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Soil Test Calibration in West Asia and North Africa

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Foreword

Currently, many farmers in the ICARDA region (West Asia and North Africa) use N and P fertilizers but have little information on which to base their decisions on how much to apply. The result is that many of the soils receive more fertilizer than can be used by the crop, and the unused portion is either lost or accumulated in the soil. For example, in some soils that have been fertilized yearly at rates recommended by agricultural ministries, the available phosphorus determined by the Olsen test has risen to about two or three times the amount needed for maximal yields of wheat, according to studies to date. Bringing the application rates more in line with crop requirements could save hundreds of thousands of tonnes of fertilizer each year.

The International Center for Agricultural Research in the Dry Areas is currently cooperating with countries in West Asia and North Africa that wish to improve the criteria they use for recommendations on fertilization with nitrogen and phosphorus. At present, Cyprus, Jordan, Morocco, Pakistan, Syria, and Turkey are participating in the network and have been undertaking fertilizer trials -- primarily with barley and wheat but also legumes -- for use in the calibration of soil tests. The aim is to accumulate data on crop responses to fertilizer in dry areas on as many different agricultural soils as possible to provide reliable information on which to base recommendations to farmers on the correct rates of N and P that would adequately supply the nutrients needed by specific crops for economically optimal yields.

The network has been in place for 2 years, and representatives from the countries met in the period 1-6 September 1987 to discuss progress and compare results to date. Algeria, Tunisia, and Iran, which are considering participation, also sent representatives, and several soil specialists from outside the region attended. The meeting was held in Ankara, Turkey, and was the second in the series on soil test calibration in the region (Soltanpour 1987). The presentations clarified relationships between soils, nutrients (applied and residual), rainfall, and crops and suggested some practical methods for determining fertilizer requirements on farms with and without soil tests. Because of the remarkable similarities in findings and the potential savings in fertilizer, the papers are being prepared for wider distribution in this publication. The data on critical levels of soil phosphorus and the interactions with fertilizer responses are encouraging. Participants felt that a technical paper summarizing the data would produce useful initial guidelines for planners and users. On behalf of the regional network on soil test calibration, ICARDA will prepare a text, incorporating new results from the ongoing trials, for publication in 1989.

At the meeting in Ankara, the program of work for 1987-88 in the network was updated, and participants recommended that national scientists survey fertility levels in the major soil groups in their countries for regional comparisons.

The prospects for the network are promising and the studies it is undertaking have implications for all countries in the region and to their farming communities. The findings reported in this publication are considered of such quality and importance as to justify continued support for the network.

ICARDA offers grateful thanks to the Government of Turkey for hosting the meeting on soil test calibration and to Dr Nezmi Ulgen (Director of Soil and Fertilizer Research Institute) and his staff for the excellent arrangements they made. The support of Dr Nezmi Demir (Deputy Under Secretary of Agriculture and Member of ICARDA's Board of Trustees) was invaluable.

Thanks are also due to the Steering Committee: Drs Parvis Soltanpour, Morocco; Karl Harmsen, Holland; Necdet Yurtsever, Turkey; and Abdallah Matar, ICARDA, whose effort and hard work ensure the continuing success of the network.

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Executive Summary and Conclusions

A recent regional workshop on soil test calibration brought together 27 participants representing 12 countries to discuss the results of research based on a common experiment design. The research of the network was initiated because fertilizer is being applied almost universally in the region but little is known about nutrients available in the soil, the changes in nutrient status brought about by residual fertilizer, or the levels of nutrients that are needed to produce economically optimal yields of the crops. For instance, in several of the countries participating in the network, the Olsen test is used routinely to determine the amount of available P in the soil, but the utility of the information has been limited because researchers have been uncertain what levels of P were needed by the crops.

The meeting, which was held in Ankara, Turkey, 1-6 September, was the second in a series; the first, which took place at ICARDA in June 1986, established the guidelines for joint experiments and formed a network of participating countries to investigate fertilization of rainfed crops. The goal of the network is to determine the nitrogen and phosphorus requirements of crops grown on soils in West Asia and North Africa.

Participants -- staff from ICARDA and institutes of the region, and soil experts from Holland, USA, and Canada -- reported on their findings mainly those relating to correlations between $NaHCO_3$-extractable P in the soil and responses by barley and wheat to applications of fertilizer. Their reports clearly reflected the key role played by the two cereal crops in the region and highlighed the P-deficient status of most unfertilized agricultural lands. Complementing these reports were studies on response of food and forage legumes to phosphorus fertilization on soils in the region and on correlations between the Olsen method of extracting P ($NaHCO_3$) and other cheaper and less time-consuming methods. Seven contributions dealt with the response of cereals to nitrogen fertilization and related the findings to the tests for mineral and nitrate N in the soil.

The experimental data from the network enabled the participants to classify soils, according to whether cereals and legumes could be expected to respond to applications of phosphate fertilizer. This classification is based on values obtained by the Olsen test of surface soil samples (0-20 cm); it provides a basis for preliminary recommendations on fertilization with P:

* < 5 ppm, add about 60 kg P_2O_5/ha;
* 6-10 ppm, add 30-40 kg P_2O_5/ha; and
* > 10 ppm, plant seed without adding P.

Recommendations such as these can be further refined, and should result in better allocation of phosphate fertilizer and major savings to the farmers and agricultural departments in the region. The potential is clear from recent soil tests at ICARDA which revealed that a large portion of soils fertilized and cropped regularly in Syria now have residual levels of P equivalent to > 10 ppm. Similarly, in Tunisia, tests of vertisols indicate current levels of P exceeding 15 ppm. Halting or reducing applications of phosphate now until they are again needed will not only result in net savings in fertilizer but also protect the crop against deficiencies known to be induced by excess phosphate -- such as in zinc, manganese, and sometimes iron.

Work in Turkey and Pakistan also shows good correlation between the Olsen test and Bray and Kurtz-1, Mehlich 3, and ammonium bicarbonate-DTPA. The potential, clearly, exists for countries to use soil extractants other than $NaHCO_3$.

Preliminary findings from studies of nitrogen application on wheat and barley in the region indicate that tests for mineral and nitrate-N are correlated with levels of nitrogen in grain and total biological yields. The critical level of nitrate-N in the top 0-60 cm of the soil appears to be 50-60 kg/ha. Efforts are under way to confirm and extend this information and to develop a model that can be used to estimate the level of nitrogen required by cereal crops, based on rainfall, soil tests, target yields, and possibly other environmental parameters.

Establishment of Fertilizer Recommendations on the Basis of Soil Tests

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Abstract. Developing a basis for fertilizer recommendations involves choosing an effective soil extractant in pot experiments and calibrating soil tests against yield responses to applied nutrient in field experiments. Soils used in pot and field experiments should vary in concentration of the nutrient and in relevant factors affecting plant response. Using the results from experiments and taking into consideration the price ratio of nutrient (fertilizer) to marketable product per unit of weight, one can establish fertilizer rates that are economically optimal for various soil-test classes ranging from low to high fertility. When fertilizer is expensive and not generally used, one may recommend rates that result in a benefit (economic return) to cost ratio of at least 2. When fertilizer use is common and its price moderate, one should recommend rates that increase fertility status (P, K) as well as satisfying the crop's direct needs. In recommendations to farmers, one also must consider the effects of stress factors, like salinity and drought, in relation to fertilizer response. Methods other than soil calibration cannot determine the nutrient status of soils in specific climatic conditions. Plant analysis, for example, is seldom a substitute for soil tests, although some investigators have suggested the use of "critical" tissue levels as a guideline to fertilizer application. Where facilities for soil testing are lacking or soil tests cannot be readily interpreted, the so-called double-pot technique, though largely qualitative, is a useful tool for assessing soil-nutrient availability.

Introduction

The various steps in establishing optimal rates for fertilizer include choosing a soil extractant that provides the best indication of the "available" nutrient in the soil, comparing the available nutrient with the response in yield of crops, and then relating the information to costs of fertilizer and prices for crops. These steps involve plant and soil analyses, pot and field experiments, and attention to the economics of fertilizer inputs and net return on marketable produce. Stress factors affecting crop responses to applied nutrients also must be considered.

Choice of the Soil Extractant

Numerous soil-extraction procedures for assessing "available" nutrients in soil are known, but their effectiveness in reflecting plant uptake under various soil and climatic conditions requires further verification. To choose the most appropriate extractant, one can compare soil-nutrient concentrations against plant uptake (tissue concentration) in pot experiments, the most relevant tests being those that include soils varying widely in concentration of the nutrient studied and also in factors, such as pH, humus, clay, calcium carbonate. Soils are selected in such a way that correlations between soil factors are largely eliminated (van der Paauw 1956). As nutrient concentration changes with physiologic age of the tissue, one must strictly adhere to the sampling procedure. The effect of physiologic age is largely eliminated by adjusting nutrient concentration to a standard nitrogen concentration.

Plotting concentrations of a nutrient in plant tissue against concentrations in soil may yield a curve of best fit like that in **Fig. 1.** The deviations from the curve are plotted against relevant soil factors. Where the regression line indicates deviation to be nil, for example at soil pH a , the deviations can be corrected for pH, such that points with pH > a move upward and those with pH < a downward. The new curve presents the plant x soil nutrient relationship, following elimination of pH effect and valid for pH a . The same procedure is adopted for other relevant soil factors. Eventually, a plant x soil nutrient relationship is obtained that is valid for specific levels of relevant soil factors.

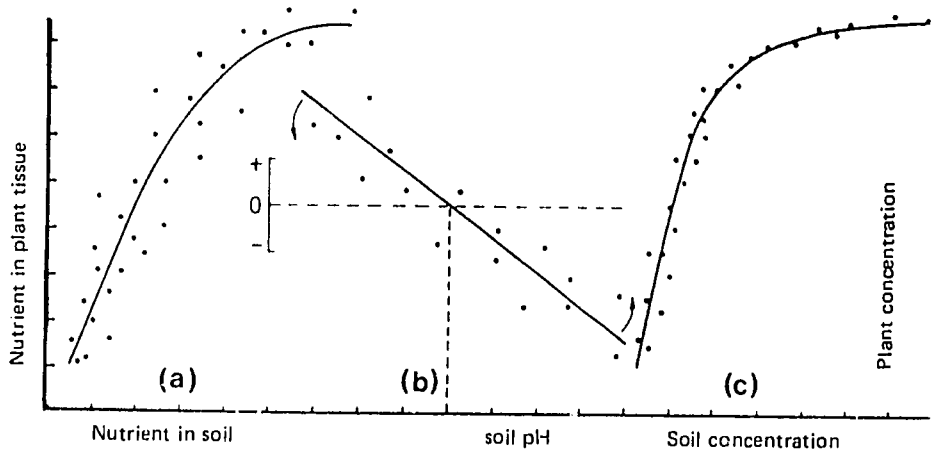

Fig. 1. (a) Best-fit curve for points showing soil-and plant - nutrient concentrations; (b) deviations from the best-fit curve after being plotted against a relevant soil factor (pH); and (c) best-fit curve corrected for soil pH and valid for pH .

Another method to judge the effectiveness of a soil extractant is to monitor crop yield in the absence of applied nutrient (Ris *et al.* 1981). The data can be obtained from pot experiments with a test plant that responds strongly to the nutrient (van der Paauw 1980). Yield without applied nutrient (y_0) is expressed as a percentage of (maximum) yield (y_m) with applied nutrient. This is to eliminate yield differences resulting from soil characteristics other than the nutrient. Furthermore, it is generally accepted that in studies of plant response to a particular nutrient, deficiencies of all other nutrients should be avoided.

The procedure for plotting data is similar to that for data on concentration in plant tissue and soil, and the curves obtained may be similar. Sometimes (maximum) yield increase (y_m - y_0) is used, rather than relative yield (y_0/y_m), in evaluating soil-test values (van der Paauw 1980).

Calibrating Soil Tests Against Yield Response

After having selected an effective soil extractant on the basis of pot experiments, one calibrates the soil-test value against yield response to the nutrient to predict fertilizer requirement. This work is conducted in field experiments with various rates of applied nutrient. Experimental sites are selected, with variation in concentration of the particular nutrient and in relevant soil factors possibly affecting plant response. Any correlations among these factors should be avoided. Yields without (y_0) and with (y_x) applied nutrient are expressed as a percentage of yield maximum (y_m) (**Fig. 2**) (Smilde 1970).

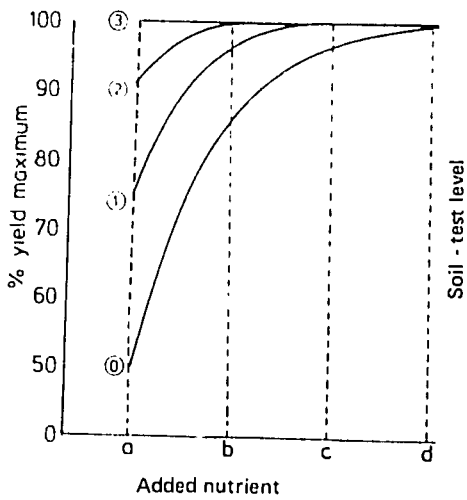

Fig. 2. Percentages of yield maximum as affected by soil-nutrient concentration and nutrient application.

Scatter about the curves may be reduced by eliminating effects of (soil) factors other than the nutrient. Adjusted curves may be constructed for specific values of these factors. An example is given by Hauser (1973), showing how the relationship between cotton response to applied P and soil P can be adjusted for the number of irrigations.

In a nutshell, the resulting graph indicates nutrient recommendations based on soil nutrient concentration. With increasing levels of soil nutrient (Fig. 2: 3 > 2 > 1 > 0), rates of added nutrient needed to prevent yield losses decrease (a < b < c < d), until no more nutrient is needed to attain maximum yield (the intersection between 100% yield and soil-nutrient concentration).

It is often argued that short-term experiments for establishing fertilizer recommendations on the basis of soil tests are not appropriate, as they do not account for variability in meteorologic conditions. Still, experiments should not last longer than one season, and, because of the accumulation of phenomena other than effects of residual and freshly applied nutrients, repeating a series of short-term trials is better than continuing a trial.

To determine economically optimal rates of fertilizer, one uses results of soil calibration in field experiments, expressing the nutrient rates and yield in monetary units; cost of nutrient is represented by a straight line from the origin. Optimal nutrient rate (o), producing maximum profit, is determined by constructing the point of tangency on the yield-response (monetary return) curve for a line parallel to the nutrient-cost line (**Fig. 3**).

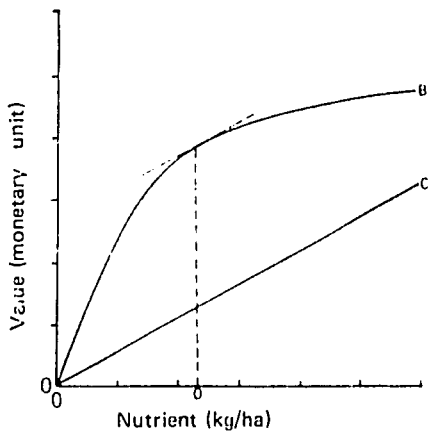

Fig. 3. Assessing the economically optimal rate (o), by constructing point of tangency on yield-response (monetary return) curve B (benefit) and cost line C.

Optimal rates obtained from the various fertilizer experiments are then compared with the corresponding soil-nutrient concentrations, pooled into fertility classes. For the various soil-test classes, ranging from "very low" to "very high," stepwise decreasing nutrient (fertilizer) rates may

be established (**Fig. 4**). The results are optimal rates for soils in different classes of fertility.

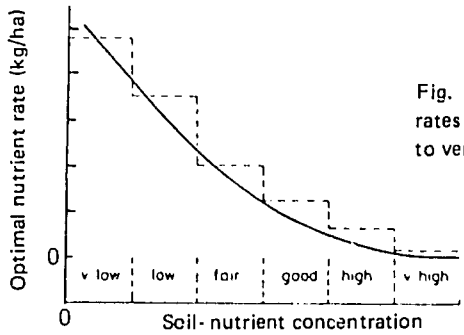

Fig. 4. Economically optimal nutrient (fertilizer) rates for soils of various fertility classes (very low to very high).

Farmers may be reluctant to increase inputs to the economic optima: their reasons include poor credit facilities, high interest rates, obsolete tenure systems, and lack of storage capacity and marketing facilities for the extra output. In such cases, monetary return, i.e., the value of the yield increment, should be at least double the cost of the fertilizer recommended -- a benefit-cost (B/C) ratio of at least 2 (Vermaat 1964) (**Fig. 5**).

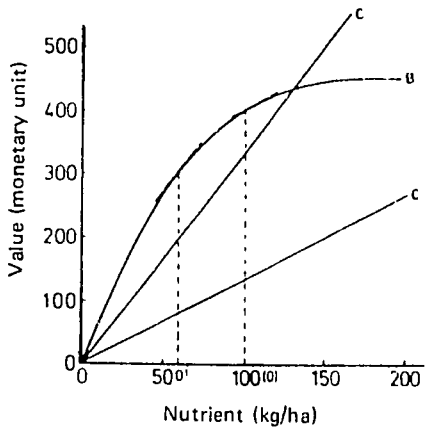

Fig. 5. Economically optimal rates (O, O') for yield-response (monetary return) curve B (benefit) and cost lines C and C'. For cost line C, net profit (B/C) is maximized at 100 kg of nutrient per hectare and B/C is 3.

Optimal rates, producing maximum net profits, are found by constructing points of tangency on various yield-response curves for lines parallel to the fertilizer cost lines (**Fig. 6**). These economical nutrient optima decrease with an increase in soil-test class or an increase in price ratio caused by rising costs for the fertilizer or by declining prices for the product (Hauser 1973; Ris and van Luit 1978; van der Paauw 1980; Ris *et al.* 1981). A relationship between price ratio and optimal nutrient rate may be established and interactions with soil-test class assessed (**Fig. 7**).

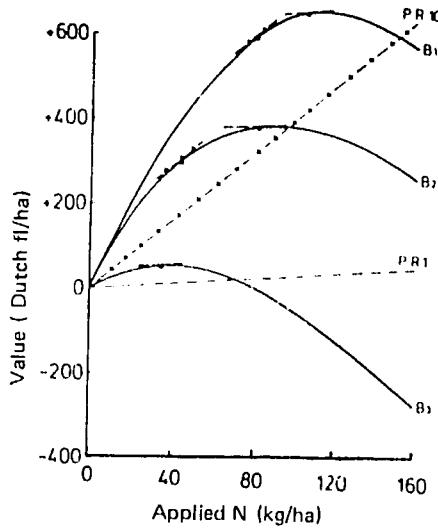

Fig. 6. Economically optimal N rates (points of tangency) for various yield-response curve (B_1, B_2, B_3, represent low, medium, high levels of soil N) and cost lines (P.R. = price ratio 10 and 1). The data were derived from experiments with winter wheat (Ris et al. 1981).

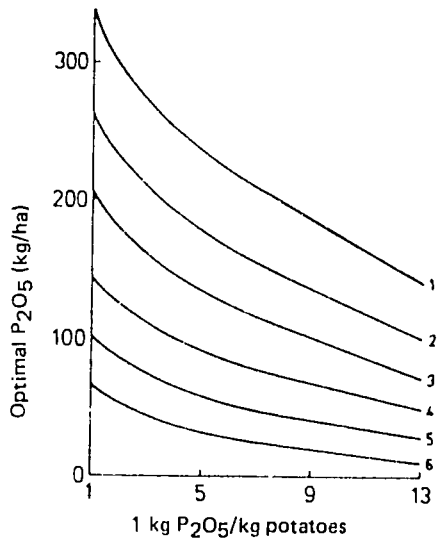

Fig. 7. Relationship between price ratio (1kg P_2O_5/1kg potatoes) and economically optimum P_2O_5 rates at various soil - P classes (1=low; 6=high) (based on Ris and vanLuit 1978).

In general, it is not feasible to establish nutrient requirements on the basis of soil tests for more than one test crop in any region. An approximation for the requirements of other crops may be obtained by plotting relative yields of the test crop against those for the crop for which the optimal rate is unknown. The data can be obtained from long-term field experiments, in which the crops are grown without applied nutrient. The relationship is supposed to be linear, and it is assumed that the yield ratio obtained in this way also holds for crops that receive nutrient. With calculated yields for the "unknown" crop, graphs can be constructed for assessment of nutrient requirements (Ris and van Luit 1978).

Basing fertilization recommendations on the "direct" needs of crops has a major drawback. It means that soil-test class (e.g., P and K status) in an area often declines, because the recommended nutrient rates do not make up for nutrient losses caused by crop removal, erosion, leaching, and fixation. In turn, yields decline, particularly for responsive crops because they demand not only an optimal rate of added nutrient but also an ample amount of soil nutrient, i.e., soil-test class "fairly high," for maximum productivity. In other words responsive crops grown in soil of low fertility produce less regardless of the amount of added nutrient (Smilde 1972). Thus when fertilizer use is not hampered by constraints in cash, storage, and marketing facilities, one should aim to bring the soil up to a fairly high level of fertility for immobile nutrients.

The method may not provide adequately for differences in response brought about by stress. In semi-arid areas the two commonest causes of stress are salinity and lack of moisture.

Salinity

Salinity affects nutrient uptake and utilization by osmosis-imposed moisture stress and by nutrient imbalances induced by excess sodium and chloride. Interpretation of tests for plant-available nutrient in saline soils may differ considerably from that under nonsaline conditions (Hagin and Tucker 1982).

Data on responses to added nutrient in saline soils are conflicting. According to Fine and Carson (1954), large amounts of phosphate fertilizer alleviated salt injury in cereals. This is in line with findings by Ravikovitch and Porath (1967) who stated that additional nitrogen and phosphate fertilizer on soils of slight to medium salinity (EC 4.3-7.0) in some instances could overcome adverse effects on crops like cowpeas, maize, millets, tomatoes, and clover. The evidence for a beneficial effect of phosphate was corroborated by Ravikovitch and Yoles (1971) for millets and clover, by Patel and Wallace (1976) for maize, tomatoes, and Sudan grass, and by Malakondaiah and Rajeswararao (1979) for peanut. Khalil *et al.* (1967) suggested that high levels of phosphate fertilizer make up for the decline in phosphorus uptake by a salt-affected root system, rather than increasing salt tolerance. Also, potassium may have to be added in saline soils to counteract the competitive effects of other cations.

In their review on salinity-fertility interactions, Bernstein *et al.* (1974) stated that salinity does not normally aggravate nitrogen and phosphorus deficiency in cereal crops and vegetables. Conversely, low nitrogen and phosphorus do not consistently decrease the salt tolerance of crops. The authors recommended equal fertilizer applications for saline and nonsaline soils, provided salinity is not so serious as to inhibit crop response to applied nutrient. by a direct limiting effect on growth or an inhibition of root growth.

In another words when salinity is the dominant factor restricting yield, reclamation is much more effective than increasing fertility. Con-

versely, when fertility is the major limiter of yield, increasing the nutrient supply has first priority.

Soil Moisture

Soil water is a major factor governing nutrient uptake, whatever the transport mechanism of the nutrient ion: mass flow, diffusion, or root interception.

In dry soils, plant absorption of nutrients is reduced and more so for nutrients like phosphorus and potassium than for nitrogen. Nitrogen, as nitrate, moves readily in and with soil water and may be stored in deeper layers of the soil profile, during periods of heavy rainfall, for later use (Tisdale and Nelson 1966). Phosphorus and potassium move by diffusion in water films between roots and soil particles. As soil-moisture tension increases, water films become thin and path length to plant roots increases.

Crop response and optimal rate of applied nitrogen decrease with increasing soil-moisture tension. Apparently, the crop is unable to utilize high rates of applied nitrogen when soil moisture is limiting (Stanberry *et al.* 1955; Shimsi 1969). Similarly, soil-water stress is more pronounced at high than at low rates of applied nitrogen. For phosphorus no such interaction has been found, water stress reducing yield to the same extent in high and low treatments.

Water increases efficiency of applied nutrients, and the reverse is also true: nutrient application increases water use efficiency, i.e., dry-matter production per unit of water used (Tisdale and Nelson 1966; Cooke 1972; Mengel and Kirkby 1978; Hagin and Tucker 1982).

Relying on Other Tests

Despite the potential drawbacks, soil-test calibration has advantages over other tests for determining the soil's nutrient status and requirements. It can seldom be replaced by, for example, plant analysis.

Plant analysis is indispensable in calibrating soil tests, but it is usually insufficient as the sole guide for defining nutrient needs (Chapman 1966; Cottenie 1980). Its use is based on the concept that concentration of a particular nutrient in a specific plant tissue reflects its availability in the soil. Relying on it as a measure of fertilizer requirements assumes that growth is restricted when the concentration of nutrient in plant tissues drops below a "critical" level. "Critical" concentrations have been established for a number of crops, indicating the nutrient level below which a yield response to that nutrient is likely to occur (Smith 1962).

For a more quantitative approach, plant-nutrient concentrations have to be calibrated against crop yields and optimal rates of applied nutrient, according to the procedure developed for calibrating soil tests. This work is conducted in field experiments.

Nutrient concentrations in plant tissue vary with physiologic age -- nutrients like nitrogen, phosphorus, and potassium decreasing and calcium, magnesium, manganese, and boron increasing with plant age. Therefore, a strict sampling procedure should be adhered to.

Interpretation of plant analysis is complicated, not only by physiologic characteristics but also by various soil and climatic factors. Generally, analysis for a single nutrient in the absence of other analyses is useless, as it does not account for nutrient interactions. For these reasons, the use of "universal" critical levels, as single values, is questionable even for diagnostic purposes.

For annual crops, tissue (leaf) analyses may come too late to prevent yield losses. A notable exception is the estimation of tissue nitrate as a guide for nitrogen as a top dressing. However, in perennial crops (fruit crops, plantation crops), where correction of nutrient deficiencies is less time dependent, leaf analysis is widely accepted as a basis for fertilizer recommendations. In other cases, plant analysis serves as a quality check, for instance in food crops and fodders. Also, when soil tests fail to estimate plant-available nutrient, for instance iron or manganese, leaf analyses or deficiency signs may be used as a guide for fertilizer application, either by foliar spray or soil application.

One advantage is that normally in plant analyses, one determines "total" nutrient and does not have to perform the complicated procedure of choosing an efficient extractant.

Where facilities for a comprehensive soil-testing program are lacking or soil tests cannot be readily interpreted, one has to resort to a qualitative method to assess soil-nutrient status. This holds true especially for micronutrients.

Double-pot Technique

An elegant technique is the "double-pot" device by Bouma/Janssen (Janssen 1974). Plants are grown in the soil under investigation in a pot with a perforated bottom placed on top of a vessel with nutrient solution. Roots pass from the soil into the nutrient solution. If a particular nutrient, say nitrogen, is omitted from the nutrient solution, plants can absorb it only from the soil. The difference in growth between plants on the minus-N and the "complete" solution reflects the capacity of the soil to release nitrogen. It is expressed as the relative growth rate, i.e., the ratio of the increase in plant height (or dry weight) during a certain time on a minus-N solution to that on a complete nutrient solution. The higher the relative growth rate, the more available the nutrient in the soil. At

unity, the availability of the nutrient in the soil equals that in the nutrient solution.

Relative growth rates for various soils may be compared with soil tests for a semiquantitative calibration. Janssen (1974) reported significant correlations between nitrate-N and exchangeable potassium and the respective relative growth rates (maize, wheat), for Turkish and Surinam soils. These results were confirmed by Muller *et al.* (1980) using cotton as the test plant on Nepal soils. For micronutrients, results have been less conclusive.

In general, the double-pot technique is very useful in identifying nutrient deficiencies in various soils and as such it serves demonstration purposes.

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Prediction of Barley Response to Fertilizers by Means of Soil Nitrogen and Phosphorus Tests

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Abstract. Thirty three N x P factorial trials with barley (Arabic Aswad) were conducted during 1984-85 and 1985-86 in farmers' fields of four provinces of Syria. Four levels of N (0, 20, 40, and 60 kg/ha) and of P_2O_5 (0, 30, 60, and 90 kg/ha) with two replicates were used. At every site, a rainfall gauge was installed, and precipitation was recorded weekly. Before sowing, contents of NH_4 and NO_3 were determined in the 0-20, 20-40, 40-60, and 60-100 cm soil layers. The $NaHCO_3$-extractable P was determined in only the 0-20 cm soil layer. Results from the trials were utilized in analyses to relate crop responses with soil tests for N and P. Two methods have been used: the Cate-Nelson graphical method with analysis of variance and the Mitscherlich-Bray equation. The $NaHCO_3$-extractable P in soils that gave near-maximal yields for total dry matter was about 5 ppm, with both methods. The Mitscherlich-Bray equation fitted closely the experimental data and formed a good basis for phosphate recommendations. Because of a close relationship between maximal yields of dry matter and precipitation ($R^2=0.59$), a rainfall parameter was included in the Mitscherlich equation. Using the Cate-Nelson method, we found that contents of NO_3 and mineral-N in the soil could guide N fertilization. Soil N that gave near-maximal yields of grain was equivalent to 17, 25, and 35 kg/ha for nitrate and 23, 41.5, and 50 kg N/ha for mineral-N (NH_4 + NO_3) in the soil layers 0-20, 0-40, and 0-60 cm respectively. Slightly higher levels were demanded for maximal yields of total dry matter (grain + straw).

Introduction

As barley is the second most widely grown cereal crop in West Asia and North Africa and is predominant in environments where rainfall is low and variable, researchers at ICARDA conducted fertilizer trials for several years at Breda, Syria, where mean annual rainfall is 278 mm and available P is equivalent to 3 ppm. The results consistently showed an economical response to fertilizers and especially to P (Harmsen *et al.* 1983). Furthermore, the efficiency of water use increased significantly ($P < 0.01$) as a result of fertilizer application (Cooper *et al.* 1983).

Several other researchers in the region have found similar responses of barley to phosphate fertilization. The response was found to be related to available P in soils at time of sowing, to soil depth, and to weather conditions (Krentos and Orphanos 1979). The relative increase in barley yield attributable to P fertilization was greatest in shallow soil and under low rainfall conditions (Matar 1977; Orphanos 1987). Under conditions in Cyprus, on soils with available P < 6 ppm, response was greatest when annual rainfall was less than 300 mm (Krentos and Orphanos 1979). A level of 10 ppm for $NaHCO_3$-extractable P is considered the sufficiency level in Cyprus: 10 ppm is the value that allows rainfed crops, including barley, to take full advantage of rainfall.

The response of barley to nitrogen application has been observed mostly during rainy years or in fields where barley was the preceding crop (Loizides 1958; Harmsen *et al.* 1983). Although total N in barley soils is less than 0.1%, mineral-N has been found to be adequate in many arid soils. Studies in the ICARDA region to date on soil test/crop response correlation studies have been limited. Therefore in 1984-85, we began studies that compare soil tests for N and P with the response of barley to fertilization.

The research was a collaborative effort between ICARDA and the Soils Directorate of the Ministry of Agriculture and Agrarian Reform of Syria and was aimed at determining the biologic and economic response of barley to N and P fertilizers in farmers' fields in various provinces of Syria, clarifying the relationships between available N and P in soils at sowing and the response in yield of barley fertilized with N and P, and establishing guidelines for fertilizer recommendations based on soil tests.

Materials and Methods

Experimental sites were in the barley-growing region of Syria: they represented major soil and climatic conditions, including shallow and deep soils, stony and stone-free soils, as well as soils with different fertility levels. Zones 2* and 3** of four provinces were included (Aleppo, Hama, Hassakeh, and Raqqa). During the second cropping season most selected sites had been preceded by fallow because the common rotation in the region is barley-fallow but six of the sites had been cultivated with barley. Each trial comprised two replicates of a complete randomized factorial design with four levels of nitrogen (0, 20, 40, and 60 kg N/ha), supplied by ammonium nitrate, and four levels of P_2O_5 (0, 30, 60, and 90 kg/ha) supplied as treble superphosphate.

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* Zone 2 = 250 - 350 mm mean annual rainfall with more than 250 mm in two-thirds of the years.

** Zone 3 = 250 mm mean annual rainfall with more than 250 mm in half the years.

Barley seed (Arabic Aswad), treated with Vitavax, was sown at the rate of 100 kg/ha with an Oyjord planter. The phosphorus fertilizer and half of the nitrogen was drilled into the soil along with the seed. The remaining nitrogen was applied as a top dressing at the tillering stage. Weeds were controlled by Brominal Plus. Soils were sampled in 20-cm increments down to 100 cm depth (or bedrock) at planting time for determination of mineral-N (NH_4 and NO_3) and $NaHCO_3$-extractable P in the top 20 cm only. A rainfall gauge was installed at every site, and rainfall was recorded weekly. Detailed information on the cultural practices and other measurements followed for these trials have been published elsewhere (ICARDA 1986).

For the crop responses to be correlated with soil tests, we used the Cate-Nelson graphical method (Nelson and Anderson 1977) and the Mitscherlich-Bray equation.

The Cate-Nelson method is to plot the relative yield (0-100%) of barley against the level of available P or N in the soil (tested at sowing). The relative yield for each location is the total dry matter obtained in the treatments without fertilizer as a ratio of maximum yields obtained when fertilizer is added. To avoid confusion between P and N responses, we prepared two graphs -- one incorporated the responses to P for treatment combinations that provided adequate N nutrition of the crop and one incorporated the responses to N when adequate P was available in the treatment. Soils were divided according to the probability (high or low) that barley will respond to fertilization. The diagram of the results is divided into quadrants that maximize the number of points in the positive quadrants and minimize the number in the negative quadrants.

The Mitscherlich-Bray equation was also used for studies of response to fertilization with P:

$$\text{Log}\ (A - Y) = \log A - c_1 b - c_2 x \qquad (1)$$

where A is the maximum yield with optimum P fertilizer (kg/ha), Y is the yield at any given P fertilizer rate (kg/ha), x is fertilizer rate (kg P_2O_5/ha) for yield Y, b is the available P in the soil (kg P_2O_5/ha) in top 20 cm of soil, c_1 and c_2 are the efficiency constants for soil and fertilizer P respectively.

This equation can be expressed in terms of relative yield (Yr), with maximum yields assumed to be equal to 100.

$$\text{Log}\ (100 - Yr) = \text{Log}\ 100 - c_1 b - c_2 x \qquad (2)$$

Results and Discussion

Phosphorus Test

Production of grain and straw responded positively and significantly to N

or P fertilizer or both at every site -- increases being observed with application of P more often than with N (**Table 1**). Details on agronomic and economic response of barley to fertilization have been published elsewhere (ICARDA 1985, 1986).

According to the Cate-Nelson methods, the critical level of Olsen-P in the top 20 cm of soil was about 5 ppm: at values of greater than or equal to 5 ppm, crops achieved about 80% of their maximal yield in the absence of fertilizer application (**Fig. 1**). The coefficient of determination, R^2, for the analysis of variance that divided sites into responsive and non-responsive to P application was 0.61.

Table 1. Grain and total dry matter production of barley obtained in farmers' fields as related to available P on soils, precipitation and level of phosphates applied for two consecutive seasons, 1984/85 and 1985/86.

		Grain Yield (kg/ha)				TDM (kg/ha)					
		Level of P applied (kg P_2O_5/ha)				Level of P applied (kg P_2O_5/ha)					
No	Site Name	0	30	60	90	0	30	60	90	Seasonal Total Precip. (mm)	Olsen-P (ppm)
1	Jifr Mansour	1383	1555	1626	1594	3348	3723	4088	4041	246.1	4.8
2	Hebar	2346	2611	2646	2724	5196	6061	6132	6612	268.2	6.1
3	Mariamine	1663	1755	1923	1923	3695	3794	4212	4272	293.7	9.9
4	Ibtin	2375	2264	2305	2224	5210	5140	5514	5415	260.0	5.8
5	Breda 1	1775	2291	2528	2654	3676	4849	5599	5944	268.2	2.8
6	Ghrerife 1	685	856	931	1004	1519	2146	2451	2787	232.0	2.2
7	Maar Shahour	1011	1291	1327	1555	2088	2887	3106	3749	323.3	2.3
8	Maboujeh									220.1	4.5
9	Skiro	656	1382	1641	1848	1582	3106	3725	4006	208.0	3.7
10	Khashouka	2286	2456	2397	2509	5018	5431	5386	5680	279.3	3.6
11	Jesaah	2917	3345	3556	3519	6389	7292	7739	7503	338.9	4.0
12	Masoudieh 2	2390	2998	2830	3154	5217	6599	6577	7266	283.5	4.37
13	Jebt el- Dgherat	363	462	663	653	843	1039	1512	1565	146.5	7.94
14	Tel Zeater (F)	1622	1863	2243	2794	3342	4068	4858	6160	293.9	5.75
15	Tel Zeater (B)	1814	2023	2251	2176	3911	4457	5139	4964	287.4	6.62
16	Tel Jesa'a	2050	2494	2948	3070	4146	5224	6481	6757	287.4	2.37
17	Abou Masnatein	1049	1164	1336	1492	2246	2721	3121	3482	181.0	3.01
18	Beer Issa (F)	888	1315	1469	1564	1879	2892	3413	3869	187.0	2.66
19	Beer Issa (B)	982	985	1436	1329	2191	2552	3443	3265	187.0	3.2
20	El Beida	1439	1567	1688	1749	3047	3425	3798	3925	174.0	5.76
21	Tel Dera (F)	1630	1791	2041	1868	4908	5225	5971	5828	242.0	10.0
22	Tel Dera (B)	1539	1755	2001	1837	3367	3794	4298	3983	242.0	9.9
23	Sayadeh (F)	1638	2233	2429	2559	3731	5067	5612	5938	265.0	2.9
24	Sayadeh (B)	1508	2092	2162	2278	3374	4483	4752	5224	265	4.22
25	Sheikh Ali 2	2247	2629	2618	2842	4885	5912	6161	6821	232.4	4.84
26	Bart Sharqi 2	1711	2001	1880	1975	3758	4279	4153	4127	218.6	6.24
27	Queres Sharqi (F)	1315	1613	1561	1717	2786	3379	3313	3652	185.1	4.43
28	Queres Sharqi (B)	1179	1375	1390	1384	2394	2766	2816	2779	185.1	5.23
29	El Safeh	1060	1364	1499	1723	4608	5566	6514	6489	200.7	4.36
30	Khanasser (F)	728	945	1129	1328	1464	1973	2436	2830	178.2	4.37
31	Khanasser (B)	666	902	976	1070	1518	2024	2233	2434	178.2	4.41
32	Breda (2)	1248	1547	1717	1743	2567	3295	3773	3850	190.9	3.48
33	Ghrerife 2	1196	1407	1812	1669	2366	2777	3569	3367	194.0	3.15

We calculated the coefficients c_1 and c_2 in the Mitscherlich-Bray method for each location (Yurtsever 1986) and the mean values for climatic zones 2 and 3. The values for c_1 and especially c_2 varied largely from one site to another and from one level of fertilizer to another. Thus calculations of c_1 and c_2 were approximations that could be used to facilitate fertilizer recommendations by region or according to great soil groups, etc.

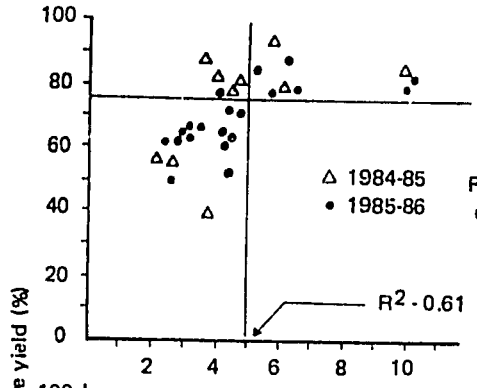

Fig. 1. Scatter diagram of relative yield (DM) compared with results of Olsen–P

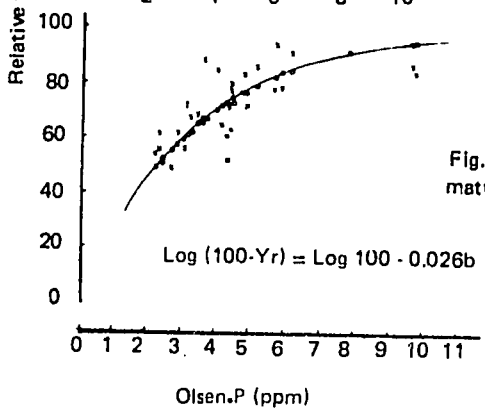

Fig. 2. Scatter diagram of relative yield: .dry matter compared with results of Olsen-P tests

Using these coefficients and the relative yield, we derived equations for zones 2 and 3 separately. The c_1 coefficients were equivalent to 0.029 and 0.024 and the c_2 coefficients were equivalent to 0.011 and 0.013 for zone 2 and zone 3 respectively. Because the values for the efficiency coefficients were similar for zones 2 and 3, we derived a general Mitscherlich-Bray equation for the two zones combined and plotted the values on a theoretical curve (Fig. 2).

At a relative yield of 80% (in the absence of applied P fertilizer), the Mitscherlich-Bray equations indicated the critical levels of available P in the soil were 4.7 ppm and 5.4 ppm for zones 2 and 3, respectively -- in close agreement with the value (5 ppm) obtained by the Cate-Nelson method (Fig. 1).

Furthermore, the equation (2) incorporating relative yield can be utilized to predict the amount of phosphate fertilizer required to give various percentages of maximum yield as affected by the level of available P in the soil at sowing. Such data are not sufficient basis for fertilizer recommendations, however, unless one assumes that farmers aim at maximizing only yield and not the rate of return on money invested. In other words, the calculations must be evaluated economically: the net revenues and rates of return must be calculated for different levels of fertilizer application.

To conduct such an analysis, we used the Mitscherlich-Bray equation (1), defining A, the theoretical maximum yield obtainable. Many workers use the Mitscherlich-Bray equation itself to produce a theoretical maximum yield, a single value to represent the whole area for which the information is being derived. This value is very close to the mean of the maximum values observed at each location.

However, in rainfed environments where moisture is limiting, the maximum yield obtainable at any given location depends not only on the available P and the amounts of fertilizer applied but also on the seasonal rainfall. For instance, in our study, over the two seasons, rainfall varied between 147 and 339 mm, and maximum dry matter varied correspondingly between 1565 and 7500 kg/ha. A simple linear regression could be derived between maximum dry matter and seasonal rainfall (RN) in mm:

$$\text{Maximum dry matter (kg/ha)} = 27.81\ RN - 1396 \qquad (3)$$
$$R^2 = 0.59$$

We thus modified the standard Mitscherlich-Bray equation, incorporating this rainfall-dependent variable for maximum yield:

$$\text{Log}\ [(27.81\ RN - 1396) - Y] = \text{Log}\ (27.81\ RN - 1396) - 0.0266 - 0.0126X \qquad (4)$$

The coefficient of determination (R^2) of the equation (3) could be improved further by inclusion of other soil parameters that affect yields significantly, e.g., slope, soil depth, stoniness, and water-holding capacity.

This approach provides economic analyses in the form of a family of curves for net revenue and rates of return to phosphate status of the soil, level of applied phosphate, and rainfall received during the season (**Fig. 3**). One can see clearly in the curves the point at which maximum increase in net revenue is obtained without a drop greater than 40% in the marginal rate of return on money invested.

These results illustrate the potential for soil tests to improve the efficiency of fertilizer use; however as phosphate is applied at seeding time, before seasonal rainfall is known, one must carefully analyze rainfall records over the long term and the probability of rain before attempting recommendations about economically optimal rates of application (and the expected increase in net revenue) for any location.

As expected, the available P in the soil has a profound impact on increases in net revenue and rates of return for P fertilizer application. In our ongoing research, we aim to determine how the phosphate fertilizers affect the available P in the soil. Effects of P fertilizer persist for 2-3 years in dry barley-growing environments (ICARDA 1986) and, therefore, one would expect regular fertilizer use to increase the available P in the soils (Orphanos 1987). Barley's uptake of P calculated from applied fertilizer at all sites (uptake in treatments without fertilizer subtracted

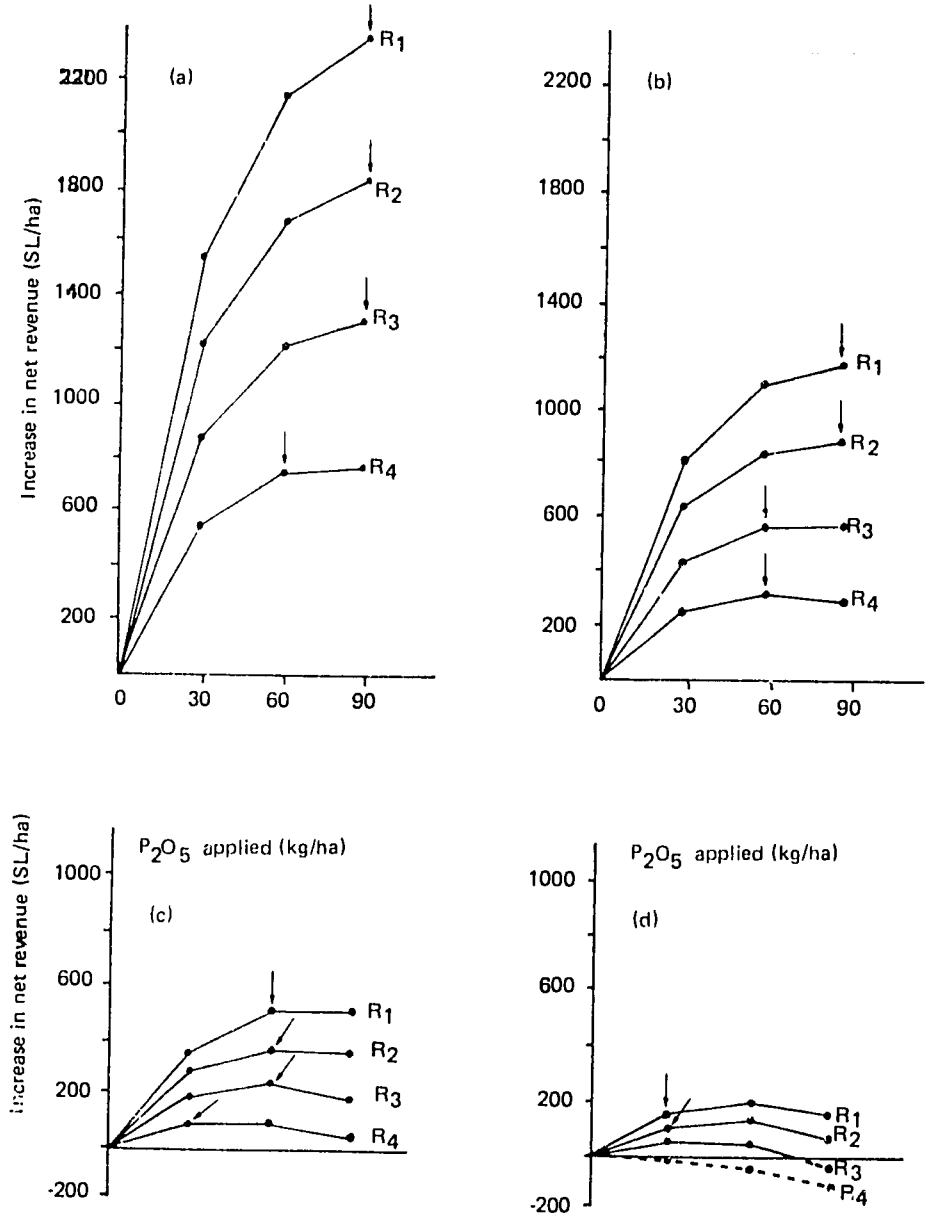

Fig. 3. The effect of applied phosphate fertilizer on the increase in net revenue derived from barley production in Syria on soils with various Olsen - P (a = 2; b = 4; c = 6 and d = 8 ppm) and various rainfall regimes (R_1 = 300; R_2 = 250; R_3 = 200 and R_4 = 150 mm). Costs and prices utilized were published elsewhere (ICARDA 1986). The arrows indicate the optimum level of P applied.

from uptake in treatments in which fertilizer was applied) (**Table 2**) indicated an efficiency between 1% and 26%; in other words, a large fraction of the phosphate remains in the soil and will be subjected to reactions that make it unavailable to future crops. For example, Matar *et al.* (1987) found that the half-life of applied phosphates at Breda, Syria (typical barley calciorthid soil), ranged from 10.1 to 15.2 months at rates of 120 and 40 kg P_2O_5/ha respectively (ICARDA 1985). A model that incorporates P uptake by the crop, the rate of P immobilization, and the available P in soils could be developed to optimize P recommendations.

Table 2. Effect of location and level of P application on percent P uptake by barley fertilizer in farmers' fields for two consecutive seasons, 1984-85 and 1985-86.

	Efficiency (% uptake)			
	Level of P applied (kg/ha)			
Site	0	30	60	90
Jifr Mansour	-	1.71	2.18	0.98
Hobar	-	13.94	7.58	6.99
Mariamine	-	18.86	6.11	1.43
Ibtin	-	0.51	0.76	3.02
Breda	-	16.77	12.36	9.55
Ghrerife	-	4.12	7.68	6.30
Maan Shahour	-	7.66	3.37	6.57
Maboujeh	-	16.85	3.70	6.66
Skiro	-	13.93	7.39	7.32
Khashouka	-	8.06	5.45	6.29
Jesaah	-	2.37	2.08	6.27
Masoudieh	-	8.62	11.35	6.23
Jebth el-Dgherat	-	0.21	2.39	1.68
Tel Zeater (F)	-	2.77	9.29	8.87
Tel Zeater (B)	-	5.76	4.43	3.14
Tel Jesa'a	-	6.15	4.42	5.30
Abou Masnatein	-	7.25	4.96	5.02
Beer Issa (F)	-	2.68	3.50	6.81
Beer Issa (B)	-	0.79	4.35	3.73
El Beida	-	0.10	3.46	4.49
Tel Dera (F)	-	10.61	7.70	6.49
Tel Dera (B)	-	18.38	10.64	9.15
Sayadeh (F)	-	9.08	10.89	16.63
Sayadeh (B)	-	5.93	5.78	4.23
Sheikh Ali	-	26.14	11.85	8.70
Bari Sharqi (F)	-	4.63	2.05	3.31
Queres Sharqi (F)	-	11.23	6.62	7.08
Queres Sharqi (B)	-	14.32	10.14	5.00
El Safeh	-	8.46	6.40	5.90
Khanasser (F)	-	2.86	3.53	5.06
Khanasser (B)	-	6.00	4.78	4.46
Breda (F)	-	1.31	2.68	1.31
Ghrerife	-	6.34	6.80	5.42

Nitrogen Test

In a similar approach for nitrogen, the Cate-Nelson graphical method (GM) with analysis of variance (ANOVM) was used to relate the relative yield of barley grain or total dry matter with the nitrogen available in various soil layers at planting (Nelson and Anderson 1977).

The levels of NO_3-N that gave nearly maximal yield for dry matter were 27, 33, and 40 kg/ha at sowing in the 0-20, 0-40, and 0-60 cm soil layers respectively (**Fig. 4**). However, the levels of NO_3-N needed to optimize grain production were 17, 26, and 35 kg/ha at planting.

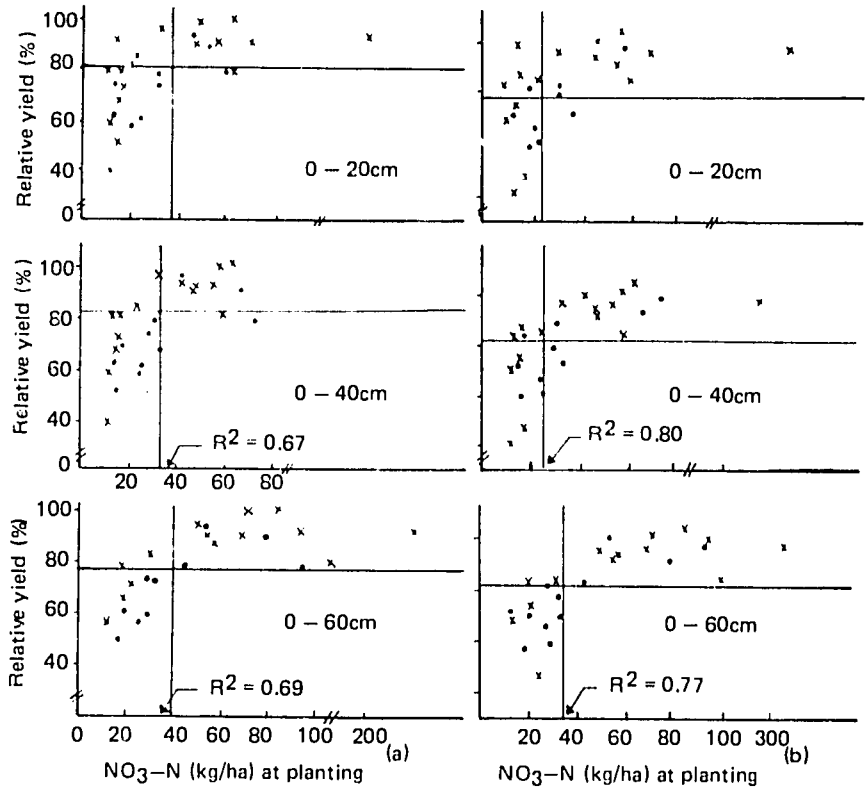

Fig. 4. Scatter diagram (• = 1984 - 85; x = 1985 -86) of relative yield of (a) total dry matter (DM) and (b) grain of barley as related to NO_3–N in soils at planting.

The critical levels of the mineral-N (NH_4 + NO_3) associated with maximum yields of dry matter and grain were 32, 47, and 55 kg/ha and 23, 41.5, and 50 kg/ha for the soil layers 0-20, 0-40, and 0-60 cm deep (**Fig. 5**).

Clearly, soil tests for NO_3 or mineral-N are equally good in dividing the barley soils of Syria into responsive and nonresponsive for N fertilization, but the NO_3 test is easier to perform so is widely used in other countries.

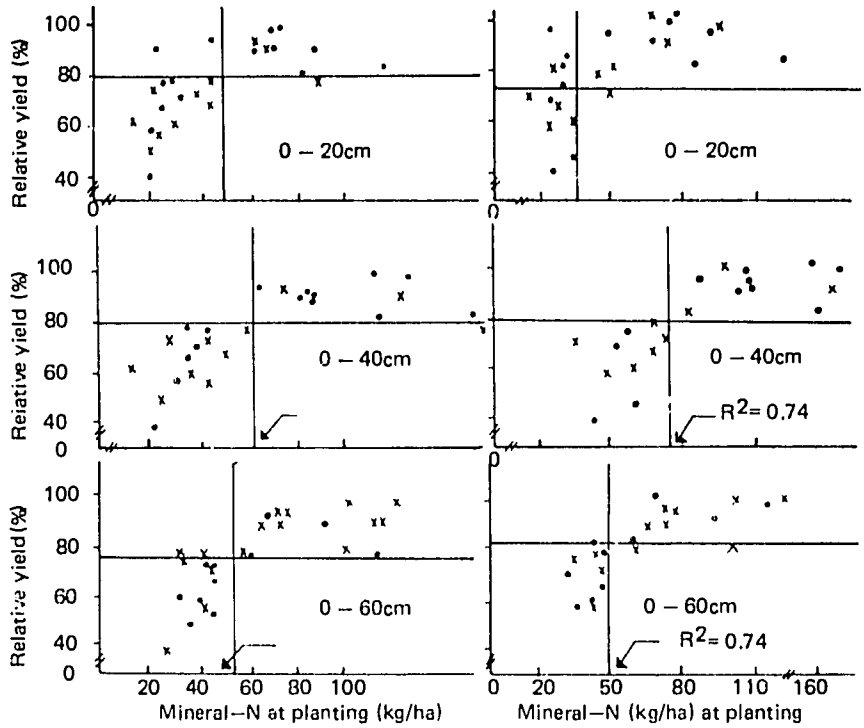

Fig. 5. Scatter diagram (• = 1984-85; x = 1985-86) of relative yield of (a) total dry matter (DM) and (b) grain related to mineral–N in soil at planting.

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Interpreting Data from On-farm Fertilizer Trials for Use Where Soil-test Values Are Not Available

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Abstract. Results from fertilizer trials for soil-test calibration may be used to develop general fertilizer recommendations to apply where soil-test values are not available. From the data of 32 on-farm barley trials, quadratic equations (response surfaces) relating yield and cash value of crops to rates of N and P fertilizers have been computed for different sub-groups of sites (recommendation domains), and the profitability of different fertilizer rates in those different domains calculated. The most clear-cut differences lay between rotation "domains" (barley preceded by fallow vs barley preceded by barley); between northwest and northeast Syria; and between different rainfall ranges. Phosphate fertilizer was fairly generally profitable, but profitability was often enhanced by the concurrent use of nitrogen. Nitrogen fertilizer was most profitable in barley-barley rotations, in high rainfall areas, and in northwest Syria but usually only in the presence of phosphate fertilizer. The limitations of the methods used are discussed.

Introduction

With any series of fertilizer trials, the ultimate purpose is the creation or improvement of recommendations to farmers on rates of fertilizer use. To be applicable, the recommendations need to take into account physical environment and economic factors, i.e., fertilizer costs, crop prices, etc. By physical environment I mean the various climate and soil conditions likely to influence fertilizer effectiveness, from rainfall through soil type and depth to soil-nutrient status. Thus, for instance, where soil-test values are available, a simple recommendation for a particular crop and district might be: if Olsen-P is less than 5 ppm, apply two bags of phosphate fertilizer per hectare; if 5-8 ppm, one bag; if > 8 ppm, nil.

However, in many countries for the foreseeable future, soil-test values will be available for only a minority of fields to which fertilizer ought to be applied. Even where governments give high priority to the establishment of an efficient soil-testing service, for many years a substantial minority (if not majority) of farmers will fail to use it. For their ben-

efit and that of the extension services that advise them, there must always be a second level of recommendations based on criteria other than soil-test values. Thus, for any program of fertilizer trials there are likely to be two purposes: first, to determine safe general rates of fertilizer application for the particular crop in specified zones or "recommendation domains," and, second, to produce more specific recommendations based on soil-test values. These purposes are not in conflict, and both can be achieved from the results of the same series of trials.

My intention here is to consider the production of general, i.e., non soil-test, recommendations. In this, the major interrelated problems are how to translate yield data from multiple field trials into safe, economic rates of fertilizer for specified "domains"; and how best to delimit those domains. Of course, neither problem has a single correct solution. The answer always depends on local circumstances and on the experience and judgment of the scientists involved. What I want to do in this paper is to explore both problems to demonstrate what is involved; and to do this I shall use the same data set from the 32 on-farm barley trials conducted in Syria during 1984-85 and 1985-86 as used in the paper on the Mitscherlich and Cate-Nelson soil-test methods (Matar *et al.* elsewhere in this volume).

Methods

Any increase in crop yield with increasing fertilizer application is, ultimately, curvilinear, although there is always argument as to the best algebraic representation of that curve. I shall use here quadratic expressions, while recognizing that crop response rarely fits precisely to so simple a curve. (In fact, in the examples, the fit of each calculated curve to the treatment means is excellent, with an R^2 value between 90% and 100%.) Further, since the trials involved both nitrogen and phosphate fertilizers, the effects of which generally interacted, the equation must be quadratic with respect to each nutrient, viz:

$$Y = a + bN + cP + dN^2 + eP^2 + fNP$$

where Y is the biological yield (grain, straw, or total dry matter, as required); N and P are the fertilizer rates (kg/ha of N and P_2O_5, respectively); and a-f are derived constants. The equation is produced by standard computer software, as a regression of yield in individual plots on the fertilizer rates in those plots, across a chosen set of trials.

Though interesting, such expressions of biological yield do not indicate what the most economic fertilizer dressing would be. For this, one must calculate another, similar regression for the cash value of the crops, using for each plot a figure based on the price that could be obtained for the yield (grain and straw) in that plot, minus fertilizer and harvest costs. Of course, unlike the regression of biological yield, that for

"value" is heavily dependent on the particular economic parameters chosen. It can be varied to take account of current or expected costs and prices, to give updated estimates of the optimal fertilizer application. In the present paper, the prices and costs used are those for the 1985-86 season.

The second problem is that of achieving the best delimitation of recommendation domains. Our 32 data sets may be variously subdivided, according to a number of site criteria, both administrative and environmental:

* By province (Aleppo, Raqqa, Hassakeh and Hama);
* By agricultural stability zones (based on rainfall amount and reliability);
* By rotation (barley after fallow, B/F; barley after barley, B/B);
* By rainfall values (totals from some weeks prior to planting until harvest, ranging from 147 mm to 339 mm); and
* By various soil classes and depths.

The question is which of these criteria, or combination of criteria, is best for delimiting areas needing different recommendations. A few of the fairly large number of possibilities are examined below.

Results

Rotational Effects

Of the 32 trials, 12 were organized as 6 paired trials. In each pair, the two trials were sited adjacently and so had almost identical soil type, depth, Olsen-P value, and rainfall. They differed only in rotation, one B/F and the other B/B. Although the sample size was far too small for one to draw firm conclusions, the differences that emerged indicate "rotation" as a major factor in fertilizer response.

Grain and straw were not treated separately from total dry matter, as their response surfaces are usually similar. In the absence of fertilizer, yields in the B/B rotation were lower than those for the B/F rotation, by almost 1000 kg/ha; but with nitrogen added without phosphate, they matched and even exceeded those of the B/F rotation. In fact, B/F yields were appreciably depressed by nitrogen fertilizer applied alone. Phosphate fertilizer, however, was effective in both rotations, at all rates of applied nitrogen (**Figs. 1** and **2a**, **Table 1**).

These patterns were reflected in the economic data (**Figs. 2b** and **2c**). At the same rate of fertiiization, barley in the B/B rotation had a lower value than in B/F -- except where high nitrogen rates were used in conjunction with zero or low phosphate rates. In contrast, the increase in value over the zero-fertilizer control, from fertilizer use, was much greater in the B/B rotation, provided at least 40 kg N/ha had been applied. Nitrogen fertilizer, used alone, was moderately profitable in the B/B rotation, highly unprofitable in the B/F rotation.

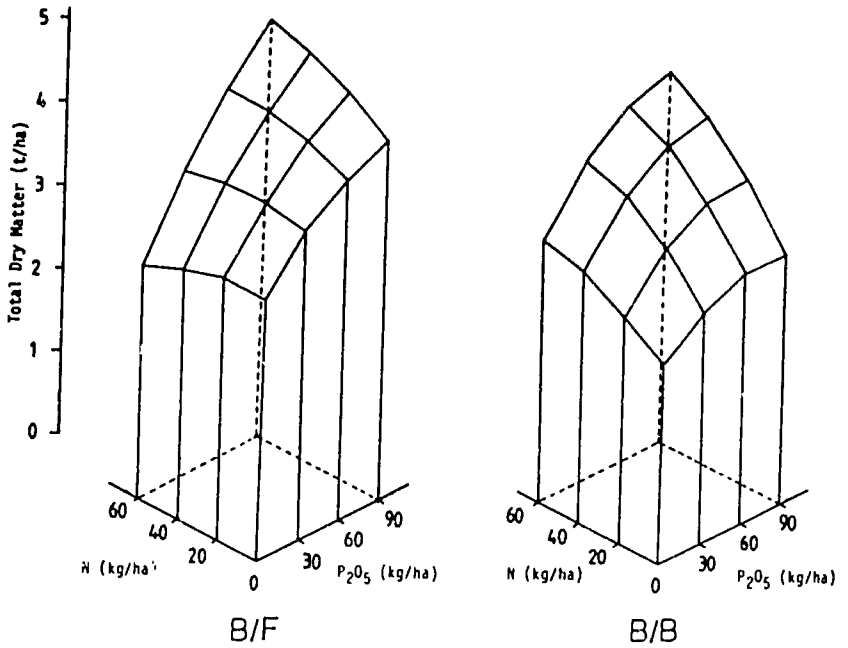

Fig. 1. Barley dry matter response to nitrogen and phosphate fertilizer after fallow and after a previous barley crop: surfaces fitted to data of paired trials at six sites.

For recommendations, the goal is the economically optimal rate of fertilizer. From the present equations, the optimum, per hectare, in the B/B rotation was 63 kg N + 75 kg P_2O_5, which increased crop value by nearly SL850/ha over control. In the B/F rotation, however, the optimal rate, at least that for phosphate, was well above the rates applied experimentally and beyond any valid extrapolation. (The same is true for most of the other "domains" examined.)

Stability Zone Effects

Since rotation can substantially affect barley response to fertilizer, it is desirable to separate the rotations when looking at the effects of other site criteria. In fact, the only B/B trials completed by the end of the 1985-86 season were those in the six paired trials. All other comparisons therefore derive from the results of the remaining 26 B/F trials and concern only the B/F rotation.

For planning and advisory purposes, Syria is divided into five "agricultural stability" zones, based on rainfall amount and reliability. All trial sites in this study lay in either zone 2* or zone 3**, and one might

* Zone 2 = 250 - 350 mm mean annual rainfall with more than 250 mm in two-thirds of the years.

** Zone 3 = 250 mm mean annual rainfall with more than 250 mm in half the years.

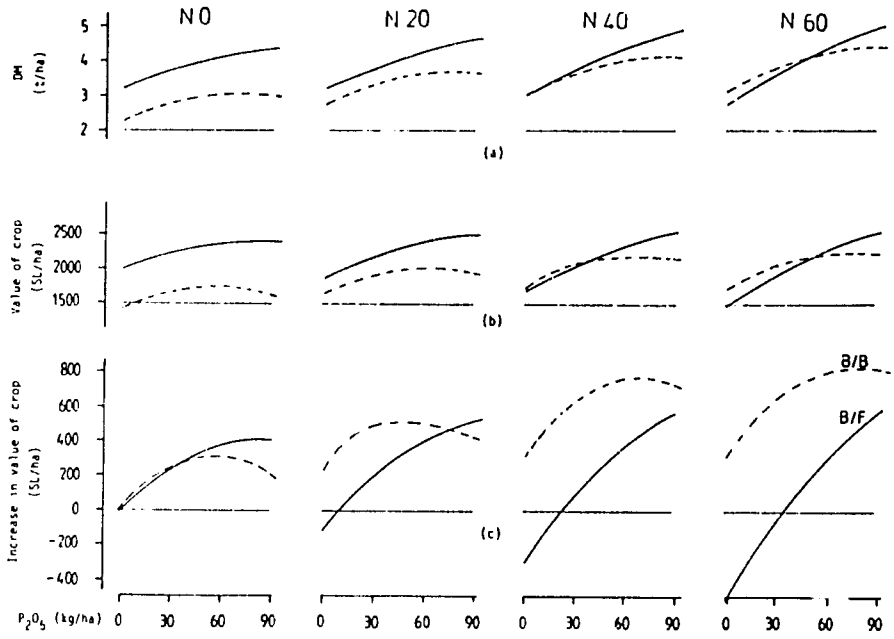

Fig. 2. Comparison of surfaces fitted to data from six barley/fallow trials (——) and six barley/barley trials (– – –) obtained over the fertilizer ranges, 0–60 kg N/ha and 0–90 kg P_2O_5/ha: (a) total aboveground dry matter, DM; (b) value of crop, grain + straw, SL/ha; and (c) increase in crop value over zero–fertilizer control.

reasonably expect that this division would provide a good basis for separating response domains. Yields were lower in zone 3 than in zone 2 at all levels of fertilization, and this may be attributed largely, if not entirely, to the difference in rainfall (preplanting until harvest) (**Fig. 3**):

Zone	Trials	Mean rainfall (mm)	Standard deviation (+/-)	Mean dry matter (kg/ha)
2	11	266.2	51.6	4906
3	15	216.0	39.1	3792
Difference		50.2		1114

Over all 26 trials, mean yield of dry matter increased linearly and significantly ($P < 0.001$) with increasing rainfall, 21.1 kg/ha for every millimetre. From the 50.2 mm difference between the rainfall means of the two zones, one would expect a yield-mean difference of 1060 kg/ha, and this is close to the 1114 kg/ha difference actually found.

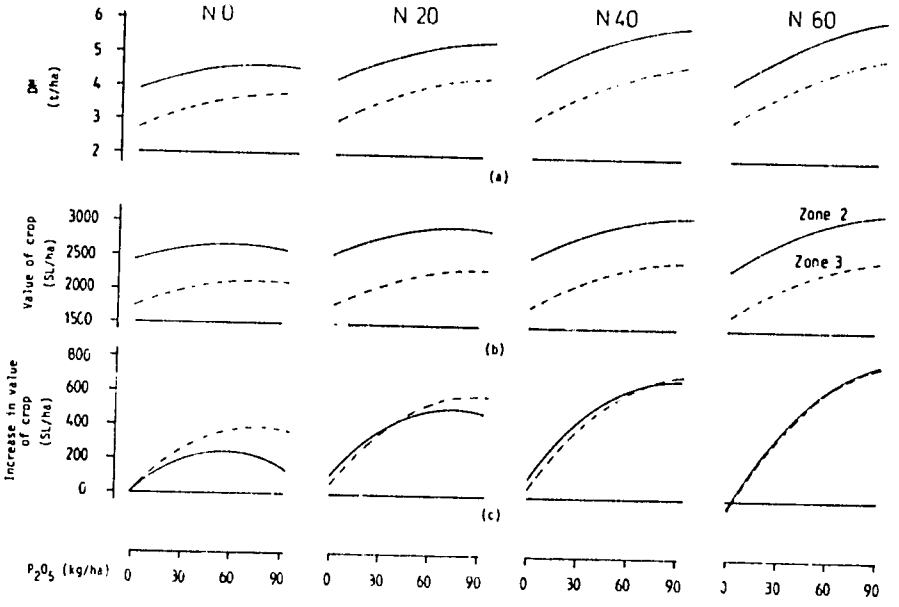

Fig. 3. Comparison of surfaces fitted to data from barley/fallow trials in zone 2 (——) and zone 3 (– – –) obtained over the fertilizer ranges, 0–60 kg N/ha and 0–90 kg P_2O_5/ha : (a) total aboveground dry matter, DM; (b) value of crop, grain + straw, SL/ha; and (c) increase in crop value over zero-fertilizer control.

The result is hardly surprising. What perhaps is surprising is the lack of difference between zones when it comes to the profitability of fertilizer use (i.e., increase in crop value over that of the zero-fertilizer control). In the absence of nitrogen fertilizer, phosphate was less profitable in zone 2 than in zone 3, but for all other fertilizer combinations, differences between zones were small, even negligible. On this evidence, it may be doubted whether zones 2 and 3 do constitute distinct recommendation domains.

Soil-type Effects

Choosing sites for trials each year demands care to find a representative range of soil types. Among the commonest soils used for barley by farmers are calciorthids and xerochrepts, and so far there have been 7 and 8 B/F trials, respectively, on these two soil types. Calciorthids have tended to outyield xerochrepts (**Fig. 4**), but, similar to the "zones," the difference appears to derive largely from a difference in rainfall:

Soil	Mean rainfall (mm)	Standard deviation (+/-)	Mean dry matter (kg/ha)
Calciorthids	259.6	35.1	4940
Xerochrepts	202.2	22.9	3460
Difference	57.4		1480

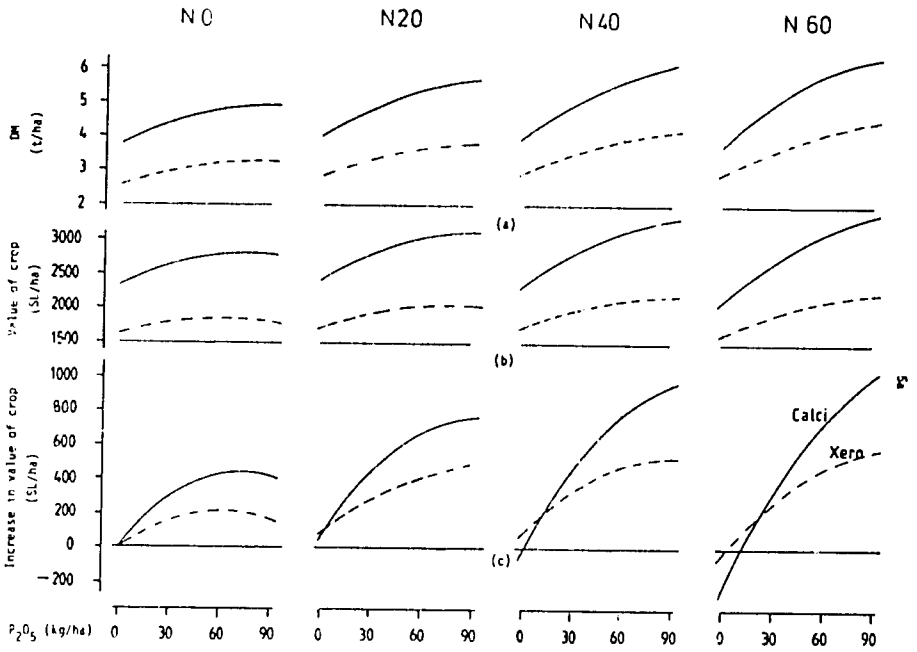

Fig. 4. Comparison of surfaces fitted to data from barley/fallow trials on calciorthid (——) and xerochrept soils (- - -) obtained over fertilizer ranges, 0–60 kg N/ha and 0–90 kg P_2O_5/ha: (a) total aboveground dry matter, DM; (b) value of crop, grain + straw, SL/ha and (c) increase in crop value over zero-fertilizer control.

However, in contrast to what was found with "zones," the effect of fertilizer treatment differed between soil types. Response to phosphate was stronger in calciorthids, at all levels of nitrogen fertilization, and this was reflected in quite large differences in fertilizer profitability. [There was no obvious link here to differences in the availability of native soil phosphate; Olsen-P means were 4.5 (+/-2.76) ppm for calciorthids and 4.3 (+/-1.38) ppm for xerochrepts.]

Rainfall Effects

To look at rainfall effects *per se*, one can divide the 26 B/F trials rather arbitrarily into three groups, according to the rainfall ranges: > 275 mm (7 trials), 200-275 mm (11 trials), < 200 mm (8 trials).

As would be expected, yields and crop values were highest where rainfall was highest (**Fig. 5**). Phosphate fertilizer increased yields and crop value strongly in all rainfall ranges, but those increases were appreciably magnified where there was a combination of higher rainfall (>200 mm) and nitrogen fertilizer. Used alone, however, nitrogen increased yield only in the highest rainfall range, and, except in the presence of high rates of phosphate, it decreased crop value in the two lower ranges.

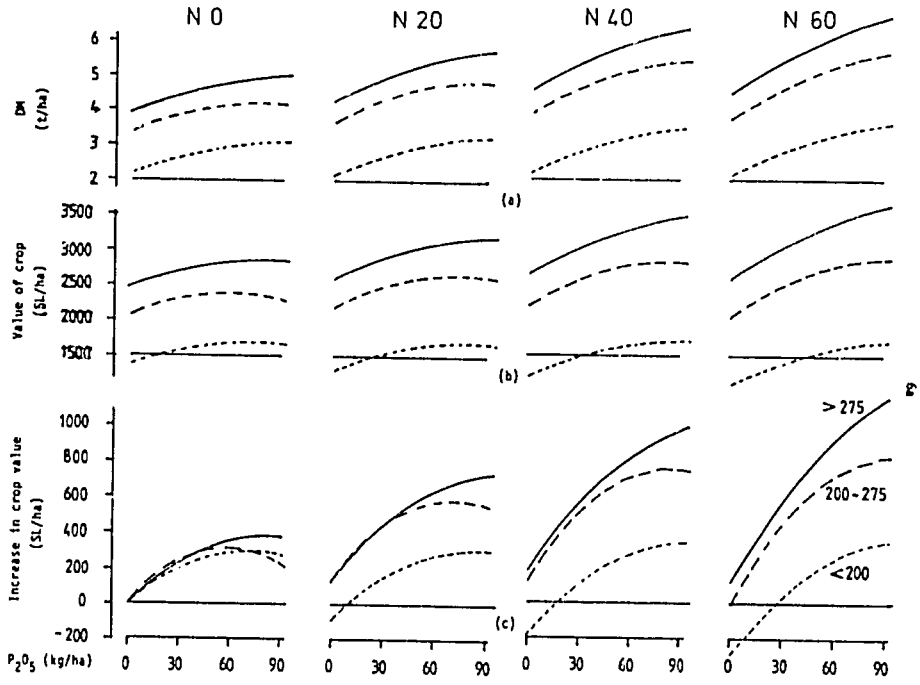

Fig. 5. Comparison of surfaces fitted to data from barley/fallow trials within three ranges of growth-period rainfall, 275 mm (——), 200–275 mm (– – –) and 200 mm (·····) obtained over the fertilizer ranges, 0–60 kg N/ha and 0–90 kg P_2O5/ha: (a) total aboveground dry matter, DM; (b) value of crop, grain + straw, SL/ha; and (c) increase in crop value over zero-fertilizer control.

In the absence of nitrogen fertilizer, the profitability of phosphate use was only modest and very similar in all three rainfall ranges. With increasing amounts of nitrogen fertilizer, profitability increased in the two higher rainfall ranges but tended to decrease in the lowest.

Differences between Geographic Areas

Eleven of the B/F trials were in northwest Syria (Aleppo province) and another 10 were in northeast Syria (Hassakeh and Raqqa provinces) (Fig. 6). Yields and crop values tended to be higher in the northeast but not because of differences in rainfall: means, 227.9 mm (+/-39.7) in the northwest and 238.0 mm (+/-65.6) in the northeast, were similar. What is noticeable is that much of the yield difference between the two areas derived from treatments with zero or low rates of nitrogen fertilizer. Area differences were minimized at applications of 60 kg N/ha.

This observation suggests a local difference in the availability of native soil nitrogen, and this is supported by the mean soil data (0-20 cm depth) obtained at planting time: NW, 13.3 ppm; NE, 20.7 ppm of mineral-N. If found to be consistent over a much larger number of sites, such a difference would likely justify separating northeast and northwest into different recommendation domains for nitrogen fertilization.

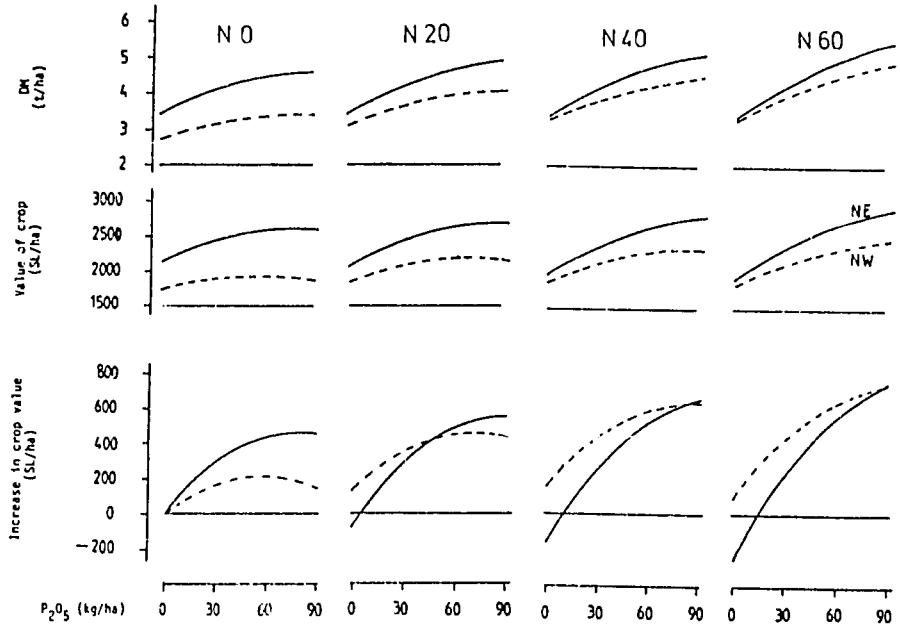

Fig. 6. Comparison of surfaces fitted to data from barley-fallow trials in northwest Syria (Aleppo province) (---) and northeast Syria (Hassakeh and Raqqa provinces) (——) obtained over the fertilizer ranges, 0–60 kg N/ha and 0–90 kg P_2O_5/ha: (a) total aboveground dry matter; (b) value of crop, grain + straw, SL/ha; and (c) increase in crop value over zero.

Certainly, the trial data showed some differences in the profitability of fertilizer use. Phosphate used alone was moderately profitable in the

northeast, much less so in the northwest. Nitrogen used alone was marginally profitable in the northwest but markedly unprofitable in the northeast. However, where relatively high rates of nitrogen and phosphate fertilizer were used together, differences between the two areas were quite small.

Effects of Fertilizer Price

Calculations of crop value and profitability in this paper assume 1985-86 costs and prices, and such calculations rapidly become out of date as prices and costs change. For this reason, fertilizer recommendations need frequent revision. Fortunately, the equations are easily recalculated with different prices and cost (**Fig. 7, Table 1**).

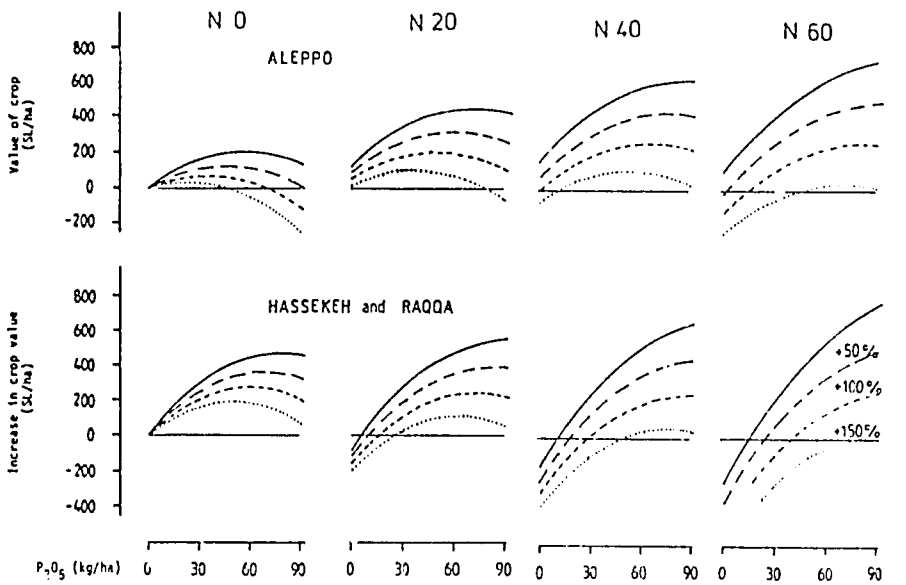

Fig. 7. Effect of fertilizer prices on the increase in crop value over zero-fertilizer control in barley-fallow trials in northwest and northeast Syria: 1985-86 prices (——); price of fertilizer increased by 50% (– – –); by 100% (·····).

At the highest cost (+ 150%), only moderate rates of phosphate used alone remain appreciably profitable and then only in the northeast. At intermediate levels (+50% and +100%), relatively high rates of nitrogen and phosphate used together remain profitable though less attractive. Rates of return (on cash investment in fertilizer) have not been calculated in this paper, but clearly they would fall rapidly with any increase in fertilizer costs.

Table 1. Equation constants of fitted surfaces.

Graphically displayed in Fig. no.	Number and description of trials [a]	a Constant	b N	c P	d N^2	e P^2	f NP
		Total dry matter					
1,2	6 B/F	3199.4	-0.5457	20.082	-0.1108	-0.0842	0.2036
1,2	6 B/B	2240.6	28.617	22.181	-0.2306	-0.1553	0.1023
3	11 zone 2	3883.5	21.354	18.646	-0.2645	-0.1215	0.1541
3	13 zone 3	2746.0	14.157	21.453	-0.1396	-0.1136	0.[illegible]357
4	7 calciorthid	3795.7	17.635	24.281	-0.2986	-0.1307	0.[illegible]26
4	8 xerochrept	2606.4	15.985	15.433	-0.1771	-0.0908	0.1549
5	7 R>275 mm	3912.0	22.331	20.123	-0.2107	-0.0941	0.2077
5	11 200<R<275 mm	3333.4	22.230	21.877	-0.2650	-0.1454	0.2021
5	8 R<200 mm	2176.4	-0.3109	18.195	-0.0167	-0.0960	0.1113
6	11 NW Syria	2701.4	21.610	16.011	-0.1984	-0.0960	0.1664
6	10 NE Syria	3402.9	0.4487	24.224	-0.0252	-0.1245	0.1698
		Cash value of crop [b]					
2	6 B/F	1974.0	-4.936	9.406	-0.0612	-0.0532	0.1239
2	6 B/B	1405.2	13.552	10.841	-0.1414	-0.0958	0.0595
3	11 zone 2	2414.9	8.355	8.402	-0.1505	-0.0743	0.1261
3	13 zone 3	1730.9	4.687	10.368	-0.0888	-0.0696	0.0855
4	7 calciorthid	2354.3	6.429	11.951	-0.1757	-0.0816	0.1558
4	8 xerochrept	1637.6	6.590	6.690	-0.1194	-0.0546	0.0826
5	7 R>275 mm	2465.8	8.734	9.337	-0.1148	-0.0567	0.1202
5	11 200<R<275 mm	2054.4	9.322	10.597	-0.1600	-0.0901	0.1121
5	8 R<200 mm	1377.4	-4.123	8.242	-0.0129	-0.0572	0.0649
6,7	11 NW Syria	1714.5	8.539	7.017	-0.1170	-0.0604	0.0948
6,7	10 NE Syria	2134.4	-4.109	11.726	-0.0000	-0.0738	0.0995
7	11 NW (+50%)	1714.5	6.624	5.592	-0.1170	-0.0604	0.0948
7	10 NE (+50%)	2134.4	-6.024	10.301	-0.0000	-0.0738	0.0995
7	11 NW (+100%)	1714.5	4.709	4.167	-0.1170	-0.0604	0.0948
7	10 NE (+100%)	2134.4	-7.939	8.876	-0.0000	-0.0738	0.0995
7	11 NW (+150%)	1714.5	2.794	2.742	-0.1170	-0.0604	0.0948
7	10 NE (+150%)	2134.4	-9.854	7.451	-0.0000	-0.0738	0.0995

[a] R = Rainfall.

[b] Equations for profitability (relative to control) are the same as for cash value but with the constant, a, omitted. The data graphically displayed in Fig. 7 show profitability when the cost of fertilizer is increased by 50%, 100%, and 150%.

However, the calculations (**Fig. 7**) are unrealistic to the extent that large rises in fertilizer costs would likely be accompanied by at least some rise in crop prices, offsetting losses in profitability. Most recalculations of fertilizer recommendations would need to include changes in both costs of fertilizer and prices of crops.

Discussion

Simple equations can relate crop yield, crop monetary value, and the profitability of fertilizer use to fertilizer rate within variously defined "recommendation domains." Assuming that the findings of past seasons are a

guide to what will happen in the future, one can calculate optimal fertilizer rates on the basis of current fertilizer costs and crop prices. However, a number of reservations must be recorded.

First, the "recommendation domains" used here have been chosen uncritically. They may not represent the best partitioning of the data base. (In fact, with a large data base, a great deal of work may be required to find the best partitioning, and then compromises may be required to translate that partitioning into administratively feasible recommendations. However, the present work suggests that separations according to crop rotation and to rainfall are probably important, although more data are needed to confirm this.

Rainfall effects, however, are problematic, because to a large degree rainfall is unpredictable. It is of limited usefulness to know, for instance, that nitrogen fertilizer greatly improves the profitability of phosphate fertilizer under relatively high rainfall, unless one is able to take account also of rainfall probabilities in the area to be cropped. The stability zones compared above are defined in terms of rainfall amounts and probabilities, and a difference in mean rainfall between the two zones was apparently responsible for a difference in yields; but in yield and value responses to fertilizer, zone differences were found to be small or negligible. This contrasts with what was found when trials were separated according to the amounts of rainfall actually received. Similar differences may emerge between zones as the trials are continued. The 2-year span of data used here is too short to give a comparison that is valid for the long term.

Similarly, differences between soil types and geographic zones need to be monitored for longer than 2 years because of the effect of rainfall. No comparison has yet been made between deep and shallow soils (because few trials so far have been on shallow soils), but this criterion may prove important. Further, one may need to separate domains on the basis of several criteria simultaneously, for instance rotations, zones, and soil depths. That will be possible only with an appreciably larger data base.

A second set of reservations concerns the method of surface fitting. Each equation presented in this paper includes all the factors -- constant, N, P, N^2, P^2, NP -- even though in many equations not every factor was statistically significant. An alternative set of "statistically pure" equations was also calculated, omitting all nonsignificant factors, but these did not fit the data as precisely as did the other set (i.e. lower r^2 value). ("Fit" here means fit to the 16 treatment values, each being a mean across all trials included in the domain. Every mean, however, has a standard deviation. One way to delimit domains, therefore, would be to minimize the standard deviations, particularly those referring to profitability. That has not been attempted here.)

Thirdly, there is the question of how to deal with "yield gap." All the data used here derived from the trials conducted on farmers' fields.

Nevertheless, as Mazid (ICARDA 1987) has pointed out, yields even on the zero-fertilizer control plots of such a trial are usually much higher than those achieved in the same field by the farmer, because of differences in husbandry. These commonly include differences in plant population and degree of weed control. In such circumstances it is almost certainly over-optimistic to assume that crop-yield (and, therefore, cash) responses to fertilizer will be as large for the farmer as they appear from our trials. How best to allow for this is debatable. In our work next season, we aim to organize simple "farmer-managed" trials alongside our "researcher-managed" trials. These, we hope, will give us a measure of the magnitude of the researcher-farmer yield gap both in the presence and in the absence of fertilizer.

It is unlikely that the information obtained in this way will be sufficiently uniform to permit us thereafter to use a simple factor, say 75%, to convert research findings to the farmer situation. Farmers' methods vary too widely. But any information that enables us to interpret our results more relevantly is useful. Ultimately, we might aim to tie fertilizer recommendations to certain minimal standards of husbandry. Comparison of researcher-managed trials will assist us in defining what those standards should be.

Acknowledgments

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Two Soil Tests for Phosphorus Calibrated with Barley Responses to Fertilizer in Rainfed Conditions of Turkey

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Abstract. Data on grain yields of Tokak barley were obtained from multilocational trials held in 1978-79 in central Anatolia, Turkey, and were compared with values for available phosphorus as measured by Olsen and Bray and Kurtz-1 methods. The yields were correlated with the soil-test values and rates of fertilizer application by Bray's modified version of the Mitscherlich equation. Calibration curves of the data showed that barley responded to P up to 100 kg P_2O_5/ha (16.4 ppm) and 200 kg P_2O_5 (32.7 ppm) by the Olsen and Bray-1 methods, respectively. The most economic amount of fertilizer was calculated for soils with different levels of available P. It was considered to be the sum of increments for which the final increment in fertilizer still produces an increase in profit.

Introduction

In Turkey and throughout the Middle East, the Olsen bicarbonate soil test is commonly used to test for available P in calcareous soils. In fact, it has been used for about 30 years in Turkey, and reliable data on responses by cereals to P application have been accumulated. This paper reports a correlation between the Olsen and Bray-1 tests and the response of barley to phosphorus fertilization. The results have been used to calculate economic levels of fertilizer P for semi-arid calcareous soils in the central Anatolia region, which is the principal barley-producing area in the country. The approach used in this study is that suggested by Bray through a modified form of the Mitscherlich equation.

Materials and Methods

The data used were derived from multilocational trials held in 1978-79 to determine effects of P application on barley in central Anatolia. The region is a dissected plateau that includes mountains, foothills, lake basins, and a few narrow alluvial plains: elevations vary from 700 to 1500 m.

Annual rainfall is about 400 mm and is not distributed ideally for crop production. Highest amounts occur during winter and early spring, with very little rain during summer. Thus, winter crops grow fairly well, but spring-sown crops require irrigation. Under Turkish conditions, dryland farming usually involves fallow every other year. The soil groups are principally red and reddish brown, fine, shallow to medium deep, low in organic matter, and calcareous. They are moderately infertile, especially in nitrogen and phosphorus, and are suitable for the production of small grain only. Yields fluctuate widely, depending on annual rainfall.

The original experiments were conducted as a 4 x 4 latin square, with fertilizer rates of 0, 40, 80, and 120 kg P_2O_5/ha as treble superphosphate. Fertilizer was drilled into the soil along with seeds of Tokak barley. Soil samples were collected before seeding, at 0-20 cm, and analyzed for available phosphorus by the methods of Olsen and of Bray and Kurtz-1. The pH was determined on a saturated paste, by glass electrode, and free carbonates were determined by acid neutralization (**Table 1**).

Table 1. Physical and chemical properties of soils for 18 experiments, Anatolia, Turkey.

Texture	pH	CCE[a] (%)	Total salts (%)	Available P by Olsen	Available P by Bray and Kurtz-1	K_2O (kg/ha) (NH_4AC)	Organic matter (%) (Walkley Black)
Clay-loam	7.60	15.4	0.089	2.6	5.9	1950	0.86
Clay-loam	7.60	7.4	0.084	2.6	4.8	900	0.69
Loam	7.20	31.6	0.063	3.8	6.7	1120	0.79
Clay-loam	7.55	3.6	0.102	6.0	11.1	2000	1.94
Clay-loam	7.80	32.8	0.100	4.7	11.0	3200	1.09
Loam	7.90	18.6	0.070	7.0	14.7	6010	2.80
Clay-loam	7.60	14.6	0.074	7.2	10.7	1200	1.99
Clay-loam	7.70	29.8	0.088	6.4	12.7	2510	1.20
Clay-loam	7.70	12.3	0.082	4.4	7.9	1970	0.72
Loam	7.80	12.8	0.068	4.1	7.6	620	1.08
Loam	7.80	23.3	0.049	6.0	10.6	560	1.20
Loam	7.70	29.6	0.055	8.0	14.6	610	1.25
Loam	7.90	28.9	0.058	6.4	11.8	2030	1.57
Sand	8.25	47.0	0.033	3.9	6.1	920	0.82
Loam	7.80	36.0	0.059	3.7	6.5	500	1.25
Loam	7.85	0.8	0.040	4.0	6.8	640	0.99
Loam	7.80	8.8	0.046	3.9	7.3	430	0.80
Loam	7.80	17.2	0.052	4.5	9.2	880	0.67

[a] CCE = Calcium carbonate equivalent.

Grain yields from each location were analyzed statistically to determine whether the crop showed any significant response to the fertilizers added. The yields were correlated with soil-test values and rates of fertilizer application by Bray's modified version of the Mitscherlich equation. This equation takes the form, $\log (A - y) = \log A - c_1 b_1 - cx$, where A is the yield on the fully phosphorus-treated plot, y the yield for any given phosphorus rate, b_1 the soil-test value, x a given fertilizer rate.

The constants c_1 and c are for b_1 and x, respectively, and were calculated for the yield percentages in each experiment. Once the constants in the Mitscherlich equation were known, the percentage response of barley to phosphorus fertilization for any soil-test value could be determined as could the fertilizer rates for maximal yields. Then the highest level of fertilizer that could be applied at a profit was calculated. This value was deemed to be a practical basis for fertilization.

Results and Discussion

Statistical analysis of field trials showed that phosphorus treatments significantly increased yields of barley under dryland conditions (**Table 2**). Large seasonal differences in barley yields were obtained, but the response data are statistically significant. For calculation of c_1 for b_1 -- the soil-test value -- the average yield from 120 kg P_2O_5/ha treatments was used as A, the average yield from the no-phosphorus treatments as y, and the indicated Olsen or Bray-1 soil-test values as b_1. For the calculation of c for x -- the fertilizer rate -- the average barley yield from the 120 kg P_2O_5/ha treatments was used as A, the average barley yield from the first rate of phosphorus as y, the previously calculated c_1 value for that field, and the soil-test value as b_1.

Table 2. Soil-test values and the response of barley to phosphorus applications in 18 experiments, Anatolia, Turkey.

Yields (kg/ha) from soil with P_2O_5 applied at (kg/ha)						Soil-test values (ppm)	
0	40	80	120	LSD (0.05) (kg/ha)	Increase in yield (%)	Olsen	Bray & Kurtz-1
569	1151	1720	1686	288.3	66.2	2.6	5.9
1011	2495	2564	2785	381.7	63.7	2.6	4.8
919	1415	1415	1653	236.1	44.4	3.8	6.7
2050	2996	3201	3036	448.4	32.5	6.0	11.1
2182	2943	3155	3353	481.4	34.9	4.7	11.0
2374	2983	3591	3677	520.5	35.4	7.0	14.7
2057	2705	2778	2903	128.3	29.1	7.2	10.7
3135	3552	4167	4544	622.4	31.0	6.4	12.7
2507	3624	4636	4874	531.7	48.6	4.4	7.9
995	1716	1817	1846	94.0	46.1	4.1	7.6
2026	3244	3683	3539	344.7	42.8	6.0	10.6
2387	3776	4175	3929	354.9	39.2	8.0	14.6
1600	2078	2500	2555	181.3	37.4	6.4	11.8
573	1071	1345	1406	94.0	59.2	3.9	6.1
964	1403	1724	1782	230.0	45.9	3.7	6.5
1999	2509	2882	3270	407.5	38.9	4.0	6.8
802	1392	1617	1722	238.8	53.4	3.9	7.3
1366	1982	2980	3133	224.9	56.4	4.5	9.2

In some experiments, the yield obtained from the first rate (40 kg/ha) of phosphorus was 90% or more of maximal yield so could not be used in calculations of the constant c for x. In many cases, the barley yields from 80 kg P_2O_5/ha and 120 kg P_2O_5/ha were essentially equal, indicating that 80 kg/ha had corrected the deficiency. Therefore, barley yields from the 120 kg P_2O_5/ha treatments should present a valid "A" for the Mitscherlich equation -- that is the yields at which adequate but not excessive amounts of fertilizer have been used.

Average c_1 values of 0.0122 and 0.0066 were obtained for Olsen and Bray-1, respectively, and an average c value of 0.0087 was calculated. The constant c was used for calculations of A for each rate on each field, using the formula $A = yk - y_0/k - 1$, where y_0 was yield from the untreated plot, y the yield for any given phosphorus rate, and k the antilog of cx. The values for each rate were averaged and used as "A" for that field (**Table 3**). Average "A" for all the fields was calculated to be 2940 kg/ha, which is very close to average "A" obtained -- 2872 kg/ha.

Table 3. Percent and maximal yields and Mitscherlich constants.

Yields (% of maximum) obtained at rates (kg/ha) of P_2O_5				Maximum yield (kg/ha)		Mitscherlich constants			
						c_1		c	
0	40	80	120	Calculated	Obtained	Olsen	Bray and Kurtz-1	for P_2O_5 40 kg/ha	for P_2O_5 80 kg/ha
33.7	68.3	102.0	100.0	1711	1686	0.0111	0.0049	0.0080	-
36.3	89.5	92.1	100.0	2958	2785	0.0124	0.0066	-	0.0113
55.6	85.6	85.6	100.0	1695	1653	0.0151	0.0086	0.0122	-
67.5	98.7	105.4	100.0	3134	3036	0.0133	0.0072	-	-
65.1	87.8	94.1	100.0	3477	3353	0.0159	0.0068	0.0114	0.0097
64.6	81.1	97.7	100.0	3735	3677	0.0106	0.0050	0.0068	-
70.8	93.2	95.7	100.0	2974	2903	0.0122	0.0082	-	0.0104
69.0	78.2	91.7	100.0	4556	4544	0.0129	0.0066	0.0038	0.0072
51.4	74.4	95.1	100.0	4938	4874	0.0116	0.0065	0.0069	0.0124
53.9	93.0	98.4	100.0	1977	1846	0.0136	0.0072	-	-
57.2	91.7	104.1	100.0	3689	3539	0.0100	0.0057	-	-
60.8	96.1	106.3	100.0	4082	3929	0.0083	0.0046	-	-
62.6	81.3	97.8	100.0	2617	2555	0.0109	0.0059	0.0075	-
40.8	76.2	95.7	100.0	1502	1406	0.0095	0.0061	0.0099	-
54.1	78.7	96.7	100.0	1846	1782	0.0148	0.0085	0.0083	-
61.1	76.7	88.1	100.0	3141	3270	0.0168	0.0099	0.0056	0.0064
46.6	80.8	93.9	100.0	1834	1722	0.0114	0.0061	0.0111	0.0118
43.6	63.3	95.1	100.0	3059	3133	0.0091	0.0044	0.0047	-

The soil-test values calculated for each field were in fairly good agreement with responses and values for Olsen and Bray-1 soil tests (**Tables 3** and **4**). Calibration curves of the data showed that soils with less than 100 kg P_2O_5/ha (16.4 ppm) and 200 kg P_2O_5/ha (32.7 ppm) by the Olsen and Bray-1 methods, respectively, are deficient in phosphorus (**Fig. 1**).

Table 4. Calculated sufficiencies for barley in central Anatolia, based on the equation log (100 - y) = log 100 - $0.0122b_1$ - 0.0087x for Olsen method and log (100 - y) = log 100 - $0.0066b_1$ - 0.0087x for Bray-1 method.

Olsen-P (ppm)	Bray-1 (ppm)	Calculated sufficiency (%) for P_2O_5 applied (kg/ha) at 0 Olsen	0 Bray-1	40 Olsen	40 Bray-1	80 Olsen	80 Bray-1	120 Olsen	120 Bray-1	Chi-square value Olsen	Chi-square value Bray
2.6	5.9	36.4	42.3	71.4	74.1	87.2	88.4	94.2	94.8	3.20	4.58
2.6	4.8	35.8	36.2	71.2	71.4	87.1	87.2	94.2	94.2	5.35	5.22
3.8	6.7	48.0	46.3	76.7	75.9	89.5	89.2	95.3	95.1	2.64	3.50
6.0	11.1	64.4	64.3	84.0	84.0	92.8	92.8	96.8	96.8	4.54	4.55
4.7	11.0	55.3	64.1	80.0	83.9	91.0	92.8	96.0	96.8	2.77	0.32
7.0	14.7	69.7	74.4	78.4	88.5	93.9	94.8	97.3	97.7	0.69	2.05
7.2	10.7	70.8	62.8	86.9	83.3	94.1	92.5	97.4	96.6	0.53	2.30
6.4	12.7	66.9	69.2	85.2	86.2	93.3	93.8	97.0	97.2	0.76	0.87
4.4	7.9	53.3	52.1	79.0	78.5	90.6	90.3	95.8	95.7	0.74	1.10
4.1	7.6	50.2	50.6	77.6	77.8	90.0	90.0	95.5	95.5	4.32	4.18
6.0	10.6	64.4	62.5	84.0	83.2	92.8	92.4	96.8	96.6	2.99	2.92
8.0	14.6	74.6	74.1	88.6	83.4	94.9	94.8	97.7	97.7	4.61	5.77
6.4	11.8	66.6	66.5	85.0	85.0	93.3	93.2	97.0	97.0	0.71	0.71
3.9	6.1	49.0	43.4	77.1	74.6	89.7	88.6	95.4	94.6	2.00	1.07
3.7	6.5	47.4	45.4	76.4	75.5	89.4	89.0	95.2	95.1	1.83	2.68
4.0	6.8	49.6	46.7	77.4	76.1	89.8	89.3	95.4	95.2	2.93	4.70
3.9	7.3	49.0	49.2	77.1	77.2	89.7	89.8	95.4	95.4	0.72	0.70
4.5	9.2	53.4	57.6	91.1	81.0	90.6	95.1	95.8	96.2	5.36	7.42

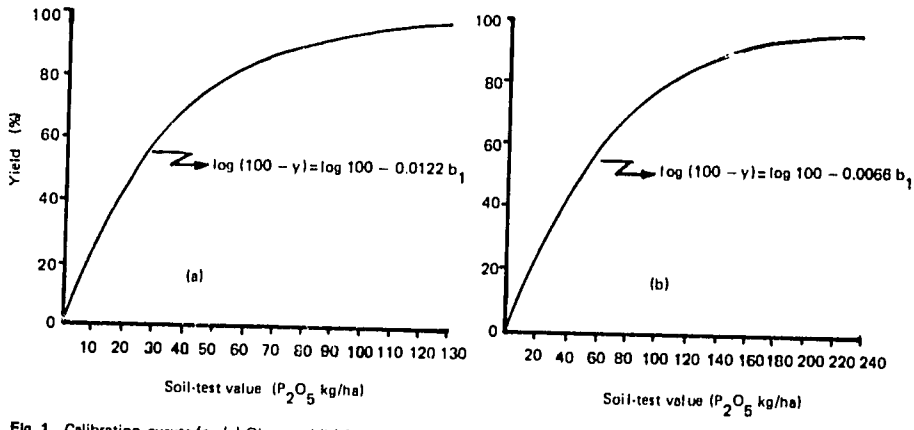

Fig. 1. Calibration curves for (a) Olsen and (b) Bray and Kurtz-1 soil tests.

The amount of phosphorus required to correct the deficiency is determined essentially by four variables: the level of available phosphorus in the soil, the upper limit of desired yield, the method of applying fertilizer, and the crop to be grown.

Both the Olsen and the Bray-1 soil tests provide a guide on levels of sufficiency of phosphorus that is applied in bands with seed. For example, if the Olsen soil-test value were 20 kg P_2O_5/ha (3.3 ppm), the soil would be producing only 43% of the yield possible with adequate phosphorus (**Table 5**). To raise the yield to 90% requires 76.9 kg P_2O_5/ha; to raise it to 92%, 94%, 96% requires 98.4, 112.2, 132.9 kg P_2O_5/ha, respectively; and to get to the 98% production level requires 167.4 kg P_2O_5/ha.

Table 5. Calculated quantities of phosphorus fertilizer required to attain various sufficiency levels for barley based on the Olsen and Bray-1 soil tests for Anatolia region, Turkey.[a]

Soil test, kg P_2O_5/ha (ppm)		(%) sufficiency		Required fertilizer rates (kg P_2O_5) 90% yields		98% yields	
Olsen	Bray-1	Olsen	Bray-1	Olsen	Bray-1	Olsen	Bray-1
5 (0.8)	10 (1.6)	13	14	107.9	107.4	188.4	187.8
10 (1.6)	20 (3.3)	24	26	100.9	99.8	181.4	180.2
15 (2.5)	30 (4.9)	34	37	93.9	92.2	174.4	172.6
20 (3.3)	40 (6.5)	43	46	86.9	84.6	167.4	165.0
25 (4.1)	50 (8.2)	50	53	79.9	77.0	160.3	157.5
30 (4.9)	60 (9.8)	57	60	72.9	69.4	153.3	149.9
35 (5.7)	70 (11.5)	63	65	65.9	61.8	146.3	142.3
40 (6.5)	80 (13.1)	68	70	58.8	54.2	139.3	134.7
45 (7.4)	90 (14.7)	72	74	51.8	46.7	132.3	127.1
50 (8.2)	100 (16.4)	75	78	44.8	39.1	125.3	119.5
55 (9.0)	110 (18.0)	79	81	37.8	31.5	118.3	112.0
60 (9.8)	120 (19.6)	81	84	30.8	23.9	111.3	104.4
65 (10.6)	130 (21.3)	84	86	23.8	16.3	104.2	96.8
70 (11.5)	140 (22.9)	86	88	16.8	8.7	97.2	89.2
75 (12.3)	150 (24.5)	88	90	9.8	-	90.2	81.6
80 (13.1)	160 (26.2)	89	91	2.8	-	83.2	74.0
85 (13.9)	170 (27.8)	91	92	-	-	76.2	66.4
90 (14.7)	180 (29.5)	92	94	-	-	69.2	58.8
95 (15.5)	190 (31.1)	93	94	-	-	62.2	51.3
100 (16.4)	200 (32.7)	94	95	-	-	55.1	43.7
110 (18.0)	210 (34.4)	96	96	-	-	41.1	36.1
	220 (36.0)	96		-		28.5	
	230 (37.6)	97		-		20.9	
	240 (39.3)	97		-		13.3	
	250 (40.9)	98		-		-	

[a] Fertility classifications by Olsen-P and Bray-1 values, respectively are very low < 10, < 20; low 10-30, 20-60; medium 30-60, 60-100; good 60-80, 100-150; high 80-100, 150-200; very high > 100, > 200.

If the available phosphorus were equivalent to a sufficiency less than 30%, the soil is classified as very low; if 30-60%, low; if 60-80%, medium; 80-90%, good; 90-95%, high; and more than 95%, very high. This means that, under the rainfed conditions of central Anatolia, barley planted on calcareous soils having Olsen soil-test values greater than 100 kg P_2O_5/ha (16.4 ppm) would not respond to phosphorus fertilization.

Economically Optimal Rates

The Mitscherlich equation gives a standard polynomial parabolic curve:

$$\log (2940 - y) = \log 2940 - 0.0122\, b_1 - 0.0087X \qquad \text{(Olsen)}$$
$$\log (2940 - y) = \log 2940 - 0.0066\, b_1 - 0.0087X \qquad \text{(Bray-1)}$$

where 2940 is the theoretical maximum yield A, and 0.0122 and 0.0066 and 0.0087 are average c_1 and c values respectively.

Table 6. The calculated total yields, yield changes with successive increments of fertilizer use, and economically optimal rates for fertilizer P, based on equation log (2940 - y) = log 2940 - 0.0122 b_1 - 0.0087x.[a]

	b_1 = 10 kg P_2O_5/ha (Olsen)			b_1 = 30 kg P_2O_5/ha (Olsen)		
Rate of applied P_2O_5 (kg/ha)	Total yield (kg/ha)	Average yield change per increment of P_2O_5 (kg/ha)	Net value of the barley yield increase (TL/ha)	Total yield (kg/ha)	Average yield change per increment of P_2O_5 (kg/ha)	Net value of the barley yield increase (TL/ha)
0	720	-	-	1674	-	-
10	1123	403	32,000	1904	230	18,400
20	1453	330	26,400	2092	188	15,040
30	1723	270	21,600	2246	154	12,320
40	1944	221	17,680	2372	126	10,080
50	2125	181	14,480	2475	103	8,240
60	2273	148	11,840	2560	85	6,800
70	2394	121	9,680	2628	68	5,440
80	2493	99	7,920	2685	57	4,560
90	2574	81	6,480	2731	46	3,680
100	2640	66	5,280	2769	38	3,040
110	2695	55	4,400	2802	32	2,560
120	2739	44	3,520	2826	25	2,000
130	2776	37	2,960	2846	20	1,600
140	2806	30	2,400	-	-	-
150	2830	24	1,920	-	-	-
160	2850	20	1,600	-	-	-

[a] The prices for the calculation were TL190/kg of P_2O_5 as superphosphate and TL80/kg for barley. Therefore, each increment of fertilizer (10 kg) would cost TL1900.

Using these equations, one can calculate the optimal fertilizer rates for different soil-test values obtained by Olsen or Bray-1 tests in this region. These rates, however, may not be the practical maxima, which are a measure of the farmers' costs and potential revenue for the fertilization (**Table 6**).

Two types of production costs are involved, namely the fixed and the variable costs. The fixed costs include such items as plowing, seedbed preparation, harvesting, etc. Under Turkish village conditions, there is no extra cash outlay for the family labor to spread the extra fertilizer or harvest the increased yields. The variable costs, therefore, were considered only as those representing the cost of the fertilizer.

If the potential applications of fertilizer are broken into equal increments, the most economic amount of fertilizer is the sum of increments for which the final increment still produces an increase in profit (**Table 6**). For example under the conditions of central Anatolia, when soil-test value (b_1) is 10 kg P_2O_5/ha (1.6 ppm) Olsen-P, the first 10 kg P_2O_5/ha costs TL1900 and gives a yield increase of 400 kg/ha of barley. The net return is TL32,000/ha. Each successive 10 kg P_2O_5/ha fertilizer gives a smaller yield increase, and net return; the 15th increment, which gives a 24 kg/ha yield increase, valued at TL1920 is the last successive

10 kg P_2O_5/ha increment of fertilizer for which the value of the increased yield exceeds the cost of the fertilizer. When 160 kg P_2O_5/ha is used, instead of 150, the yield increase is valued at TL1600 or TL300 less than the cost of the fertilizer increment. The economically optimal rate, therefore, is 150 kg P_2O_5/ha when the Olsen soil-test value (b_1) is 10 kg P_2O_5/ha (1.6 ppm), and it is 120 kg P_2O_5/ha when soil-test value (b_1) is 30 kg P_2O_5/ha (4.9 ppm) (**Table 6**).

If one compares the economically optimal rates with the quantities of phosphorus fertilizer required to attain various sufficiency levels (**Table 5**), one can see that it won't be economic to apply phosphorus fertilizers for a yield at 98% of maximum.

Conclusions

The value of any rapid soil-testing program for phosphorus depends essentially on how accurately the soil-test method measures the available form or forms of phosphorus in the soil and how accurately the test results can be related to dependable data from field experiments. The data presented here show that the Olsen bicarbonate and Bray and Kurtz-1 methods are both capable of measuring the available form, or forms, of phosphorus in central Anatolia and that the Mitscherlich equation can be used to correlate such soil-test values with barley's response to P in the field. On the basis of current prices of fertilizer and barley, the Mitscherlich equation is capable of calculating the most economic amount of a fertilizer to be used by farmers of the region.

Direct and Residual Effect of Fertilizer Phosphorus on Barley in Cyprus

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Abstract. In a long-term experiment, barley was grown in seven successive seasons (1980-87) in the same field, the soil of which was a sandy loam containing 20% $CaCO_3$ and $NaHCO_3$-extractable P equal to 4 ppm. For the first five seasons, treatments were 0, 30, or 60 kg P/ha, broadcast as treble superphosphate and tine-cultivated into the soil prior to sowing; in the last two seasons P was not applied so that the effect of residual P could be assessed. The crop was harvested for hay in mid-April at the milk stage of the grain. Rainfall was mostly less than 300 mm, which is the water requirement of the crop. As a result the crop suffered various degrees of water stress in the different growing seasons. Fertilizer P increased yield significantly in all seasons but one, in which there was relatively high rainfall in November, December, and January. Application of 30 kg P/ha was sufficient for maximum yield and increased $NaHCO_3$-extractable P to 15 ppm after two growing seasons. The difference between the amount of P removed by the unfertilized and the fertilized crop plus the increase in $NaHCO_3$-extractable soil P accounted for about 30% of the fertilizer P applied. In agreement with established norms, 8 ppm $NaHCO_3$-extractable soil P in the plow layer was sufficient for maximum yield

Introduction

In Cyprus where 95% of the cereal hectarage is taken up by barley, all soils are inherently low in N (less than 0.1% in the plow layer) and P (< 5 ppm) but are, with the exception of the hilly soils of the igneous part of the Troodos massif, adequately supplied with K (250 ppm exchangeable K). Fertilizers have long been available at reasonable prices to Cypriot farmers and have been recommended by the Ministry of Agriculture for wheat and barley: N and P_2O_5 in the ratio 1:1.5. Thus the $NaHCO_3$-extractable P in soils tested by the Ministry of Agriculture is commonly 8-10 ppm. What effects this residual fertilizer has on barley under conditions common in Cyprus is unclear so the present work aimed to test the response of barley to directly applied P, to monitor the changes in $NaHCO_3$-extractable P in the soil and to assess the value of residual fertilizer P. To this end, an

experiment was run on one field with barley for 7 consecutive growing seasons (1980-87).

Materials and Methods

The soil of the experimental field, which was situated at Athalassa farm, Nicosia (35° 9' N, 33° 21'E, altitude 160 m), was a fine sandy loam containing $CaCO_3$ at 21% (**Table 1**) and $NaHCO_3$-extractable P at 4 ppm in the plow layer (**Table 2**). The phenologic stages of the variety used, Athenais,

Table 1. Particle size distribution, pH, $CaCO_3$, and organic matter contents of the experimental soil.

Depth (cm)	Particle size distribution (%) Clay	Silt	Fine sand	Coarse sand	pH[a]	$CaCO_3$ (%)	Organic matter (%)
0-30	20	12	52	16	8.5	21	0.9
30-60	19	15	46	20	8.6	18	0.5
60-90	19	16	46	17	8.6	16	0.4

[a] 1:2.5 water.

Table 2. $NaHCO_3$-extractable P (ppm) as affected by P fertilizing, 1980-84 (last application was made on 22/11/84).

Date	Depth of sampling	Available P (ppm) from annual applications of fertilizer P (kg/ha) at: 0	30	60
29/11/80	Surface	4.0	4.0	4.0
18/11/83	0-15 cm	4.3	15.0	30.0
	15-30 cm	2.4	6.4	10.7
21/11/84	Surface	5.1	17.8	36.1
23/9/85	0-15 cm	4.0	15.5	24.8
	15-30 cm	1.7	3.1	4.2
	30-45 cm	0.8	1.6	2.0
10/6/87	Surface	3.9	7.1	12.4

were recorded: emergence 12 December, second leaf 31 December, tillering 28 January, booting 13 March, heading 29 March, flowering 3 April, milk stage 11 April, and dough stage 24 April. Rainfall over the barley growing season, i.e., November-April, averages 240 mm and ranges from 160 to 310 mm (Methochis 1979).

The field was grown with Athenais cut for the production of hay at the milk stage of grain. A uniform N dressing of 60 kg/ha was applied together with 0, 30, or 60 kg P/ha as treble superphosphate. All fertilizers were broadcast and were tine-cultivated before the seed was drilled into the soil. Phosphorus application was discontinued in the 1985-86 and 1986-87 seasons so that the effect of residual fertilizer P could be assessed.

The surface layer of soil was analyzed at intervals for $NaHCO_3$-extractable P. In September 1985, when P fertilizing was discontinued, the soil profile to 45 cm deep was analyzed for P to enable, in conjunction with the amount of P removed in the harvested matter, a P balance to be made for 1980-85.

Results

Extremely dry spells occurred in January 1982, March 1985, and February 1987. As a means to salvage the crop, the field was irrigated (50 mm water) on 25 January 1982, 19 March 1985, and 24 February 1987. Rainfall (including irrigation) over the growing season (November-April) was below average in two seasons, about average in another two, and above average in three seasons (**Fig. 1**). However, even above average rainfall was < 300 mm, which represents the water requirement of the crop in the Athalassa area, and rainfall was erratic. The crop suffered water stress in all seasons, and in 1982-83 when rainfall was only 140 mm, dry matter production was very low and was harvested in bulk to clear the field for the following season. In five of the remaining seasons including the two during which P fertilizer application was discontinued, response to P was significant. In only one season (1984-85), in which there was relatively high rainfall in November, December, and January, was there no response to P (**Fig. 1**).

Concentration of P in the harvested matter invariably increased with P fertilizer (**Table 3**). However, at heading, the leaf below the flag leaf had increased with P fertilizer in only one of the two seasons it was sampled (**Table 4**): at 0, 30, and 60 kg P/ha, respectively, P constituted 0.27%, 0.27%, and 0.28% in 1980-81 and 0.22%, 0.26%, and 0.28% in 1981-82. Fertilizer P conspicuously promoted growth and advanced heading by about a week.

In the 0-15 cm soil layer, $NaHCO_3$-extractable P increased to 15 and 30 ppm following application of 30 and 60 kg P/ha for only two seasons. It also increased in the 15-30 cm layer through mixing of the soil by cultivation (**Table 2**). From the data for the 0-45 cm soil profile and the amounts

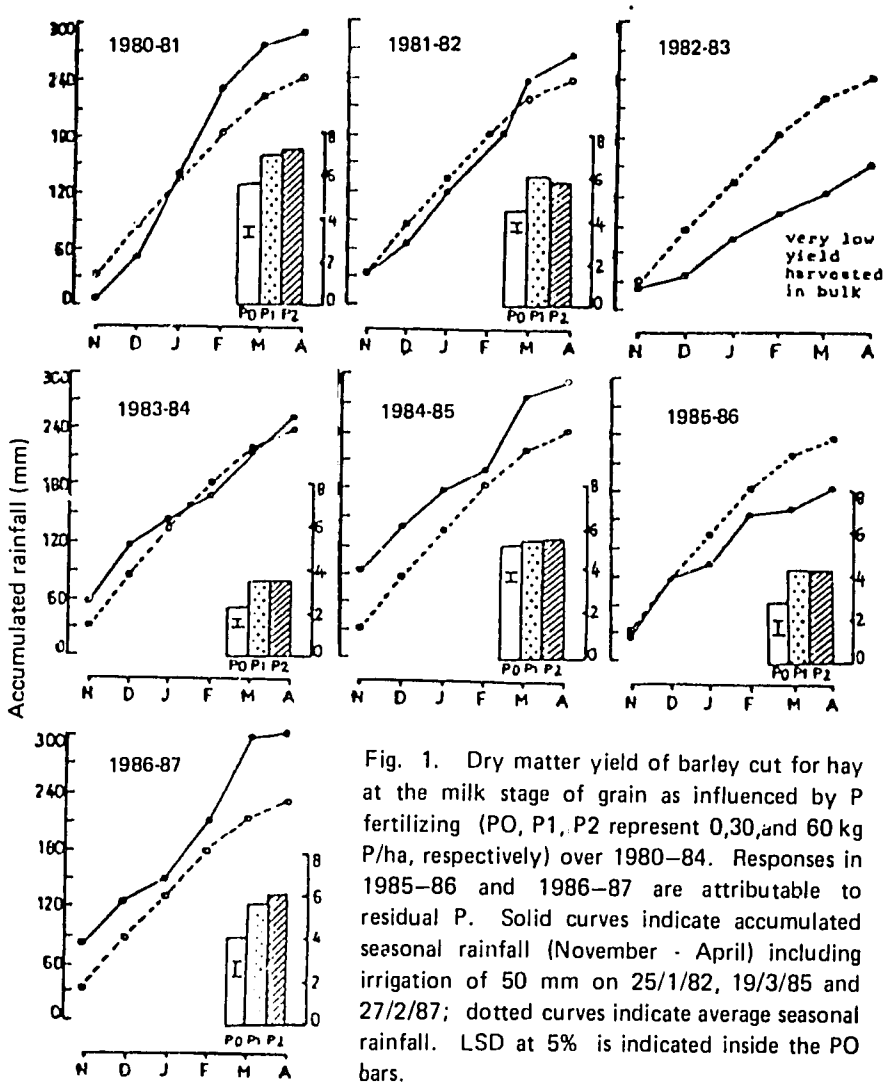

Fig. 1. Dry matter yield of barley cut for hay at the milk stage of grain as influenced by P fertilizing (PO, P1, P2 represent 0,30, and 60 kg P/ha, respectively) over 1980–84. Responses in 1985–86 and 1986–87 are attributable to residual P. Solid curves indicate accumulated seasonal rainfall (November - April) including irrigation of 50 mm on 25/1/82, 19/3/85 and 27/2/87; dotted curves indicate average seasonal rainfall. LSD at 5% is indicated inside the PO bars.

of P removed in the harvested matter (**Table 2**) in the first five seasons (the 1982-83 season was excluded), a P balance was estimated on the assumption that the same amount of indigenous soil P was taken up in plots that received fertilizer P. Bulk density was 1500 kg/m^3 soil. The amount of P removed in the dry matter harvested plus that found as an increase in $NaHCO_3$-extractable P accounted for 30% of the fertilizer P applied (**Table 4**). However, the total amount of P removed in the harvested matter over the entire experimental period (1980-87) under the 30 kg P/ha treatment, in excess of that removed under the no-fertilizer P treatment, was only 16% of the fertilizer P applied.

Table 3. Concentration (%) and total (kg/ha) of P in barley matter cut for hay as influenced by P fertilizing (1980-81 to 1984-85 direct effect; 1985-86 and 1986-87 residual effect).

	P (% dry matter) from application (kg/ha) at			Total P (kg/ha) from applications (kg/ha) at		
	0	30	60	0	30	60
1980-81	0.17	0.19	0.21	9	13	15
1981-82	0.14	0.15	0.18	6	9	10
1982-83	-	-	-	-	-	-
1983-84	0.14	0.20	0.23	3	7	8
1984-85	0.16	0.24	0.27	8	13	15
1985-86	0.14	0.20	0.23	4	8	10
1986-87	0.15	0.19	0.19	6	10	12

Table 4. Balance of fertilizer P applied over five seasons (1980-85).

P applied	P removed (kg/ha)	Increase in $NaHCO_3$-extractable soil P (kg/ha)	Fertilizer P unaccounted for (kg/ha)
0	26	0	0
150	42	28	106
300	48	55	223

Discussion

The availability of a reliable and almost universally applicable soil test for available P ($NaHCO_3$-extractable or Olsen-P test) greatly facilitates soil test calibration for P. The extensive body of correlation studies made since this test was proposed (Olsen *et al.* 1954) has helped to define soil P fertility norms that have remained valid (Fielder *et al.* 1987). A sufficiency range of 8-14 mg P/kg soil in the plow layer receives support from the present experiment and was reached within two growing seasons. In plots that did not receive fertilizer P, available P remained unchanged at 4 ppm -- a finding in agreement with the results of the long-term study by

Halvorson and Black (1985) with a soil at 6 ppm. These authors showed that an initial application of P caused a rise in available P and then a leveling after a few years, depending on the rate of P applied.

The present study clearly illustrates the well-documented effects of rainfall, particularly early in the season. However, these findings should not be overemphasized, as the aim should be to maintain sufficient P for the crop to take full advantage of whatever rainfall occurs, especially during years with high rainfall. The absence of signs of P deficiency in the plants in which significant responses to P were obtained further supports the value of soil testing as the criterion on which to base fertilizer P application.

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Diagnostic Norms for Nutrients in Soils Supporting Cereals

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Abstract. Optimal levels of nutrients in soil were derived as a guide to fertilization in Tunisia. Data were collected from 13 fertilizer trials conducted in various sites of the central-western region and were plotted on graphs: wheat and barley yields against the corresponding soil nitrogen and Olsen-P values taken from the fertilized and unfertilized plots at tillering. A boundary line was drawn to confine the resultant scatters of points and, hence, to indicate soil mineral nitrogen and phosphorus levels at tillering stage that maximize yields. It was found that optimal concentrations were equivalent to 32.5 and 34.0 ppm for durum wheat and 34.5 and 33.5 ppm for barley for mineral nitrogen and Olsen-P, respectively.

Introduction

Wheat and barley cover 20% and 30% of the total arable land in Tunisia (FAO 1986), but production in average years has seldom exceeded 81,500 t and 25,300 t (El Felah 1985) -- only 58% of the country's requirements for small grains (FAO 1986). The low yields -- 0.9 t/ha of wheat and 0.6 t/ha of barley (El Felah 1985) -- can partly be attributed to inadequate fertilization.

In Tunisia, fertilizer norms are empirical, based generally on the farmer's agricultural background and often on inapplicable field trials rather than on soil testing of the level of nutrients available and determination of supplements required by any given crop (Geraldson 1975). The quality of recommendations based on soil testing depends on the data available for calibration and interpretation and on the relevance of correlations provided by research on crop production (Melsted and Peck 1973; Geraldson 1975).

Establishing reliable soil norms for diagnostic purposes has been for years the concern of both agronomists and researchers; the reasoning is that if a single growth factor predicts plant performance then that factor could be manipulated to optimize plant performance (Walworth *et al.* 1986). Recently, regression relationships developed between soil tests and crop yields have led to the definition of the critical value, currently used

for diagnostic purposes. The critical value -- the concentration of a soil nutrient that is needed to support 90-95% of maximal yield for a given crop -- separates soils for which probability of response to fertilizers is large from those for which probability of response is small (Nelson and Anderson 1975). Critical values, determined through the use of unifactor multilevel fertilizer trials, are specific to the conditions of the experiments and do not apply under different conditions in the soil-plant system (Hylton *et al.* 1967; Peck *et al.* 1969; Barber 1973). Thus, a sufficiency range was proposed as an alternative to critical value. To derive the sufficiency range, one plots the curve representing the regression relationship between crop yield and nutrient level, identifying, on the curve, a range rather than a single point for optimal yields (Munson and Nelson 1973).

The difficulty in applying this approach derives from the interactions between the nutrients studied and the environment -- interactions that strongly affect regression relationships. Combining research data from different sites or from different growing seasons ignores the interactions (Walworth *et al.* 1986).

Varying as many growth factors as possible in the same research trials and replicating these trials in different sites would permit one to alleviate problems induced by interactions between soil nutrients and between soil nutrients and environment. Data generated this way could be collected in a bank covering as many environmental conditions as possible. Plotting yield data against the concentrations of nutrients in the soil supporting the crops would produce a scatter diagram that peaks at an optimal level for the nutrient being studied (Webb 1972; Walworth *et al.* 1986). Then one could draw a boundary line confining the data. The level of the soil parameter corresponding to the crop yield apex would be considered the norm for diagnostic purposes. This approach has been used with preliminary data to determine optimal levels for nitrogen and phosphorus in soils to support wheat and barley grown in central-western Tunisia.

Materials and Methods

A databank containing results of soil tests and corresponding crop yields from 13 fertilizer trials conducted in central-western Tunisia during 1985-86 and 1986-87 provided the data. The design for 10 of the experiments consisted of N x P factorial trials with four levels of N (0, 33, 49, and 99 kg/ha) and four levels of P (0, 19, 48, and 68 kg/ha). Two experiments with NPK were also a factorial design, with two levels of K (0 and 50 K_2O/ha) and four levels of N and P as for the other experiments. The results from one trial with N alone at 0, 9, 18, and 36 kg/ha were also included. Soils ranged from inceptisols to vertisols. The cropping system is dominated largely by cereals, grown under rainfed conditions.

The fertilizer trials were multifactor and multilevel, designed to study the effects of different rates of nitrogen, phosphorus, and potassium on durum wheat (*Triticum durum*) and on barley (*Hordeum vulgare*). Soil samples had been collected on each plot at tillering stage (sampling depth of 15 cm), oven-dried 24 h at 105°C, ground, passed through a 2-mm mesh screen, and analyzed for mineral nitrogen according to the micro-Kjeldahl technique and for available phosphorus by the Olsen procedure.

Barley and wheat yields were plotted against soil parameters; a boundary line confining the scattered points was drawn with as much accuracy as possible. Although the boundary is normally determined by the best least-squares fit of common mathematical methods including linear, exponential, power, hyperbolic, logarithmic, and quadratic functions (Walworth *et al.* 1986), the hyperbolic function was used alone because results were expected to be preliminary. The boundary line follows points of maximum yield under a given set of conditions. Its shape confirms that, with increasing amounts of soil nutrients, maximal yields increase until they reach an optimal level and then decrease. Thus, the boundary line can be divided into two sections, one on each side of the apex of the scatter diagram; the intersection between these lines is considered to be the optimal level for the soil nutrient.

Results and Discussion

The scatter diagrams (**Figs. 1 and 2**) confirmed that, at any given value for soil nutrients, different crop responses are obtained because of interactions between nutrients or between other growth factors. They showed

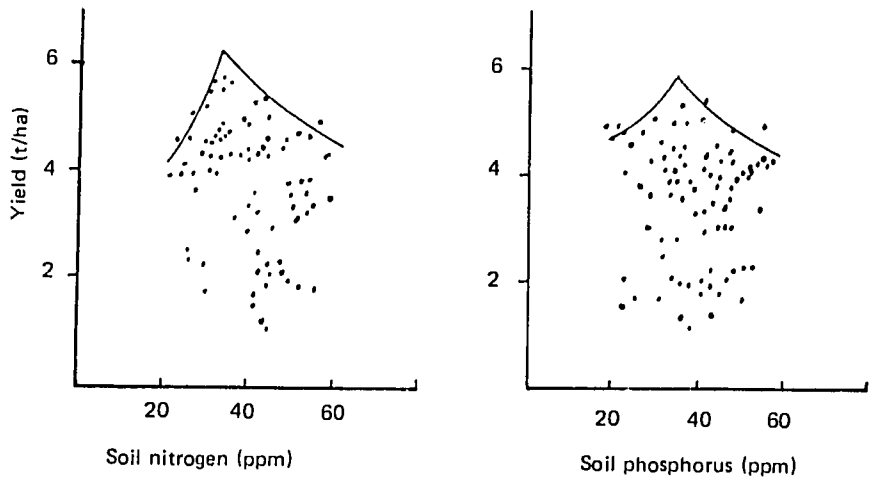

Fig. 1. Scatter diagrams showing relationships between durum wheat yields and soil nitrogen and phosphorus at tillering stage in Tunisia.

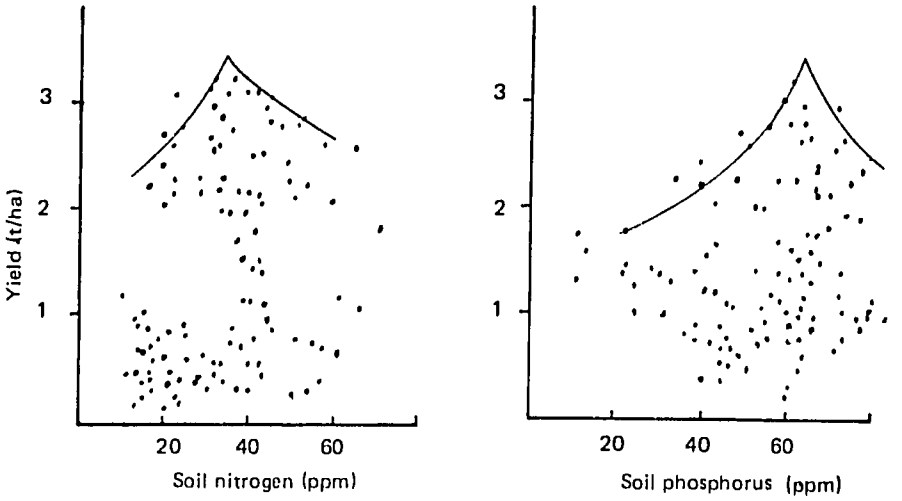

Fig. 2. Scatter diagrams showing relationships between barley yield and soil nitrogen and phosphorus at tillering stage in Tunisia.

that a relative paucity of data has been obtained for very small rates of fertilizer and very high ones (left and right sides of diagram). They also showed (no data in the upper left and right corners) that neither deficient nor toxic nutrient values could generate high yields.

From the diagrams, the concentrations of soil nitrogen and phosphorus at tillering stage deemed optimal are 32.5 and 34.0 ppm for durum wheat and 34.5 and 33.5 ppm for barley respectively. Keeping soil nutrient levels at, or close to, these optima would be a realistic strategy for fertilization recommendations. The exact amount of fertilizer to be added can be determined by soil calibration. These preliminary data had to be confirmed by more comprehensive field and laboratory research.

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Soil Test Calibration with N and P for Wheat under Dryland Conditions in Syria

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Abstract. Twenty N x P factorial trials with a durum wheat (Sham 1) were conducted during 1986-87 in farmers' fields of northeast and northwest Syria. Four levels of N (0, 40, 80, and 120 kg N/ha) and four levels of P (0, 20, 40, and 80 kg P_2O_5/ha) were used with two replications.

These trials were complemented by trials in three locations in the northwest region to compare methods of P application: (a) broadcasting and incorporating P in the plow layer just before planting, (b) banding P with the seed at sowing and (c) broadcasting P with the seeds on ridges and then splitting the ridges to cover the seeds (farmers' practice). At each site, a rainfall gauge was installed and precipitation recorded daily. Before planting, NH_4 and NO_3-N in the soil were determined down to 100 cm deep, at 20-cm increments, and $NaHCO_3$-extractable P was determined in the 0-20 and 20-40 cm soil layers. Three common rotations (chickpea-wheat, lentil-wheat, and summer crops-wheat) and four available soil-P levels (poor, < 4 ppm; medium, 4-7 ppm; high, 7-10 ppm; and very high > 10 ppm) in each rotation system were studied.

Grain and straw responded positively and significantly to N fertilizer at 16 and 19 of the 20 sites respectively. Compared with the control, yield increased 32% and 40% in grain, 36% and 46% in straw by applications of 40 and 80 kg N/ha respectively. Grain and straw responded significantly to P at only 4 and 5 of the sites. Except at one site banding did not differ significantly from broadcasting and incorporating P in the plow layer, but both were significantly better than the farmers' practice, with increases being, respectively, 25% and 21% in grain and 20% and 12% in straw.

Grain and straw yields also differed significantly among rotations and were highest for summer crops-wheat. A Cate-Nelson graph of the results showed that the $NaHCO_3$-extractable P in soils that gave 80% of maximum total dry matter was about 5 ppm. The mineral-N and NO_3-N in the top 40 cm of soil correlated fairly well with relative yields of dry matter and gave near-maximal yields at 42 and 33 kg/ha, respectively.

Introduction

In northwestern Syria, wheat growers have been using fertilizer for some time, basing their practices on factors such as soil type, previous crop, and rainfall (Rassam and Tully 1985). In general, less fertilizer is used on poor soils than on good ones, and, regardless of soil type, nitrogen is applied to wheat more often and in larger quantities after summer crops such as watermelon than after legumes. Bailey (1982) reported that farmers in two Hama villages believed that irrigated summer crops depleted the nutrient in soil, whereas legumes did not. On-farm trials, however, suggested that use of phosphate and nitrogen has little effect on grain yield from wheat following summer crops but that nitrogen after chickpea did increase grain yield significantly (Pala *et al.* 1986).

Since fertilizer is not a new input in wetter areas of the region, research on this subject should be oriented toward optimization of the technology. The oldest -- and still the most trusted -- method of estimating fertilizer requirements is by field trials; however, two cheaper and less time-consuming methods are now being investigated: soil tests and plant tests. These methods, combined with data from experiments conducted in different regions, may permit one to determine fertilizer requirements quickly.

Only very recently have soil tests for N and P begun to be compared with wheat response to N and P fertilization in the region. ICARDA has initiated some work and is cooperating with several countries to accumulate data over a wide spectrum of conditions. Some related findings are already available. For example, under dryland conditions in Turkey, Yurtsever (1987), through multiple-season, multiple-location trials on farmers' fields, found that 9 ppm was the critical level for available P -- the level beyond which an economic response by wheat could not be expected. Matar *et al.* (1987) reported that for wheat under rainfed conditions in northwest Syria the critical level of available P was about 6.7 ppm/ha, giving about 90% of maximum total dry matter. Their findings were based on multiple-location trials conducted in 1 year.

Our objectives were to extend such studies, assessing the biologic and economic response of wheat to N and P fertilizer through multiple-season, multiple-location trials on farmers' fields in areas of northern Syria where mean annual rainfall is more than 325 mm. The aim was to test the available N and P in soils at the time of sowing and to determine the critical levels for N and P; to establish guidelines for fertilizer recommendations on wheat; and to determine the effects of method of P application (banding vs broadcasting vs farmers' practice).

Materials and Methods

Sites were chosen in northwest and northeast Syria where two major soil groups were reported (Chromoxererts and Vertic Xerochrepts). Three common

rotations -- chickpea-wheat, lentil-wheat, and summer crops-wheat -- were tested in sites representing poor (< 4 ppm Olsen-P), medium (4-7 ppm P), high (7-10 ppm P), and very high (> 10 ppm P) soil fertility levels in the northwest region.

A complementary set of trials to test fertilization method was conducted in three locations where P levels were 4.03, 3.51, and 5.12 ppm Olsen-available P (Afes, Atareb, and Tel Hadya). In these trials the phosphate was applied by one of three methods: broadcast and incorporated in the plow layer just before seeding; banded with the seed at sowing; or broadcast over the ridges with the seeds, as is the farmers' practice.

Each trial comprised two replicates of a complete randomized factorial design with four levels of phosphorus (0, 20, 40, and 80 kg P_2O_5/ha) supplied as treble superphosphate and four levels of nitrogen (0, 40, 80, and 120 kg N/ha), supplied as ammonium nitrate, 32 plots in all. As the complementary trials incorporated different methods of applying P, the total number of plots was 96.

Seeds of durum wheat (Sham 1), which had been treated previously with Vitavax, were sown at the rate of 150 kg/ha. In the northwest region, they were broadcast along with fertilizer over ridged land; then the ridges were split to cover the seeds and fertilizer. The planting method in the northeast was also to broadcast fertilizer and to seed with a disc harrow on which the seedbox was mounted.

Phosphorus and 20 kg N/ha were applied at planting; the remaining nitrogen was top-dressed at the tillering stage.

Weeds were controlled by a single application of bromoxynil and diclopmethyl (0.5 kg ai/ha + 1.0 kg ai/ha) at the four-leaf stage.

Rainfall was recorded daily at each site.

Plants were sampled at tillering (N_0P_0, N_3P_3 treatments), at anthesis (all treatments), and at maturity (all treatments). At each sampling, plants along 1-m sections of two rows were cut at ground level. The final sampling was used for determination of harvest index. A Hege plot combine was used for determination of grain yield. Yields of straw and total dry matter were calculated from the harvest index. The samples were subsequently analyzed for N and P content.

At planting time, soils in 20-cm increments were sampled down to 100 cm deep for the determination of mineral-N. Available P was measured by the Olsen method only at 0-20 cm and 20-40 cm (**Table 1**). Subsequently, a soil pit was dug at each site, for the purpose of determining soil type and depth, and samples were taken then for full chemical and physical analysis.

Results and Discussion

Nitrogen fertilizer significantly increased yields of grain and straw, at

Table 1. Soil nutrient availability at planting time, 1986-87.[a]

Site	Previous crop	NO_3-N (kg/ha) in soil layer (cm)					Mineral-N (kg/ha) in soil layer (cm)					P_2O_5 (kg/ha) in soil layer (cm)[b]	
		0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	90-100	0-20	20-40
Afes	Chickpea	13.57	12.08	8.37	7.67	6.47	17.31	15.40	10.99	11.25	9.80	23.94	11.29
J. Kaas	Chickpea	21.22	12.43	4.08	3.24	4.42	25.11	15.59	7.66	7.07	8.61	23.18	10.28
Tel Rifaat	Chickpea	15.65	14.42	3.50	8.11	14.83	21.58	21.30	9.43	13.08	19.47	39.46	35.12
Tel Rifaat	Chickpea	26.09	22.66	6.43	8.28	7.69	31.96	31.65	14.51	14.62	13.32	59.31	33.81
Taoum	Lentil	9.58	6.12	3.36	2.77	2.48	17.24	13.09	9.36	8.77	7.85	16.83	11.59
Afes	Lentil	15.04	2.73	2.11	1.61	1.26	19.62	7.30	8.62	6.33	6.66	20.31	8.31
Tel Hadya	Fallow	16.77	10.13	6.75	1.76	1.49	24.21	14.29	12.52	8.03	6.88	25.80	15.27
Afrin	Lentil	12.17	21.63	15.4	12.60	9.03	16.76	23.91	18.83	15.78	12.25	26.56	17.38
Alkamieh	Lentil	13.85	21.23	8.48	13.01	12.91	25.54	38.20	37.27	29.77	26.80	46.01	37.29
Atareb	S. crop	15.04	35.15	14.94	13.21	14.27	19.83	43.23	19.81	20.21	22.14	17.69	13.10
Taoum	S. crop	19.26	26.15	12.30	5.66	2.98	29.44	41.44	21.20	14.85	10.44	20.36	20.16
Tel Rifaat	S. crop	34.53	31.12	7.09	5.73	7.17	42.48	41.55	14.92	12.87	13.20	46.28	36.58
Atareb	S. crop	13.20	31.49	16.29	14.08	13.03	18.38	36.25	19.73	18.60	19.07	21.92	16.68
Afrin	S. crop	9.52	42.91	13.85	12.09	8.03	11.40	49.76	21.76	20.32	16.19	20.31	17.38
Demkieh	Chickpea	27.28	22.32	9.59	14.82	23.23	32.24	24.08	11.72	16.87	25.45	23.38	12.09
Tel Tishreen	Chickpea	19.99	1.97	1.21	1.34	1.55	26.82	5.33	3.86	3.53	3.90	43.13	7.46
Om el Rabia	Lentil	17.69	3.14	2.73	3.18	3.81	21.63	5.44	4.73	4.85	5.50	9.52	9.93
Tel Tishreen	Lentil	11.40	1.88	2.86	3.43	1.39	16.97	8.57	7.85	7.79	2.74	15.92	5.09
Neametli	S. crop	12.52	24.15	9.32	5.19	4.12	16.14	25.92	11.58	7.76	6.92	11.69	8.77
Demkieh	S. crop	49.89	32.24	23.41	18.27	10.05	55.18	34.24	25.59	20.49	11.90	19.60	8.72

[a] S. crop = summer crop such as watermelon.
[b] P_2O_5 in kg/ha is equivalent to 6.11 ppm P.

16 and 19 of the 20 sites, whereas application of P significantly increased grain at only 4 sites and straw at only 5 of the sites (**Tables 2** and 3). For plants on sites receiving 40 and 80 kg N/ha, yields, over all, were about a third higher than those for plants on unfertilized plots -- increases over the control plants being: 32% and 40% for grain, 36% and 46% for straw. Overall increases noted on plots receiving 20 and 40 kg P_2O_5/ha were not significant: 4% and 5% for grain, 4% and 7% for straw. At two sites for grain and one for straw, yields increased significantly with increasing amounts of both N and P. In the complementary trials to test effects of the method of P placement, responses of grain and straw to P were positive and significant ($P < 0.05$) only at Atareb, where soil was lowest in available P (3.51 ppm).

Table 2. Summary of grain and straw responses to fertilizers at individual sites, 1986-87.[a]

Site (region)	Previous crop	Grain			Straw		
		N	P	NxP	N	P	NxP
Afes (NW)	Chickpea	**	NS	NS	**	NS	NS
J. Kaas (NW)	Chickpea	NS	NS	NS	*	NS	NS
Tel Rifaat (NW)	Chickpea	**	NS	*	**	NS	NS
Tel Rifaat (NW)	Chickpea	NS	NS	NS	**	NS	NS
Taoum (NW)	Lentil	**	NS	NS	**	NS	NS
Afes (NW)	Lentil	**	NS	**	**	NS	*
Tel Hadya (NW)	Fallow	**	NS	NS	**	NS	NS
Afrin (NW)	Lentil	**	NS	NS	**	NS	NS
Alqamieh (NW)	Lentil	NS	NS	NS	NS	NS	NS
Atareb (NW)	S. crop	**	*	NS	**	*	NS
Taoum (NW)	S. crop	**	NS	NS	**	NS	NS
Tel Rifaat/1 (NW)	S. crop	**	*	NS	**	NS	NS
Atareb (NW)	S. crop	**	**	NS	**	NS	NS
Afrin (NW)	S. crop	NS	NS	NS	*	NS	NS
Demkieh (NE)	Chickpea	**	NS	NS	**	**	NS
Tel Tishreen (NE)	Chickpea	**	NS	NS	**	NS	NS
Om el Rabia (NE)	Lentil	*	NS	NS	*	*	NS
Tel Tishreen (NE)	Lentil	*	NS	NS	**	*	NS
Neamatli (NE)	S. crop	**	**	NS	**	**	NS
Demkieh (NE)	S. crop	**	NS	NS	*	NS	NS

[a] Significance: * = $P < 0.05$; ** = $P < 0.01$.

Although banding resulted in only slightly higher yields than broadcasting and incorporating fertilizer before seeding, both methods gave significantly higher yields than the farmers' method: broadcasting fertilizer and seed over ridges and splitting the ridges to cover them (**Table 4**). Mean increase over the farmers' practice was 25% in grain, 20% in straw.

Yields of grain and straw also differed significantly among rotations (**Tables 5** and 6), with the summer crops-wheat rotation producing significantly higher yields than the other two. The large yields following summer

Table 3. Grain and straw yield of wheat obtained in 20 trials on farmers' fields as related to precipitation and level of applied N and P, 1986-87.

Site (region)	Previous crop	Yield (kg/ha) N (kg/ha) 0	40	80	120	P_2O_5 (kg/ha) 0	20	40	80	LSD 0.05 (N And P)	CV (N & P) (%)	Season rainfall (mm)
						GRAIN						
Afes (NW)	Chickpea	1383	2027	1976	1922	1852	1681	2046	1731	323	16.5	309
J. Kaas (NW)	Chickpea	2158	2304	2350	2361	2171	2230	2322	2449	-	13.1	296
Tel Rifaat (NW)	Chickpea	999	1901	1836	2030	1705	1787	1503	1770	259	14.4	412
Tel Rifaat (NW)	Chickpea	2187	2453	2631	2454	2415	2486	2381	2443	-	12.3	412
Taoum (NW)	Lentil	1696	2278	2551	2589	2301	2179	2298	2336	234	9.6	373
Afes (NW)	Lentil	1151	1606	1684	1573	1521	1386	1545	1562	140	8.7	309
Tel Hadya (NW)	Fallow	1385	2469	2367	2250	1999	2092	2096	2284	336	14.9	343
Afrin (NW)	Lentil	2526	4015	4301	4549	3523	3907	3930	4032	694	16.9	571
Alqamieh (NW)	Lentil	2625	2937	3094	2877	2791	2738	2968	3037	-	19.3	503
Atareb (NW)	S. crop	2666	3463	3864	3509	3098	3376	3498	3529	330	9.1	409
Taoum (NW)	S. crop	1830	2485	2934	2801	2381	2484	2615	2571	363	13.5	373
Tel Rifaat (NW)	S. crop	2115	2548	2646	2591	2263	2411	2527	2699	258	9.8	412
Atareb (NW)	S. crop	3179	3635	4061	4262	3397	3993	3643	4094	415	10.5	409
Afrin (NW)	S. crop	2595	2926	3216	3290	2813	2994	3111	3108	-	18.9	571
Demkieh (NE)	Chickpea	1031	1565	1516	1552	1428	1415	1426	1394	193	12.8	305
Tel Tishreen (NE)	Chickpea	1087	1849	1855	1944	1790	1661	1563	1721	213	11.8	343
Om el Rabia (NE)	Lentil	539	708	808	803	675	650	773	759	201	26.3	300
Tel Tishreen (NE)	Lentil	833	1236	1115	1160	1059	1074	1002	1209	230	19.8	343
Neamatli (NE)	S. crop	1633	2043	2188	1860	1872	1918	1730	2204	212	10.3	353
Demkieh (NE)	S. crop	1274	1623	1961	1580	152.	1631	1634	1644	228	13.3	305
Mean, over all		1744	2304	2448	2398	2129	2205	2231	232[illegible]			

Table 3. Continued

						STRAW						
Afes (NW)	Chickpea	2643	4519	4937	4820	4152	4081	4682	4004	847	18.8	309
J. Kaas (NW)	Chickpea	3908	4351	4464	4839	4421	4321	4294	4525	511	10.9	296
Tel Rifaat (NW)	Chickpea	1881	3790	3500	4299	3561	3510	3079	3319	946	26.4	412
Tel Rifaat (NW)	Chickpea	3965	4661	5531	5801	4954	5062	4799	5142	839	15.7	412
Taoum (NW)	Lentil	3192	4279	4805	5272	4489	4159	4105	4795	910	19.5	373
Afes (NW)	Lentil	2427	3925	4322	4264	3795	3378	3725	4040	546	13.7	309
Tel Hadya (NW)	Fallow	2664	5097	5468	5422	4521	4660	4363	5098	988	19.9	343
Afrin (NW)	Lentil	4345	6771	7111	7326	5893	6150	6452	7058	1202	17.6	571
Alqamieh (NW)	Lentil	3834	4402	4973	4744	4447	4249	4697	4559	-	21.3	503
Atareb (NW)	S. crop	4713	6494	7400	6754	5414	6475	6816	6656	976	14.4	409
Taoum (NW)	S. crop	3987	5311	5758	5767	4651	5310	5704	5158	791	14.2	373
Tel Rifaat (NW)	S. crop	3850	5839	6136	6215	4754	5739	5677	5869	1116	19.0	412
Atareb (NW)	S. crop	5349	6216	6889	7622	5897	6919	6396	6863	925	13.3	409
Afrin (NW)	S. crop	4719	5771	6008	6754	5310	5754	6090	6099	1248	20.1	571
Demkieh (NE)	Chickpea	5055	6350	5927	6486	5940	5492	7160	5226	759	11.9	305
Tel Tishreen (NE)	Chickpea	2127	3300	3244	3455	3152	3028	2914	3033	462	14.3	343
Om el Rabia (NE)	Lentil	1587	1830	2255	2305	1823	1891	1810	2452	460	21.6	300
Tel Tishreen (NE)	Lentil	1965	2894	2915	3351	2479	2659	2781	3208	443	14.9	343
Neamatli (NE)	S. crop	3095	4128	4333	3948	3598	3776	3676	4453	387	9.4	353
Demkieh (NE)	S. crop	5877	7121	7672	7759	6725	7058	7059	7787	1257	16.6	305
Mean, over all		3559	4857	5192	5360	4499	4684	4814	4967			

Table 4. Three methods of applying P and their effects on yields of wheat (grain and straw) obtained in farmers' fields in three northwestern sites, Syria 1986-87.

Site (P ppm)	P placement	Grain (kg/ha) P_2O_5 (kg/ha) 0	20	40	80	Mean yield of grain (kg/ha)	Straw (kg/ha) P_2O_5 (kg/ha) 0	20	40	80	Mean yield of straw (kg/ha)
Afes (4.03)	Banding	1682	1703	1689	1726	1700**	4154	4136	4439	4315	4261**
	Broadcast	1622	1668	1713	1709	1678	3928	3985	4290	4243	4111
	Farmers'	1521	1386	1545	1562	1503	3795	3378	3725	4040	3734
	Mean	1608	1586	1649	1666	1627	3959	3833	4151	4199	4035
	LSD (0.05) placement 63 kg/ha						LSD (0.05) placement 287 kg/ha				
Tel Hadya (5.12)	Banding	2481	2591	2603	2616	2573**	4858	5062	5100	5341	5090
	Broadcast	2490	2392	2513	2522	2479	4847	4764	4959	4910	4870
	Farmers'	1999	2092	2096	2294	2120	4529	4660	4363	5115	4667
	Mean	2323	2358	2404	2477	2391	4745	4829	4807	5122	4876
	LSD (0.05) placement 136 kg/ha										
Atareb (3.51)	Banding	3961	4905	4466	4500	4458**	7353	9353	8425	8016	8287**
	Broadcast	4165	4229	4122	4692	4302	6734	7658	7289	8557	7560
	Farmers'	3098	3376	3498	3529	3375	5414	6475	6816	6656	6340
	Mean	3742	4170	4028	4240	4045	6500	7828	7510	7743	7396
	LSD (0.05) placement 215* kg/ha phosphorus 248 kg/ha placement x P 429 kg/ha						LSD (0.05) placement 785 kg/ha phosphorus 906 kg/ha				

[a] Significance: * = $P < 0.05$; ** = $P<0.01$

Table 5. Summary of grain and straw yield of wheat by rotation system and available P in the soil at planting, northwest region, Syria 1986-87.[a]

Site grouping (locations)	Yield (kg/ha) at: N (kg/ha) 0	40	80	120	P_2O_5 (kg/ha) 0	20	40	80	LSD (0.05)	Grain Mean
Previous crop				GRAIN						
Chickpea (4)	1682	2171**	2198	2192	2036	2046	2063	2098	157	2061**
Lentil (4)	2000	2709**	2907	2897	2534	2553	2685	2742	217	2628
Summer crop (5)	2477	3011**	3344	3289	2790	3052**	3079	3200	172	3030
				STRAW						
Chickpea	3099	4330**	4608	4940	4272	4244	4214	4248	399	4244**
Lentil	3450	4844**	5303	5402	4656	4404*	4745	5113	443	4750
Summer crop	4523	5926**	6438	6622	5205	6039**	6137	6129	438	5878
P level (ppm)				GRAIN						
<4 (5)	2090	2586**	2889	2901	2483	2607*	2642	2734	162	2617**
4-7 (5)	2023	2856**	2972	2918	2528	2657*	2779	2805	180	2692
7-10 (3)	1913	2462**	2525	2499	2253	2312	2333	2502	226	2350
>10 (1)	2197	2453	2631	2454	2415	2486	2381	2443	-	2431
				STRAW						
<4	3935	5100**	5556	5936	4828	5104*	5204	5391	409	5132**
4-7	3655	5446**	5874	5832	4880	5137*	5322	5468	394	5202
7-10	3188	4677**	4869	5086	4254	4299	4485	4583	554	4455
>10	3965	4661**	5531	5801	4954	5062	4799	5142	839	4989

[a] Significance: * = P < 0.05; ** = P<0.01.

Table 6. Summary of grain and straw yield of wheat by previous crop and available P in the soil at planting, northeast region, Syria 1986-87.[a]

Site grouping (locations)	Yield (kg/ha) at: N (kg/ha) 0	40	80	120	P_2O_5 (kg/ha) 0	20	40	80	LSD (0.05) (N & P)	Grain Mean
Previous crop				GRAIN						
Chickpea (2)	1059	1707**	1685	1748	1609	1538	1495	1557	132	1550**
Lentil (2)	686	972**	962	981	867	862	887	984	142	900
Summer crop (2)	1454	1833**	2074	1720	1700	1775**	1682	1924	143	1770
				STRAW						
Chickpea	3591	4825**	4586	4971	4546	4260**	5037	4129	408	4493**
Lentil	1776	2362**	2585	2828	2151	2275**	2296	2830	293	2388
Summer crop	4486	5624**	6102	5854	5161	5417*	5368	6120	613	5517
P level (ppm)				GRAIN						
<3.5 (3)	1002	1329**	1370	1274	1202	1214**	1168	1391	120	1244**
3.5-7 (2)	1152	1594**	1738	1566	1477	1523	1531	1519	168	1513
>7 (1)	1087	1849**	1855	1944	1790	1661	1563	1721	213	1684
				STRAW						
<3.5	2216	2951**	3168	3201	2633	2776**	2756	3371	240	2884**
3.5-7	5466	6735**	6899	7123	6332	6275	7109	6507	735	6556
>7	2127	3300**	3244	3455	3152	3028	2914	3033	462	3032

[a] Significance: * = P < 0.05; ** = P < 0.01.

crops may be explained by the available N or the moisture in the soil profile. Other studies have shown that summer crops such as melon do not utilize all stored water in the profile, and a subsequent wheat crop can utilize the residual amounts (ICARDA 1984; Cooper *et al.* 1987; Pala *et al.* 1986). Other significant differences among the yields from different rotations can be attributed to nitrogen, paralleling the results for different sites.

The responses to nitrogen fertilization were positive irrespective of P available in the soil. Application of P fertilizer significantly increased yields of crops on sites representing poor (< 4 ppm) and medium (4-7 ppm) levels of fertility. The increases for both grain and straw (compared with control plots) were about 5% and 10% at each fertility level from 20 and 40 kg P_2O_5/ha. The responses (**Fig. 1**) to phosphorus application are in line with findings by Matar *et al.* (1987). They reported that the critical level of available P for 80% of maximum yields is about 5 ppm. Similarly, when the Cate-Nelson graphical method was used to divide soils in our study into two classes -- responsive and nonresponsive to P application -- the P available in soils that maximized the number of points in both compartments of the graph was about 5 ppm.

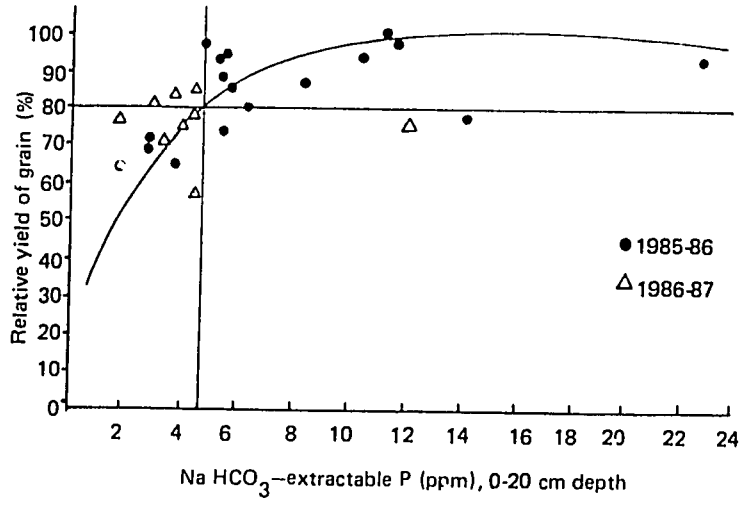

Fig. 1. Scatter diagram of relative yield percent of wheat grain at harvest as related to available–P in soils at sowing in farmers' fields, Syria 1985–87.

Likewise, the relative yields of total dry matter at harvest correlated fairly well with mineral-N (NH_4 + NO_3) and nitrate-N in the top 40 cm of soil (**Fig. 2**). The analysis of variance method of Cate and Nelson indicated that the critical levels of available N for near-maximal yields of dry matter were about 33 and 42 kg/ha of nitrate and mineral-N respectively. However, relative yields of wheat grain were poorly correlated

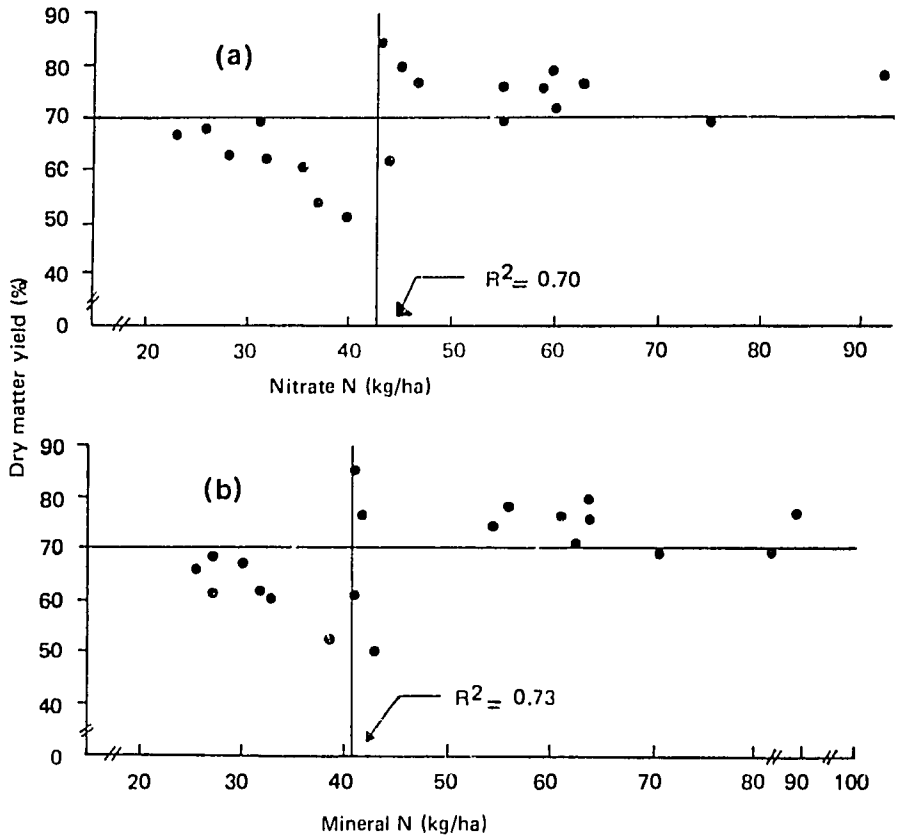

Fig. 2. Relative yields of total dry matter of wheat vs (a) NO_3-N and (b) mineral-N at planting in the top 0-40 cm of soil, 1986-87.

with mineral-N or nitrate-N. The critical levels were impossible to establish: even in soils with high levels of mineral-N or nitrate-N, plants were found to respond to N fertilization, and the relative yields calculated were far below the actual maximums. Apparently, mineral-N and NO_3-N as tests for N, to be used as means for fertilizer recommendations to maximize grain yield, need further study, including research on mineralization potential and contribution of organic N to nitrogen nutrition of wheat.

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Nitrogen and Phosphorus Soil-test Calibration Studies in the Chaouia Region of Morocco

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Abstract. A series of on-farm factorial N and P studies for use in soil test calibration were initiated in the fall of 1985 to determine the critical level of $NaHCO_3$-extractable P for wheat crops grown in soils of the Chaouia region in the province of Settat, Morocco; the effect of previous crop, yield level, initial soil nitrate, and N mineralization potential on the N requirement of wheat crops grown in the region; and the efficiency of banding as compared with broadcasting superphosphate. Three different soil types were selected based on their potential productivity, namely shallow (rendolls), moderately deep (calcixerolls), and deep (chromoxererts and their intergrades). The previous crops were wheat or barley and legumes in all soils, weedy fallow in shallow soils, and corn in deep soils. The details of experimental methods are given elsewhere (Soltanpour 1987). No interaction between applied N and P fertilizers on the yield of wheat was observed. In 1985-86, rainfall was 300 mm with an excellent distribution. In 1986-87, rainfall was 200 mm for calcixeroll and chromoxerert sites and 240 mm for the rendoll site. The distribution in the latter year was poor.

The results showed that for rendolls no nitrogen fertilization was required when wheat followed a legume crop or weedy fallow, but about 30 kg/ha was required after cereals. In these shallow soils, N uptake or yield was not related to residual soil NO_3-N, probably because of variability in soil depth or other factors.

Nitrogen uptake in check plots was well correlated with soil NO_3-N in 20-, 40-, and 60-cm profiles of calcixerolls and chromoxererts indicating the importance of a NO_3-N soil test. Relative yield was a linear function of nitrate content in the soil profile. For a grain yield of 2 t/ha, 18, 31, and 50 kg NO_3-N/ha was required in 0-20, 0-40, and 0-60-cm profiles. An N model based on critical level of NO_3-N in the profile, soil NO_3-N, apparent efficiencies of fertilizer N and soil NO_3-N, yield goal, and previous crop was developed and will be verified under farmers' conditions of management.

Relative response to P was small in the wet year, large in the drier year, but highly economic in both years. A critical level of 5 mg/kg of $NaHCO_3$-P was obtained, separating responsive from nonresponsive soils for a relative yield of 90%. For rendolls and calcixerolls (20% lime), response to P was economic up to a soil-test level of 8 mg P/kg. Phosphorus-placement studies showed that banding was more efficient than broadcasting. The response to broadcasting of P reached a plateau at 20 kg P_2O_5/ha, but the response to banding continued to the highest rate of P. This difference in response indicated that banding of concentrated superphosphate has beneficial effects on the growth of wheat crops. Use of rates of N and P derived from soil tests is highly economic. Significant responses of grain yield to N averaged 76% for both years and to P 40% in the drier year and 8% in the wet year. Benefit-cost ratios averaged 4.4 for both N and P at recommended rates.

Introduction

In the rainfed agricultural zones of Morocco, many fertilizer experiments have been conducted but, unfortunately, have not incorporated analysis of plant response to N and P as related to the initial soil fertility. The objectives of the experiments reported here, therefore, were to determine what the critical level of $NaHCO_3$-extractable P is for wheat crops grown in soils of the Chaouia region of Settat province in Morocco; how the previous crop, yield level, initial soil nitrate, and nitrogen mineralization potential affect the N requirement of wheat crops; and how efficient banding is compared with broadcasting as a method of application of concentrated superphosphate. The long-term objective is to develop guidelines for fertilizer recommendations for a region in Morocco extending from Casablanca in the north to the High Atlas mountains in the south and the Mid Atlas in the east. The precipitation in the region ranges from 200 mm to 450 mm/year.

Materials and Methods

A series of on-farm factorial N x P studies for use in soil test calibration were initiated in the fall of 1985. The details are given elsewhere (Soltanpour *et al.* 1987). Briefly, the methods are worth reiterating. Three agriculturally important soil types were selected based on their water-holding capacity (productivity) as determined by soil depth, namely rendolls (35-40 cm deep and coded as soil unit 15), calcixerolls (about 60 cm deep and coded as soil unit 34), and chromoxererts or their intergrades (>60 cm deep and coded as unit 10). Four levels of N: 0, 30, 60, and 90 kg/ha were used with 0, 20, and 40 kg P_2O_5/ha in a factorial combination in 1985-86. The N rates were the same in 1986-87 for shallow (unit 15) and moderately deep (unit 34) soils but were 0, 40, 80, and 120 kg N/ha for

deep (unit 10) soils. In the latter year, an additional 80 kg P_2O_5/ha was used. The number of replications was four and three for 1985-86 and 1986-87, respectively. The previous crops were wheat or barley and legumes in all soils, weedy fallow in shallow soils, and corn in deep soils. The rotations reflect the farmers' practices, although continuously growing cereal is not very common. In both years, a randomized complete block (RCB) design was used. The placement study was carried out in the shallow soil in 1986-87. The rates were 0, 20, 40, 80, and 120 kg P_2O_5/ha. The methods of application were broadcasting followed by disking versus banding with seeds. An RCB factorial experimental design with four replications was used. A blanket rate of 60 kg N/ha was broadcast on the surface followed by disking. In both seasons, all the on-farm experiments carried out on the same soil type were within a few kilometres of each other. In all experiments, soil samples were obtained before planting. The depth of soil-sample cores was 60 cm subdivided into 20-cm increments. In shallow soils, the entire profile was sampled and subdivided into increments.

Samples for each block were obtained so that 12-16 profiles were sampled in every experiment. Soil samples were analyzed for NO_3-N. $NaHCO_3$-P, nitrogen mineralization potential, and other properties (**Table 1**). Total dry-matter yield at anthesis to milk dough stages of growth and grain and straw yields after physiologic maturity were determined. Whole-plant samples were analyzed for N and P.

Table 1. Properties of the soils used in this study[a].

Soil unit and code	pH	OC (%)	EC (ds/m)	N_0 (mg/kg)	Lime (%)	Clay (%)	Silt (%)	K (mg/kg)
Rendoll (15)	8.1	1.9	0.2	144	21.1	59	13	160
Calcixeroll (34)	8.2	1.2	0.1	164	27.3	58	21	165
Chromoxerert (10)	8.2	1.0	0.1	179	1.6	58	16	192

[a] OC= organic carbon; N_0= nitrogen mineralization potential.

Results and Discussion

The analysis of variance showed that there was no significant interaction between applied N and P fertilizers on total dry-matter yield or grain yield. Therefore, the yield at different rates of N was averaged over all P rates and replications, the result being 12 observations per mean. The yield at different rates of P was averaged over all N rates and replications such that 16 and 12 observations resulted for each mean during 1986 and 1987, respectively.

N fertilizer prompted no response in grain yields on deep soils (vertisols) (Fig. 2) where NO_3-N in the soil was 60 kg/ha in the top 60 cm. The results indicated that, with 300 mm of excellently distributed rainfall (Fig. 1), about 3 t of grain was obtainable. In the experiment coded

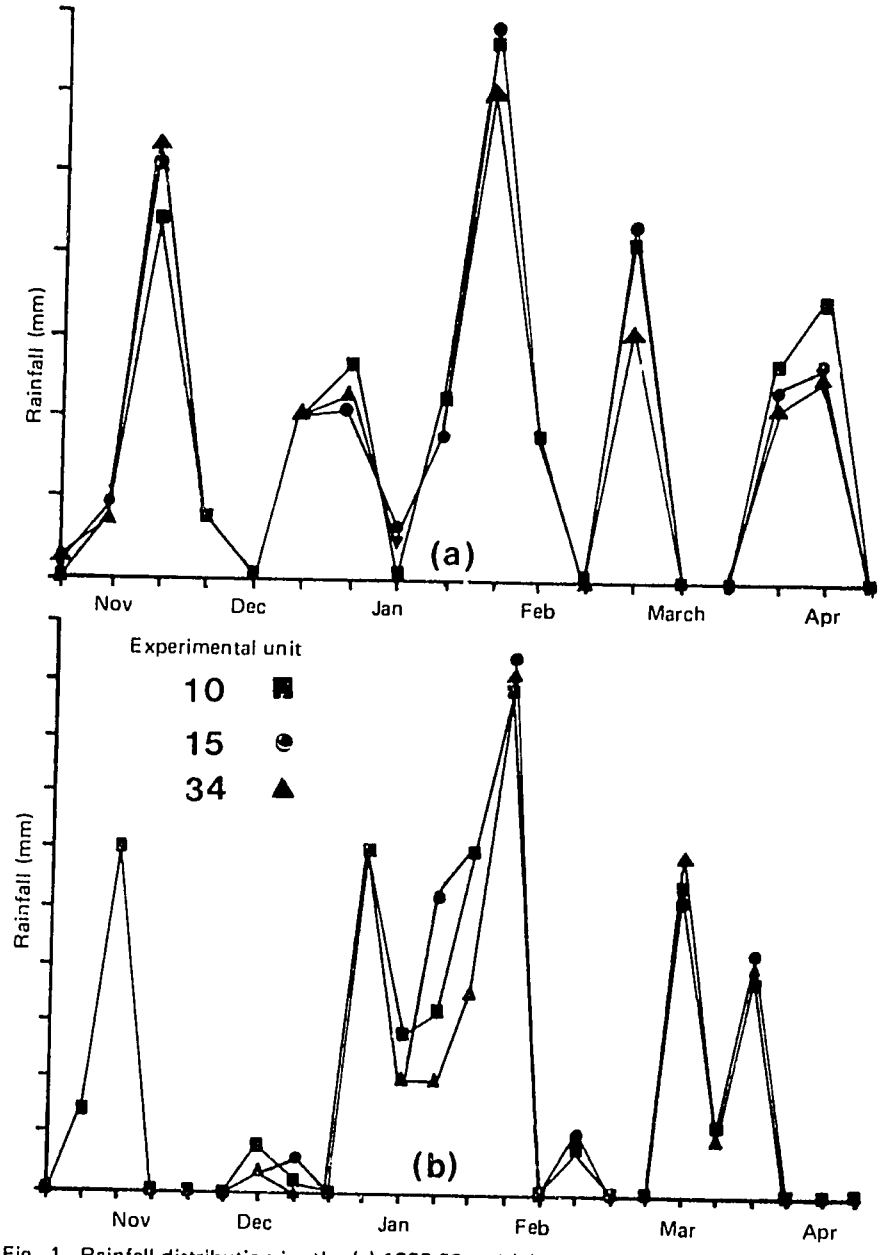

Fig. 1. Rainfall distribution in the (a) 1985-86 and (b) 1986-87 growing seasons in the Chaouia region of Morocco.

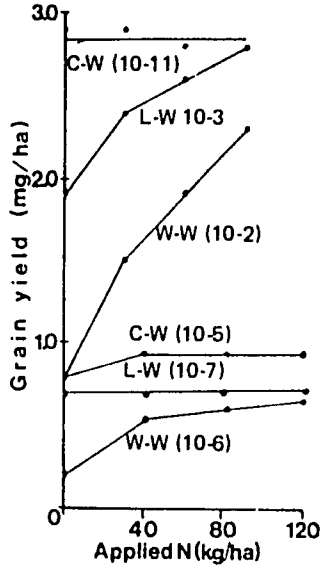

Fig. 2. Grain yield as a function of N rates added to chromoxererts in 1985-86 and 1986-87 seasons. The letters indicate the rotations: C = corn; L = legume; W = wheat. The numbers in parentheses indicate the experimental codes.

as 10-3 where wheat followed a legume (lentils), a response to N was obtained up to 90 kg/ha, at which point the yield potential, as set by the highest yield obtained in our experiment, was reached. The NO_3-N in this soil was intermediate (24 kg/ha). However, when wheat followed wheat (experiment 10-2), the yield at 90 kg N/ha was not as high as the potential, and we assumed additional nitrogen was required. The level of NO_3-N reinforced this conclusion as it was only 15 kg/ha. Comparing the check yields of 0.8 t/ha and 1.9 t/ha for 10-2 and 10-3 farms reveals why farmers in the area are reluctant to grow wheat after wheat. Without fertilization, the grain yield after wheat is less than one half of that after a legume crop. The data underline that the previous crop is a key determinant of fertilizer needs of wheat crops. In experiment 10-1, the high residual nitrogen in the soil was mainly attributable to the high rate of manure applied in previous years. In 1986-87, a season with only 200-240 mm of rainfall, the same patterns were observed. The yield of wheat in check plots after a legume crop (10-7) was about three times that obtained after wheat (10-6). The two fields had similar soils and were within 100 m of each other. In 1986-87, the response in grain yield was significant for N after wheat and corn but not after a legume crop.

In both seasons, the response to N in moderately deep soils (60 cm) (calcixerolls) was negligible when wheat followed a legume crop (**Fig. 3**) but was significant after wheat or barley.

Similarly, the response to N in shallow soils (rendolls) was not significant after fallow or legumes but was significant after barley and wheat in both years (**Fig. 4**). The weedy fallow was frequented by *Medicago*

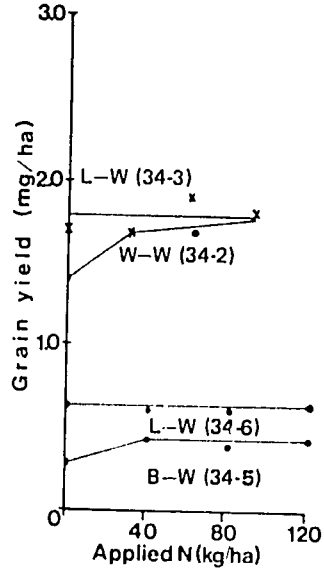

Fig. 3. Grain yield as a function of N rates added to calcixerolls in 1985-86 and 1986-87 seasons. The letters indicate the rotations: B=barley, L=legume, W=wheat. The numbers in parentheses indicate the experimental codes.

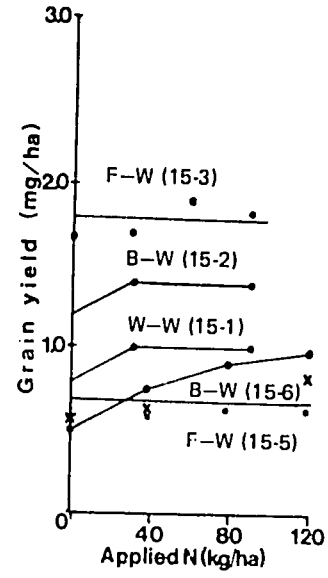

Fig. 4. Grain yield as a function of N rates added to rendolls in 1985-86 and 1986-87 seasons. The letters indicate the rotations: B=barley, L=legume, W= wheat. The numbers in parentheses indicate the experimental codes.

species (Tanji 1968) and, thus, provided N for the following crop. The differences in yields of check plots were caused by the previous crop (legumes vs cereals), the soil depth, and the water-holding capacity of the soil.

N uptake was significantly related to NO_3-N level in check plots for both calcixerolls and chromoxererts (**Table 2**), with r values of 0.89, 0.76, and 0.64 for nitrate content in 20-, 40-, and 60-cm profiles, respectively. In farms with shallow soils, no such relationship existed.

The data showed that one may use the surface (20-cm) level of nitrate to predict N requirements of crops. This conclusion is supported by the high degree of correlation between nitrate in the 60-cm profile and in the 20-cm profile of both calcixerolls and chromoxererts (**Table 2**). The NO_3-N was distributed relatively evenly (**Fig. 5**) throughout 0-60 cm. The regression equations (**Table 2**) can be used to calculate NO_3-N in the 60-cm profile from data for the 20- or 40-cm profiles and, thus, obviate the need for samples when soils are dry.

Relative yields (yields of check plots divided by maximal yield obtained by N application) were regressed on initial NO_3-N in 20-, 40-, and 60-cm profiles for soils 60 cm or deeper. In shallow soils, relative yield

Table 2. Regression coefficients and constants for calcixerolls and chromoxererts: relations between uptake in check plots at anthesis and NO_3-N in the soil; between NO_3-N content of the 0-60-cm profile and NO_3 -N content of 0-20 and 0-40-cm profiles; and between relative yield of check plots and NO_3-N.[a]

Depth (cm)	Nitrogen uptake vs NO_3-N			NO_3-N in 0-60 cm vs NO_3-N in 0-20, 0-40cm			Relative yield vs NO_3-N		
	constant	coefficient	r^2	constant	coefficient	r^2	constant	coefficient	r^2
0-20	-23.2	5.91**	0.89	-4.7	3.1**	0.82	11.0	5.0**	0.87
0-40	-14.7	2.90**	0.76	-4.4	1.7**	0.96	6.4	3.0**	0.94
0-60	7.0	0.94**	0.64	-	-	-	9.2	1.8**	0.89

[a] Significance (different from zero): ** = $P < 0.01$.

was not related to initial soil NO_3-N, but the relationship was linear between the two parameters for seven farms (**Fig. 6**). Three farms where wheat followed legumes (two cases) and corn (one case) did not produce relative yields that fitted the regression line (**Table 2**). Solving the regression equations for 100% relative yield resulted in critical NO_3-N values of 18, 31, and 50 kg/ha in 20-, 40-, and 60-cm profiles, respectively. Matar *et al.* elsewhere in this publication found values of 17, 26, and 35 kg NO_3-N/ha were needed in the 20-, 40-, and 60-cm profiles, respectively, for relative yields of 80% for barley grain in Syria. Adjusting their values to support maximal yields, one obtains 21, 32, and 44 kg N/ha -- very close to the values we found for wheat in Morocco. Pala and Matar, also in this publication, report a value of 33 kg N/ha at 40 cm soil depth for a yield of 70% of maximal dry matter of wheat in Syria. Similarly, Olson (1984) cited work by D.E. Smika that showed grain response to fertilizer N when residual NO_3-N was less than 45 kg/ha in the Great Plains of the USA. The agreement in data from Syria, the US, and Morocco is remarkable and increases our confidence in the data we obtained.

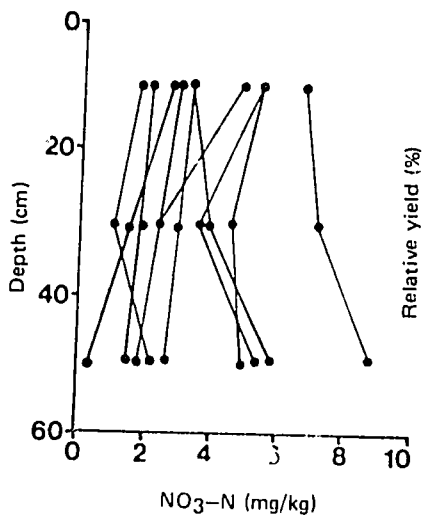

Fig. 5. Nitrate nitrogen distribution in the profiles of calcixerolls and chromoxererts, 1985-86 and 1986-87.

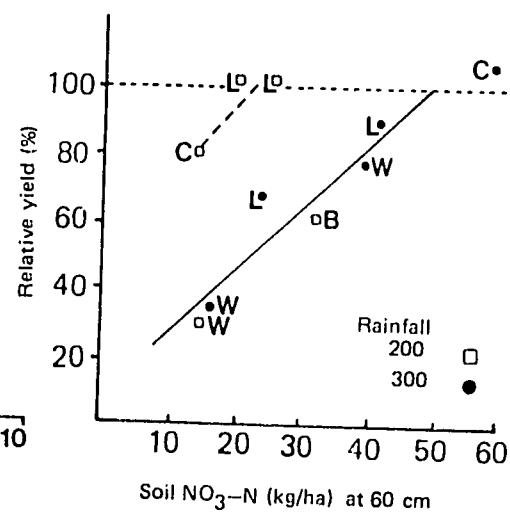

Fig. 6. Relative yield as a function of NO3–N in the profile of calcixerolls and chromoxererts, 1985-86 and 86-87.

The nitrogen mineralization potentials were 144, 164, and 179 mg/kg for topsoil (0-20 cm) in rendolls, calcixerolls, and chromoxererts (**Table 1**), respectively, and the results showed the latter two soils had similar potential for practical purposes. This is the reason that N uptake and relative yields were highly correlated with NO_3-N in check plots.

The apparent recovery of fertilizer N was about 50% in the wet year and 34% in the drier year, with an average of 42% for both years. Abdelmonem *et al.* (elsewhere in this volume) found apparent recoveries of 55% in a year with 373 mm of rainfall and 27% with 232 mm of rainfall.

A Model for Making N Recommendations

In our studies, we found the critical level for soil N to be 50 kg NO_3/ha (for grain yields of 2 t/ha). To this amount one would need to add the mineralized N and NH_4-N to get the actual critical level. We did not include NH_4-N in our model. Harmsen *et al.* (1983) indicated that NH_4-N did not affect the N requirement of cereal crops in Syria. Matar *et al.* (elsewhere in this publication) and Matar (1977) indicated that inclusion of NH_4-N with NO_3-N did change the critical level but did not improve the reliability of an NO_3-N test. In our studies, nitrogen mineralization potentials for calcixerolls and chromoxererts were about the same as were the levels of organic carbon (**Table 1**). The work of El Gharous *et al.* (in press) also indicated that mineralization potentials of Chaouia soils, except rendolls, were similar. However, we did not include mineralizable N in our model.

A model was developed for making N recommendations for wheat crops grown in soils 60 cm deep or deeper in the Chaouia region of Morocco:

$$NR = [50 - (NO_3\text{-}N)_{0\text{-}60}] \times 2$$

where NR is fertilizer nitrogen requirement in kg N/ha; 50 is the critical NO_3-N level in the 60-cm profile for a yield goal of 2 t grain/ha; (NO_3-N) is the amount of NO_3-N found in the 60-cm profile; and 2 is the ratio of apparent uptake efficiencies for NO_3-N in the 60-cm profile and fertilizer N. When soil samples from 60 cm deep are not available, one can calculate NO_3-N by using values for either 20-cm or 40-cm profiles:

$$(NO_3\text{-}N)_{0\text{-}60} = (NO_3\text{-}N)_{0\text{-}20} \times 2.8$$

or

$$(NO_3\text{-}N)_{0\text{-}60} = (NO_3\text{-}N)_{0\text{-}40} \times 1.4$$

where units are in kg N/ha.

One can change N values from mg/kg to kg/ha by assuming a bulk density of 1.35 g/cm^3 in the equation:

$$\text{kg N/ha}_{0\text{-}20\ \text{cm}} = [\text{mg/kg of } (NO_3\text{-}N)_{0\text{-}20}] \times 2.7$$

This equation also can be used for 20-40 and 40-60 cm depths; alternatively nitrogen concentrations in mg/kg (ppm) can be summed up for the

three depths and multiplied by 2.7, the result being kg NO_3-N in the 60-cm profile.

One can adjust NR for grain yield goals (YG) lower than 2 (more data are needed to develop relationships for higher yields because the response function is not linear):

$$NR_{YG} = NR\ (YG/2)$$

To adjust NR for contributions of N by legumes, one can subtract 30 kg N/ha from NR. The value of 30 was estimated from our data and from the literature (Soltanpour *et al.* 1985). At this time, there is no quick test available that measures the amount of mineralizable N in the soil to allow for differences among legumes.

The data showed good agreement between predicted and actual N requirements (**Table 3**), but the model should be verified under farmers' conditions of management. Of course, any N model is highly yield dependent.

Table 3. Predicted and actual N requirements for wheat grown in calcixerolls and chromoxererts[a]

Code	Actual NR (kg/ha)	Predicted NR for actual yield (kg/ha) grain			Actual grain yield (t/ha)	Predicted NR for grain yield of 2 t/ha (kg/ha)
		0-20	0-40	0-60		
10-1	0	0	0	0	2.8	0
10-2	90	74	77	78	2.3	68
10-3	90(L)	37	41	41	2.8	20
34-2	<30	14	28	19	1.8	21
34-3	0(L)	0	0	0	1.8	0
34-5	<30	10	9	7	0.4	35
34-6	0(L)	0	0	0	0.6	30
10-5	<40	27	32	36	1.0	72
10-6	<40	18	19	18	0.5	72
10-7	0(L)	0	0	0	0.7	18

[a] L denotes legume as previous crop.

If precipitation or stored soil moisture shows a grain yield potential of more than 2 t/ha, one may add more N at tillering (up to jointing stage). One needs to know the yield-moisture relationship to adjust N fertilization rates. Harmsen (1987) showed such relationships in his presentation to the first workshop on soil calibration in West Asia and North Africa.

Relative response to P was small during the wet year but large in the drier year (**Fig. 6**). Matar (1977), Krentos and Orphanos (1979), and Harmsen *et al.* (1983) have all made the same observations. In our study, furthermore, response to P was more frequent in shallow rendolls than in calcixerolls or vertisols because soil P was lower in rendolls.

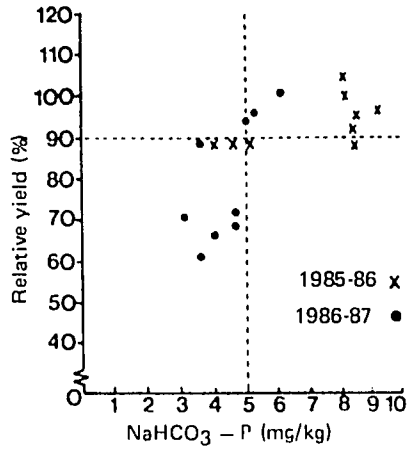

Fig. 7. Relative yield as a function of $NaHCO_3$ – P in rendolls, calcixerolls, and chromoxererts, 1985-86 and 1986-87.

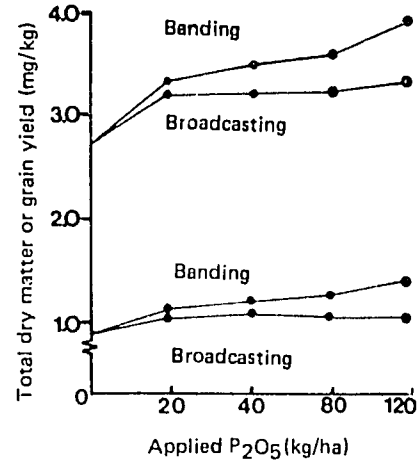

Fig. 8. Effect of placement of concentrated superphosphate on total dry matter yield and grain yield, 1986-87.

The Cate-Nelson graphical method was used to define the critical level (5 ppm) of $NaHCO_3$-P for a relative yield of 90% (**Fig. 7**). When analysis of variance was done on combined data for rendolls and calcixerolls in 1985-86, response to P was significant. Interestingly enough, the F values for single experiments were not significant. Our data indicated that crops on soils with a high level of lime (20%) in the surface layer (rendolls and calcixerolls) responded to P when the soil-test value was between 5 and 8 ppm. However, crops on deep soils (vertisols) with low levels of lime in the surface layer showed no response when P was more than 5 ppm.

For the P placement study, trials were conducted on a shallow soil (rendoll) with a soil-P level of 4.5 ppm. The response of grain to broadcasting followed by disking reached a plateau at 20 kg P_2O_5/ha, but response to banding of P continued to be positive up to 120 kg P_2O_5/ha (**Fig. 8**). This indicates that response to applications of more than 20 kg P_2O_5/ha was not caused by P nutrition but by other beneficial effects of banded concentrated superphosphate.

Economics of Fertilizer Use

Costs and prices obtaining in Morocco during 1986-87 were used for economic analysis of the data, and costs of fertilizer application (including extra labor) were assumed to be negligible compared with fertilizer cost. Gross and net revenues over the fertilizer cost were calculated. Then the net revenue over the fertilizer cost minus the revenue without fertilizer use was divided by the cost of fertilizer for each fertilizer rate significantly different from zero, the result being the benefit-cost ratio (B/C). The Food and Agriculture Organization (FAO) of the UN recommends a B/C

Table 4. Gross revenues, net revenues over the fertilizer cost, and fertilizer benefit-cost ratio (B/C) for N responses significantly different from zero (P < 0.05), 1985-86.

N rate (kg/ha)	Fertilizer cost (MAD/ha)	Revenue (MAD/ha) Gross	Net	B/C	Revenue (MAD/ha) Gross	Net	B/C
		10-2			10-3		
0	0	2200	2200	-	5150	5150	-
30	111	4050	3939	15.6	6500	6389	11.1
60	222	5250	5028	12.7	6950	6728	7.1
90	333	6250	5917	11.1[a]	7500	7167	6.1
		15-1			15-2		
0	0	2350	2350	-	3200	3200	-
30	111	2850	2739	3.5	3850	3739	4.8
60	222	2950	2728	1.7	3800	3578	1.7
90	333	2950	2617	0.8	3850	3517	1.0
		15-3			34-2		
0	0	4050	4050	-	3800	3800	-
30	111	4650	4539	4.4	4650	4539	6.6
60	222	4700	4478	1.9	4750	4528	3.3
90	333	4800	4467	1.3	4950	4617	2.5

[a] More N was needed to reach the optimal yield.

Table 5. Gross revenues, net revenues over the fertilizer cost, and fertilizer benefit-cost ratio (B/C) for N responses significantly different from zero (P < 0.05), 1986-87.

N rate (kg/ha)	Fertilizer cost (MAD/ha)	Revenue (MAD/ha) Gross	Net	B/C	Revenue (MAD/ha) Gross	Net	B/C
		10-5			10-6		
0	0	2325	2325	-	705	705	-
40	148	3020	2872	3.7	1650	1502	5.4
80	296	3000	2704	1.3	1830	1534	2.8
120	444	3045	2601	0.6	2055	1611	2.0
		15-4			34-5		
0	0	1605	1605	-	841	841	-
30	111	2275	2164	5.0	1320	1209	3.3
60	222	2815	2593	4.4	1244	1022	0.8
90	333	3015	2682	3.2	1334	1001	0.5

ratio of at least 2 for practices that are to be recommended to small farmers; we use this criterion.

The costs in Moroccan dirhams were 124 MAD/100 kg of ammonium nitrate (33.5% N) and 97 MAD/100 kg of concentrated superphosphate (45% P_2O_5). The prices were 200 MAD/100 kg of grain and 50 MAD/100 kg of straw.

Table 6. Gross revenues, net revenues over the fertilizer cost, and fertilizer benefit-cost ratio (B/C) for P responses significantly different from zero ($P < 0.10$), 1985-86.

P_2O_5 rate (kg/ha)	Fertilizer cost (MAD/ha)	Revenue (MAD/ha) Gross	Net	B/C	Revenue (MAD/ha) Gross	Net	B/C
		15-1			15-2		
0	0	2650	2650	-	3500	3500	-
20	43	2950	2907	6.0	3600	3557	[a]
40	86	2850	2764	1.3	3850	3764	3.1
		15-3			34-2		
0	0	4350	4350	-	4400	4400	-
20	43	4700	4657	7.1	4650	4607	4.8
40	86	4500	4414	0.7	4700	4614	2.5
		34-3					
0	0	4700	4700	-			
20	43	5100	5057	8.3			
40	86	4850	4764	0.7			

[a] The response to 20 kg P_2O_5/ha was not significant.

Table 7. Gross revenues, net revenues over the fertilizer cost, and fertilizer benefit-cost ratio (B/C) for P responses significantly different from zero ($P < 0.05$), 1986-87.

P_2O_5 rate (kg/ha)	Fertilizer cost (MAD/ha)	Revenue (MAD/ha) Gross	Net	B/C	Revenue (MAD/ha) Gross	Net	B/C
		10-7			15-4		
0	0	1935	1935	-	2200	2200	-
20	43	2230	2187	5.9	2215	2172	[a]
40	86	2330	2244	3.6	2475	2389	2.2
80	172	2420	2248	1.8	2810	2638	2.5
		15-5			15-6		
0	0	1685	1685	-	1780	1780	-
20	43	1935	1892	4.8	2045	2002	5.2
40	86	2160	2074	4.5	2270	2184	4.7
80	172	2320	2148	2.7	2590	2418	3.7

[a] The response to 20 kg P_2O_5/ha was not significant.

The results of economic analysis (**Tables 4, 5, 6,** and **7**) showed that use of fertilizers is highly economic for wheat production in the Chaouia region of Morocco. The B/C ratios for recommended rates varied from 3 to 11 for N and 2 to 8 for P. The results showed also that if the price of fertilizers were doubled, fertilizer use at the recommended rates would have remained economic.

With the present state of the art in weather forecasting, it is not possible to predict yields accurately. Therefore, an estimated yield based on precipitation probabilities should be used for N recommendations. When our N model was used to predict nitrogen needs of wheat on the experimental sites for a yield goal of 2 t grain/ha (**Table 3**), the recommended rates (zero or higher) were economic in 8 of 10 cases (Tables 4 and 5). On two farms where N use was calculated to be economic in a dry year, the previous crops were lentils and field peas. For P, soil-based recommendations (zero or higher) would have been economic in all cases (**Tables 6** and 7).

Since 1985-86 was a season when yields were average, and 1986-87 below average, we have concluded that fertilization is economic if based on soil-test results and practiced over a long period.

Conclusions

The results of our experiments conducted in Chaouia region of Morocco and of more than 100 experiments with wheat and barley in Syria, Turkey, Jordan, and Cyprus show that application of phosphorus fertilizers can increase yields when soil-test values for P are lower than 5 ppm ($NaHCO_3$). Our results also show that in soils that are highly calcareous (20% lime), P fertilization pays when the soil-test value is between 5 and 8 ppm. Furthermore, the relative response to P is more pronounced in dry than in wet years. In addition, our data and those of ICARDA show that banding concentrated superphosphate has beneficial effects other than P nutrition on the yield of cereals.

The results of our experiments and those of about 60 experiments conducted at ICARDA showed that an NO_3-N content of 44-50 kg/ha in the top 60 cm of soil is sufficient for optimal yields of wheat and barley and that nitrogen requirement of wheat or barley following a cereal crop is higher than that following a fallow or legume crop.

Our analysis of the findings, when related to 1986-87 costs and prices in Morocco, showed that N and P fertilizers could be applied economically based on soil tests.

From the work undertaken so far, we can say that critical NO_3-N levels should be determined for different yield levels and for soils with different mineralization potentials. For such calculations, one should enlist the help of soil taxonomists so that results are soil specific.

Some notable tasks yet to be done include:

* Determinations of NO3-N and fertilizer N needed under different soil and climatic conditions;

* Development of a quick test to determine mineralization potential of different soils and to assess the effect of previous crop on N availability;
* Investigations of cause (or causes) of the positive effects of banding concentrated superphosphate;
* Research into distribution of NO3-N and NaHCO3-P in soil samples as well as the effects of time of sampling; and
* Clarification of relationships between precipitation (soil moisture before and after tillering) and yield.

Acknowledgment

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Response of Wheat to Nitrogen and Phosphorus in Rainfed Areas of Jordan

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Abstract. Fertilization trials were carried out in 1986 at Maro (north), Mushakar (central), and Rubbah (south), Jordan, as part of a cooperative project with ICARDA. The objectives were to determine the response of wheat to nitrogen and phosphorus under the conditions found in the country and to compare two methods of applying P fertilizer -- broadcasting and banding. For trials of nutrient requirements, 0, 40, 80, and 120 kg N/ha and 0, 20, 40, 80 kg P_2O_5 were used, and for trials of method of application, 60 kg N/ha for all plots and 0, 40, 80, and 120 kg P_2O_5. In Rubbah, where rainfall was only 286 mm and poorly distributed during the year, yields were low and the variety Deir Alla 2 did not respond significantly to fertilizer application. In Mushakar, where the P available in the soil was only 4.85 ppm, according to the Olsen test, responses by the wheat (Hourani Nawawi) to P applications of 40 kg and 80 kg P_2O_5/ha were highly significant. At Maro, where rainfall was 513 mm during the year, the response by Hourani Nawawi to nitrogen application was significant. Banding gave slightly but not significantly higher yields than broadcasting.

Introduction

In 1986, Jordan began cooperating with ICARDA to carry out trials on fertilization of wheat in rainfed areas. The move was one of the government's efforts to bring local production of wheat (100,000-150,000 t/year) more in line with consumption (about 500,000 t). Six trials were initiated in three of the country's agricultural research centers -- Maro in the north (350-450 mm rainfall annually), Mushakar in central Jordan (300-400 mm), and Rubbah in the south (250-350 mm). All the stations are on the eastern bank where virtually all the cultivable land is found -- about 13% of the total land in the country (6% of the total is now cultivated and employs about 40% of the population). The objectives of the trials were (i) to estimate the nitrogen and phosphorus requirements for increased yields of wheat under the conditions found in the country and (ii) to compare two methods of applying P fertilizer (broadcasting and banding).

Materials and Methods

The soils in the experimental sites are vertic chromoxererts and are very fine, montmorillonitic, and thermic (**Table 1**): the previous cropping season, the fields were fallow. Planting for trials in Maro and Rubbah was done on 26 November, harvesting in June; in Mushakar, seeds were sown 18 December, and plants were harvested in July. The varieties chosen for the trials were Hourani Nawawi (Maro and Mushakar) and Deir Alla 2 (Rubbah), and fertilizers were applied as ammonium sulfate and triple superphosphate. Spacing between plants at Maro was 17-18 cm, at Mushakar 25 cm, and at Rubbah 30 cm. Treatments were compared solely on the basis of yield. The experimental design was a randomized complete block, with factorial combinations. For trials of nutrient requirements of wheat, four rates of nitrogen (0, 40, 80, 120 kg/ha) and four rates of phosphorus (0, 20, 40, 80 kg P_2O_5/ha) were used. For trials of banding and broadcasting as methods of P application, nitrogen was 60 kg/ha for all plots, and phosphorus was applied at 0, 40, 80, and 120 kg/ha.

Table 1. Rainfall and chemical properties of the soils at Maro, Mushakar, and Rubbah, Jordan.

	Maro	Mushakar	Rubbah
N (kg N/ha, 0-60 cm deep)			
$N\text{-}NO_3$	35.20	33.37	15.35
$N\text{-}NH_4$	19.42	16.58	11.47
Total N	54.60	49.95	26.82
P-Olsen (ppm)	9.4	4.9	10.7
pH (H_2O)	7.9	8.0	8.1
$CaCO_3$ (%)	8.2	18.5	20.4
Rainfall (mm)	513	378	286

Results and Discussion

Rainfall was the greatest determinant of yield for all trials. In Rubbah, where total rainfall was only 286 mm during the year, and about 100 mm had fallen before the wheat was planted, and another 39 mm came on 18 March, yields were very low (**Tables 2** and **3**) -- overall mean for trials of different levels of fertilizer, 933 kg/ha; and for trials of method of P application, 491 kg/ha. Variety and rate of seeding (200 kg/ha) may have also played a role in the low yields; there was no significant response to fertilizers.

Table 2. Effects of fertilization with N (0-120 kg/ha) and P_2O_5 (0-80 kg/ha) on yields (kg/ha) from wheat in Maro, Mushakar, and Rubbah, Jordan.

N, P_2O_5 (kg/ha)	Maro	Mushakar	Rubbah
0,0	2721	3550	922
0,20	2764	3073	929
0,40	2995	3807	1031
0,80	2775	3837	941
40,0	2856	3067	1044
40,20	2925	3327	1067
40,40	2943	3820	1183
40,80	3227	3600	958
80,0	3107	3150	942
80,20	2807	3593	785
80,40	2880	3880	936
80,80	3268	3503	881
120,0	2999	3217	919
120,20	3001	3360	908
120,40	2614	3420	798
120,80	3022	3780	681

Table 3. Effects of broadcasting and banding P_2O_5 (0-120 kg/ha) on yields (kg/ha) of wheat in Maro, Mushakar, and Rubbah, Jordan.

Method and rate of P_2O_5	Maro	Mushakar	Rubbah
Broadcasting			
0	3607	3595	485
40	3650	3583	479
80	3692	3693	463
120	3672	3755	562
Banding			
0	3488	3365	508
40	3430	3792	490
80	3543	3793	443
120	3928	3668	492

In Mushakar, where rainfall during the year was 100 mm more than in Rubbah and the distribution was much better -- between 30 and 80 mm each month from planting through March -- mean yields for the two trials were 3499 kg/ha and 3656 kg/ha. For the fertilization trials at Mushakar, where

the P available in the soil was only 4.85 ppm, responses to P applications (40 kg and 80 kg P_2O_5/ha) were highly significant ($P < 0.01$); no other responses were significant, although the yield was highest (3880 kg/ha) at 80 kg N/ha and 40 kg P_2O_5/ha (Table 2).

At Maro, where rainfall and yields were highest, the response to N application was significant ($P < 0.05$), as was the interaction between N and P. For three treatments (80 kg N/ha; 40 kg N/ha, 80 kg P_2O_5; and 80 kg N/ha, 80 kg P_2O_5), yields were significantly higher than those for the control.

For none of the trials was the method of application of P a significant factor, although banding generally gave slightly higher yields (**Table 3**). Since the soils generally had sufficient levels of P before application of fertilizer, the placement method had little influence. Further research, on P-deficient soils, may be warranted.

Calibration of Three Tests for Determining Phosphorus Fertility of Soils to Support Cereals, Legumes, and Oilseeds

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Abstract. Three soil tests ($NaHCO_3$, NH_4HCO_3-DTPA, and Mehlich 3) were evaluated for their ability to predict the amount of P that cereals, legumes, and oilseeds could extract from soils in Pakistan. In greenhouse studies, yields and P contents of grain and foliage were determined for five species grown on an alkaline, calcareous, P-deficient (Olsen-P, 3.9 mg P/kg soil) typic ustochrept supplied with 0, 10, 20, 40, and 80 mg P_2O_5/kg soil. Grain yield without P fertilizer was mustard (*Brassica juncea*), 14%; wheat (*Triticum aestivum*), 17%; lentil (*Lens culinaris*), 19%; barley (*Hordeum vulgare*), 26%; and chickpea (*Cicer arietinum*), 42% of the maximum obtained with adequate P. The results were used for calibration of soil tests investigated in an incubation study in the laboratory; samples of the soil were supplied with 0, 10, 20, 40, and 80 mg P_2O_5/kg and allowed to equilibrate at 25 +/- 1°C. Extractable P was determined by the three methods at weekly intervals. The P extracted by all three soil tests correlated well with crop yield and P uptake, and correlation coefficients demonstrated the tests' value in predicting requirements for fertilization with P. As the universal soil tests (NH_4HCO_3-DTPA and Mehlich 3) are cheaper, easier, and less time-consuming than the $NaHCO_3$ test now used routinely in Pakistan, they could be used for quick, site- and crop-specific recommendations about fertilizer applications.

Introduction

A research program was recently initiated at the National Agricultural Research Centre, Islamabad, Pakistan, to develop a scientific basis for fertilizer recommendations. As a first step in the effort, we investigated the comparative sensitivity of wheat, barley, chickpea, lentil, and mustard to P deficiency. The results were used to calibrate three soil tests for assessing requirements for P fertilizer.

Materials and Methods

A sample of surface soil, Missa series (silty, mixed, hyperthermic), collected from Fateh Jang, District Attock, was air-dried, crushed through a 6.4-mm sieve, divided into portions, and placed in polyethylene-lined plastic pots. Consisting of 18% clay, 68% silt, and 14% sand, the soil had pH 8.2, electrical conductivity of 0.31 ds/m, $CaCO_3$ equivalent to 9.4%, and a field capacity of 17%. Contents of organic C were 0.48%, $NaHCO_3$-extractable P, 3.78 mg/kg; and NH_4OAc-extractable K, 117 mg/kg. DTPA-extractable Zn and Cu were 0.54 mg/kg and 0.76 mg/kg respectively.

Basal fertilizers, other than P, were applied in solution to the surface of the soil, and mixed thoroughly.

For studies of plant response to P, wheat (*Triticum aestivum* L. cv. Sonalika), barley (*Hordeum vulgare* L. cv. Jav-83), chickpea (*Cicer arietinum*, L. cv. CM-72), lentil (*Lens culinaris* L. cv. Lentil 9-6), and mustard (*Brassica juncea* L. cv. S-9) were planted in 5-kg portions of the soil. A total dose of 800 mg N/kg as urea was applied to nonleguminous crops (wheat, barley, and mustard) in three installments, and 10 mg N/kg was applied to legumes. All plants received 1170 mg K/kg as K_2SO_4; 10 mg Zn/kg as $ZnSO_4$; 5 mg Cu/kg as $CuSO_4$; and 1 mg B/kg as H_3BO_3.

Five levels of P -- 0, 10, 20, 40, and 80 mg P_2O_5/kg soil -- were applied as $CaHPO_4 \cdot 2H_2O$ and mixed with the soil. Pots for each crop were arranged in the greenhouse according to a randomized complete block design with three replications. Soil moisture was maintained near field capacity with distilled water. Two plants (seedlings) of each crop were harvested when about 30 cm high, and their P concentrations were determined for correlations with plant growth. The per-pot number of plants grown to maturity was wheat, 5; barley, 5; mustard, 3; and lentil, 5. The most recently matured leaves of every crop were sampled at flower initiation, and at maturity the plants were harvested 1 cm above the soil surface. Grains were threshed manually, and straw was rinsed with distilled water. Grain and straw were oven-dried at 70°C for 2 days, weighed, and ground in a Wiley mill. Plant material was digested with a nitric and perchloric acid mixture (2:1), and P in the digests was determined by the yellow color method (Jackson 1958).

For soil tests, 1-kg portions of prepared soil were placed in plastic pots with 0, 10, 20, 40, and 80 mg P_2O_5/kg (as $CaHPO_4$ $2H_2O$), 200 mg N/kg (as urea), and 293 mg K/kg (as K_2SO_4). The experiment was replicated thrice. Soil moisture was maintained near field capacity by daily addition of distilled-deionized water. The soils were incubated in a growth chamber at 25 +/- 1°C, and samples from each pot were analyzed weekly for extractable P by three soil tests: $NaHCO_3$ (Olsen *et al.* 1954); ammonium bicarbonate-DTPA (AB-DTPA) (Soltanpour and Workman 1979); and Mehlich 3 (Mehlich 1984).

Results and Discussion

Sensitivity of Crop Species to P Deficiency

Crop species differed widely in sensitivity to P deficiency in the Missa soil. Mustard was the most sensitive: without P application, it yielded only 14% of the grain obtained with the highest dose of P. Chickpea was relatively tolerant of P deficiency, yielding 42% of its maximum. Wheat, lentil, and barley yielded 17%, 19%, and 26%, respectively. The data for production of total dry matter (less grain) were similar to data for grain yield. Without P fertilizer, mustard yielded 19%; wheat, 25%; barley, 26%; and chickpea, 44% of the respective totals produced with the highest dose of P (**Table 1**). Agronomists are well aware that plant species, even varieties, differ in their ability to extract soil phosphate. The reasons are not fully understood, but root geometry (the amount and distribution of roots in soil) plays a role (Nye and Tinker 1977). Roots of grasses are twice as long as those of legumes (Barley 1970), but legumes depend on mycorrhizal associations more than grasses do (Mosse 1981). Therefore, more efficient utilization of soil P by chickpea under stress could be the result of more effective mycorrhizal associations.

Table 1. Dry matter yield of crops as a function of P fertilizer applied to Missa soils.[a]

	Dry matter yield (g/plant)			
	Wheat	Barley	Chickpea	Mustard
P_2O_5 applied (mg/kg)				
0	1.14d	5.0d	2.13d	1.50d
10	1.53cd	7.98cd	2.60cd	2.40cd
20	2.04bc	9.52bc	3.34bc	3.45bc
40	2.86b	13.05b	4.13ab	5.96b
80	4.63a	19.48a	4.82a	7.98a
LSD	0.87	4.51	1.13	1.83

[a] Dry matter yields not followed by the same letter are significantly different at $P < 0.01$.

The yields of grain and dry matter from all crop species progressively increased with application of fertilizer P, but the levels of P were not high enough to maximize yield (**Fig. 1**). Therefore, the results of this study were not used to determine the plants' requirements for P, sufficient levels of P in plant tissues, or sufficient levels in soil to support near-maximal yields.

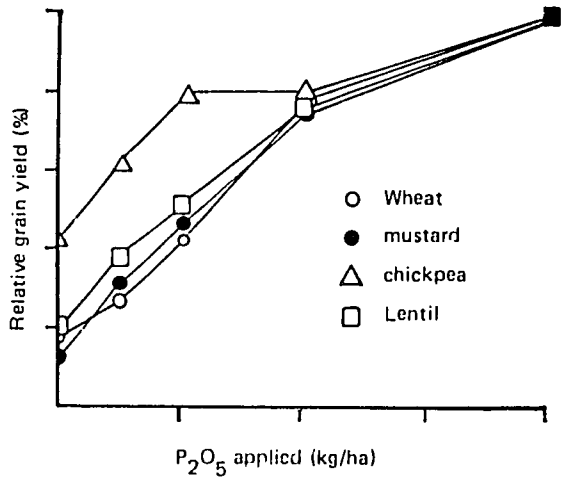

Fig. 1. Relationship between P fertilizer rate and grain yield (maximum grain yield: Wheat, 5.09 g/plant; mustard 1.90/plant; chickpea, 7.44 g/plant; and lentil, 3.66 g/plant)

Suitability of Soil Tests for Predicting P Fertilizer of Soil

The suitability of a soil test for predicting P status of a soil can be evaluated by correlation of P with plant growth parameters such as yield, % relative yield, P uptake, and P concentration. The Olsen ($NaHCO_3$) method has been studied more widely than other extracting solutions. In fact, this soil test has proved quite suitable for alkaline and calcareous soils of Pakistan. Despite its routine use in the country, however, the results have not been extrapolated into sufficiency levels of extractable P for different soil-crop combinations. Recently, universal soil tests (like AB-DTPA and Mehlich 3) have become popular primarily because of their economy in terms of time and money. With these soil tests, one can assess nutrient availability for about 10 elements by a single extraction. For example, AB-DTPA is an effective test of the availability indices of P, K, Zn, Fe, Mn, Mo, Pb, Ni, Cd, and Se (Soltanpour 1985), and the Mehlich 3 soil test is being widely used in the United States as the method of extracting P, K, Ca, Mg, Na, B, Cu, Fe, Mn, and Zn from the soil (J.B. Jones, Jr., personal communication, 1987). The adoption of multielement analyses, like inductively coupled plasma spectrometry, in soil-testing laboratories has helped realize the benefits of universal soil tests.

In our incubation study, P fertilizer applications increased extractable P significantly (**Fig. 2**; $P < 0.01$), and the recovery of soil-applied P decreased with time. Phosphorus extractable by $NaHCO_3$ and AB-DTPA soil tests decreased for up to 42 days and thereafter remained stable (**Fig. 2**). Therefore, P determinations by all the soil tests included in this study were made after 56 days of incubation, and these P levels were correlated with plant yields, P uptake, and other parameters of plant growth (**Table 2**).

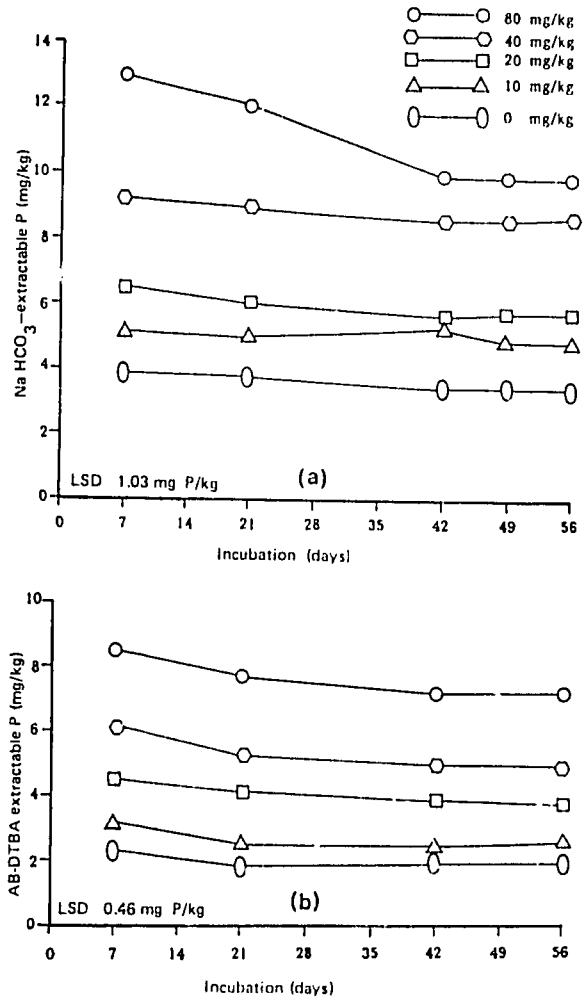

Fig. 2. Phosphorus extractable from Missa soil by (a) $NaHCO_3$ and (b) AB-DTPA after application of P fertilizer and incubation at 25 +/- 1°C and at moisture levels of field capacity.

Extractable P contents determined by the three soil tests were closely correlated with grain or dry matter yield of all the crops ($r > 0.92$, **Table 3**). The soil's content of P was correlated with concentrations of P in seedlings, diagnostic leaf tissues, and straw ($r > 0.91$) (**Table 3**). The correlation coefficient between P concentration of lentil grains and extractable P in the soil was 0.97 ($P < 0.01$). In contrast, the soil contents of P showed no relation to concentrations of P in the grain of wheat, chickpea, or mustard.

Table 2. Soil test P levels (incubation study), plant yields and associated plant growth parameters.

P_2O_5 applied (mg/kg)	Soil test P: $NaHCO_3$ (mg/kg)	Soil test P: AB-DTPA (mg/kg)	Soil test P: Mehlich 3 (mg/dm^3)	Yield (g/plant): Grain	Yield (g/plant): Dry matter	P concentration (%): Seedlings	P concentration (%): Leaves	P concentration (%): Grain	P concentration (%): Straw	P uptake (mg/plant)
			Wheat							
0	3.4	1.9	7.5	0.89	1.14	0.29	0.15	0.11	0.097	2.09
10	4.8	2.5	7.8	1.31	1.54	0.29	0.25	0.14	0.101	3.39
20	5.7	3.7	10.1	1.97	2.04	0.35	0.37	0.17	0.108	5.55
40	8.6	4.8	15.2	3.87	2.86	0.37	0.5[illegible]	0.15	0.116	9.13
80	9.9	7.1	16.6	5.09	4.63	0.40	0.77	0.18	0.124	14.90
			Barley							
0	3.4	1.9	7.5		5.00	0.12	0.29		0.102	5.1
10	4.8	2.5	7.8		7.98	0.17	0.34		0.109	8.7
20	5.7	3.7	10.1		9.52	0.18	0.40		0.117	11.1
40	8.6	4.8	15.2		13.05	0.29	0.57		0.123	16.1
80	9.9	7.1	16.6		19.48	0.35	0.66		0.130	25.3
			Chickpea							
0	3.4	1.9	7.5	3.14	2.13	0.17	0.32	0.09	0.104	5.05
10	4.8	2.5	7.8	4.63	2.60	0.19	0.42	0.09	0.116	7.19
20	5.7	3.7	10.1	5.91	3.33	0.24	0.45	0.12	0.119	11.05
40	8.6	4.8	15.2	5.97	4.13	0.26	0.60	0.12	0.128	12.45
80	9.9	7.1	16.6	7.44	4.82	0.31	0.80	0.20	0.137	21.48
			Lentil							
0	3.4	1.9	7.5	0.73		0.09	0.26	0.10		
10	4.8	2.5	7.8	1.38		0.09	0.34	0.11		
20	5.7	3.7	10.1	1.85		0.15	0.49	0.13		
40	8.6	4.8	15.2	2.81		0.24	0.69	0.14		
80	9.9	7.1	16.6	3.66		0.29	0.92	0.16		
			Mustard							
0	3.4	1.9	7.5	0.27	1.50	0.16	0.24	0.17	0.118	2.23
10	4.8	2.5	7.8	0.58	2.39	0.19	0.37	0.17	0.122	3.91
20	5.7	3.7	10.1	0.89	3.45	0.31	0.45	0.29	0.127	6.96
40	8.6	4.8	15.2	1.43	5.96	0.41	0.61	0.29	0.133	12.08
80	9.9	7.1	16.6	1.90	7.98	0.45	0.82	0.25	0.157	17.28

Historically, seed composition has been considered a poor indicator of the nutritional status of soils, but reports conflict. For example, seed analyses were reported to be valuable for evaluating the soil's ability to supply Mo, S, and Zn (Lavy and Barber 1963; Fox *et al.* 1977; Rashid 1986). A review of the literature indicated that seeds of leguminous crops invariably are better indicators of the nutrient-supplying status of soils than are seeds of nonleguminous crops. In our study, the range of P concentration of lentil seeds was not wide (0.10-0.16%). Therefore, further studies are warranted to investigate the usefulness of lentil seeds as a diagnostic tissue for P and other elements.

Strong correlations between various soil tests for P ($r > 0.95$; $P < 0.05$ **Table 3**) indicate that universal soil tests (AB-DTPA and Mehlich 3) are as effective for evaluating P fertility of soils as the $NaHCO_3$ method is. Equally, P extracted by various soil tests correlated well with concentration or uptake of P by the plants. Therefore, universal soil

Table 3. Correlation coefficients of extractable P in soil (incubation study) and plant growth and nutrition parameters.[a]

	Correlation coefficient (r)		
	$NaHCO_3$ P	AB-DTPA P	Mehlich 3 P
Soil tests			
$NaHCO_3$ P	-	0.97**	0.99**
AB-DTPA P	0.97**	-	0.95*
Mehlich 3 P	0.99**	0.95*	-
Wheat			
Yield			
Grain	0.99**	0.98**	0.99**
Dry matter	0.95*	0.99**	0.94*
P concentration			
Seedling	0.94*	0.96**	0.95*
Leaves	0.98**	0.99**	0.96**
Grain	0.77	0.82	0.70
Straw	0.99**	0.99**	0.98**
Total P uptake	0.97**	0.99**	0.95*
Barley			
Dry matter yield	0.97**	0.99**	0.94*
P concentration			
Seedlings	0.99**	0.97**	0.98**
Leaves	0.99**	0.97**	0.99**
Straw	0.99**	0.97**	0.95*
Total P uptake	0.97**	0.99**	0.94*
Chickpea			
Yield			
Grain	0.92*	0.94*	0.87*
Dry matter	0.99**	0.98**	0.98**
P concentration			
Seedlings	0.96**	0.99**	0.95*
Leaves	0.98**	0.99**	0.95*
Grain	0.86	0.96**	0.84
Straw	0.98**	0.96**	0.94*
Total P uptake	0.93*	0.99**	0.91*
Lentil			
Grain yield	0.99**	0.98**	0.97**
P concentration			
Seedlings	0.98**	0.97**	0.99**
Leaves	0.97**	0.99**	0.98**
Grain	0.97**	0.98**	0.95*
Mustard			
Yield			
Grain	0.99**	0.99**	0.98**
Dry matter	0.99**	0.99**	0.98**
P concentration			
Seedlings	0.98**	0.95*	0.98**
Leaves	0.99**	0.99**	0.96**
Grain	0.66	0.62	0.69
Straw	0.91*	0.98**	0.89*
Total P uptake	0.99**	0.99**	0.98**

[a] Significance: * = $P < 0.05$; ** = $P < 0.01$.

tests could be adopted for evaluating soils in Pakistan and would save time, labor, and expenses. However, further research is needed to establish sufficiency levels in soil tests -- i.e., how much P and other nutrients are required in local soils -- to support local genotypes -- before their routine use is adopted by soil-testing laboratories in the country.

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Soil Testing as a Guide to Phosphate Fertilization of Five Legumes in Syria

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Abstract. The relationship between P available in the soil and response of food and forage legumes to phosphate fertilization was investigated in Syria. In 1986-87, pea, chickpea, faba bean, lentil, and vetch were grown at the main agricultural station of ICARDA at Tel Hadya on soils having 2-21 ppm of $NaHCO_3$-extractable (Olsen) P. In the previous season, the plots had been fertilized with P at 0, 50, 100, 150, and 200 kg P_2O_5/ha and had been cultivated with barley. At planting time the crops received 0, 50, or 100 kg P_2O_5/ha. At harvest, grain and total biological yields were determined. The results were analyzed according to Cate-Nelson methods -- graphical representation and analysis of variance -- for the estimation of critical levels of P in soil (i.e., levels beyond which crops are unlikely to respond to P fertilization). For two of the crops -- chickpea and lentil -- the analysis was extended to include data from trials the previous year. In these 18 trials, conducted on farmers' fields where Olsen-P ranged from 4 to 24 ppm, the crops were fertilized with 0, 50, 100, and 150 kg P_2O_5/ha (three replications). Findings were that the critical levels were 6 ppm for pea, 5.5-7 ppm for chickpea, 7 ppm for faba bean, 7-8 ppm for lentil, and 5.5-7 ppm for vetch. These values suggest that all five legumes will thrive on soils with available P at 8 ppm, although testing under other soil and environmental conditions is required for confirmation.

Introduction

In the Mediterranean, food and forage legumes are grown after cereals under rainfed conditions and on highly calcareous soils with little available phosphorus. Not surprisingly, therefore, economic responses to phosphorus application have been observed for lentil, vetch, and faba bean in Syria (Loizides 1970; Matar 1976a,b), Libya (Badawy 1976), Pakistan (Sharar *et al.* 1976), and other parts of the region. However, the relationships between the level of available P in soil and the response of food and forage legumes to phosphate fertilization have remained unclear. One of us (Matar 1976a) found that in normal years 3.5-4 ppm of available P in soils would lead to maximum production of lentil seeds on the Houran

plain of Syria but that higher levels were required during dry years. We have expanded the earlier work in the present study (i) to clarify the effects of residual and newly applied phosphate on grain and total biologic yields of pea, chickpea, faba bean, lentil, and vetch; (ii) to relate soil tests for P with the response of legumes to P fertilization; and (iii) to determine the levels of soil P that maximize production of food and forage legumes.

Materials and Methods

The experiments were conducted in north Syria on soils derived from calcareous rocks and classified as vertic xerochrepts or typic chromoxererts. Average annual rainfall is 330-450 mm. In 1986-87 we conducted the trials at Tel Hadya, ICARDA's main research station near Aleppo, Syria. The previous season, soils in farmers' fields were sampled, and values recorded for available P ranged from 3.7 to 24.0 ppm; we had also conducted fertilization trials during that season on the 18 sites sampled (**Table 1**), but part of the yield was pilfered. The data derived from those trials were still deemed useful for evaluation of soil-calibration methods and have, thus, been included here. The methods for the earlier trials deserve brief mention: lentil and chickpea were planted (November-December 1985) in a randomized complete block design with four levels of P (0, 50, 100, and 150 kg P_2O_5/ha) and three replications. For chickpeas, rows were 30 cm apart and plants 10 cm; spacings for lentils were 25 cm between rows and 1.5 cm between plants. Weeds were controlled by preemergence herbicides. At 100% flowering and at physiologic maturity, 2-m rows were harvested; the samples were oven-dried at 80°C for 48 h, weighed, and analyzed for

Table 1. Physical and chemical characteristics of the soil samples collected at sowing from on-farm trials for the soil-test calibration (1985-86 season).

pH	EC(1:1)	$CaCO_3$	Organic matter	P-Olsen	Min N (ppm)		Kjel dahl-N	Mechanical analysis		
(1:1)	(µS/cm)	(%)	(%)	(ppm)	NH_4	NO_3	(ppm)	Clay	Silt	Sand
8.3	0.30	27.5	1.47	7.8	5.1	12.7	726	73.7	16.2	8.8
8.2	0.35	19.9	1.77	10.4	5.7	17.1	867	69.3	20.9	8.4
8.3	0.27	24.9	1.40	7.5	5.0	7.2	632	69.4	17.0	11.1
8.3	0.38	30.8	1.18	6.8	15.0	28.3	582	76.2	13.3	8.0
8.2	0.27	22.6	1.11	4.2	4.6	8.5	447	76.4	17.0	5.8
8.4	0.39	31.0	1.41	4.8	3.0	9.0	653	70.8	18.8	9.5
8.2	0.43	20.6	1.74	7.8	10.1	25.4	932	68.1	21.5	8.8
8.2	0.34	29.8	1.51	11.2	4.9	18.9	746	69.4	18.2	10.1
8.4	0.27	21.0	1.19	6.3	3.9	8.2	541	79.2	16.5	4.1
8.4	0.29	35.7	1.23	10.0	4.4	8.6	496	73.2	19.6	6.2
8.3	0.35	20.6	1.21	10.3	27.9	18.4	565	74.7	16.9	7.7
8.3	0.25	30.0	1.22	10.1	4.6	7.6	854	74.8	18.7	5.9
8.1	0.62	17.5	1.60	16.4	10.2	52.0	739	76.6	15.7	7.4
8.2	0.54	21.6	1.24	21.0	15.7	42.9	532	78.5	16.8	3.5
8.3	0.28	28.2	1.44	3.7	4.6	11.1	675	70.7	20.4	7.1
8.1	0.79	21.3	1.65	24.0	28.4	32.4	764	79.0	16.4	4.6
8.3	0.28	33.4	1.23	7.1	3.4	16.3	614	68.9	19.8	9.4
8.4	0.34	30.5	1.33	8.0	5.6	10.9	505	69.9	19.5	8.9

total P. For the trials at Tel Hadya, we found soils with variability in available P (2-21 ppm) similar to the sites in 1985. The fields had been cropped with barley in 1985-86 and had been fertilized with P at 0, 50, 100, 150, and 200 kg P_2O_5/ha (**Table 2**).

Table 2. Residual P in soils fertilized with P_2O_5 and cropped with barley the previous season, Tel Hadya, Syria, 1986-87.

P_2O_5 applied in previous season (kg/ha)	Available P in three samples (ppm)		
0	2.7	2.4	2.8
50	7.4	8.6	7.2
100	10.9	11.0	12.8
150	13.6	13.7	16.5
200	18.1	18.6	19.5

Main plots, which consisted of five levels of residual phosphorus, were split by fertilizer treatment -- 0, 50, and 100 kg P_2O_5/ha placed with the seeds at planting -- and by legume planted -- pea, chickpea, faba bean, lentil, and vetch. Plots for each crop were 10 m x 5 m, and spacings were 30 cm x 10 cm (pea), 30 cm x 10 cm (chickpea), 40 cm x 10 cm (faba bean), 25 cm x 1.5 cm (lentil), and 25 cm x 1.5 cm (vetch). The sites were plowed into a fine seedbed in October, and planting was conducted between 18 November and 3 December 1986.

At five or six samplings, all plants along 2 m of a row were harvested, oven-dried at 80°C for 48 h, and weighed for measurements of total biological yield. At maturity, the 20 m of remaining plants were harvested, air-dried, weight, and threshed. Grain and straw weights were recorded

The relative yields of grain for each of the five legumes were correlated with the $NaHCO_3$-extractable P found in soils at sowing; the Cate-Nelson graphical method was used to divide the sites according to whether or not the crop responded to P application (responsive and nonresponsive). Analysis of variance was conducted for the division, and the soil-test values that maximized R^2 were considered to be critical levels beyond which the particular crop would not respond to P application.

Results and Discussion

Total dry weight rose in all treatments throughout the experiment, slowly at first and rapidly later with increases in ambient temperature (**Fig. 1**).

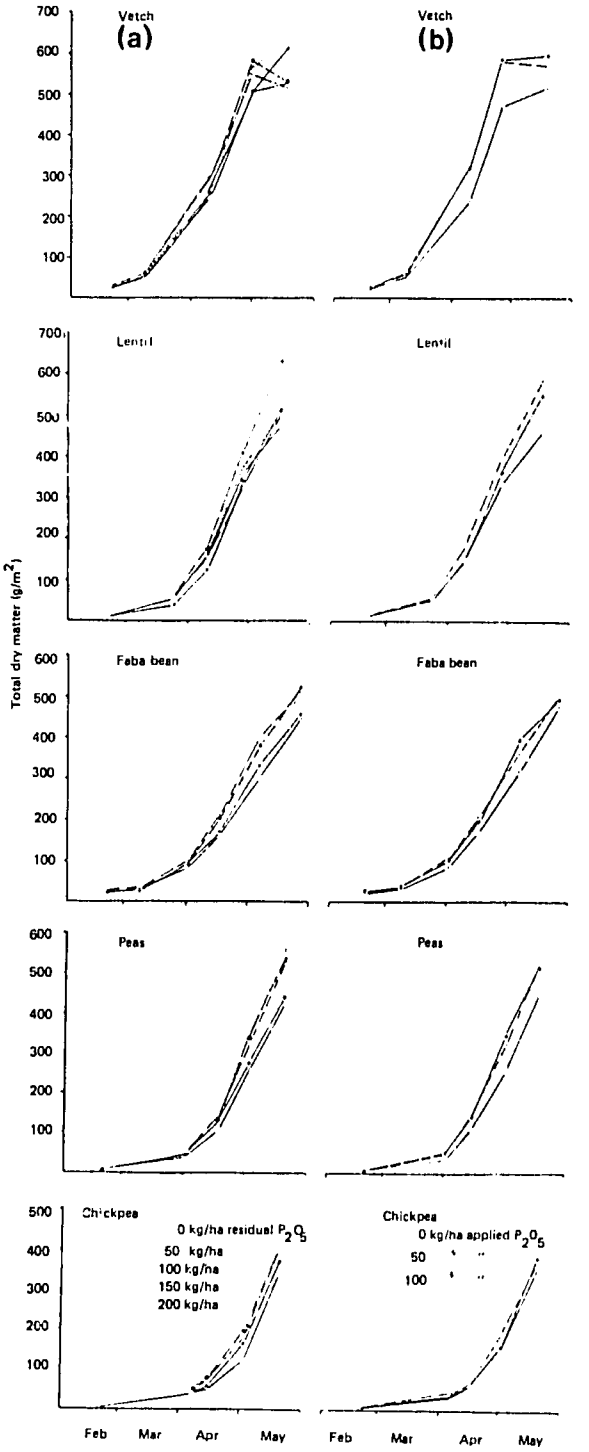

Fig. 1. Buildup of dry matter as influenced by (a) residual and (b) applied phosphorus, Tel Hadya, 1986/87.

Table 3. The means of effects from residual phosphorus on total biological yield (kg/ha) and seed yield (kg/ha) of faba bean, pea, vetch, lentil, and chickpea, Tel Hadya, 1986-87.

Crop	Yield (kg/ha)	Residual phosphorus (kg P_2O_5/ha) 0	50	100	150	200	LSD (5%)	CV%
Faba bean	Biological	3513	3851	3954	4004	4255	NS	11.2
	Seed	1727	1916	2180	1998	2087	147	6.9
Pea	Biological	4027	4641	4977	5342	5295	1000	18.7
	Seed	1478	1805	2004	2042	2445	512	24.1
Vetch	Biological	5670	6248	6407	6772	6297	623	11.0
	Seed	1779	2016	2188	2156	2048		18.9
Lentil	Biological	3860	4427	4843	4831	4928	NS	15.5
	Seed	1664	1852	1982	1956	1981	NS	11.4
Chickpea	Biological	2555	3204	3425	3737	3158	NS	35.1
	Seed	1055	1323	1432	1610	1374	NS	

Table 4. Means of effects from applied phosphorus on total biological and seed yields (kg/ha) of faba bean, pea, vetch, lentil, and chickpea, Tel Hadya, 1986-87.

Crop	Yield (kg/ha)	Applied phosphorus (kg P_2O_5/ha) 0	50	100	LSD (5%)	CV (%)
Faba bean	Total biological	3678	3924	4144.	NS	13.6
	Seed	1812	2029	2087	179	11.4
Pea	Total biological	4245	5194	5295	519	13.9
	Seed	1717	2101	2048	299	20.1
Vetch	Total biological	5634	6519	7351	512	10.4
	Seed	1884	2064	2162	127	8.2
Lentil	Total biological	4293	4577	4863	331	9.5
	Seed	1830	1891	1940	NS	11.4
Chickpea	Total biological	3044	3180	3423	288	11.8
	Seed	1297	1313	1467	123	18.4

At harvest, faba bean, peas, and vetch showed similar trends (**Table 3**): plots that had only the residual phosphorus from treatments with 0 or 50 kg P_2O_5/ha the previous season produced much less total dry matter than did plots with residual phosphorus from applications of 100, 150, and 200 kg P_2O_5/ha. In other words, when barley is fertilized at rates up to 50 kg P_2O_5/ha, it leaves little available P for a succeeding crop of faba beans, peas, or vetch. At rates higher than 50 kg P_2O_5/ha, phosphorus applied the previous season (residual P) increased significantly the seed yields of peas and faba beans as well as the total biological yields of vetch. The yields of peas, particularly, delineated the value of residual phosphorus: seed yields increased from 1.5 t/ha to 2.5 t/ha when peas were grown on

plots that had received 200 kg P_2O_5/ha the previous season. The increase in yields from plots where 100 kg P_2O_5/ha was applied directly at planting peas was equivalent to only 0.3 t/ha. For applied phosphorus, the optimum was about 50 kg P_2O_5/ha (**Table 4**).

For lentils and chickpeas, the buildup of dry matter and the final yields were not significantly different for any of the levels of residual phosphorus, although the highest yields for chickpeas were obtained on plots that had been fertilized with 150 kg P_2O_5/ha the previous season (**Table 3**) and for lentils, 200 kg P_2O_5/ha. Applied phosphorus did not influence significantly the pattern of dry-matter accumulation in chickpea, nor did it have any significant impact on the yields of lentils from plots that had received 50 kg P_2O_5/ha or more the previous year. It did improve yields of lentils on plots with no residual P, with the effect of 100 kg P_2O_5/ha appearing earlier than that of 50 kg P_2O_5/ha (**Table 3**); however, the yields from plots receiving 50 kg P_2O_5/ha at planting were lower than those with residual P from applications of 100 kg P_2O_5/ha or more the previous year. This finding suggests the importance of the fertility of the plow layer.

The Cate-Nelson procedure for determining the critical levels of available P in soils indicated 5.5 ppm for faba beans (**Fig. 2**), 6 ppm for pea (**Fig. 3**), 6-7 ppm for vetch (**Fig. 4**), 7 ppm for lentil (**Fig. 5a**), and 6-7 ppm for chickpea (**Fig. 6a**). The results for chickpea and lentil were virtually unchanged when data were included from the fertilization trials conducted the previous year on farmers' fields (**Fig. 5b** and **6b**).

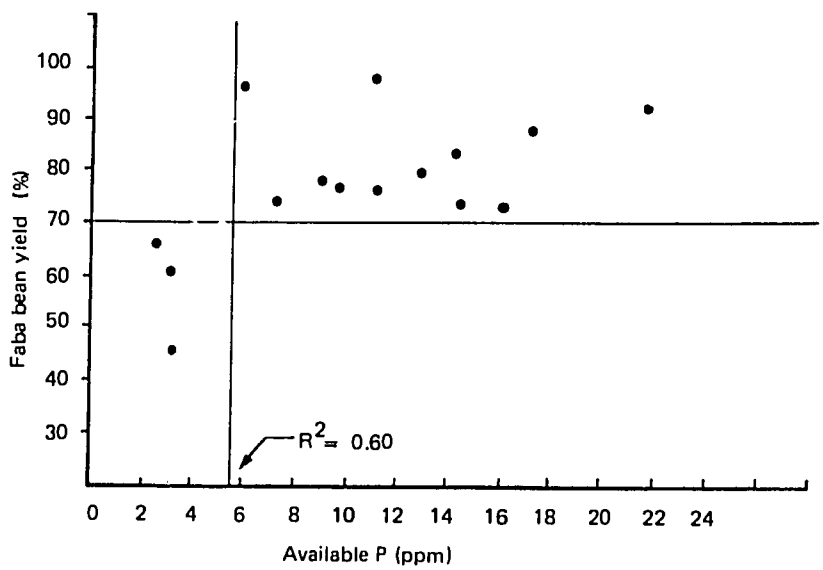

Fig. 2. Scatter diagram of the relative yield of faba bean seeds in relation to available P in soils, 1986-87 season.

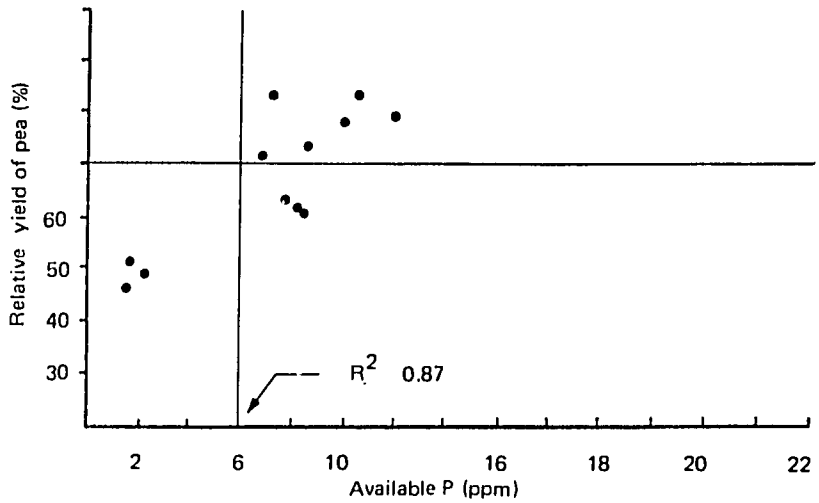

Fig. 3. Scatter diagram of relative yield of peas in relation to available P in soils, 1986-87 season.

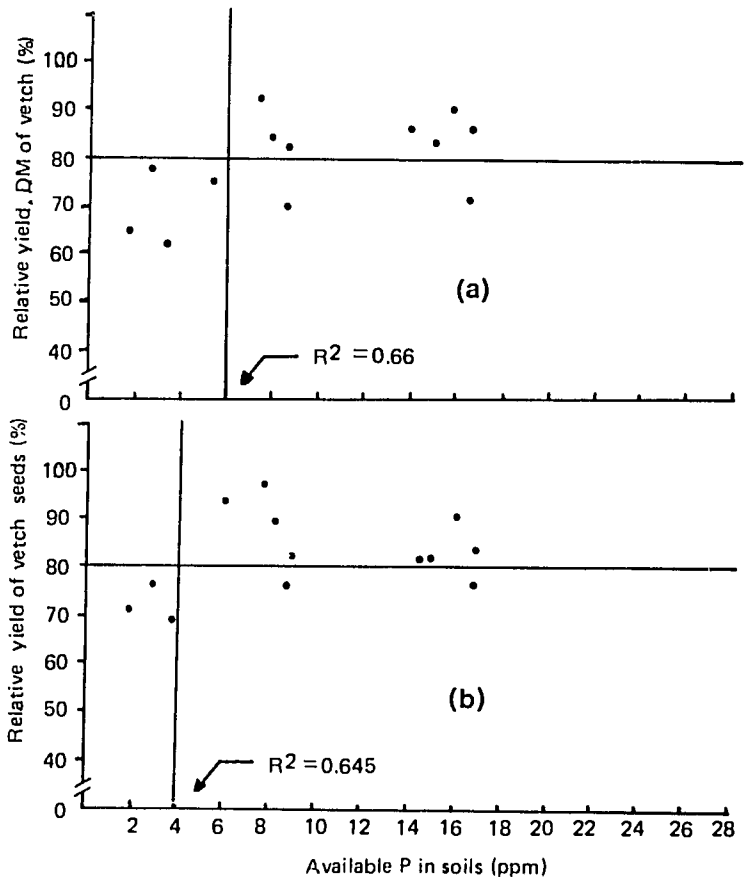

Fig. 4. Scatter diagrams of the relative yield of vetch (a) dry matter (DM) and (b) seeds in relation to available P in soils, 1986-87 season.

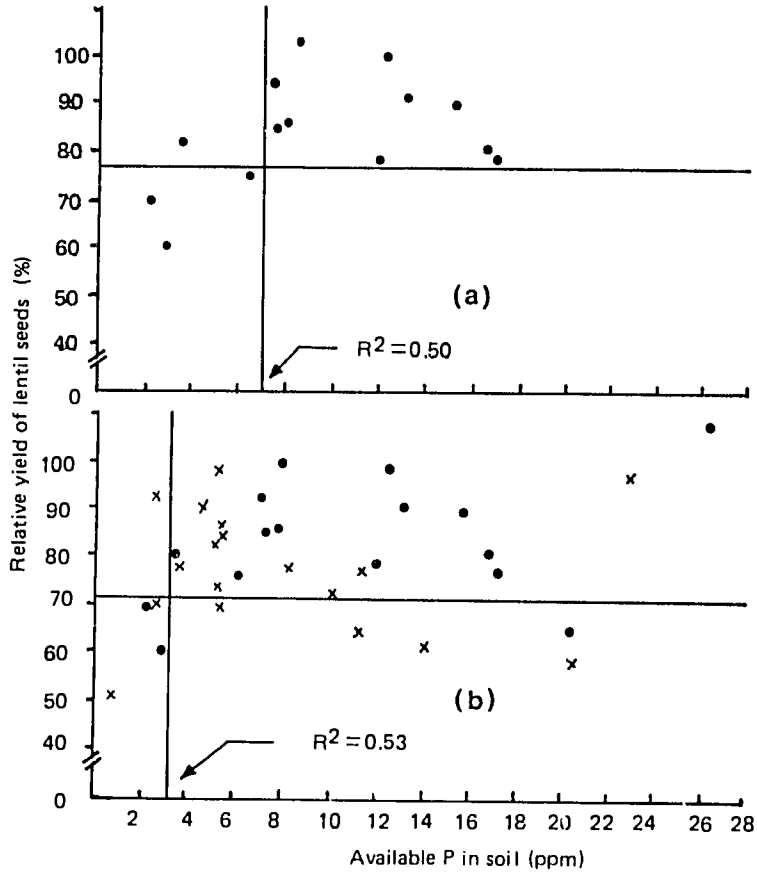

Fig. 5. Scatter diagram of relative yield of lentil seeds in relation to available P in soils: (a) 1986-87 season; (b) 1985-86 and 1986-87 seasons.

The results indicate that a level of available P in soils equivalent to 7 ppm is adequate to secure maximal yields of grain from any of the five legumes studied, although additional studies on other soils and under other environmental conditions are needed for confirmation.

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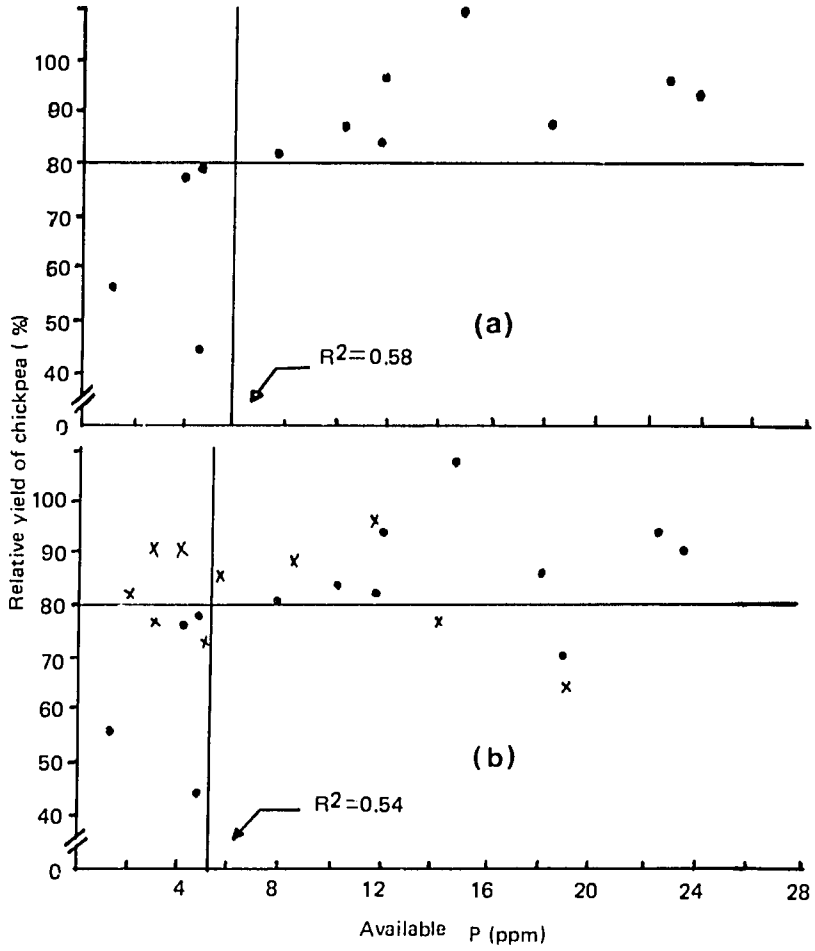

Fig. 6. Scatter diagrams of the relative yield of chickpea seeds in relation to available P in soils: (a) 1986-87 season; (b) 1985-86 and 1986-87 seasons.

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Fate of Nitrogen-tagged Urea Applied to Wheat in the Arid Mediterranean Region

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Abstract. This study was conducted to determine the agronomic efficiency of urea fertilizer in supplying the N requirements of dryland wheat and to make up a mass balance for the nitrogen fertilizer under the Mediterranean environment. Field experiments were conducted with ^{15}N-labeled fertilizer in northwest Syria. In the first year (1984), at Tel Hadya, Syria, seasonal rainfall was 232 mm, and the nitrogen uptake, residual nitrogen, and nitrogen losses were 20%, 69%, and 11%, respectively. In the second season (1985) at Tel Hadya and Breda, Syria, rainfall was 373 mm and 268 mm, respectively, and the corresponding values for nitrogen uptake, residual nitrogen, and nitrogen losses were 49%, 33%, and 18% (Tel Hadya) and 29%, 53%, and 18% (Breda). These findings suggest that, despite the calcareous nature of the soils, the risk of nitrogen losses is small because of the high clay content and high cation exchange capacity (CEC) of the soils.

Introduction

Twenty-five countries from the Middle East and North Africa have a Mediterranean-type climate and are in the semi-arid region where limited water and low crop productivity have discouraged the widespread use of (and, hence, research on) nitrogen. However, current efforts to increase food production have prompted investigations into the various components of the ecosystems and their interactions (Russell 1977). In this region, 40% of all the nitrogen fertilizer applied is urea (IFDC, personal communication), and the share is likely to increase since most of the planned production capacity is for urea (Harris and Harre 1979).

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Urea has several advantages as a fertilizer. Matocha (1976) referred to the decrease in cost of production of urea-based fertilizers as compared with other dry nitrogen fertilizers. Gasser (1964) pointed out that urea is also less costly to transport and spread per unit of nitrogen (45% of urea) than any other solid nitrogen fertilizer. Studies of the efficiency of urea as fertilizer under the dry conditions in the Mediterranean region have been limited to date, although one may assume that leaching below the root zone and denitrification are negligible because low rainfall is generally accompanied by shallow moisture penetration, good aeration, and insignificant waterlogging (West and Skujins 1978). Nevertheless, Feigenbaum *et al.* (1984) found that, at an annual precipitation of 256 mm, only 22-30% of the applied nitrogen was recovered by wheat plants. The low rates of uptake prompted us to investigate the utilization efficiency of ^{15}N-tagged urea applied to wheat under rainfed conditions in the arid region of the Mediterranean.

Materials and Methods

The experiments were conducted in 1984 and 1985 at experimental stations of ICARDA in Tel Hadya and Breda, Syria. The soils at Tel Hadya are transitional between vertisols and alfisols (**Table 1**). Buringh (1980) classified them as Chromoxererts-Rhodoxeralf according to USDA taxonomy (1975). The soils at Breda have been classified as Typic Calciorthids (**Table 1**) (USDA 1975; Buringh 1980).

1984 Experiment

The 1984 experiment was conducted at Tel Hadya. The design was a randomized complete block (RCB) with five replicates. Plot size was 12.5 x 6.3 m. The fertilizer was top-dressed at the rate of 40 kg N/ha. In the center of the plots, 2 x 2 m^2 areas were marked out where labeled urea (5 atom % excess nitrogen-15) was applied.

Spring wheat (Sahl) was planted 10 December 1983 with an Oyjord seed drill. The row spacing was 17.5 cm (12 rows were planted at a time). The seeding rate was 120 kg seed/ha; triple superphosphate (90 kg P_2O_5/ha) was mixed with the seed at planting. Urea fertilizer was applied at the rate of 20 kg N/ha, mixed with the seed.

On 2 February 1984, a second application of urea was applied as a top dressing. In the microplots, the labeled fertilizers were used. The plants were harvested 12 May 1984. The central 1 m^2 of each microplot was harvested (whole plant) by hand; then a representative subsample of about 20 plants was taken. Roots were collected from the microplot to 20 cm depth to be analyzed separately.

Soil samples were taken from two locations in the central 1 m^2 of each

Table 1. Chemical and physical properties of the two experimental soils at Tel Hadya and Breda, Syria, 1983.

Depth (cm)	Mechanical analysis (% w/w) 2 mm-50 m	0.5-2 m	< 2 m	Lime equivalent (% w/w)	pH 1:1	Organic carbon (% w/w)	Total-N (ppm)	Na HCO_3-P (ppm)	Mineral-N (ppm) NH_4-N	NO_3-N
				Tel Hadya						
0-20	7	37	55	25	8.1	0.4	530	6.8	11	22
20-40	7	37	55	27	8.1	0.3	441	2.9	7	12
40-60	6	36	57	27	8.1	0.3	382	1.1	5	2
				Breda						
0-20	25	42	29	34	8.3	0.6	647	3.5	3	8
20-40	19	39	38	37	8.4	0.4	386	2.2	3	3
40-60	13	40	44	49	8.5	0.3	281	1.7	3	4

microplot, down to a 60 cm depth (0-20, 20-40, and 40-60 cm intervals). The surface layer was sampled with a 17.5 x 17.5 cm metal frame down to a 20 cm depth. Soil samples deeper than 20 cm were taken with an auger (Edelman type).

1985 Experiment

The second experiment was conducted at two sites, Tel Hadya and Breda. The experimental design was RCB for both locations with five replicates. Plot size was 12.5 x 2.5 m. Microplots -- each 2 m x 1.8 m -- were marked in treatments with urea top-dressed at a rate of 40 kg N/ha. Labeled urea (5 atom % excess nitrogen-15) was applied in the microplot at the rate of 40 kg N/ha as a top dressing.

Spring wheat (Sham 2) was planted with a seed drill on 10 November 1984 at Breda and on 15 November 1984 at Tel Hadya. The seed and fertilizer rates and row spacing were the same as in the 1984 trial at Tel Hadya.

Urea fertilizer was applied as a top dressing on 6 February 1985 at Breda and 5 February 1985 at Tel Hadya. In the microplots ^{15}N-labeled urea was applied.

Plants were harvested on 26 and 31 May 1985 at Breda and Tel Hadya, respectively. The central 1 m^2 of each microplot was harvested (whole plant) by hand, and 20 plants were taken as representative subsamples. The plants were separated into heads, straw, and roots. Roots were dried and added to the soil for analysis.

Soil samples were taken from the central 1 m^2 as for the 1984 trial, down to a 60 cm depth (0-20, 20-40, and 40-60 cm).

Analytic Methods

Total soil nitrogen was determined by the Kjeldahl digestion method (Buresh *et al.* 1982) with one modification: 40 ml concentrated H_2SO_4 was added instead of 30 ml. Without the extra acid added the digests dried quickly because the soils of Tel Hadya and Breda contain 25% and 34% $CaCO_3$, respectively. Similarly, total plant nitrogen was determined by the Kjeldahl digestion method described by Buresh *et al.* (1982).

Isotope-ratio analysis was performed on a mass spectrometer (V.G. Micromass Model 622) by the IFDC technique.

Results and Discussion

Nitrogen Uptake and Residual Nitrogen

Seasonal rainfall was the most important factor influencing nitrogen uptake and use by the plant (**Fig. 1**). The total nitrogen uptake by wheat was 144% higher in the 1985 season (373 mm rainfall) than in 1984 (232 mm) in Tel Hadya and was 70% higher in Tel Hadya in 1985 than in Breda (268 mm).

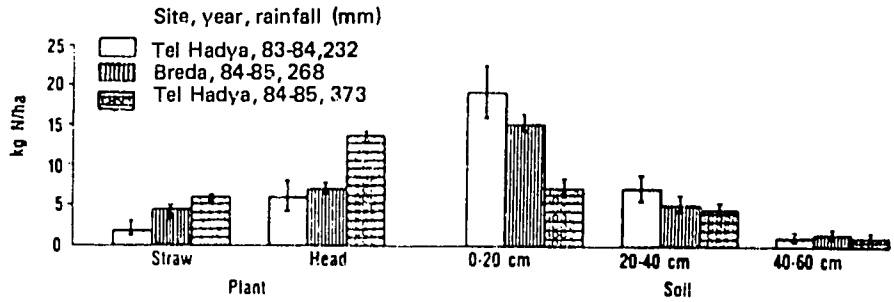

Fig. 1. Plant uptake and soil content of nitrogen at harvest in Tel Hadya and Breda.

Similar results were reported by Feigenbaum *et al.* (1984) who also conducted an experiment with wheat and ^{15}N-labeled fertilizer in a semi-arid Mediterranean-type climate. They reported that plant growth was limited by moisture deficiency in the dry season (200 mm). Also, Oza and Subbiah (1980) showed that only 20-30% of labeled urea was utilized by wheat under semi-arid conditions, and Stumpe and Abdelmonem (1986) reported that plant uptake of ^{15}N-labeled urea was limited when crops were under moisture stress.

The results indicate that, when wheat growth is limited by available soil water, a large fraction of the applied fertilizer nitrogen remains in the soil unutilized by the plant. When 40 kg N/ha was applied as urea to the soil at Tel Hadya for 2 years having different seasonal rainfall, the nitrogen remaining in the soil at harvest time was 27.4 and 13.0 kg N/ha for the dry and wet season, respectively. Similarly, the nitrogen remaining in the soil at Breda was much higher (21.1 kg N/ha) than that at Tel Hadya in the wet season. These findings agree with those of Buresh *et al.* (1986) who found that 40-65% of the fertilizer nitrogen remained in the soil at harvest under simulated semi-arid conditions. When adjusted for fertilizer nitrogen in the soil, total recoverable nitrogen did not differ significantly among water regimens.

In 1985 at Tel Hadya and Breda, respectively, 1.5 and 9.9 kg N/ha were found as total mineral-N (**Table 2**), so more mineral-N was used up by the crop under wet conditions than under dry conditions. Such residual effects must be considered by authorities making fertilizer recommendations for crop production under rainfed conditions in arid and semi-arid areas.

Nitrogen Balance for Urea Fertilizer

The loss of nitrogen was low (11-18%) -- probably because the soils contain large amounts of clay and have high cation exchange capacities (**Table 1**). Such soils retain exchangeable ammonium on the clay particles and retard its conversion to NH_3 and, hence, slow its loss through volatilization. Jain *et al.* (1981) reported that, in clay and sandy loams, the

Table 2. The NH_4-N, NO_3-N, and total mineral-N recovery as kg N/ha at harvest, for urea fertilizer applied as 40 kg N/ha, Tel Hadya and Breda, Syria, 1984-85.

	NH_4-N recovery (kg N/ha)			NO_3-N recovery (kg N/ha)			Total mineral-N recovered
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	(kg N/ha)
Tel Hadya	0.5	0.2	0.1	0.5	0.1	0.1	1.5
Breda	4.4	0.6	0.1	3.8	0.7	0.2	9.9
LSD							
0.05	1.8	0.4	0.2	1.8	0.2	0.2	3.8
0.01	2.9	0.6	0.3	3.0	0.3	0.3	6.2

nitrogen losses were 2% and 12%, respectively, whereas in our studies at Tel Hadya and Breda, the losses of nitrogen in 1985 were the same (18%) at the two sites, despite a large difference in rainfall. Thus, water regimens did not greatly affect the total recoveries but did affect the distribution of labeled nitrogen between soil and crop. Craswell and Strong (1976) showed the same relationship in their studies using nitrogen-15 with wheat.

Nitrogen Recovery: Apparent and Isotope-Labeled

Apparent recovery represents the fraction of applied nitrogen fertilizer apparently recovered in the crop. The apparent recovery is calculated by subtracting total nitrogen taken up by plants growing in nonfertilized plots from the total nitrogen taken up by plants growing in fertilized plots:

$$\text{Apparent recovery } \% = [(TN)_F - (TN)_C] / (N)_H \times 100$$

where $(TN)_F$ = total nitrogen in plants from nitrogen fertilized plots; $(TN)_C$ = total nitrogen in plants from control plots; $(N)_H$ = rate of applied nitrogen.

The apparent recovery in our studies was significantly higher than the nitrogen-15 recovery in the 1984 season and higher but not significantly for the 1985 season (**Table 3**). This supports the hypothesis that the mineralization-immobilization turnover was at least partly responsible for the observed difference between the two recovery fractions. Jansson and Persson (1982) explained that, provided the soil contains a newly established inorganic pool of tagged N, turnover will cause this pool to lose tagged nitrogen by immobilization and to gain nontagged soil nitrogen by mineralization.

This means that tagged nitrogen is immobilized at the same time that the nontagged nitrogen is mineralized. In a review of quantitative estimates of nitrogen-cycling processes, Hauck (1971) reported that percent uptake of applied nitrogen was normally overestimated by the difference method when compared with the nitrogen-15 method.

Table 3. Recovery of fertilizer nitrogen in wheat as estimated by recovery of nitrogen-15 and by the difference method of calculation, Tel Hadya and Breda, Syria, 1984-85.

Year	Site	^{15}N recovery	Apparent recovery	LSD at 5%
1984	Tel Hadya	19.3	26.5	4.0
1985	Breda	28.9	35.6	8.4
	Tel Hadya	49.3	55.4	6.2

Conclusions

The study shows that when wheat growth was limited by available soil water, a large fraction of applied fertilizer nitrogen remained in the soil unutilized by the plant. When 40 kg N/ha was applied as urea, the nitrogen remaining in the soil at harvest was 27 kg N/ha and 13 kg N/ha for the dry and wet season at Tel Hadya and 21 kg N/ha at Breda where rainfall was limited in 1985. Of the remaining nitrogen contents, 47% and 12% were found as mineral nitrogen in Breda and Tel Hadya, respectively. The nitrogen balance for the urea fertilizer showed that the losses of nitrogen were low at both locations (11-18%), the retention probably being a reflection of the high-cation exchange capacity of the soils at the experimental sites. High CEC favors retention of exchangeable NH_4 on the clay particles and prevents its conversion to NH_3 and subsequent loss through volatilization. The findings suggest little risk in using urea as fertilizer for these soils under the Mediterranean climate.

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Appendix. Program of Work for the Regional Network of Soil Test Calibration Study Sites in Limited Rainfall Areas

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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 the yield of crops. In this paper 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 find out what is the optimal rate, one can conduct soil tests and calibrate them with crop responses, but the studies require a team of scientists with laboratory and field experience and an adequate budget so 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 experimental sites to the farmers' fields. To increase the probability of success, they must seek maximal variation among sites and minimal variation within sites; they must select (i) on-farm sites with soil families 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 the farmers; and (v) accessible locations for trials. They should cooperate with soil taxonomists and request classification of soils to the family level. The new US 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 US 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 a crop growing on it: the height, density, and appearance. By use of simple colorimetric tests for nitrate and phosphorus, researchers can determine the 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

Two types of experiments are recommended for N and P: factorial experiments for calibration of N and P soil tests and placement experiments for comparisons of 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.

Nitrogen and Phosphorus Factorial Experiment on Wheat or Barley

Aim	To determine the field responses of wheat and barley crops to N and P fertilizer, in relation to measured environmental conditions (rainfall, soil type, depth, and fertility) as a basis for calibration of soil tests for P and N.
Rainfall	The experiment will be carried out at various sites in the zone receiving 200-500 mm rainfall annually.
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.
Other soil type (Optional)	The sites should also include (i) a soil with medium depth and; (ii) a soil with shallow depth.
Rotations	Experiments should be sited on land under at least two different rotations -- for instance, wheat following cereals; legumes; fallow; or summer crops.
Soil test for P	The level of P, tested by the Olsen method, should be less than 7 ppm at a majority of sites. Few sites should have high P (more than 10 ppm).
Rates of fertilizer	Suggested rates in areas where rainfall is more than 300 mm are 0, 40, 80, and 120 kg N/ha and in areas where rainfall is less than 300 mm, 0, 20, 40, 60 kg N/ha; in all areas, 0, 20, 40, and 80 kg P_2O_5/ha.

Forms of fertilizer	Ammonium nitrate and concentrated superphosphate are recommended.
Placement of fertilizer	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.
Time of fertilizer application	All fertilizers should be applied before or at planting time.
Variety	The commonest variety of wheat or barley in each area should be used.
Experimental method	A complete factorial combination of N and P rates in a randomized complete block design, with three replications, is recommended.

Phosphorus Rate and Method of Application for Wheat or Barley

Aim	To compare the response of wheat (or barley) to banded and broadcast phosphate fertilizer.
Location	The experiment should be done in countries where, at present, farmers do not band P fertilizers.
Rainfall	The experiments will be carried out in a zone receiving 200-500 mm of rainfall annually.
Soil test of P	The sites should have low P: preferably less than 5 ppm when tested by the Olsen method.
Soil type	The sites should include important soil types in the area.
Variety	The most common wheat variety in each area will be used.
Fertilizer rates	0, 20, 40, 80, and 120 kg P2O5/ha, with a blanket rate of 60 kg N/ha, is suggested.
Form of fertilizer	Concentrated superphosphate and ammonium nitrate are recommended.
Placement of fertilizer	Banding will be compared with broadcasting with incorporation as methods of placement.
Time of fertilizer application	Fertilizers should be applied before or at planting time, with the times of application being as close as possible for the two methods of placement.
Experimental method	A complete factorial combination of P rates and two placement methods in a randomized complete block design, with four replications, is recommended.

Phosphorus Experiment 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 nitrogen rate: 20 kg N/ha 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. Phosphates would be broadcast and incorporated before planting or drilled with the seeds. The experimental design would be a complete randomized block.

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 minimal 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 is drilled with the seed.

Measures to control insects, diseases, and weeds should be instituted so that results do not become confounded.

Soil Sampling and Analysis

If possible, the soil moisture in the profile (0-120 cm) should be measured at least two times during the season: once before planting and once after harvest. For testing for available soil P and N, soil samples must be taken before fertilizer application and planting and, 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 sampled from each block (replication). For soils shallower than 60 cm, samples of the entire soil profile will be obtained. Samples should be divided into 20-cm increments by depth. If subsoil samples are moist, they should be placed in tight plastic bags, placed 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), exchange capacity (EC), 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-CaO 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_4AC, lime by the acid-neutralization method and texture by the hydrometric method. These methods (except acid neutralization) are given in *Methods of Soil Analysis* (Agronomy monograph 9 published by the American Society of Agronomy, Madison, Wisconsin).

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:

* 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.
* At anthesis, the same sampling as at tillering.
* 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.

Other Observations

Measurements of rainfall, on a daily or weekly basis, are essential.

Dates of emergence, tillering, heading, and physiologic maturity should be recorded.

Interpretation

Analysis of variance and regression analysis will be used for the data. For P, initially, the Cate-Nelson graphical method, Mitscherlich, and quadratic methods will be used for estimates of critical levels. For N, models will be developed to relate fertilizer requirement to yield, inorganic nitrogen in the profile, nitrogen mineralization potential or OM, and previous crop. Soil N and P availability will also be determined by the 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 x-axis.

Soil Sampling Studies

Soils from farms should be sampled on a grid system to determine sampling distribution of organic matter, nitrate, phosphorus, etc. Based on the results of this kind of study, strategies for sampling plan and intensity should be devised. We suggest that first the soil test data from N and P trial sites be analyzed. Then based on these data sampling studies be devised.

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. Each 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 obtained.

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