARCH IN THE DRY AREAS
ICARDA, P.O. Box 5466, Aleppo, Syria

ICARDA-167 En/700/Apr 199