SYRIAN ARAB REPUBLIC
MINISTRY OF AGRICULTURE AND
AGRARIAN REFORM
SOILS DIRECTORATE

INTERNATIONAL CENTER FOR
AGRICULTURAL RESEARCH IN THE
DRY AREAS
ICARDA

PROCEEDINGS
OF
THE SOILS DIRECTORATE/ICARDA WORKSHOP ON FERTILIZER USE IN THE DRY AREAS

Held at

ICARDA, Aleppo, March 26th - 29th 1984

INTRODUCTION

This publication presents the proceedings of a joint workshop held by the Soils Bureau of the Syrian Ministry of Agriculture and Agrarian Reform and the International Center for Agricultural Research in Dry Areas, Aleppo, Syria. The workshop was designed to present and discuss in detail recent research studies which have investigated the potential for fertilizer use in dryland barley growing areas in regions experiencing a Mediterranean Climate, with particular emphasis on phosphate fertilizer.

These proceedings represent the first stage of a joint Soils Bureau / ICARDA Cooperative Research Program aimed at investigating ways of increasing the productivity and stability of the Barley/Livestock Farming Systems in Syria.

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ACKNOWLEDGEMENTS

Grateful thanks are extended to the Workshop Organizing Committee of Dr G. Soumy and Mr Khazza'a El-Haj (Soils Bureau) and Dr S. Ahmed and Dr P. Cooper (ICARDA) and to all participants who made such valuable contributions through the presentation of papers and discussion.

Thanks are also due to Dr S. Ahmed and Mr Abdul Bari Salkini for their vital role in translation of papers and to Miss Leila Brahimsha who typed them so accurately and quickly.

Special thanks and gratitude are extended to Dr Juma'a Abdul Karim, Director of the Soils Bureau, and Dr Mohamed A. Nour, Director General of ICARDA whose guidance and support contributed so much towards the success of this workshop.

Soils Bureau/ICARDA Cooperation Programme

MINUTES OF
SOILS BUREAU/ICARDA WORKSHOP ON FERTILIZER USE IN DRYLAND BARLEY-GROWING AREAS

(26 - 29 March, 1984)

ICARDA, Aleppo

April, 1984

Soils Bureau/ICARDA Cooperation Programme

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I. Introducion

The workshop was organized by: (1) the Soils Bureau, Minsitry of Agriculture and Agrarian Reform, Syria and (2) the International Center for Agricultural Research in the Dry Areas (ICARDA), and hosted by the latter. It aimed to review the current research related to fertilizer use in dry land barley-growing areas, and to initiate an effective co-operative research programme between the Soils Bureau, ICARDA and any other potential institutes that might wish to cooperate.

The invitation was extended to several parties. These are: the Ministry of Planning, the University of Aleppo, the Agricultural Research Corporation (ARC), the Extension Bureau, the Arab Center for Studies of Arid Zones and Dry Lands (ACSAD), the Agricultural Research Institute of Cyprus, and Reading University in the United Kingdom. The list of participants appears in Annex 1.

The meeting was opened by Dr Peter Goldsworthy, Deputy Director General, Research, who, on behalf of Dr Mohamed A. Nour (Director General of ICARDA), extended a warm welcome to the participants, expressed pleasure that ICARDA through this meeting would have a new opportunity to enlarge and extend its cooperation with the national research programmes in Syria, and wished great success for the meeting in achieving its objectives.

Dr Juma'a Abdul Karim, Director Soils Bureau, responding to Dr Goldsworthy's address thanked ICARDA for hosting the meeting, expressed his anticipation for a successful outcome and made a brief introduction to the workshop. Then, Dr Peter Cooper, Leader, Farming Systems Research Program, presented the workshop details.

II. The Agenda

The meeting adopted the following Agenda (see Annex 2 for more details).

(a) Three work sessions in addition to the final session and a field trip to Breda area (35 km southeast Aleppo) were conducted in three effective work days (March 27, 28 and 29, 1984). The work days started at 08:30 hr and ended at about 16:00 hr with 75 minutes break for coffee and lunch.

(b) Eleven papers on research activities closely related to the topic of main interest, i.e. fertilizer use in dryland barley growing areas were presented and discussed. These are:-

Paper 1: Soil Conditions in Barley Growing Areas of North West Syria.
By Dr. Karl Harmsen, ICARDA.

Paper 2: Chemical Fixation of Phosphorus in Calcarious Soils.
By Dr. Karl Harmsen, ICARDA.

Paper 3: The Influence of Rainfall Characteristics on Crop Management in Dry Areas of Nortern Syria.
By Dr. Dyno Keatinge, ICARDA.

Paper 4: Rotations and Yield Expectations in Barley Production in Syria.
By Dr. Kutlu Somel, ICARDA.

Paper 5: The Fertilizer (NP) and Water Requirements of Barley in Cyprus.
By Dr. P.I. Orphanos, Cyprus.

Paper 6: (The written text of the paper presented by Dr. Abdallah Matar, ACSAD was not available and will be sent later), however, Dr. Matar made an interesting presentation on correlation and regression models of barley yields with respect to several factors including soil nutrients.

Paper 7: The Relationship Between Soil Content of Phosphorus and the Response of Wheat to Phosphorus in Rainfed Agriculture.
By Mr. Khazza'a El-Haj, Soils Bureau.

Paper 8: Barley Response to Fertilizer Applications in North West Syria.
By Dr. Karl Harmsen, ICARDA.

Paper 9: Effect of Phosphorus Fertilizer on Root Growth of Barley and its Effect on Moisture Extraction.
By Dr. P.J. Gregory, Reading University, England.

Paper 10: The Effect of Fertilizer on Water Use and Water Use Efficiency of Barley in Dryland Regions.
By Dr. Peter Cooper, ICARDA.

Paper 11: Combined Analysis of Multiple Season - Multiple Location Seed Rate - Nitrogen - Phosphorus Trials.
By Dr. Kutlu Somel, ICARDA.

(c) All papers (except that of Dr. Orphanos) were written in both English and Arabic. Speakers were allowed 45 minutes each for presentation and discussions.

(d) The sessions were chaired as follows:-

Session 1: Dr. Juma'a Abdul Karim, Soils Bureau.

Session 2: Dr. Mohamed A. Abdul Salam, ACSAD.

Session 3: Dr. Mohamed Rashid Kanbar. ARC.

Final Session: It was planned that Dr. Geoffry Hawtin (Deputy Director General Outreach, ICARDA) to chair this session, and due to his absence (outside Syria) the session was chaired by Dr. Samir Ahmed (ICARDA).

(e) The field trip to Breda area (35 km Southeast Aleppo) was carried out 09:00 - 12:00 Wednesday, 28 March. The main objective of the trip was to visit ICARDA's trials conducted on a typical dryland barley - growing area, and particularly to observe the effect of fertilizer use on barley.

III. The Final Session: Conclusions and Recommendations

The closing session started with a general discussion on the papers presented and the field trip, and ended with the formulation of basic outlines for the proposed cooperative research project.

The following points were clear and approved by the participating parties of the workshop:

1. All papers presented in the meeting (and other literature work of relevance) have shown that in many dryland barley - growing areas, deficiencies of soil nitrogen and phosphorus occur which can greatly reduce grain and straw yields. As a result of these deficiencies, pronounced and economic responses to fertilizer, especially phosphate are often observed, even at quite low levels of application. However, due to marked year to year variation in rainfall totals and seasonal variations, dryland farmers are very cautious about adopting a management practice which they feel might further add to the instability of their crop production systems.

2. *It will be very fruitful to initiate and implement a cooperative research* programme (between Soils Bureau, ARC, ACSAD, ICARDA and any other potential institutes) to further examine the question of fertilizer application on dryland barley - growing areas. This research programme is assumed to cover locations agro-climatically representative to all dryland barley - growing areas in Syria. It is also envisaged that the cooperative programme must have a moderate start which might grow and develop by time. Outlines of the proposed programme are shown below under Clause IV.

3. ACSAD participation in the proposed research programme is bent to its Director General's approval which will be sought for officially by the Ministry of Agriculture and Agrarian Reform.

4. Within a 1-2 month period of time another meeting will be held between the parties actually participating in the cooperative research programme to finalize detailed aspects of the programme.

5. Proceedings of the workshop and all papers presented will later be published by ICARDA in English and Arabic.

6. Scientists of the Soils Bureau and ARC expressed their interest in rotation trials and supplementary irrigation. They recommended that these research areas can be the subject for future cooperation with ICARDA and ACSAD.

   Dr. Cooper (ICARDA) indicated that ICARDA is very interested in these two research areas; that our rotations research programme has been established several years ago, and an international workshop will be held at ICARDA's headquarters next year (1985), that all the participants in the Barley Workshop will be invited to participate in the Rotations Workshop. He also briefed ICARDA's recent endeavours to initiate a research programme on supplementary irrigation; that Dr. Arar, an expert in water resources management was invited by ICARDA to study and prepare documents relevant to water resources and supplementary irrigation in ICARDA's mandate countries. This document is designed to help the initiation and establishment of a research programme on supplementary irrigation. However, the effective involvement of ICARDA in the supplementary irrigation research is not expected to start before 1985.

7. The participants agreed that, in general, the dryland regions have, so far, received a very little attention and consideration with respect to national planning and resources allocation, and with regard to agricultural research. That more attention and consideration should be directed to these areas.

8. Finally, Dr. Samir Ahmed (Chairman of the final session), Dr. Abdul Salam (ACSAD) and Dr. Orphanos (Cyprus) expressed their warm feelings and thanks to the participants for their effective and valuable contributions to the success of the workshop, and to ICARDA for its generous hospitality.

9. Closing the final session Dr. Juma'a Abdul Karim (Director Soils Bureau) summarized the workshop discussions and conclusions, and on behalf of the Ministry of Agriculture and Agrarian Reform, Syria, extended deep thanks and gratitudes to ICARDA, ACSAD and all national, regional and international institutes that actively contribute to the agricultural research and development on Syria.

IV. Outlines of the Proposed Cooperative Research Programme

The following trial outline was proposed as a vehicle by which barley responses to phosphate and nitrogen fertilizer could be related to soil conditions and rainfall. A 5x5 factorial was suggested with N rates 0, 15, 30, 45, 60 kg/ha and P_2O_5 rates of 0, 20, 40, 60, 80 kg/ha. It was proposed that each cooperating institute would be responsible for a given barley growing area in Syria and would carry out such a trial at, at least, 10 locations in each area. Prior to planting, soil amples would be taken from each site for the depths 0-20 and 20-40 cm and would be analysed for available P (Olsen-P) and N (NO_3^-). A rain-gauge would be installed near each location, and weekly rainfall totals would be recorded. Crop yields and total dry matter production would be recorded at harvest.

Yields from all trials could then be related in the following manner:-

$$Y = (a)R + b(S_N) + c(S_P) + (d)N + e(P) + \text{interactions terms}$$

where R = rainfall, S_N, S_P, P and N are soil applied nitrogen and phosphate levels.

By inclusion of the rainfall term, and its interaction then with other measured parameters, yields and the economics of fertilizer use could then be related to the probabilities of long term rainfall distribution by utilizing existing rainfall data. As data accumulates over a 3-4 year period, it will become possible to expand the rainfall term to consider rainfall totals for specific periods.

It was agreed that in order for this approach to succeed, there was a clear need for standardization of experimental techniques and laboratory analyses. Dr. Jouma'a Abdul Karim of the Soils Bureau undertook to convene a meeting of interested cooperating agencies in the near future to settle these details.

ANNEX 1 LIST OF PARTICIPANTS

A. From Syria and Outside

1.	Dr. Juma'a Abdul Karim	Director of Soils Bureau
2.	Dr. George Soumy	Deputy Director of Soils Bureau
3.	Mr. Khaza'a El-Haj	Head of Soil Fertility and Plant Nutrition
4.	Mr. Fadel Na'anaa	Soils Bureau, Aleppo
5.	Dr. Mohamed Rashid Kanbar	Director of Research, ARC, Douma
6.	Dr. Rafik Al-Saleh	Agronomy Dept., ARC, Douma
7.	Mr. Fouad Kardous	Directorate of Agricultural Affairs, MAAR
8.	Miss Da'ad Rihawi	Ministry of Planning
9.	Miss Ina'am Rihawi	Ministry of Planning
10.	Dr. Mohamed Atef Abdul Salam	ACSAD
11.	Dr. Shaher Mohamed	ACSAD
12.	Dr. Abdallah Matar	ACSAD
13.	Dr. Khaldoun Dermosh	Head of Soils Dept., Faculty of Agriculture, University of Aleppo
14.	Dr. Nazir El-Sankary	Head of Crop Science Dept., Faculty of Agriculture, University of Aleppo
15.	Dr. P.I. Orphanos	Agricultural Research Institute, Cyprus
16.	Dr. Peter J. Gregory	Reading University, U.K.

B. From ICARDA

1.	Dr. Peter Goldsworthy	Deputy Director General, Research
2.	Dr. Geoff Hawtin	Deputy Director General, International Cooperation
3.	Dr. Adnan Shuman	Assistant Director General
4.	Dr. Samir El-Sebae Ahmed	National Research Coordinator
5.	Mr. Ahmad Musa El-Ali	Head, Public Relation
6.	Dr. Mark Winslow	Cereals Improvement Program
7.	Mr. Issam Naji	Cereals Improvement Program

8.	Dr. Ahmed Osman	Pasture and Forage Improvement Program
9.	Dr. Peter Cooper	Leader, Farming Systems Program, Soil Physicist
10.	Dr. Kutlu Somel	FSP, Agricultural Economist
11.	Dr. Karl Harmsen	FSP, Soil Chemist
12.	Dr. Dyno Keatinge	FSP, Crop Physiologist
13.	Mr. Abdul Bari Salkini	FSP, Agricultural Economist
14.	Mr. Hisham Salahieh	FSP, Research Assistant
15.	Dr. Richard Hawkins	FSP, Visiting Scientist
16.	Ms. Eglal Rashed	FSP, Ph.D. Student
17.	Mr. Ibrahim Sa'eed	FSP, Research Assistant

ANNEX 2

AGENDA FOR SOILS BUREAU/ICARDA WORKSHOP ON FERTILIZER USE IN DRYLAND BARLEY-GROWING AREAS

March 27, Tuesday

08:00	Pick-up at Tourism Hotel	
08:15	Meet in the Conference Room, Office 1	
	SESSION I (Chairman, Dr. Juma'a Abdul Karim)	
08:30	Welcome Address	- Dr. Peter Goldsworthy, ICARDA, Director of Research
08:45	Introduction to Workshop	- Dr. Juma'a Abdul Karim, Director of Soils Bureau
09:00	Workshop Details	- Dr. Peter Cooper
09:15-10:00	Paper 1: Soil Conditions in Barley Growing Areas of N.W. Syria, ICARDA	
10:00-10:45	Paper 2: Chemical Fixation of Phosphate in Calcarious Soils, ICARDA	
10:45-11:00	COFFEE BREAK	
11:00-11:45	Paper 3: The Influence of Rainfall Characteristics on Crop Management in Dry Areas of N. Syria, ICARDA	
11:45-12:30	Paper 4: Rotations and Yield Expectations in Barley Production in Syria, ICARDA	
12:30-13:15	LUNCH BREAK	
	SESSION II (Chairman, Dr. M.A. Abdul Salam)	
13:15-14:00	Paper 5: The Fertilizer (NP) and Water Requirements of Barley in Cyprus, by Dr. Orphanos, Agricultural Research Institute, Cyprus.	
14:00-14:45	Paper 6: Paper by Dr. Matar, ACSAD	
14:45-15:00	TEA BREAK	
15:00-15:45	Paper 7: The Relationship Between Soil Content of Phosphorus and the Response of Wheat to Phosphate in Rainfed Agriculture, by Mr. El-Haj, Soils Bureau	
15:45-16:30	Paper 8: Barley Responses to Fertilizer in N. Syria, ICARDA.	
	PARTICIPANTS RETURN TO HOTEL	

March 28, Wednesday

08:15	Pick-up at Tourism Hotel
08:30	Meet in the Conference Room, Office I. COFFEE
09:00	Depart for Field Trip to Breda Area (35 km SE of Aleppo)
12:00	Return to Office I, Aleppo
13:15-14:00	LUNCH BREAK
	SESSION III (Chairman: Dr. M.R. Kanbar)
14:00-14:45	Paper 9: Effect of Fertilizer on Barley Root Growth and Moisture Extraction, Dr. Gregory, Reading University, U.K.
14:45-15:30	Paper 10:Effect of Fertilizer on Barley Water Use and Water Use Efficiency, ICARDA
15:30-16:15	Paper 11:Analyses of Multi-Season/Location Seed Rate, Nitrogen and Phosphorus Trials on Barley and its Economic Implications, ICARDA

March 29, Thursday

08:15	Pick-up at Tourism Hotel
08:30	Meet in the Conference Room, Office I
	FINAL SESSION (Chairman: Dr. Samir El-Sebae Ahmed, ICARDA)
08:45-10:30	Discussion on Papers and Field Trip
10:30-11:00	COFFEE BREAK
11:00-12:30	Soils Bureau/ICARDA Future Cooperation
12:30-13:30	LUNCH
13:30-14:15	Workshop Summary and Conclusion - Dr. Juma'a Abdul Karim
	PARTICIPANTS DEPART

DRYLAND BARLEY PRODUCTION IN NORTHWEST SYRIA:

I. Soil Conditions

by

Karl Harmsen
Soil Chemist

Farming Systems Program
ICARDA

March 1984

Introduction

Most of the barley in Syria is grown under rainfed conditions, in areas with an average annual rainfall of less than about 300 mm/y. Until 1979, most of ICARDA's research on barley in Syria was conducted at ICARDA's main experiment station at Tel Hadya, with an average rainfall of about 335 mm/y, or in farmer's fields in the barley-growing areas's.

In 1979, a number of off-station experimental sites were established, two of which were located in areas with a lower annual rainfall than at Tel Hadya: Breda (260 mm/y) and Khanasser (220 mm/y); see Figure 1. One of the objectives of establishing these sites was to study the productivity of barley under controlled experimental conditions at low-rainfall locations. In 1981, two more low-rainfall sites were established, as part of a research program on biological nitrogen fixation: Nasrieh (300 mm/y) and Ghrerife (250 mm/y); see Figure 1. The site at Ghrerife is presently being used for barley variety and barley agronomy trials.

Soils in the lower-rainfall zone (300-150 mm/y) have been classified as Cinnamonic Soils by Van Liere (1965), because of their reddish and yellowish brown colors. Soils with a gypsic horizon at shallow depth have been classifield as Gypsiferous Soils by Van Liere. In the FAO/UNESCO (1974) system of soil classification, many of these soils would be classified as calcic or gypsic Xerosols.

Soils at the experimental sites have been sampled and analyzed for a number of soil parameters, in ICARDA's laboratory for soil and plant analysis at Tel Hadya. The objective of this presentation is to discuss some of the characteristics of soils at Tel Hadya and the off-station sites, as well as at a number of locations along the Breda-Khanasser-Sfireh road (Figure 1), where barley trials are being conducted in farmer's fields during the 1983/84 season.

Materials and Methods

Soils were sampled in the field with a hand-auger, put in labeled plastic bages, and transported to Tel Hadya in cool-boxes. At Tel Hadya, soil samples were stored in freezers until room was available to dry them. Air-dried samples were ground to pass a 2-mm sieve and stored in labeled plastic bottles. Subsampling for analysis was done with a riffle-type sample splitter. All analyses, unless otherwise indicated, were carried out in air-dried soil samples.

Soil texture in non-gypsic soils was determined by the hydrometer method (clay and silt) and by wet sieving (sand). Clay contents in non-gypsic soils were calculated from 2 h hydrometer readings, according to Hesse (1974).

Calcium carbonate equivalent was determined by a titrimetric method, using hydrochloric acid to dissolve the carbonates, and sodium hydroxide to titrate the remaining acid with bromothymol blue indicator. Active calcium carbonate in non-gypsic soils was determined by extraction with acid ammonium oxalate and titration with potassium permanganate.

Oxidizable organic carbon was determined by wet oxidation with potassium dichromate in acid medium, and titration with ferrous ammonium sulphate solution. Total organic carbon and organic matter contents were calculated from the oxidizable organic carbon contents through multiplication with 1.33 and 2.3, respectively. Kjeldahl-nitrogen was determined by digesting the soil in sulphuricacid with potassium sulfate—copper sulfate—selenium catalyst (100:10:1 weight ratio). Ammonium in the digest was determined by steam distillation, using sodium hydroxide to raise the pH of the digest, and boric acid to collect the distillate.

For the measurement of electrical conductivity (EC) and acidity (pH), 1:1 (w/v) soil-water suspensions were prepared. The pH was measured in the suspension, and the EC in the filtrate, after filtration of the suspension.

Mineral nitrogen was determined by extracting the soils with potassium chloride for ammonium-nitrogen (NH_4-N) and water for nitrate-nitrogen (NO_3-N). Both forms of nitrogen were determined in each extract by a steam distillation procedure, using magnesium oxide for NH_4-N, followed by Devarda's alloy for NO_3-N (Bremner and Keeney, 1966). The distillate was collected in boric acid solutions, and titrated with dilute sulphuric acid.

Available phosphorus (P-Olsen) was determined by extracting the soils with a sodium bicarbonate solution ratio. The suspensions were filtrated using activated carbon to decolorize the filtrate. Phosphorus in solution was measured colorimetrically at a wavelength of 660 nm, using ammonium molybdate and stannous chloride in sulphuric acid (Olsen et al., 1954).

Results

1. Soil Texture

Clay contents in soils tended to decrease with lower rainfall (Figure 2). This may reflect higher carbonate contents of soils in drier areas, but also differences in weathering conditions, and parent materials. Clay contents at Tel Hadya (TH) and Nasrieh (Nas) were high and quite uniform with depth. Clay contents at Breda (Br), Ghrerife (Ghr) and Khanasser (Kh), tended to increase with depth in the upper part of the profile. Soils at Khanasser had a gypsic horizon below 60 cm depth (Gypsiferous soils) and soils at Breda, Ghrerife and Nasrieh contained some gypsum below 90 cm depth (dotted lines in Figure 2).

Soil texture ranged from silty clay and clay to loam and silt loam (Figure 3; Table 1). Most of the soils analyzed were relatively high in silt. In the lighter-textured soils this may make the soils liable to surface-sealing during high-intensity rainfall, and to wind erosion during the summer. The lighter-textured soils do not form cracks in spring, and may therefore be more efficient in conserving moisture during spring, than the deep-cracking heavier-textured soils.

2. Calcium carbonate

All soils analyzed were calcareous, with total carbonate contents ranging from about 25 to more than 50 per cent (Figure 4). Calcium carbonates, or mixed calcium-magnesium carbonates play a major role in the chemistry of soils in Northwest Syria. The solubility of calcium and magnesium, and the pH of the soil are directly controlled by carbonates. The solubility of calcium phosphates and other calcium minerals depends on the calcium concentration in soil solution. The generally high pH (7-8) resulting from the presence of carbonates decreases the availability of micronutrients such as iron and zinc, and increases the volatilization of ammonia from soils, which is probably one of the major loss mechanisms of nitrogen from calcareous soils.

The fraction of active calcium carbonate is thought to include easily-soluble and adsorbed forms of calcium carbonate. It can be seen from Figure 4 that the ratio of active to total calcium carbonate is quite constant : about 0.30 ± 0.05 for the soils analyzed.

3. Organic matter and Kjeldahl nitrogen

Organic matter contents in all soils were in the low range : between 0.3 and 1.3% in the surface horizon, and decreasing with depth (Figure 5). The wet oxidation of organic carbon with potassium dichromate in sulphuric acid medium, and titration of the residual potassium dichromate against ferrous ammonium sulfate (Walkley-Black method) recovers a variable fraction of the total soil organic carbon. To calculate total organic carbon, the results obtained with the Walkley-Black method are usually multiplied by a factor 1.33. This factor, however, may vary between soils, and with depth in soils.

The distribution of Kjeldahl nitrogen in the soils was very similar to that of oxidizable organic carbon. The C/N ratio, expressed as the ratio of oxidizable organic carbon to Kjeldahl nitrogen, varied between 5 and 7.5, with a mean value of 6.7 ± 0.5. The conventional C/N ratio, based on total organic carbon, varied between 7 and 10, with a mean value of 3.9 ± 0.7.

Hence, C/N ratio's were in the low range, and carbon rather than nitrogen would be expected to limit microbiological activity in the soils under moisture and temperature conditions suitable for microbial growth.

The low organic matter contents are an unfavourable characteristic of these soils. This is because organic matter generally increases the stability and water-holding capacity of soils, and increases the solubility of many essential plant nutrients through the formation of soluble organic complexes.

4. pH

Values of pH were all in the high range: between 7.9 and 8.5; see Figure 6 and Table 1. The pH is one of the most important characteristics of soils. The pH is a factor in the solubility of most minerals, in the stability of organic complexes, and H^+ is a potential determining ion in oxides and many other minerals with a variable surface charge.

The pH in calcareous soils is mainly determined by the presence of calcium carbonate, gypsum, and aqueous ions, such as sodium. The pH of an aqueous solution in equilibrium with calcium carbonate, at atmospheric CO_2 levels would be 8.34. If gypsum would be present alongside calcium carbonate, the pH would be about 7.8. Hence, the presence of gypsum in calcareous soils tends to decrease pH.

In all calcareous soils, the pH tends to decrease with higher CO_2 levels, such as those encountered in the rooting zone of growing crops. For example, the pH of an aqueous solution in equilibrium with calcium carbonate at a CO_2 level of 1% (v/v), would be about 7.3, that is, about one pH-unit lower than under atmospheric conditions (0.03% CO_2). Similarly, in the presence of gypsum, the pH would decrease from about 7.8 under atmospheric conditions, to about 7.0 at 1% CO_2. Hence, in the root zone of a growing crop, pH values are likely to be lower than those determined under laboratory conditions, in equilibrium with atmospheric CO_2.

Although the determination of pH is one of the most common soil tests, it is one of the least standardized tests among laboratories. Factors that influence the results of pH-measurements include the pretreatment of the samples (drying and storage conditions), the composition of the solution and the ratio of soil to solution used in the preparation of suspensions, the time of equilibration, temperatures during equilibration and pH-measurement, etc. Solutions used to prepare soil suspensions include 1.0 N KCl and 0.01 M $CaCl_2$ solutions, and water. Common ratio's of soil to water (w/v) are 1:1, 1:2.5, 1:5 and 1:10. In addition, pH is often measured in a saturated soil paste. Figure 7 (top) shows the effect of soil solution ratio on pH values determined in different soil-water suspensions for soils at Tel Hadya. It follows that there is a difference of about one pH-unit between the pH determined in a saturated soil paste (7.99 ± 0.07) and in a 1:10 suspension (8.99 ± 0.07). It further follows from Figure 7 (bottom) that a plot of the hydrogen ion activity against the soil-solution ratio yields a straight line. From this regression equation the pH of the soil solution can be estimated. For example, at a moisture content of 30% (w/w) the pH would be about 7.6.

The relation between pH and calcium carbonate is rather complex, as can be seen from Figure 7. The increase in pH with decreasing soil-solution ratio, results in a decrease in solubility of calcite, such that equilibrium with the solid phase is maintained. The behaviour of pH can be explained on the basis of simple adsorption-desorption considerations, but other factors, such as a fractional increase in aqueous sodium ions in the more dilute suspensions, probably play a role as well.

5. Electrical conductivity

The electrial conductivity of a solution is a measure for the amount of soluble salts in a soil. At the drier sites, EC increased with depth, probably becuase of the presence of gypsum at depth in these soils (Figure 8).

The EC-values of surface soil samples taken in farmer's fields were generally in the range of 0.2 to 0.6 mS/cm (Table 1). At three locations, the EC-values were higher: at Nawara (No.9) and Mezeileh (No.10) this was probably due to the presence of gypsum in the surface horizon, whereas at Qorbatieh (No.11) this was likely to be due to a soluble sodium salt, such as sodium chloride. The high salinity at these three locations may adversely affect crop production.

If only soluble salts would be present in the soil, the EC of a 1:1 extract would be about 5 times higher than the EC of 1:5 extract, disregarding the effect of ionic strength and of ion exchange on the electrical conductivity. Such a situation was encountered at Haklah, a saline site near the salt lake of Jabbul, southeast of Sfireh (see Figure 1). Here the relationship between the EC of the saturated soil paste, EC_{sat}, and of the 1:5 soil-water extract, EC_5, was given by:

$$EC_{sat} = 9.23\ (EC_5 - 0.16) \qquad n=20,\ r^2=0.99$$

The moisture percentage of the saturated soil paste was 50-54% (w/w). Therefore the soil contained highly soluble salts, probably sodium chlorides and some sulfates. The solubility of carbonates was probably slightly higher in the 1:5 extract than in the saturation extract.

For soils at Tel Hadya the relationship between EC_1 and EC_5 was found to be:

$$EC_1 = 1.91\ EC_5 \qquad n=36,\ r^2=0.53$$

Hence, at Tel Hadya salts with a limited solubility played an important part. This is further illustrated in Figure 9, where the water-soluble ions (1:5 w/v soil-water extract) are plotted as a function of depth. The data represent average values for 24 profiles at Tel Hadya; the analyses were performed at the soils laboratory of the Ministery of Agriculture at Aleppo. The chlorides and sulfates represent soluble salts, whereas carbonates are relatively insoluble.

Cation exchange probably plays a role in determing the composition of the 1:5 soil-water extract. The sodium-calcium exchange reaction may be represented as follows:

$$\mathrm{Ca}^{2+}_{ex} + 2\mathrm{Na}^{+} \rightleftharpoons 2\mathrm{Na}^{+}_{ex} + \mathrm{Ca}^{2+}$$

where 'ex' refers to the adsorbed phase. Under equilibrium conditions, the relation between the ratio of cations in the adsorbed phase and in the solution phase, may be described by the Gapon equation:

$$\frac{q_{Na}}{q_{Ca}} = K \frac{c_{Na}}{\sqrt{c_{Ca}}}$$

where K is the Gapon coefficient, q_i denotes the amount of component i in the adsorbed phase (meq/100 g), and c_i denotes the aqueous concentration of component i (mol/l). As an approximation, one may write the Gapon equation in monovalent (Na^+ and K^+) and divalent cations (Ca^{2+} and Mg^{2+}):

$$\frac{q_{+}}{q_{2+}} = K \frac{C_{+}}{\sqrt{C_{2+}}}$$

From this equation it follows that the proportion of monovalent cations in solution increases, if the solution is diluted. This is illustrated in Figure 10, where it is assumed that only cation exchange occurs. The amount of water-soluble cations is taken as 1.0 meq/100 g, and the Gapon coefficient is calculated as 1.626, from the data in Table 2. It is further assumed that equilibrium is maintained with the composition of the adsorption complex as given in Table 2. It follows that if the solution-soil ratio increases from 0.2 (that is, 20% moisture by weight) to 10, the fraction of monovalent cations in solution would increase from about 0.15 to about 0.65.

In the Tel Hadya soils, cation exchange is certainly not the only process occurring, and therefore the trends illustrated in Figure 10 have to be interpreted with caution. It may be assumed, however, that the composition of a 1:5 extract overestimates the amount of sodium in the soil solution at field capacity, and underestimates the concentrations of calcium and magnesium. Further proof for this is provided by the behaviour of the pH (Figure 11, left). The increase in pH with depth is not observed in saturation extracts of soil, and is thought to be due to the dissolution of calcite:

$$CaCO_3 + H^+ \longrightarrow Ca^{2+} + HCO_3^-$$

followed by cation exchange:

$$2Na^+_{ex} + Ca^{2+} \longrightarrow Ca^{2+}_{ex} + 2Na^+$$

Therefore, $Na^+HCO_3^-$ remains in solution, which causes the pH to increase, and this, in turn, decreases the solubility of calcium carbonate. It follows from Figure 11 (right) that there is a significant correlation between pH and $[Na^+ HCO_3^-]$, calculated as the difference between the sum of the divalent cations, $[Ca^{2+} + Mg^{2+}]$, and the bicarbonate concentration $[HCO_3^-]$.

It follows from the data in Table 2 that the exchangeable-potassium contents of soils at Tel Hadya are in the range of 450 to 600 ppm in the top 60 cm of the soils. Potassium deficiencies, therefore, would not be expected at Tel Hadya.

The distribution of water-soluble ions in soils at Breda clearly shows the presence of gypsum at 120 to 150 cm depth. Figure 12 is based on analyses performed by Mr. Mahmoud Wahoud at the University of Aleppo.

The total amount of calcium in solution, in equilibrium with gypsum, would be about 14.25 meq/100 g in a 1:5 (w/v) soil-water extract, assuming that the activity coefficients of calcium and sulfate are about 0.5 at an ionic strength of 0.033. Hence the calculated solubility of calcium is very close to the measured value, considering that some magnesium sulfates are present as well.

6. Mineral Nitrogen

The dynamics and transformations of mineral nitrogen in soils in Aleppo Province have been studied over the past 4 years, as part of a UNDP sponsored research program on increasing the efficiency of moisture and nitrogen use in rainfed agriculture*. The results of these studies have shown that the ammonium contents in soils at the drier sites were generally low during the summer, and quite uniform with depth. From Table 1 it follows that ammonium contents in the surface horizon of soils in farmer's fields were all in the range of 2-3 ppm. The onset of the rainy season is usually followed by a flush in mineralization, resulting in a temporary increase in ammonium-nitrogen in these soils. Results of measurements of ammonium- and nitrate-nitrogen throughout the growing season, suggested that in soils at the drier sites only part of the ammonium-nitrogen was converted into nitrate-nitrogen (nitrification), the remainder probably being immobilized in the hetrotrophic biomass of the soil. As a result, ammonium-nitrogen did not contribute significantly to plant-available nitrogen, except in situations where nitrogen was highly deficient.

Nitrate-nitrogen in soils appeared to be highly correlated with crop uptake of nitrogen, and it was concluded that nitrate-nitrogen in soils, determined at sowing, would be a suitable test for plant-available nitrogen (Harmsen, 1984). Figure 13 shows that at the wetter sites, Tel Hadya and Nasrieh, nitrate-nitrogen was low, and decreased with depth. At Breda and Ghrerife, nitrate-nitrogen increased with depth below 60 cm, and at Khanasser nitrate-nitrogen was very high throughout the profile. Much of the nitrate-nitrogen at depth is probably not available to the crop, except in very wet years.

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* UNDP/ICARDA Global Project 78/003.

The nitrate-nitrogen contents in surface soil samples from farmer's fields (Table 1) varied widely between fields, ranging from 1.5 ppm at Batraneh (No.3) to 58.3 ppm at Qorbatieh (No.11). A barley crop of 2-3 t/ha (dry matter yield) would require about 20-30 kg N/ha, which is equivalent to 10-15 ppm NO_3-N in the top 20 cm of the soil. Hence, in most of the fields sampled, nitrogen deficiencies would not be expected to occur, considering that the soils also contain nitrates below 20 cm depth. The nitrate-nitrogen contents in soils at Qorbatieh (No.11) and Qubattein (No.17) were significantly lower in fields where a barley crop was grown the previous season (B/B), than in fields where the land had been fallowed (F/B). A similar trend has also been observed at the experimental site at Breda: after fallow, soils were higher in nitrate-nitrogen than after a barley crop.

It may be concluded that most of the soils studied, appeared to be medium to high in plant-available nitrogen, and therefore nitrogen deficiencies, that is, responses to nitrogen-fertilizer application, would not be expected to be of major importance.

7. Available phosphorus

Available phosphorus in calcareous soils is commonly determined through extraction with a 0.5 M $NaHCO_3$ solution at pH 8.5 (Olsen et al., 1954). The solubility of calcium carbonate in this extractant solution is low, because of the high bicarbonate concentration and the high pH. As a result, the solubility of calcium phosphates is relatively high in this solution. The soil test also recovers part of the adsorbed phosphorus in soils. The amount of phosphorus that dissolves in the sodium bicarbonate solution depends on the pretreatment of the soil samples, the soil-solution ratio, the shaking frequency, the temperature during extraction, and the duration of the equilibration. Furthermore, the use of activated carbon (free of P) during filtration, to decolorize the solution, is generally recommended. It has to be emphasized that results of P-Olsen determinations may differ between laboratories, if analytical procedures are not carefully standardized.

The available-phosphorus contents in soils at Tel Hadya and the off-station sites were low in the surface horizon and decreased with depth (Figure 14). A value of 5-6 ppm is usually given as the deficiency limit in soils. Hence all soils in Figure 14 would be deficient in phosphorus. Results of agronomy research at ICARDA suggest that the deficiency limit for phosphorus in soils would be higher than 6 ppm at sites with an annual rainfall below 300 mm (Harmsen and Anderson, in preparation). These results are in agreement with Matar (1976), who reported that in a dry year yields of wheat at Ezraa Experiment Station increased linearly with available phosphorus in the range of 2 to 9 ppm.

The available-phosphorus contents of soils in farmer's fields (Table 1) were all below 6 ppm, with the exception of one field at Nawara (No.9). Hence, crop responses to phosphorus would be expected in most of the farmer's field trials, provided other factors, such as available moisture, would not be limiting crop production.

Soil samples taken in 158 farmer's fields in the barley producing area of Western and Northeastern Syria (Figure 15) showed that available-phosphorus contents of most soils were in the low range: 68.3% of the soils sampled were below 6 ppm.

It may be concluded that phosphorus deficiencies in soils are probably widespread in the barley-producing area in Syria. It has to be emphasized, however, that the application of phosphorus fertilizer does not necessarily increase yields, even if soils are highly deficient in phosphorus. Whether crops respond to application of phosphorus fertilizer depends on whether phosphorus is the factor actually limiting yields. For example, in a low-rainfall season, available moisture may limit actual yields, and application of phosphorus fertilizer would thus have little effect on yields.

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جدول ١ – نتائج تحليل التربة لحقول المزارعين في تجارب الشعير المقامة في موسم ١٩٨٣ – ١٩٨٤.

Table 1. Soil data for farmer's fields in 1983/84 on-farm barley trials.

Site Number	Location	Rot.	EC_1 (mS/cm)	pH_1	Mechanical Analysis clay	silt	sand	P-Olsen (ppm)	Mineral-N (ppm) NH_4-N	NO_3-N
					(% w/w)					
الرقم	الموقع	الدورة	التوصيل الكهربائي	PH	طين	سلت	رمل	فوسفور (أولسن)	الأمونيوم	النترات
1	كفر عبيد Kafr Abeid	F/B	0.27	8.4	20.5	42.5	36.7	2.5	2.8	7.7
2	بويضة صغيرة Boweida Saghira	F/B	0.27	8.4	12.5	37.0	49.9	2.7	2.0	10.6
3	بطرانة Batraneh	B/B	0.21	8.3	33.0	32.0	32.3	1.7	2.0	2.9
	Batraneh	F/B	0.22	8.3	34.5	34.9	30.3	1.9	2.0	1.5
4	جفر المنصور Jafr Mansour	F/B	0.37	8.2	33.0	36.4	29.3	3.5	2.6	10.8
5	ارجل Irjel	F/B	0.30	8.3	49.5	32.9	17.6	2.0	2.7	3.3
6	منبطح Monbateh	F/B	0.31	8.3	44.0	39.1	15.8	3.5	2.6	7.5
7	تواليل Tawaleel	F/B	0.33	8.3	23.0	39.5	36.1	3.6	2.7	5.6
8	حانوتة Hanouteh	F/B	0.60	8.5	40.5	48.3	9.7	2.5	3.0	11.9
9	نواره Nawara	F/B	2.83	7.9	*	*	23.9	7.2	2.9	46.3
10	معيزيلة Mezeileh	B/B	2.45	7.9	*	*	32.3	5.7	3.2	9.6
11	قرباطية Qorbatien	F/B	3.76	8.0	(35.0)	(51.2)	11.6	4.2	2.8	58.3
	Qorbatien	B/B	3.00	7.9	(31.0)	(50.7)	16.2	5.0	2.5	17.5
12	خناصر Khanasser	F/B	0.41	8.3	20.5	43.1	34.2	4.2	2.3	19.3
13	هواز Hawaz	B/B	0.31	8.3	27.5	52.1	16.4	3.8	2.4	3.6
14	مزرعة Mazraa	F/B	0.37	8.3	26.0	50.9	22.7	5.5	2.2	14.7
15	رويهب Roweheb	F/B	0.32	8.3	22.5	48.0	27.9	3.9	2.5	11.2
16	جنيد Jeneid	F/B	0.32	8.4	31.0	43.2	21.7	4.0	2.2	7.5
17	قبتين Qubbatein	F/B	0.46	8.4	41.5	49.6	5.9	2.8	2.5	17.4
	Qubbatein	B/B	0.37	8.5	39.5	49.4	7.3	2.1	2.5	4.6

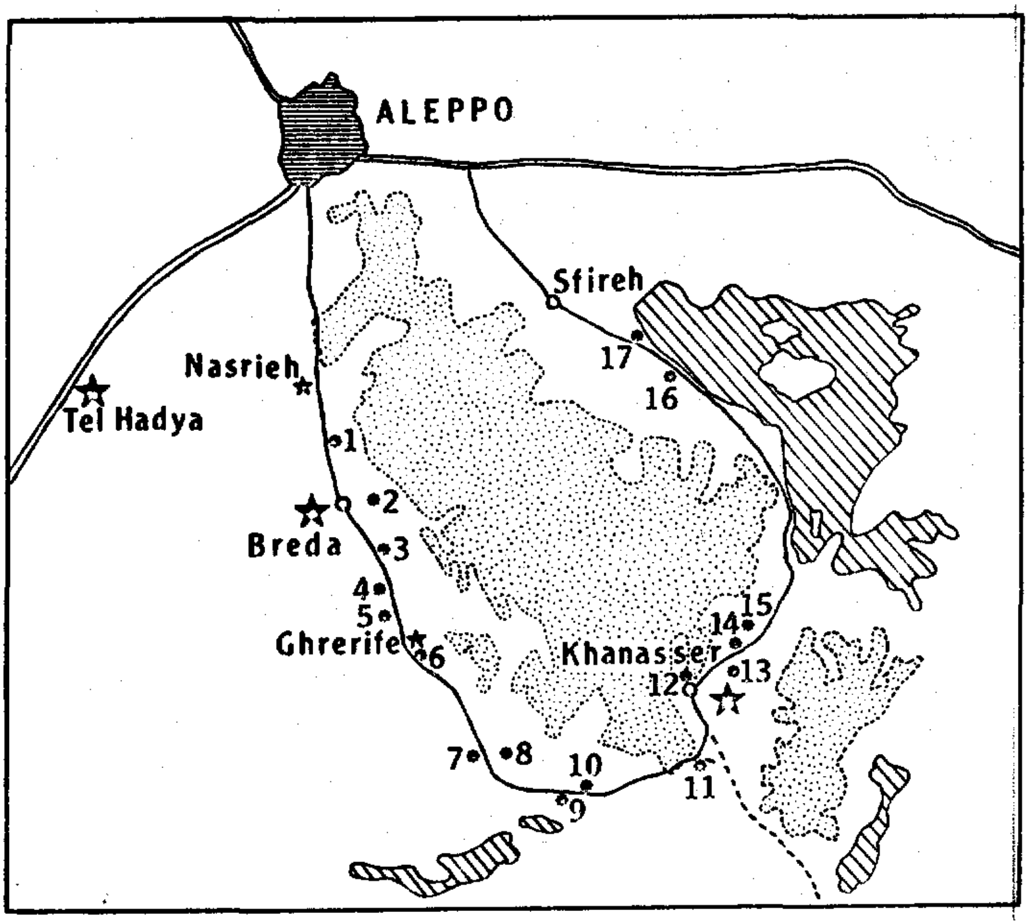
Table 2. Water-soluble ions (1:5 w/v soil-water extract), pH (1:2.5 extract), and exchangeable cations for soils at Tel Hadya.

جدول ٢ _ الايونات القابلة للذوبان (١:٥ تربة:ماء)، PH (١:٢ر٥ مستخلص)، كاتيونات قابلة للتبادل _ لعينات تربة من تل حديا.

Depth	الأيونات القابلة للذوبان Water-soluble ions (meq/100g)									EC$_5$
(cm) العمق	Ca^{2+} كالسيوم	Mg^{2+} مانغنيسيوم	Na^+ صوديوم	K^+ بوتاسيوم	Σ cat مجموع كاتيونات	HCO_3 بيكربونات	SO_4^{2-} كبريتات	Cl^- كلوريد	Σ an مجموع انيونات	(mS/cm)
0-15	0.471	0.117	0.303	0.038	0.929	0.640	0.165	0.156	0.961	0.195
15-30	0.422	0.102	0.532	0.029	1.085	0.661	0.253	0.229	1.143	0.234
30-60	0.336	0.090	0.630	0.018	1.074	0.708	0.242	0.175	1.125	0.227
0-60	0.391	0.100	0.524	0.026	1.041	0.679	0.226	0.184	1.089	0.221

Depth	كاتيونات قابلة للتبادل Exchangeable cations (meq/100g)						pH
(cm) العمق	Ca^{2+} كالسيوم	Mg^{2+} مانغنيسيوم	Na^+ صوديوم	K^+ بوتاسيوم	Σ cat مجموع كاتيونات	CEC القدرة التبادلية الكاتيونية	(1:2.5)
0-15	37.67	8.18	1.43	1.58	48.86	48.86	8.29
15-30	35.71	8.54	2.19	1.38	47.82	47.82	8.32
30-60	34.56	8.85	2.68	1.16	47.25	47.29	8.43
o-60	35.63	8.61	2.25	1.32	47.80	47.82	8.37

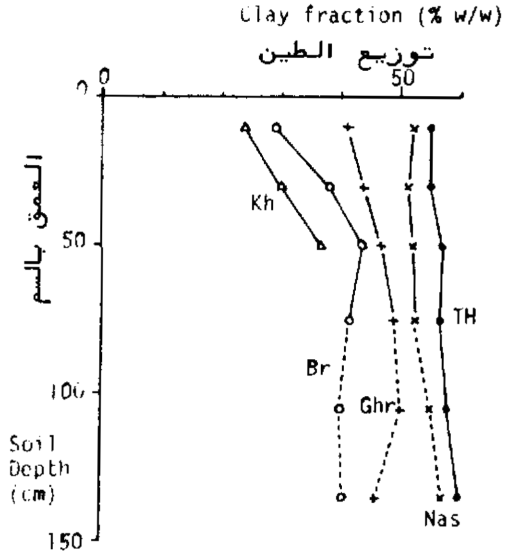
Figure 1. Map showing the approximate locations of Tel Hadya experiment station and the 4 off-station sites (stars), and the 17 farmer's field trials (asterisks). The numbers refer to Table 1. The area with an altitude higher than 400 m above sea level (dotted area) largely coincides with the basaltic plateau SE of Aleppo. Salt lakes are indicated by dashed area's.



شكل ١ - خريطة تبين المواقع التقريبية لمحطة تجارب تل حديا - والاربع مواقع التجريبية الاخرى وكذلك مواقع تجارب ١٧ حقل للمزارعين - ويرجع للارقام في جدول (١).

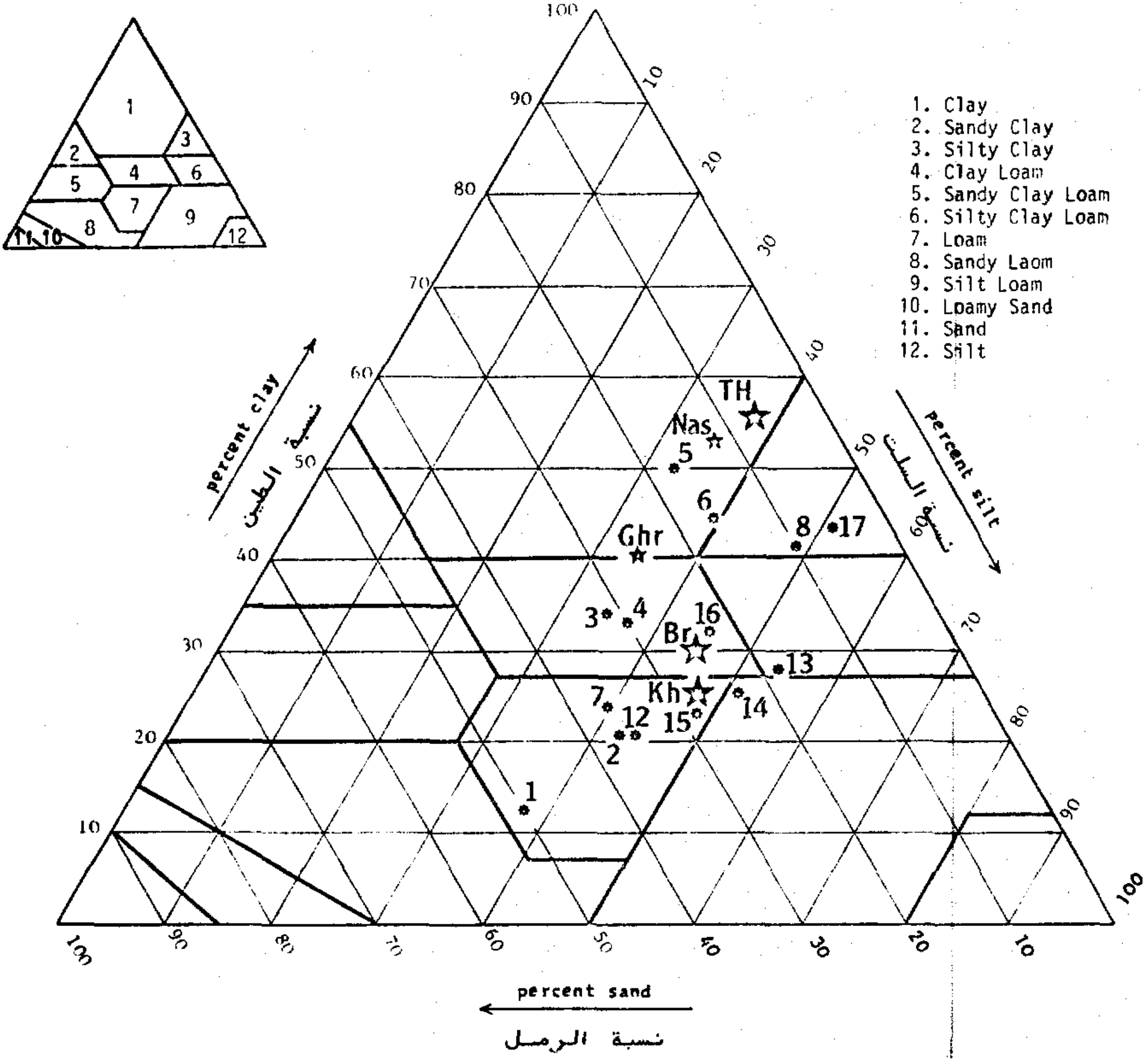
المنطقة ذات المستوى الاعلى من ٤٠٠ متر فوق سطح البحر (المنطقة المنقطة) تساير المنطقة ذات الهضبة البازلية في حلب. البحيرات المالحة موضحة بالمنطقة ذات الخطوط المتقطعة.

Figure 2. Clay contents at five sites, as a function of depth in the soil.



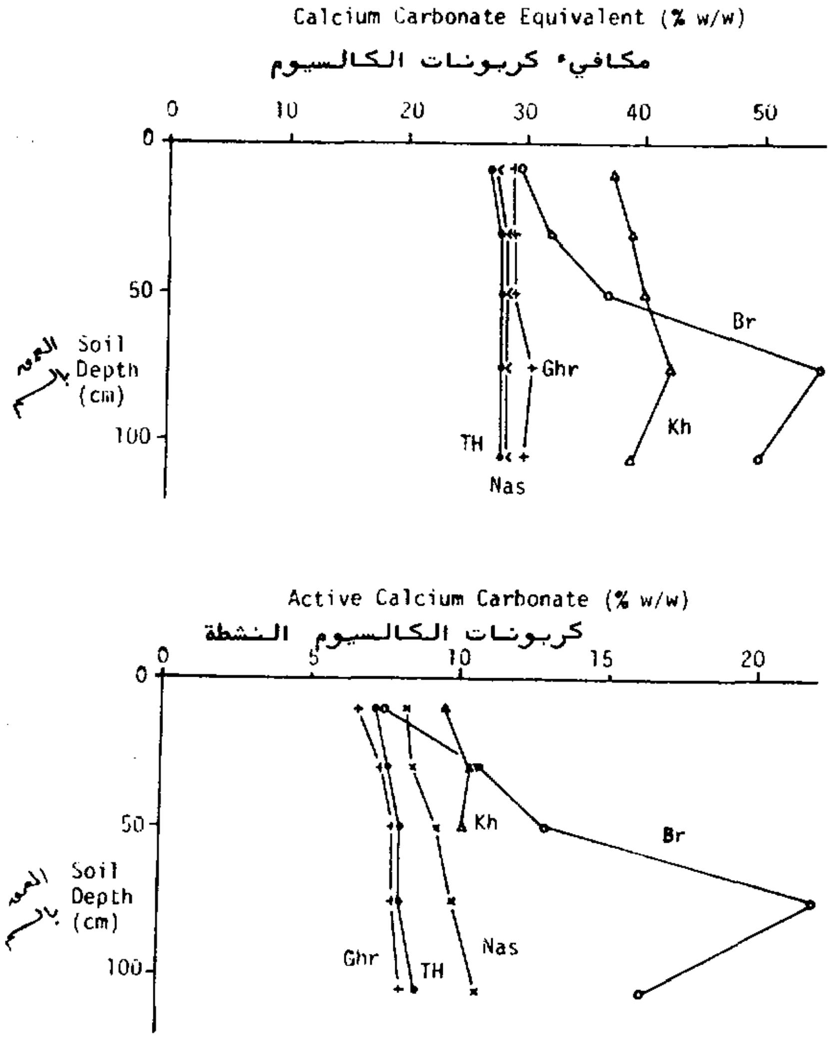
شكل ٢ - يوضح محتوى الطين في ٥ مواقع وتغيرها مع العمق في الارض

Figure 3. Texture of soils (0-20 cm depth) at 5 experimental sites and 17 farmer's fields, according to the USDA Soil Taxonomy.



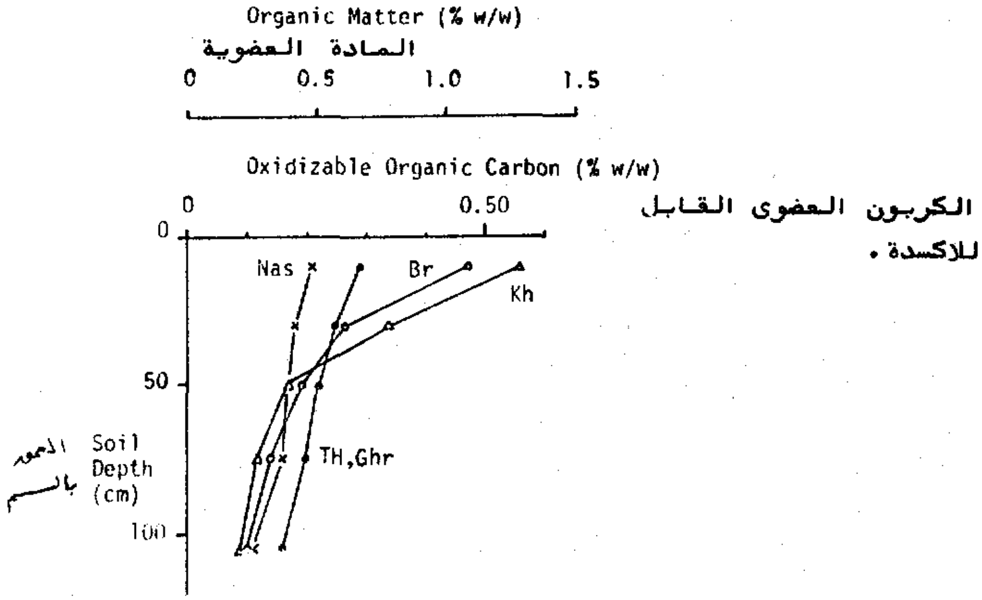
شكل ٣ ـ يوضح قوام التربة (عمق صفر ـ ٢٠ سم) في ٥ مواقع تجريبية و ١٧ من حقول المزارعين. (طبقا لتقييم الاراضي في USDA).

Figure 4. Calcium carbonate equivalent (top) and active calcium carbonate contents (bottom) at five experimental sites, as a function of depth in the soil.



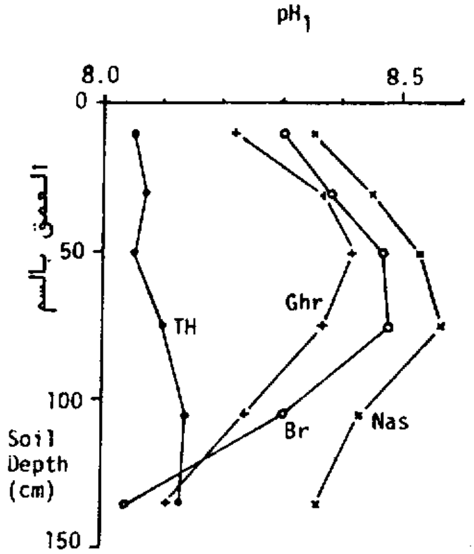
شكل ٤ - يوضح مكافيء كربونات الكالسيوم (في القمة) - المحتوى من كربونات الكالسيوم (في القاع) في ٥ مواقع تجريبية - وتغيرها مع العمق في الارض

Figure 5. Oxidizable organic carbon contents at five experimental sites, as a function of depth in the soil. Organic matter contents are approximately a factor 2.3 higher (top scale).



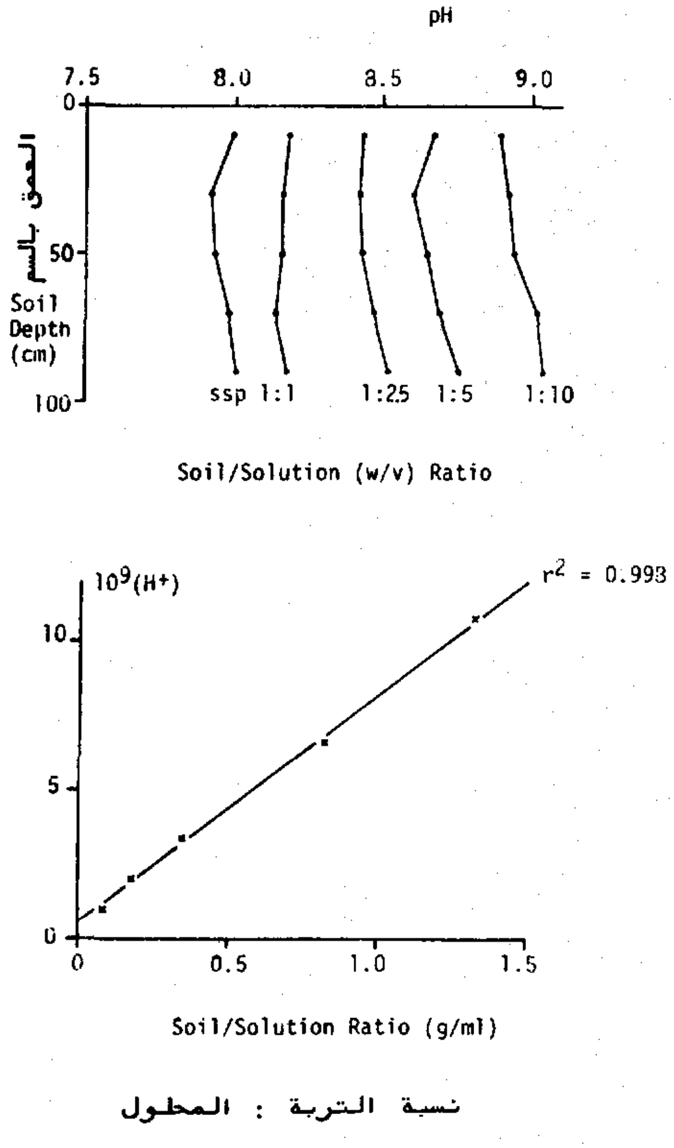
شكل ٥ – يوضح محتوى الكربون القابل للاكسدة في ٥ مواقع تجريبية – وتغيرها مع العمق . يلاحظ ان محتوى المادة العضوية يعتبر اعلا بعامل ٢ر٣.

Figure 6. pH determined in 1:1 (w/v) soil-water suspensions of soils at four sites.



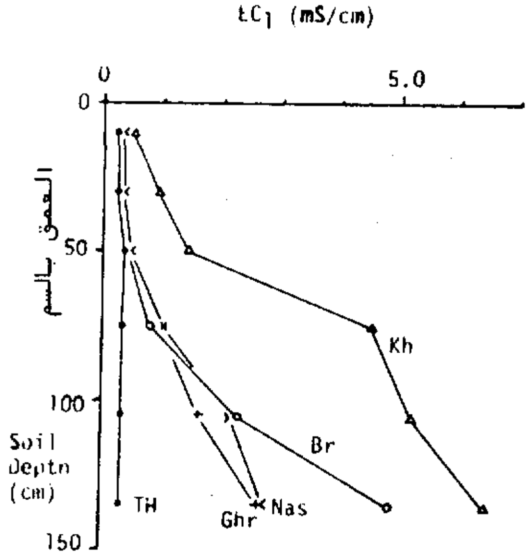
شكل ٦ _ يوضح PH التربة المقدر في معلق التربة : الماء (١:١) في ٤ مواقع.

Figure 7. pH determined in saturated soil paste (ssp) and suspensions of different soil-water ratio's for soils at Tel Hadya (top). Hydrogen-ion activity in solution as a function of soil-water ratio for soils at Tel Hadya (bottom).



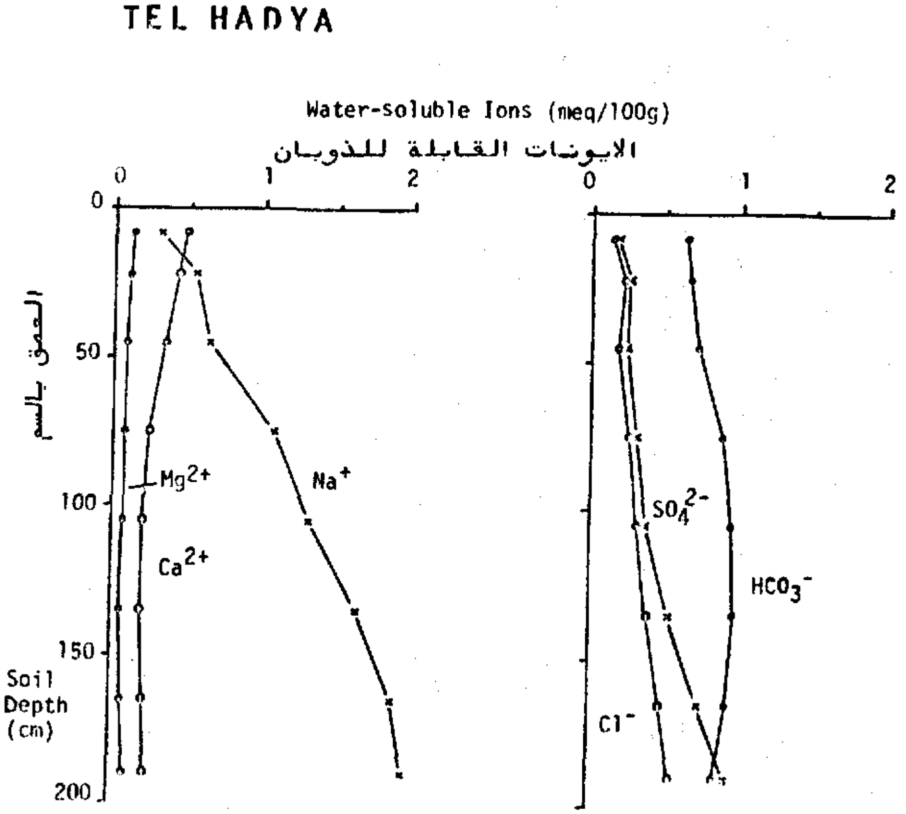
شكل ٧ – يوضح PH التربة المقدرة في عجينة التربة المشبعة – وكذلك معلقات التربة بنسب مختلفة من التربة : الماء – لعينات تربة من تل حديا (في اعلا). درجة نشاط ايون الهيدروجين في المحلول وتغيره مع نسبة الماء. التربة لعينات تربة من تل حديا.

Figure 8. Electrical conductivities determined in 1:1 (w/v) soil-water extracts of soils at five sites, as a function of depth in the soil.



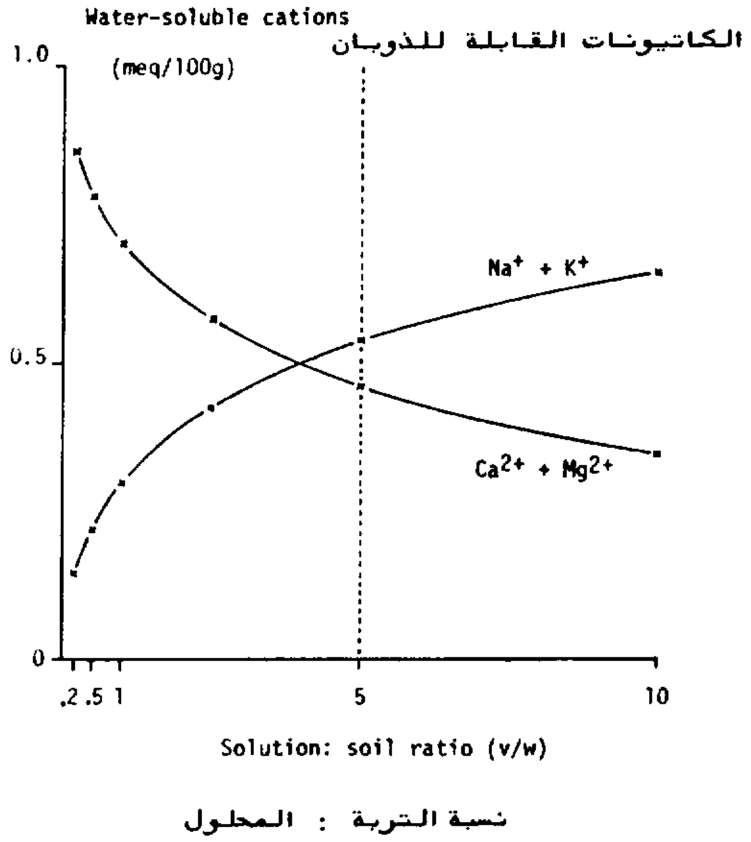
شكل ٨ – يوضح درجة التوصيل الكهربائي للتربة مقدرة في مستخلص التربة للماء (١:١) لعينات تربة في ٥ مواقع – وتغيرها مع العمق في التربة.

Figure 9. Water-soluble cations (left) and anions (right) determined in 1:5 (w/v) soil-water extracts of soils at Tel Hadya.



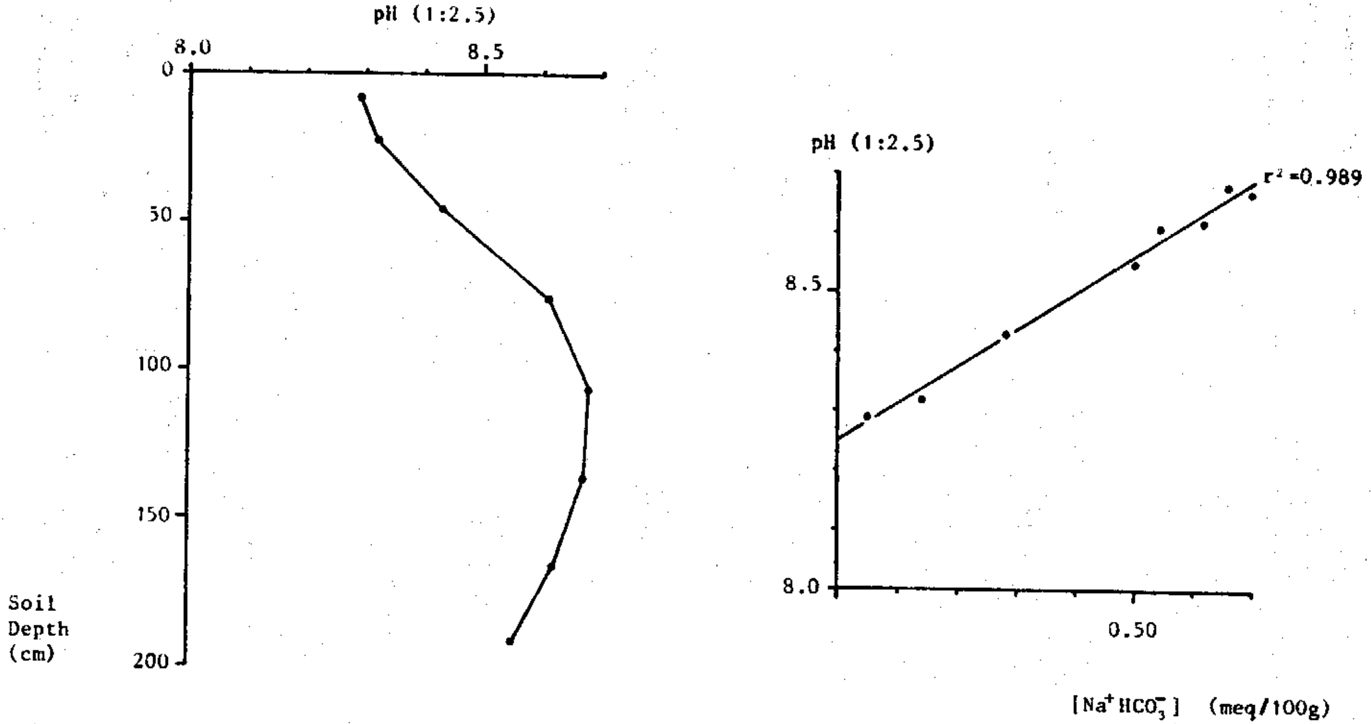
شكل ٩ ـ الكاتيونات القابلة للذوبان في الماء (يسار) ـ الانيونات (يمين) المقدرة في مستخلص التربة الى الماء (٥:١) في عينات تربة من تل حديا .

Figure 10. Water-soluble monovalent (Na^+ and K^+) and divalent cations (Mg^{2+} and Ca^{2+}) in soil-water extracts, as a function of the water: soil ratio (v/w), if only ion exchange occurs and the composition of the adsorption complex is approximately constant.



شكل ١٠ - يوضح الايونات الاحادية التكافوء القابلة للذوبان في الماء. (الصوديوم والبوتاسيوم) وكذلك الايونات الثنائية التكافوء القابلة للذوبان (الماغنسيوم والكالسيوم) في مستخلصات التربة مع الماء وعلاقته بنسبة الماء: التربة - في حالة حدوث تبادل ايوني مع حدوث ثبات تقريبي لمعدل الادمصاص.

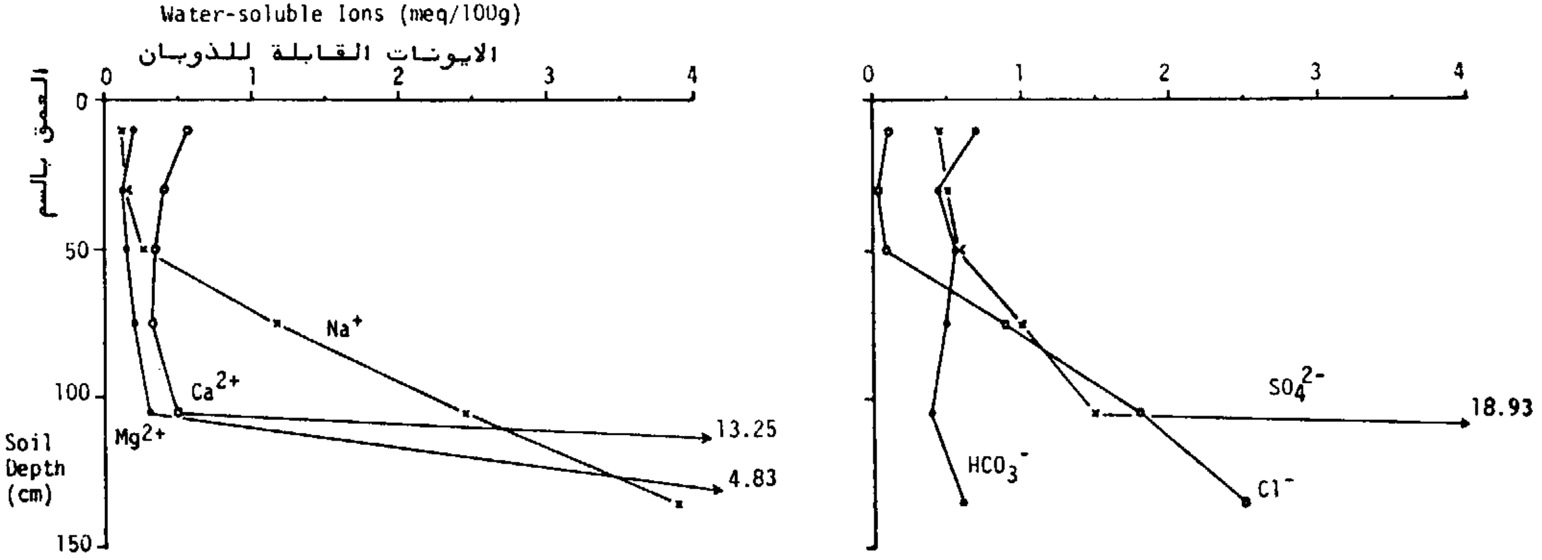
Figure 11. pH of 1:2.5 (w/v) extracts of soils at Tel Hadya (left), and pH as a function of the fractional concentration of bicarbonate ions in solution, associated with sodium ions (right).



شكل ١١ – يوضح PH التربة في مستخلصات التربة (١:٥ر٢) لعينات تربة من تل حديا (يسار). وايضا PH كدالة لتغير نسبة ايونات البيكربونات في المحلول من وجود ايونات الصوديوم (يمين).

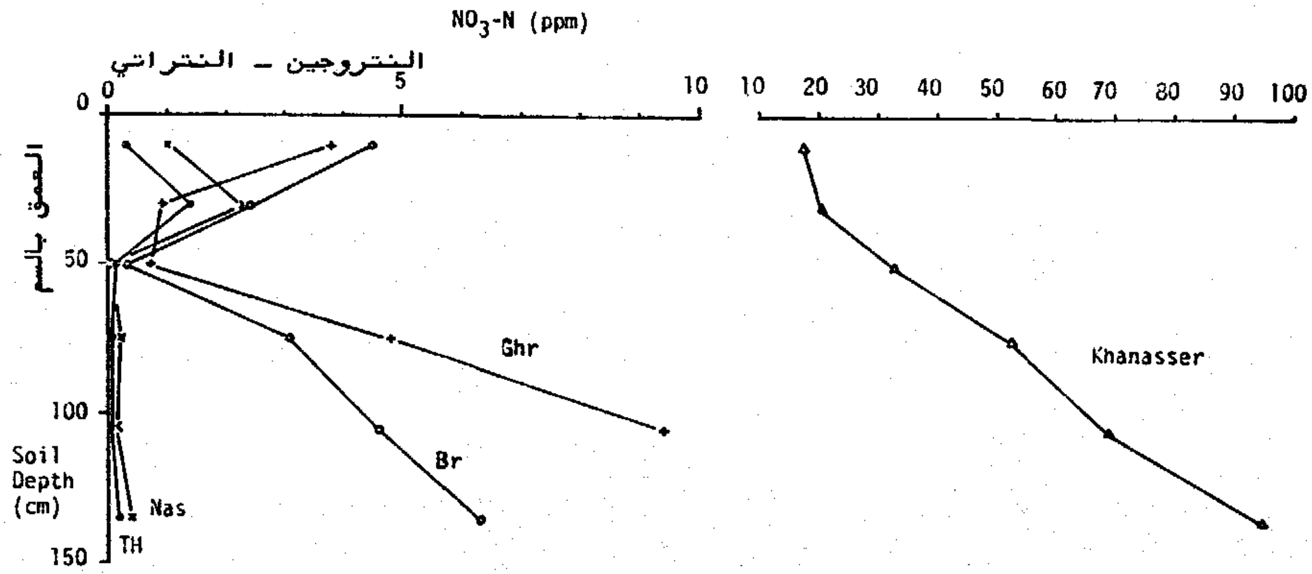
Figure 12. Water-soluble cations (left) and anions (right) determined in 1:5 (w/v) soil-water extracts of soils at Breda.

BREDA



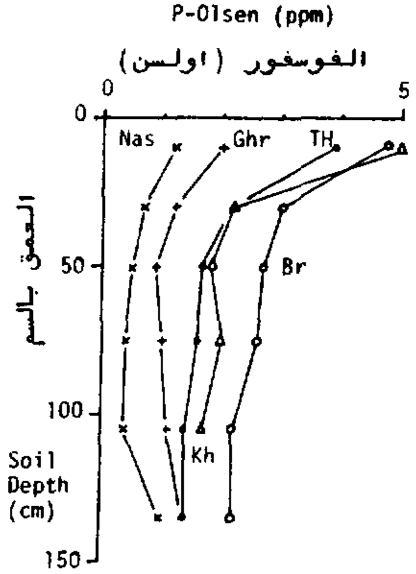
شكل ١٢ ـ الكاتيونات القابلة للذوبان في الماء (يسار) ـ والانيونات (يمين) ـ مقدرة في مستخلصات التربة مع الماء (٥:١) في عينات تربة من بريدا.

Figure 13. Nitrate-nitrogen (NO_3-N) contents of soils at five sites, sampled at sowing 1981.



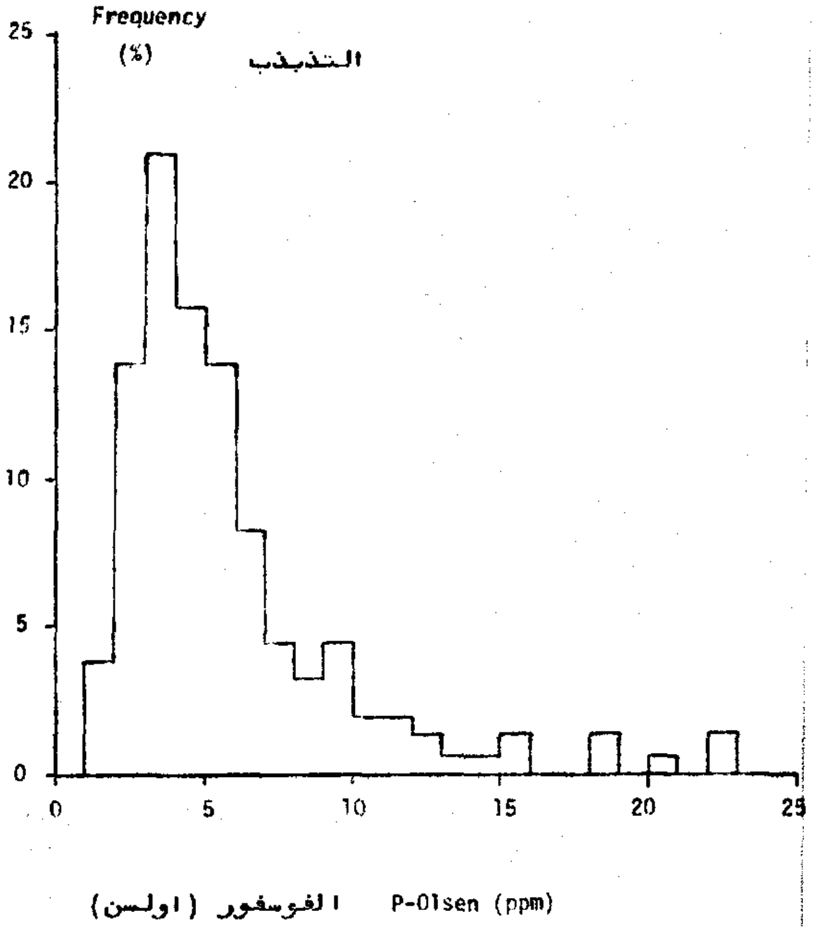
شكل ١٣ – يوضح محتوى النتروجين النتراتي في التربة في ٥ مراقع – اخذت عيناتها في موسم نثر البذور عام ١٩٨١.

Figure 14. Available-phosphorus (P-Olsen) contents of soils at five sites.



شكل ١٤ - يوضح محتوى الفوسفور الميسر (المقدر بطريقة اولسن) في التربة في ٥ مواقع.

Figure 15. Frequency histogram of available-phosphorus contents of soils at 158 farmer's fields in the barley-producing area in Syria, sampled in spring 1982 (barley survey).



شكل ١٥ – يوضح التذبذبات البيانية لمحتوى الفوسفور الميسر في التربة في ١٥٨ حقل من حقول المزارعين في مناطق انتاج الشعير في سوريا – اخـــذت العينات في ربيع ١٩٨٢.

DRYLAND BARLEY PRODUCTION IN NORTHWEST SYRIA:

II. The chemistry and fixation of phosphorus in calcareous soils

by

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1. Introduction

Most of the soils in Syria are calcareous, that is, they contain calcium or mixed calcium-magnesium carbonates. Carbonate contents of soils tend to decrease with higher rainfall, probably due to dissolution and leaching of carbonates with the infiltrating rainwater.

Inorganic phosphate fertilizers applied to calcareous soils are transformed into less soluble mineral forms in the course of time. This process is usually referred to as 'fixation'. The mechanism of phosphorus fixation in calcareous soils is quite different from fixation in acid soils, where adsorption on aluminum and iron oxides plays a major role. In calcareous soils, the availability of phosphorus to the crop is expected to increase with the amount of fertilizer applied. In acid soils, a certain amount of phosphate may be required to satisfy the adsorption sites associated with aluminum and iron oxide surfaces, such that available-phosphorus only starts to increase after a certain amount of phosphorus-fertilizer has been applied to a soil. Furthermore, adsorption is a rapid process, whereas mineral transformations involving calcium phosphates are relatively slow.

One of the most soluble calcium phosphates is brushite or DCPD (Table 1), which is a major initial reaction product of phosphate fertilizers in calcareous soils. Apatites are among the least soluble calcium phosphates, and probably constitute the stable end products of phosphorus transfromations in calcareous soils.

It is the objective of this paper to discuss some aspects of the chemistry of calcareous soils, to provide a basis for the understanding of the transformations and availability of inorganic phosphates in calcareous soils.

2. Natural abundance of phosphorus

The mean phosphorus content of the lithosphere is 1200 ppm. Phosphorus tends to be more abundant in basic and intermediate rocks, than in acid rocks (Figure 1).

The phosphorus contents of limestone are below the average for the earth's crust (Milovsky, 1982). Hence total phosphorus contents of soils formed in limestone would be expected to be lower than of soils formed in basic rocks, such as basalt. The phosphorus content of the parent materials is only one of the factors, however, that determine the total phosphorus contents of soils. Other factors include the age of the soils and parent materials, climatic conditions during weathering and soil formation, and biological factors.

Total elemental analyses (X-ray fluorescence spectrometry) of soils in Aleppo Province, conducted at the University of Reading, have shown that the phosphorus contents of soils ranged from about 500 ppm at the driest site, Khanasser, to less than 100 ppm at the wetter sites, Nassrieh and Tel Hadya; see Figure 1 (Hedley, 1982). Hence total phosphorus contents were in the low range, in particular at the wetter sites. The decrease in phosphorus contents with higher rainfall may well reflect plant uptake of phosphorus, rather than leaching. A cereal crop that produces a dry matter yield of 2.5 t/ha, would require about 5 kg P/ha. Hence, in 100 years this crop would remove an amount of phosphorus, equivalent to about 250 ppm in the top 20 cm of the soil. Therefore, crops remove substantial amounts of phosphorus from soil, and the low available-phosphorus contents of soils in Aleppo Province may thus at least in part be ascribed to low total phosphorus contents. At the drier sites, such as Khanasser, cultivation of cereal crops probably started more recently than at the wetter locations, whereas the yield levels, and thus the amounts of phosphorus removed from the soils, are lower at the drier sites. This may partly explains the higher phosphorus levels at the drier sites.

3. The chemistry of calcareous soils

Some minerals that are important in the chemistry of phosphates in calcareous soils, are listed in Table 1. Calcite and gypsum (if present) determine the calcium activities in soil solution, and fluorite the activity of fluoride in solution. The solubility of phosphate in calcareous soils is largely determined by the aqueous calcium activity and the pH, both of which are controlled by calcite, or calcite plus gypsum, the ionic composition of the soil solution, and the CO_2 levels in soil.

3.1. Calcium carbonate equilibria

The solubility of calcite in aqueous solution is a function of pH and the partial CO_2 pressure, as follows from reaction 14 in Table 2:

$$\log Ca^{2+} = 9.74 - 2pH - \log CO_2$$

where $\log Ca^{2+}$ denotes the logarithm of the calcium ion activity, 9.74 is the logarithm of the thermodynamic equilibrium constant at 25 ^{o}C and zero ionic length, pH is the negative logarithm of the hydrogen ion activity, and $\log CO_2$ is the logarithm of the partial CO_2 pressure. By convention, $\log CO_2 = 0$ if the CO_2 pressure equals 1 atmosphere. Hence at an atmospheric CO_2 level of 0.03% (v/v), that is, at a partial CO_2 pressure of 0.0003 atm, $\log CO_2$ equals -3.52. The ionic strength, I, of an aqueous solution is given by:

$$I = \frac{1}{2} \Sigma C_i Z^2{}_i$$

where C_i is the concentration (mol/l) of ion i, Z_i is the valency of ion i, and the summation is over all ionic species in solution. The activity of an ion, a_i, is defined as:

$$a_i = \gamma_i C_i$$

where γ_i is the activity coefficient of ion i, and C_i the aqueous concentration.

Activity coefficients may be calculated from the Davies equation:

$$\log \gamma_i = -AZ_i^2 \left[\frac{I^{\frac{1}{2}}}{1 + I^{\frac{1}{2}}} - 0.3\ I \right]$$

where A is a constant, which is equal to 0.509 for water at 25 °C.

The solubility of calcite decreases with higher pH and with higher CO_2 levels (Figure 2). A CO_2 level of 0.03% (v/v) corresponds to atmospheric conditions. In soils, CO_2 levels are usually higher because of metabolic activities of living organisms, and slow exchange of CO_2 with the atmosphere. Under high-moisture conditions, the exchange of CO_2 with the atmosphere is slower than in well aerated, drier soils, because of the low rate of diffusion of CO_2 in aqueous solution. In the rooting zone of a growing crop, CO_2 levels would be in the range of 1-10% (v/v).

The equilibrium composition of a $CaCO_3$-H_2O system at a given value of $\log CO_2$, can be calculated from the electroneutraltity condition, which requires that the amount of cationic charge in solution is equal to the amount of anionic charge:

$$2[Ca^{2+}] + [CaHCO_3^+] + [H^+] = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-]$$

where square brackets refer to the aqueous concentrations of the ions involved. This equation can be written in aqueous activities (round brackets) with the help of the activity coefficients of the species involved:

$$\frac{2(Ca^{2+})}{\gamma_{Ca^{2+}}} + \frac{(CaHCO_3^+)}{\gamma_{CaHCO_3^+}} + \frac{(H^+)}{\gamma_{H^+}} = \frac{(HCO_3^-)}{\gamma_{HCO_3^-}} + \frac{2(CO_3^{2-})}{\gamma_{CO_3^{2-}}} + \frac{(OH^-)}{\gamma_{OH^-}}$$

All aqueous activities can be expressed as a function of (H^+) only, at a given value of $\log CO_2$ (Table 2). Solution of this equation for $\log CO_2 = -3.52$ (Figure 2, left) gives a pH value of 8.32, and for $\log CO_2 = -2.00$ (Figure 2, right) a value of 7.32 is obtained. It may be noted that the solution of this type of equations is an iterative process, because γ_i is a function of I, and I is a function of the aqueous concentrations, which are calculated from the aqueous activities using the estimated values of γ_i.

It can be seen from Figure 2 that the pH of a solution in equilibrium with calcite tends to decrease with higher CO_2 levels. Therefore, the pH in the rooting zone of a crop tends to be lower than in a soil with little or no biological activity. As a consequence, the availability of many nutrients, including phosphates, iron and zinc, would increase in the rooting zone of an actively growing crop.

The pH of a calcareous soil in equilibrium with atmospheric CO_2 is not only determined by the presence of calcite, but also by other minerals and ions in solution. For example, the pH may range from 7.9 or less, in gypsic soils, to 9.0 or higher in sodic soils. The behaviour of pH in equilibrium with calcite, in the presence of other salts, can be understood by considering the electroneutrality equation for such systems. It follows from Figure 2 that the electroneutrality equation for a pure $CaCO_3$-H_2O system in equilibrium with atmospheric CO_2 may be written in the approximative form:

$$2[Ca^{2+}] = [HCO_3^-]$$

if an amount of aqueous cations, other than Ca^{2+} are introduced in the system, the equation becomes:

$$[Cat^+] + 2[Ca^{2+}] = [HCO_3^-]$$

Solution of this equation requires that pH increases, as can be seen from Figure 3 (right). This situation occurs if $NaHCO_3$ is dissolved in a $CaCO_3$-H_2O system, and explains the high pH in sodic soils.

The pH of aqueous suspensions of soils at Tel Hadya increased with the concentration of *$[Na^+ HCO_3^-]$ in solution*, as was *shown in part I* of this paper. When an aqueous suspension of a soil is prepared, initially only soluble salts dissolve. The suspension will thus be undersaturated with regard to calcite. The (slow) dissolution of calcite, followed by the replacement of Ca^{2+} by $2Na^+$ through ion exchange, increases the amount of Na^+ in solution, and hence, increases pH. It can be seen from Figure 3 that pH increases almost linearly with the cation concentration, up to about 0.003 mol/l. The relation between pH and $[Cat^+]$ in this range can be approximated by:

$$pH = 8.32 + 0.659 \ [Cat^+]$$

where the cation concentration is expressed in meq/100 g of soil, for a 1:2.5 (w/v) soil-solution ratio. The regression curve shown in Figure 11 (part I of this paper) is given by:

$$pH(1:2.5) = 8.25 + 0.627 \ [Na^+ HCO_3^-] \qquad n=8, \ r^2=0.99$$

in agreement with the behaviour of pH shown in Figure 3.

If an amount of monovalent anions, other than HCO_3^-, are introduced in the $CaCO_3$-H_2O system, the elecroneutrality equation can be written in the approximate form:

$$2[Ca^{2+}] = [HCO_3^-] + [An^-]$$

Solution of this equation requires that pH decreases, as is shown in Figure 3 (left). This situation occurs if $CaCl_2$ or another soluble calcium salt, is dissolved in a $CaCO_3$-H_2O system, and explains the low pH (about 7.9) of gypsic soils.

The ionic activity coefficients decrease with increasing *ionic* strength. The dotted lines in Figure 4 indicate the activity coefficients of monovalent *and divalent ions in a pure* $CaCO_3$-H_2O *system*. The activity coefficients decreases more steeply with [An^-] than with [Ca^+]. This is because the anions are assumed to be associate with Ca^{2+} ions, whereas the cations are associated with HCO_3^- ions.

In the Olsen-test for available phosphorus, a 0.5 M $NaHCO_3$ solution at pH 8.5 is used for the extraction of phosphates from soil. From reactions 1, 2 and 14 (Table 2) it follows that:

$$\log Ca^{2+} = 1.92 - \log HCO_3^- - pH$$

For the Olsen-extract it would thus follow that $\log Ca^{2+} \simeq -6.12$. Hence, very little calcite dissolves in the extract, because of the high bicarbonate concentration and the high pH. The low calcium activity increases the solubility of calcium phophates in soils. In addition, the bicarbonate ions compete with orthophosphate ions for adsorption sites, and part of the adsorbed phosphates are released into solution. For these reasons, the sodiumbicarbonate solution is believed to be an effective extractant for phosphorus in calcareous soils (Olsen et al. 1954). It may be noted that a 0.5 M $NaHCO_3$ solution at pH 8.5 is not stable under atmospheric conditions. Carbon dioxide tends to escape and pH tends to increase. Therefore, solutions have to be stored in closed bottles.

In conclusion, it may be stated that in calcareous soils, pH tends to decrease with higher CO_2 levels, and in the presence of soluble calcium salts, such as gypsum. The pH tends to increase in the presence of soluble carbonates, such as sodium bicarbonate.

3.2. Calcium phosphate equilibria

Orthophosphoric acid in aqueous solution dissociates according to reactions 4-6 in Table 2. The mole fraction (MF) of an orthophosphate species is defined as the concentration of that species divided by the sum of the concentrations of all orthophosphate species in solution. It follows from Figure 5 that $H_2PO_4^-$ and HPO_4^{2-} are the major orthophosphate species in solution in calcareous soils.

The major phosphate mineral in superphosphate fertilizers in monocalcium phosphate monohydrate (MCPM). This compound is too soluble to persist in most soils for more than a few hours. The major initial reaction products of MCPM in soils are DCPD or DCP (Table 1). The conversion of MCPM into DCPD may be represented by:

$$Ca(H_2PO_4)_2.H_2O + H_2O \rightleftharpoons CaHPO_4 . 2H_2O + H_3PO_4^0$$

The released orthophosphoric acid dissociates according to reactions 4-6 in Table 2. Hence, the pH of the solution in the proximity of the fertilizer granules decreases. Hence, concentration gradients are established, and hydrogen ions and orthophosphates move by diffusion from the fertilizer granules to the surrounding soil. The decrease in pH is neutralized in calcareous soils by the dissolution of carbonates, which causes the calcium activity in solution to increase. As a result, a zone is formed around the fertilizer granule, where carbonates dissolve and phosphates precipitate (Figure 6). The extent of this zone depends on factors such as moisture content, CO_2 level, calcium activity in solution, and the amount and form of carbonates in the soil. Measurements of available phosphorus in fertilized soils at Tel Hadya and Breda, during two growing seasons, showed that at a distance of 1-2 cm from the fertilizer granules, the solubility of phosphorus was unaffected by the presence of fertilizer-phosphate. Hence, the mobility of fertilizer-applied phosphorus in these calcareous soils was very limited.

In a solution in equilibrium with calcite, a range of calcium phosphates, with decreasing solubilities, may be formed. Some of these calcium phosphates are listed in Table 1. The composition of a solution in equilibrium with calcite, as a function of partial CO_2 pressure, may be calculated from the electroneutrality equation for this system (Figure 7, right). The total amount of orthophosphate in solution, in equilibrium with calcite, in given by :

$$[PO_4] = [H_2PO_4^-] + [HPO_4^{2-}] + [CaH_2PO_4^+] + [CaHPO_4^0] + [CaPO_4^-]$$

The total orthophosphate concentrations in equilibrium with different calcium phosphate minerals are shown in Figure 7 (left) for the solution composition shown in Figure 7 (right). It can be seen that the solubility of most calcium phosphates increases with higher CO_2 levels, and that the solubilities decrease in the order :

$$\text{DCPD} > \text{DCP} > \text{OCP} > \beta\text{-TCP} > \text{HA} > \text{FA}$$

Hence, if fluorite is present in the soil, fluoropatite is the stable end-product of the phosphate transformations.

In case gypsum and calcite co-exist in soil, the calcium activities in solution will be higher, and the pH lower (cf. Figure 3). In such a system, the calcium activity in solution is mainly controlled by the solubility of gypsum, and approximately constant (Figure 8, left). The pH is thus determined by the approximate equation:

$$pH \simeq 6.0 - \tfrac{1}{2} \log CO_2$$

and would range from about 7.8 at 0.03 to 6.8 at 3% (v/v) CO_2.

The solubilities of calcium phosphates in equilibrium with calcite and gypsum, follow the same order as in the case of calcite only (Figure 8, right). The solubilities of all calcium phosphates are depressed in the presence of gypsum, because of the higher calcium concentrations. This is further illustrated in Figure 9, where the total orthophosphate concentration in equilibrium with β-TCP is shown for a solution in equilibrium with calcite only, and with calcite plus gypsum.

It may be concluded that the solubility of inorganic calcium phosphates in calcareous soils is mainly determined by the solubilities of calcite and gypsum, if present, by the partial CO_2 pressure in the soil, and by factors that affect the pH of the soil solution.

4. Fixation of fertilizer phosphate in calcareous soils

Fertilizer phosphates applied to calcareous soils are gradually transformed into calcium phosphates with lower solubilities than the precipitates that are initially formed, such as DCPD or DCP.

The initial rate of formation of a calcium phosphate may be approximated by an equation of the type :

$$\frac{dx}{dt} = k \quad [Ca^{2+}]^n \ [PO_4]^m$$

where x denotes the amount of precipitate formed, k is a rate constant, PO_4 denotes the reactive orthophosphate species, and n and m are coefficients that have to be determined experimentally. For the formation of DCP, only two ions have to combine, Ca^{2+} and HPO_4^{2-}, but for the formation of TCP, 5 ions have to combine, $3Ca^{2+}$ and $2PO_4^{3-}$. As a first approximation, one might assume that the formation of DCP is second order (n=1, m=1), and the formation of TCP fifth order (n=3, m=2). The kinetics of precipitation in soil-solution systems are more complex than this, and processes such as surface adsorption, and the formation of aqueous complexes play a major role. It may be assumed, however, that the formation of minerals such as OCP, TCP, or apatites, are of a higher order with respect to the concentrations of calcium and orthophosphate, than the formation of minerals such as DCPD or DCP. Therefore, the reaction rates will be higher for the simple calcium phosphates than for the more complex minerals.

The orthophosphate concentrations in solution are controlled by the most soluble calcium phosphates. Once the most soluble phosphates are all dissolved (for example, DCPD or DCP), the next most soluble phosphate (for example, OCP) will control the orthophosphate concentration in solution. As a result, the orthophosphate concentrations in the proximity of the fertilizer granules tend to decrease with time.

In conclusion, it may be stated that the rates of phosphate-mineral transformations tend to decrease with time, because of the decreasing calcium and orthophosphate concentrations in solution, and the lower rates of formation of the more complex calcium phosphates.

When an amount of phosphate fertilizer is applied to a soil, the Olsen-extractable phosphorus increases by an amount ΔP, which is equal to the amount of fertilizer-phosphorus applied, divided by the weight of the soil in the surface layer. The amount of Olsen-extractable phosphorus decreases with time, and this decrease may be described as a first order reaction in the fertilizer-phosphorus concentration:

$$-\frac{d\,\Delta P}{dt} = k\,\Delta P$$

where k is a rate constant. Inegration of this equation gives:

$$\ln \Delta P = -kt + \text{Constant}$$

where the constant equals $\ln \Delta P_0$, the natural logarithm of the amount of Olsen-extractable fertilizer-phosphorus at t=0, that is, at the time of fertilizer application. This equation may be written as:

$$\Delta P = \Delta P_0\, e^{-kt}$$

from which it follows that ΔP would decrease exponentially with time.

First order reactions may be characterized by the half-life, $T_{\frac{1}{2}}$, or the reaction, which is defined as:

$$\ln\tfrac{1}{2} = -k\ T_{\frac{1}{2}}$$

or:

$$T_{\frac{1}{2}} = \frac{0.693}{k}$$

Hence, the half-life is the time required to convert half the amount of fertilizer-phosphorus into non-extractable froms.

In rotational trials at Breda and Tel Hadya, the Olsen-extractable phosphorus contents of soils in fertilized and unfertilized plots were determined at harvest 1983, that is, about half a year after the application of phosphorus fertilizer to the fertilized plots. The half-lives of fertilizer-phosphorus in soils at Breda were in the range of 4-8 months, with an average of 6.1 months, and at Tel Hadya in the range of 6-10 months, with an average of 7.8 months. These values are in the same range as values reported by Matar (1976) who obtained half-lives in the range of 8-10 months for soils at Ezraa Experiment Station in Southern Syria.

The decrease in Olsen-extractable phosphorus in the top 15 cm of soils in fertilized plots at Breda and Tel Hadya is plotted in Figure 10. Phosphorus contents of soils in unfertilized plots (P_O) at Breda were about 2.3 ppm and at Tel Hadya about 4.1 ppm. The value for P_O in Figure 10 (3.2 ppm) therefore represents an average for the two sites. Similarly, a half-life of 7 months represents an average for the two sites. It follows from Figure 10 that a substantial amount of fertilizer-phosphorus applied in the first season, would be available to a crop in the second season (residual effect).

Olsen-extractable phosphorus contents in soils are only one factor in determining the availability of phosphorus to the crop. Other factors include the distribution and density of roots, the presence of VA mycorrhiza, the spatial distribution of phosphorus in the soil profile, soil moisture and temperature conditions, and the composition of the soil solution. Therefore, the results of the Olsen-test have to be interpreted with some caution, and other factors that contribute to the effective availability of phosphorus to the crop, in particular the concentration of orthophosphates in solution, and soil moisture conditions, have to be considered as well.

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جدول ١ ـ فوسفات الكالسيوم الهامة وبعض معادن الكالسيوم الاخرى من الاراضي الجيرية .

Table 1. Important calcium phosphates and some other calcium minerals in calcareous soils (Lindsay, 1979; Lindsay and Vlek, 1976).

المعدن mineral	الاسم name	إختصار abbreviation
$CaCO_3$	كالسيت calcite	
$CaSO_4.2H_2O$	جبس gypsum	
CaF_2	فلوريت fluorite	
$Ca(H_2PO_4)_2.H_2O$	monocalcium phosphate monohydrate فوسفات إحادي الكالسيوم - احادي الهيدريت	MCPM
$CaH PO_4.2H_2O$	dicalcium phosphate dihydrate فوسفات ثنائي الكالسيوم - ثنائي الهيدريت or: brushite أو بروشيت	DCPD
$CaHPO_4$	dicalcium phosphate* فوسفات ثنائي الكالسيوم or: monetite أو المونتيت	DCP
$Ca_8H_2(PO_4)_6.5H_2O$	octacalcium phosphate أوكتا فوسفات الكالسيوم	OCP
$Ca_3(PO_4)_2$	tricalcium phosphate** فوسفات ثلاثي الكالسيوم	TCP
$Ca_5(PO_4)_3OH$	hydroxyapatite هيدروكسي أباتيت	HA
$Ca_5(PO_4)_3F$	fluorapatite فلوريت	FA

* Or: dicalcium phosphate anhydrous (DCPA).

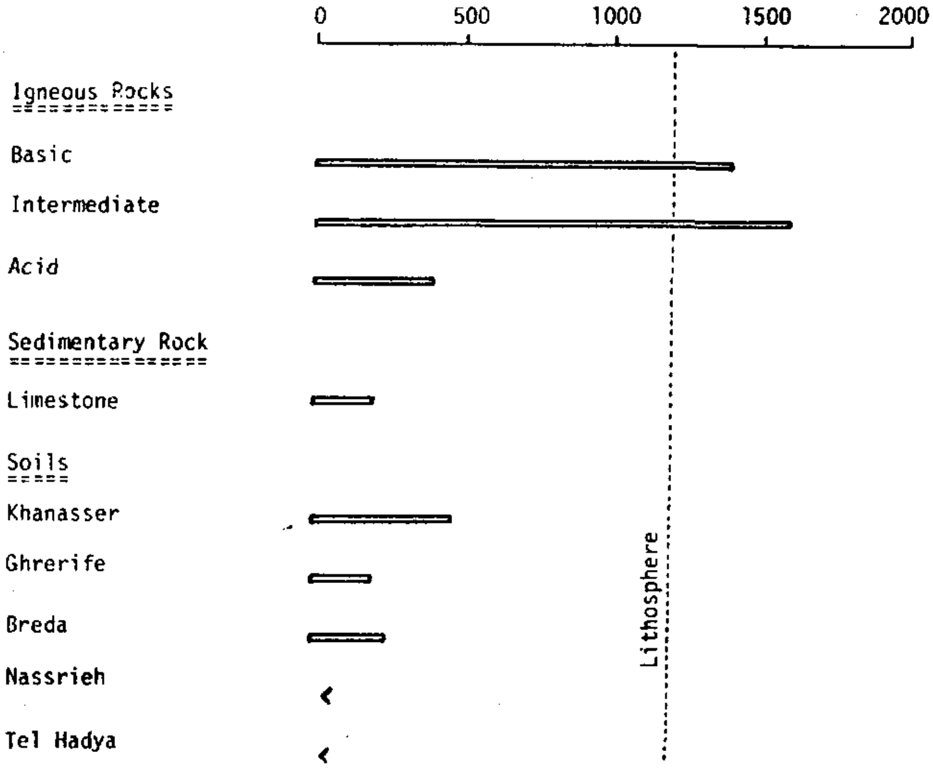
** Occurs in two distinct crystalline forms (α- and β-TCP), with different solubilities.

جدول ٢ - ثوابت الاتزان لبعض اهم التفاعلات في الاراضي الجيرية متضمنة فوسفات الكالسيوم.

Table 2. Equilibrium constants for some important reactions in calcareous soils involving calcium phosphates (Lindsay, 1979).

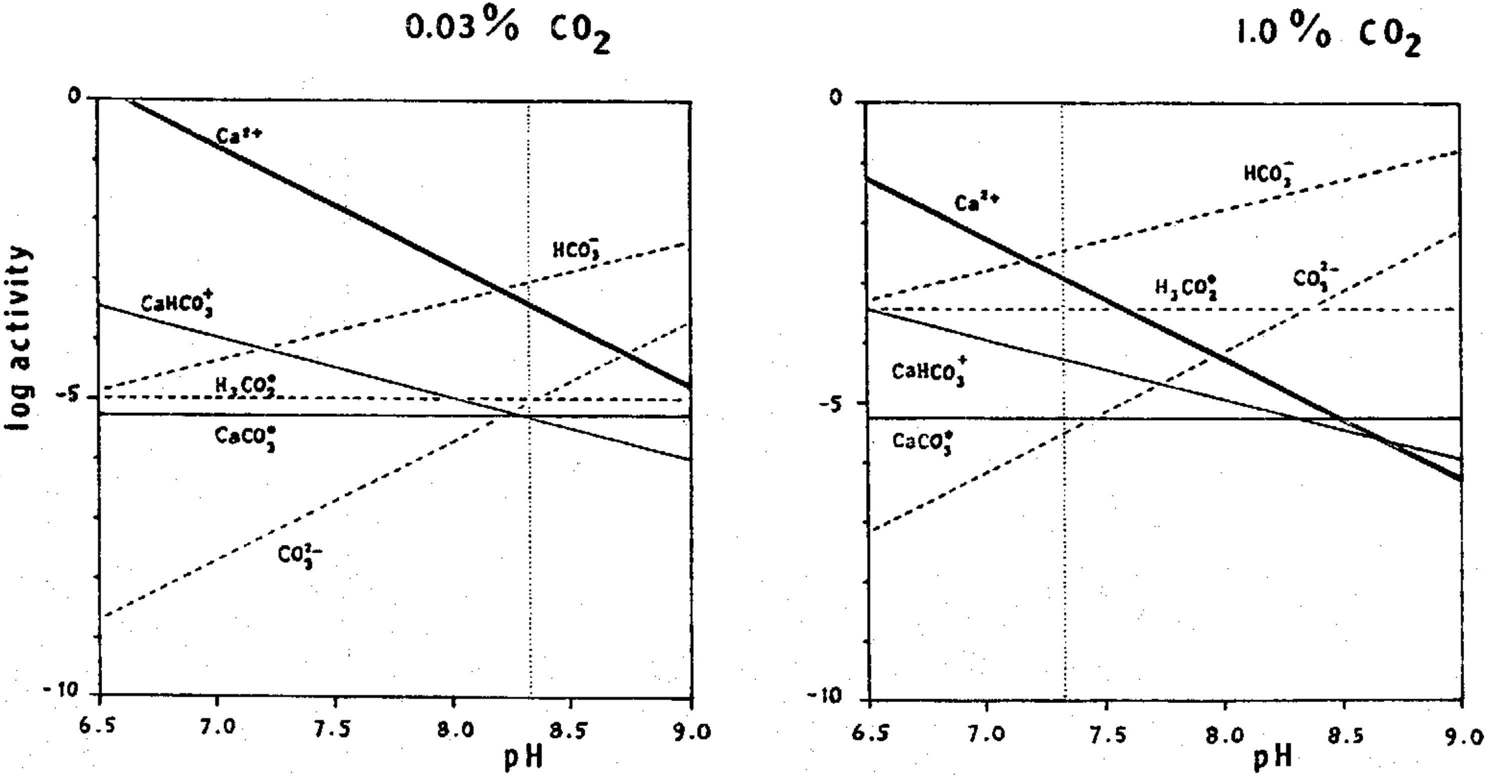
No. الرقم	تفاعل الاتزان Equilibrium reaction	ثابت التفاعل logK°
	تفكك الحامض acid dissociation	
1.	$CO_2(g) + H_2O \rightleftharpoons H_2CO_3^0$	- 1.46
2.	$H_2CO_3^0 \rightleftharpoons H^+ + HCO_3^-$	- 6.36
3.	$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$	-10.33
4.	$H_3PO_4^0 \rightleftharpoons H^+ + H_2PO_4^-$	- 2.15
5.	$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$	- 7.20
6.	$HPO_4^{2-} \rightleftharpoons H^+ + PO_4^{3-}$	-12.35
7.	$H_2O \rightleftharpoons H^+ + OH^-$	-14.00
	تكوين المعقدات complex formation	
8.	$Ca^{2+} + CO_2(g) + H_2O \rightleftharpoons CaHCO_3^+ + H^+$	- 6.70
9.	$Ca^{2+} + CO_2(g) + H_2O \rightleftharpoons CaCO_3^0 + 2H^+$	-15.01
10.	$Ca^{2+} + H_2PO_4^- \rightleftharpoons CaH_2PO_4^+$	1.40
11.	$Ca^{2+} + H_2PO_4^- \rightleftharpoons CaHPO_4^0 + H^+$	- 4.46
12.	$Ca^{2+} + H_2PO_4^- \rightleftharpoons CaPO_4^- + 2H^+$	-13.09
13.	$Ca^{2+} + SO_4^{2-} \rightleftharpoons CaSO_4^0$	2.31
	تفكك المعادن dissolution of minerals	
14.	$CaCO_3 + 2H^+ \rightleftharpoons Ca^{2+} + CO_2(g) + H_2O$	9.74
15.	$CaSO_4.2H_2O \rightleftharpoons Ca^{2+} + SO_4^{2-} + 2H_2O$	- 4.64
16.	$CaF_2 \rightleftharpoons Ca^{2+} + 2F^-$	-10.41
17.	$Ca(H_2PO_4)_2.H_2O \rightleftharpoons Ca^{2+} + 2H_2PO_4^- + H_2O$	- 1.15
18.	$CaHPO_4.2H_2O + H^+ \rightleftharpoons Ca^{2+} + H_2PO_4^- + 2H_2O$	0.63
19.	$CaHPO_4 + H^+ \rightleftharpoons Ca^{2+} + H_2PO_4^-$	0.30
20.	$Ca_8H_2(PO_4)_6.5H_2O + 10H^+ \rightleftharpoons 8Ca^{2+} + 6H_2PO_4^- + 5H_2O$	23.52
21.	$\beta\text{-}Ca_3(PO_4)_2 + 4H^+ \rightleftharpoons 3Ca^{2+} + 2H_2PO_4^-$	10.18
22.	$Ca_5(PO_4)_3OH + 7H^+ \rightleftharpoons 5Ca^{2+} + 3H_2PO_4^- + H_2O$	14.46
23.	$Ca_5(PO_4)_3F + 6H^+ \rightleftharpoons 5Ca^{2+} + 3H_2PO_4^- + F^-$	- 0.21

Figure 1. Abundance of phosphorus in igneous rocks, limestone, and selected soils in Aleppo Province (Milovsky, 1982; Hedley, 1982).



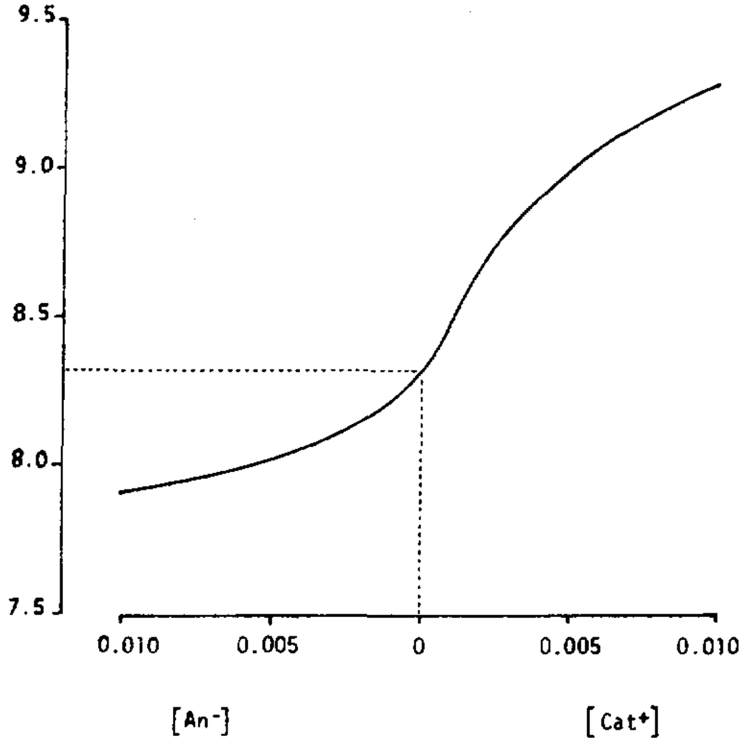
شكل ١ ـ يبين تواجد الفوسفور في الصخور النارية ـ الحجر الجيرى ـ وانواع مختارة من التربة في حلب

Figure 2. Aqueous activities of calcium and carbonate species in equilibrium with calcite, as a function of pH. The dotted lines denote the equilibrium composition of pure $CaCO_3$-H_2O systems at CO_2 levels of 0.03% (left) and 1.0% (right).



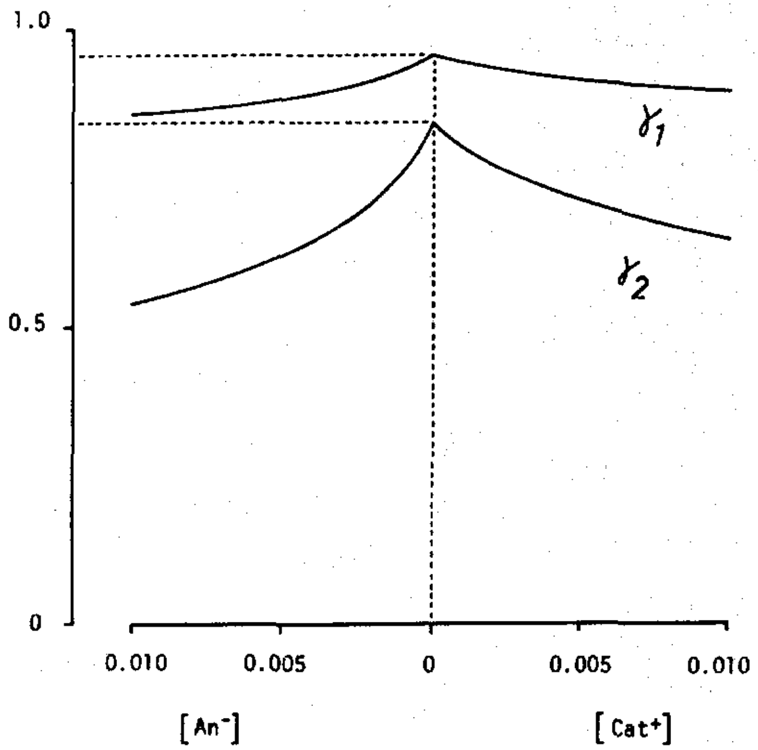
شكل ٢ ـ نشاط اشكال الكالسيوم والكربونات في الماء ـ في توازن مع الكالسيت ـ وذلك مع تغير PH . الخطوط المتقطعة تبين مكونات الاتزان في انظمة كربونات الكالسيوم ـ الماء مع مستويات متغيرة من ثاني اكسيد الكربون ـ ٠٣ر نسبة مئوية (يسار) ، ١ نسبة مئوية (يمين).

Figure 3. pH of aqueous solution in equilibrium with calcite at a CO_2 level of 0.03% (v/v), as a function of the concentrations (mol/l) of monovalent cations (right) or anions (left).



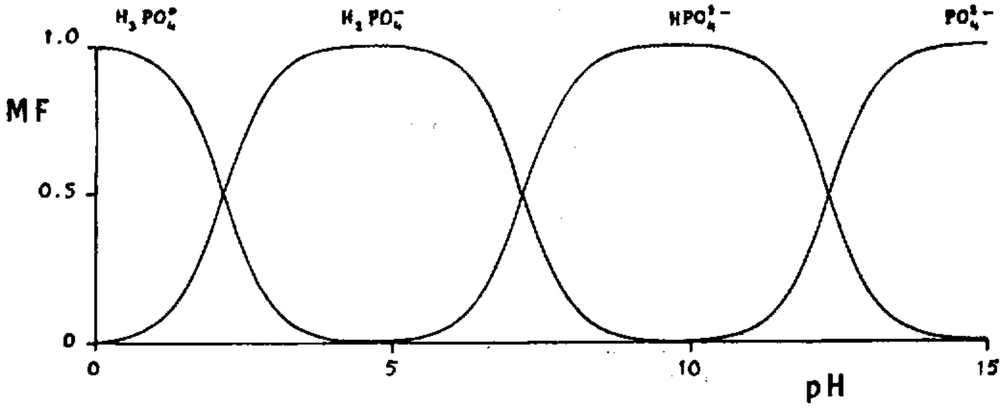
<u>شكل ٣</u> ـ يبين PH المحلول المائي في اتزان مع الكالسيت عند مستوى ثاني اكسيد الكربون (٣٠ر٠ نسبة مئوية) وذلك مع تغير تركيزات الكاتيونات الاحادية التكافوء (يمين) ـ والانيونات (يسار)٠

Figure 4. Activity coefficients of monovalent (γ_1) and divalent ions (γ_2), calculated from the Davies equation, in aqueous solution in equilibrium with calcite (0.03% CO_2), as a function of the concentrations (mol/l) of monovalent cations (right) or anions (left).



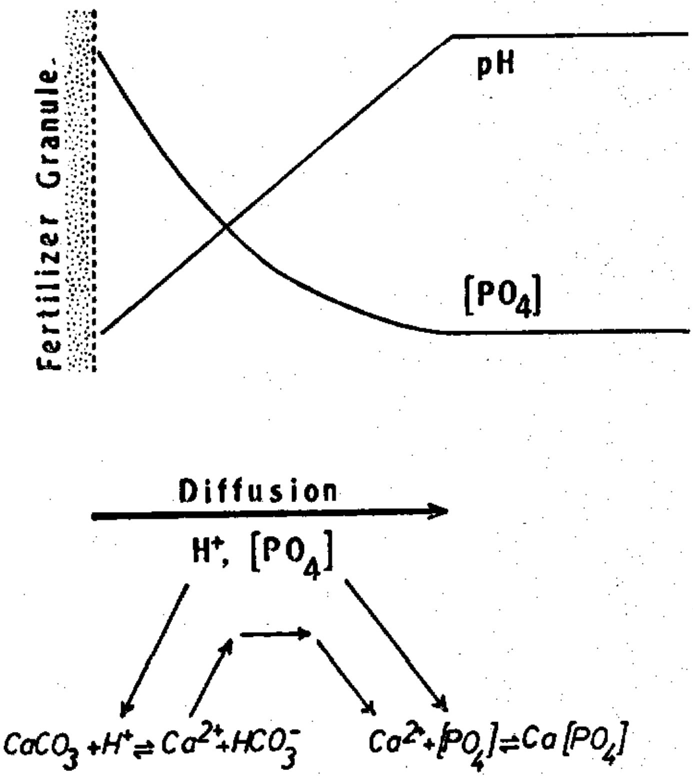
شكل ٤ – يبين معاملات النشاط للايونات الاحادية التكافوء (γ_1) – والثنائية التكافوء γ_2 – محسوبة من معادلة Davies – وذلك في محلول مائي في حالة اتزان مع الكالسيت (٠ر٠٣ نسبة مئوية ثاني اكسيد الكربون) وذلك مع تغير تركيزات الكاتيونات الاحادية (يمين) او الانيونات (يسار).

Figure 5. Aqueous phosphate species, expressed as mole fractions, MF, plotted as a function of pH in solution.



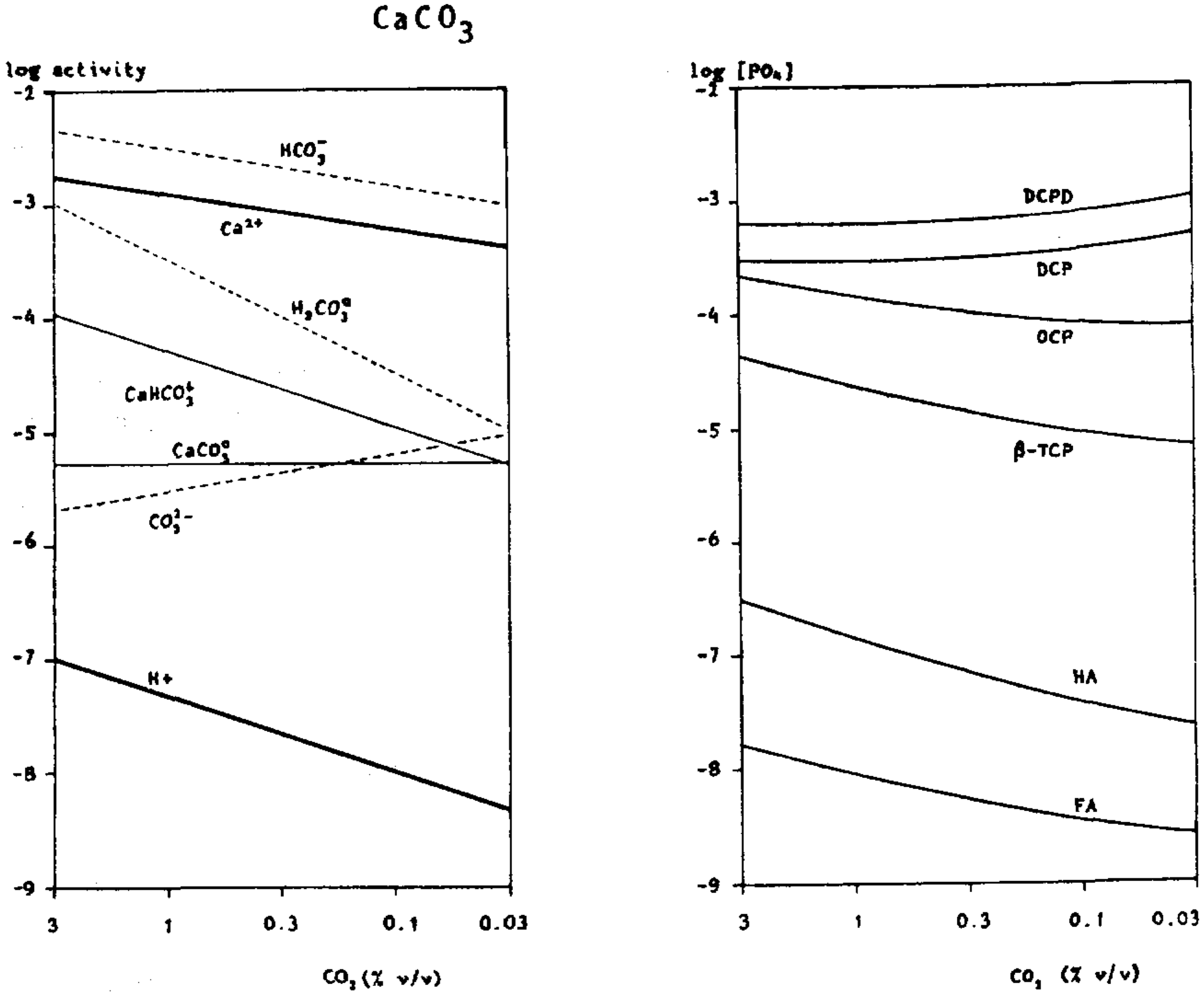
شكل ٥ ـ اشكال الفوسفات الماثية ـ معبرا عنها كاجزاء بالمول ـ وتغيرها مع تغير درجة PH المحلول.

Figure 6. Schematic representation of pH and orthophosphate concentration as a function of distance to a phosphate fertilizer granule.



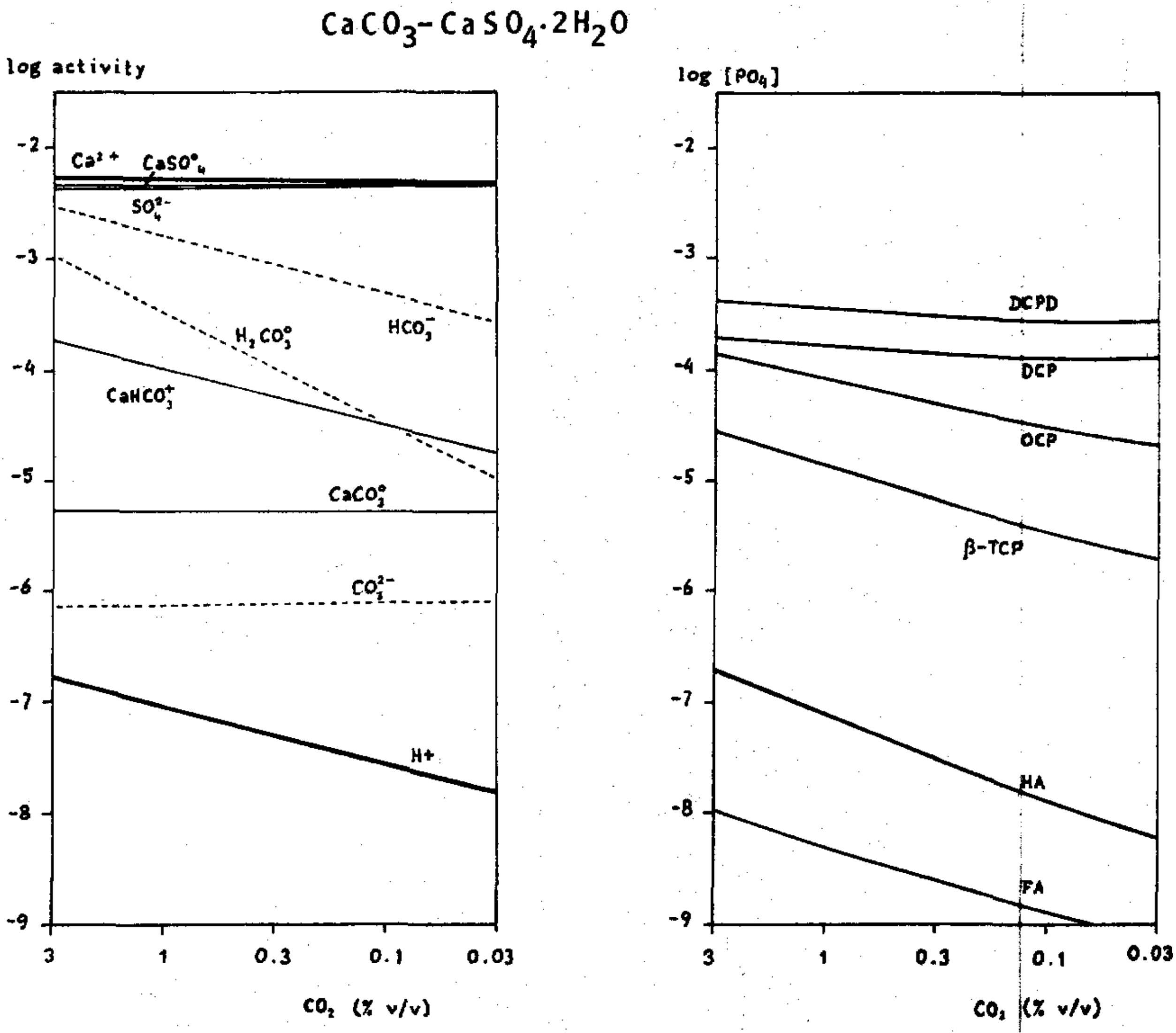
شكل ٦ - يبين عرض تدريجي للـ PH وتركيز الارثوفوسفات وتغير ذلك مع المسافة عن حبيبة السماد الفوسفاتي.

Figure 7. Aqueous calcium and carbonate species in equilibrium with calcite, as a function of CO_2 level (left). Total inorganic phosphate concentrations in aqueous solution in equilibrium with calcite and different calcium phosphates (see Tables 1 and 2) as a function of CO_2 level (right).



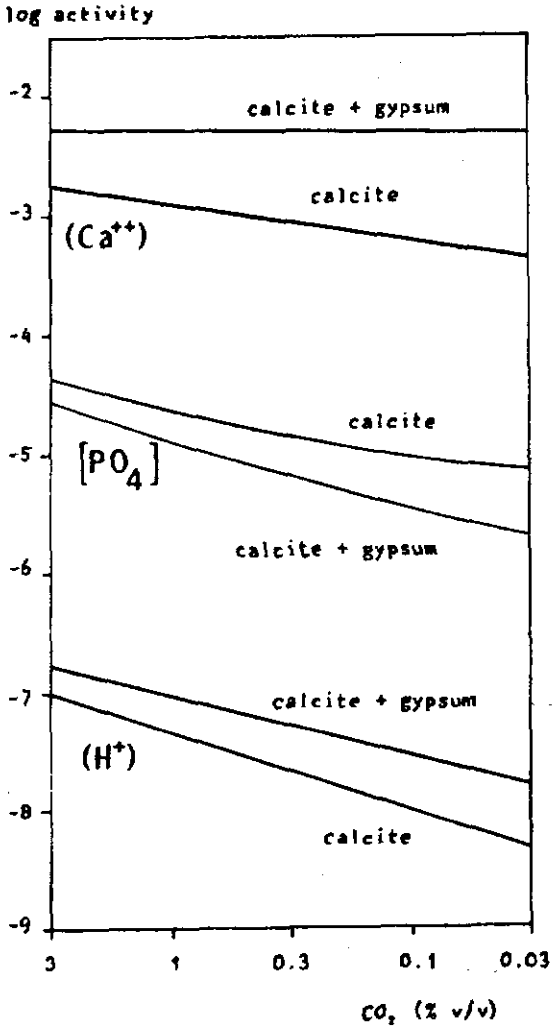
شكل ٧ – يبين اشكال الكالسيوم والكربونات في الماء في حالة اتزان مع كربونات الكالسيوم مع تغير مستوى ثاني اكسيد الكربون (يسار). تركيزات الفوسفات الكلي المعدني في المحلول المائي في حالة اتزان مع كربونات الكالسيوم وصور مختلفة من فوسفات الكالسيوم (انظر جدول ١ و ٢) وذلك على تغير مستويات ثاني اكسيد الكربون (يمين).

Figure 8. Aqueous calcium, carbonate and sulfate species in equilibrium with calcite and gypsum, as a function of CO_2 level (left). Total inorganic phosphate concentrations in aqueous solution in equilibrium with calcite and gypsum, and different calcium phosphates (see Tables 1 and 2) as a function of CO_2 level (right).



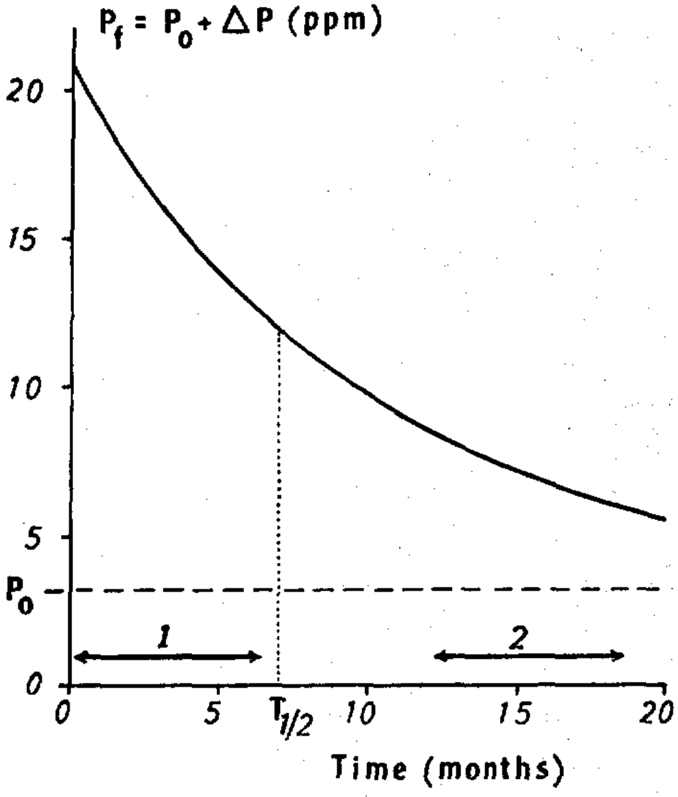
شكل ٨ – يبين اشكال الكالسيوم والكربونات والكبريتات في الماء في حالة اتزان مع كربونات الكالسيوم والجبس مع تغير مستويات ثاني الكربون (يسار). تركيزات الفوسفات الكلي المعدني في المحلول المائي في حالة اتزان مع كربونات الكالسيوم والجبس وصور مختلفة من فوسفات الكالسيوم (انظر جدول ١ و ٢) وذلك على تغير مستويات ثاني اكسيد الكربون.

Figure 9. Aqueous calcium and hydrogen ion activities, and total inorganic phosphate concentrations in equilibrium with calcite or calcite plus gypsum, and β-tricalcium-phosphate, as a function of CO_2 level.



شكل ٩ – يبين نشاط ايون الهيدروجين والكالسيوم في الماء – وتركيزات الفوسفات الكلي غير العضوى وذلك في حالة اتزان مع كربونات الكالسيوم والجبس – وبيتا فوسفات الكالسيوم الثلاثي – مع تغير مستويات مختلفة من ثاني اسكيد الكربون.

Figure 10. The decrease in Olsen-extractable phosphorus with time in soils that received 60 kg P_2O_5/ha at t=0, for an initial phosphorus content of 3.2 ppm (broken line) and a half-life of 7 months (dotted line). The first and second growing season following the application of fertilizer are indicated by arrows.



شكل ١٠ ـ نقص الفوسفور ـ المقدر بطريقة اولسن ـ مع الزمن في عينات تربة سمدت بمعدل ٦٠ كيلوغرام/هكتار P_2O_5 ـ عند الزمن T = صفر. وذلك عند محتوى فوسفورى ابتدائي قدره ٣ر٣ جزء من المليون ـ وفترة نصف عمر قدرها ٧ شهور (الخط المتقطع). ويرمز بالاسهم الى الموسمين الزراعين الاول والثاني والتي اعقبت اضافة السماد.

THE INFLUENCE OF PRECIPITATION REGIME ON THE CROP MANAGEMENT OF DRY AREAS IN NORTHERN SYRIA

by

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INTRODUCTION

In Northern Syria approximately 750,000 ha of barley are grown each year. This is almost exclusively found under rainfed conditions in an ecological zone characterized by seasonal precipitation totals between 150 and 350 mm. This precipitation is unimodally distributed in time and falls largely in the cool winter season. In this area barley is traditionally grown as, either a continuous crop, or in a two course fallow/barley rotation, or in more complex permutations of fallow and barley. Yields of barley are generally low (< 1 t/ha of grain) and cash investment in improved management practices such as the addition of fertilizer is generally minimal.

In this study we have examined the characteristics of the precipitation regime of three sites in Northern Syria in the light of the manner in which they influence crop management decisions and how the importance of this influence may vary within a single ecological zone. The sites selected are representative of the wet, intermediate and dry phases of the ecological zone in question. The sites were Aleppo (36°11'N, 37°13'E), Breda (35°55'N, 37°10'E) and Khanasser (35°47'N, 37°30'E) for which the long term average seasonal precipitation totals are 332, 278 and 214 mm respectively (Dennett, Keatinge and Rodgers, 1984).

DATA AND METHODS

Daily rainfall data for the three sites described were obtained from the Syrian Ministry of Defence, Meteorological Department. Record lengths ranged from 26 years at Aleppo to 15 years at Khanasser but some years were incomplete. The precipitation season was taken as August to July in accordance with cropping patterns.

The method of analysis adopted was to fit rainfall models of the form described by Stern, Dennett and Dale (1982). These describe how the probability of rain occurring on any day and the frequency distributions of rainfall amounts vary throughout the year. Days with less than 2 mm of rain were considered to be dry. Full methodological details and more complete meteorological results are given in Dennett, Keatinge and Rodgers (1984).

RESULTS AND DISCUSSION

Sowing Time

There are indications in this ecological zone that early crop establishment and canopy development of barley are associated with higher yields (Cooper et al., 1981 and Cooper, Keatinge and Hughes, 1983). However, early sowing will only prove to be an advantage if germination also occurs early and if the crop can survive potential drought conditions at the seedling stage. For germination to occur moisture must penetrate the upper soil profile over the range in seeding depth 2-12 cm. Whether, such moisture penetration will occur will depend upon several factors: the amount of rain, the number of days over which it falls, the associated atmospheric demand for moisture over those days and the relative dryness of the soil surface. Use of the rainfall models described in Dennett, Keatinge and Rodgers, 1984, allows examination of a wide range of alternative definitions of the events capable of causing crop germination. We have selected two such definitions for purposes of illustration.

The data shown in Table 1 indicate that germination at the wettest site, Aleppo, can be expected to occur 10-20 days earlier than at the driest site Khanasser. This will confer a potential yield advantage to the wetter site by extending the duration of the effective growth period. This is caused by the warmer temperatures (Figure 1) causing more rapid seedling emergence and canopy development which generally results in improvements in crop water use efficiency (Cooper, Keatinge and Hughes, 1983). For this effect to be of importance seedling emergence needs to occur before air temperatures fall to normal winter levels as typified by December and January.

Following crop germination, the survival of the crop in the seedling stage is dependent on both stored soil moisture from the germinating event and the length of time before the succeeding event of effective magnitude. In Figure 2a and b the data presented indicate that given a germination date of mid-November 1½-2 years out of ten the crop at Khanasser will have to withstand a drought of >20-30 days duration. For the other sites the probability of this type of seedling drought is less than one year in ten. However, it can be seen in Figure 2 that as the germination date is advanced into early November the risk of experiencing such an event begins to increase substantially.

On the evidence of this analysis early sowing would be recommended for the wetter phase of the ecological zone and some need for caution seems indicated for the drier phase. However, this recommendation is strongly influenced by sowing method considerations and their influence on crop germination.

Sowing Method

It is a common practice in this ecological zone for farmers to sow their crops dry well before the likely start of the rainy season (for migratory labour reasons). This means that their risk of experiencing post germination drought is substantial. However, their traditional sowing method provides a buffering capacity against complete crop loss from this drought risk. In this method the land is ridged up either by "feddan" plough or ducks foot cultivator, seed is then hand-broadcast at a high rate (100-150 kg/ha) over these ridges and the ridges are then split burying the seed at highly variable depths from 2-12 cms. As a result it is possible to have partial germination of the shallower placed seed from a lighter germinating rain event. This portion of the crop may be killed by drought,but if so,the deeper placed seed often remains to be germinated later thus providing a thinner,but probably adequate,replacement crop stand.

Unfortunately, the use of seed drills, which are being introduced into these areas, by sowing at a more constant and shallower depth (5 cm) do not incorporate this useful "insurance factor." Cooper _et al._, (1981), have recorded a 9% yield increase by drilling over the traditional farmer practice in a year with well distributed and above average precipitation.

The differences between sites shown in Figure 2 suggests that the risk of seedling stage drought should be a serious consideration before recommendations are made for drier sites concerning technologically "improved" sowing methods.

Nitrogen Top Dressing

In the drier barley growing areas, as represented by Breda and Khanasser, farmers rarely apply nitrogen fertilizer to rainfed barley crops. However, at the wetter end of the ecological zone, and in cases of farmers growing continuous barley, some nitrogen may be added or if not, there is at least a considerable potential for a supplemental addition. Similarly, at Breda and Khanasser the wide range in annual rainfall experienced (Figure 3), indicates that in good years top dressing with N fertilizer might be a profitable strategy where soil N levels are low.

If a farmer is to be able to take advantage of these better seasons, top dressing would have to take place no later than March 1st. This is to ensure that there will be adequate time for the fertilizer to become available to the crop and for this to occur at an early enough crop growth stage to be effective in increasing yield. As a result his decision has to be made on a basis of rainfall received, but clearly the later this can be deferred, the less is the risk of him making a wrong decision. In Table 2 the data shown indicate that at Aleppo, in more than five years out of ten, more than 200 mm will have fallen by March 1st. Top dressing with N in these years would be likely to be a profitable management practice where soil N levels are low. In contrast, at Khanasser and Breda a farmer would only have received this amount of rain one and three years out of ten respectively, fertilizer application therefore would appear to be a high risk practice.

Choice of Cultivar

In the near future, farmers in Northern Syria may have the option of choosing to seed one of several potentially higher yielding genetically uniform cultivars rather than the traditional landraces. One important factor which will influence the success of their decision will be the time to maturity of the improved cultivar. In this ecological zone, crops are often dependent on very inadequate soil moisture reserves during their grain-filling period. As a result if very little precipitation is received in the grain-filling phase, the farmer runs the risk of having a crop consisting of large proportion of small or shrivelled grains. These will not only result in lower yields but may effect the viability of his seed-stock for the following year. The risk of such an event can be seen from the data in Figure 4 to vary substantially between sites and to increase for every additional seven days in which anthesis is deferred after April 14 (a typical value for the local landrace Arabic black).

It is clear therefore that, at a very dry site such as Khanasser, if very early "improved" cultivars can be made available this might assist in reducing the risk of inadequate grain size and would help to stabilize yield levels in years with a potentially dry grain-filling period.

Furthermore, to combat this risk at dry sites it would seem feasible that farmers might adopt a policy of harvesting the crop green for hay around anthesis (currently an unknown practice in this region) thereby artificially curtailing the growth season and reducing the crops' seasonal moisture requirement. Any yield loss sustained by this practice might be offset by a likely improvement of the feeding value of the hay over that of the straw (Thomson, Nordblom and Bahhady, 1984). Straw, value often being equivalent to that of grain in this area (Nordblom, 1983).

Phosphate Application

In soils where the level of plant available phosphate is low, it is evident that the phenological development of barley can, under certain environmental conditions, be strongly influenced by the addition of phosphate fertilizer (Cooper *et al.*, 1981; Cooper, 1983 and Cooper, Keatinge and Hughes, 1983). This influence is generally expressed as an increased rate in development, resulting in physiological maturity occurring up to 10-14 days earlier in crops receiving supplemental phosphate.

As a result the risks faced by later maturing crops (Figure 4) may be reduced by application of phosphate. This would assist in the promotion of yield stability and is particularly applicable to the driest areas such as Khanasser where the risk of terminal drought is highest. This benefit from phosphate is probably additional to that of yield increases that, *per se*, are gained from an overall reduction of crop nutrient stress.

Choice of Crop Species

In this ecological zone, particularly in its drier half, barley is virtually the only crop grown. The principal reason given by farmers in Northern Syria for this practice seems to be inadequate rainfall to support other crops, (Somel, 1984). However, the potential value of other crops are currently under consideration by ICARDA scientists such as annual legume forages (Keatinge, Cooper and Hughes, 1984) and permanent pastures (Ceccarelli, 1982). The return frequency of very dry years would seem to be a powerful consideration in the future decision to be faced by farmers as to the possible introduction of new crops into their rotations with barley. Or furthermore, possibly abandoning barley altogether and opting for permanent pastures. At Khanasser for example, it can be seen from the data in Figure 3 that at least four years out of ten the site will have a seasonal rainfall of less than 175 mm. To grow barley in such dry years must increase the risk of soil degradation and erosion substantially and eventually encourage desertification. A permanent pasture, of acceptable productivity, would seem to be a desireable and in the long run probably profitable alternative crop to barley for farmers at very dry locations. Additionally, at Breda, though the return frequency of very dry years is half that of Khanasser, it is still not insignificant. The inclusion of more shorter duration hay crops, particularly those of the annual legumes, into farmer's rotations may be a mechanism in which greater yield stability can be obtained at such locations.

In a wetter site, as represented by Aleppo, the risk of a very dry year (< 175 mm) is low approximately 2% (Figure 3) and as such suggests that farmers have a much wider choice of potentially profitable crops to grow and as such this site represents a transitional phase into the next wetter ecological zone which is dominated by wheat, grain legume and summer grown crops (water melon, sesame, etc.).

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TABLE 1 Median dates for rain events causing germination after selected sowing dates.

a) Conditional on receiving > 10 mm in three days.

Median date following	ALEPPO	BREDA	KHANASSER
1/10	29/10	4/11	12/11
1/11	15/11	20/11	27/11
1/12	9/12	13/12	18/12

b) Conditional on receiving > 20 mm in three days.

Median date following	ALEPPO	BREDA	KHANASSER
1/10	22/11	1/12	25/12
1/11	3/12	8/12	1/1
1/12	22/12	27/12	16/1

TABLE 2 The probability of receiving different amounts of seasonal precipitation by March 1st.

Probability of receiving rainfall (mm) less than	ALEPPO	BREDA	KHANASSER
100	0.02	0.07	0.26
150	0.15	0.22	0.68
200	0.48	0.67	0.94
250	0.78	0.90	0.99
300	0.93	0.98	1.00

Figure 1 Mean monthly screened air temperature at Aleppo (1960-1982).

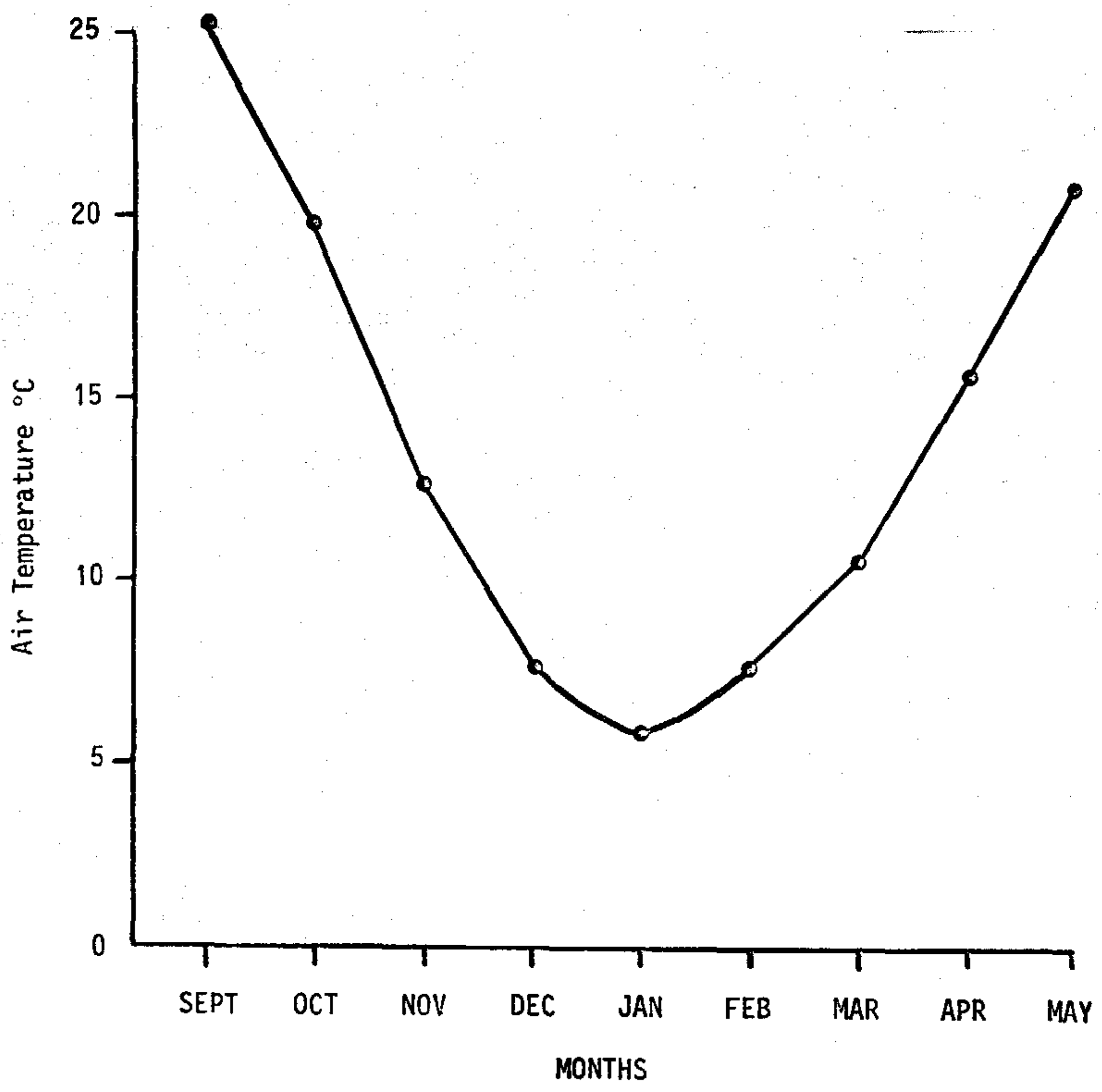


Figure 2a. The risk of receiving less than 5 mm of precipitation in the twenty days following crop germination at three sites in Northern Syria.

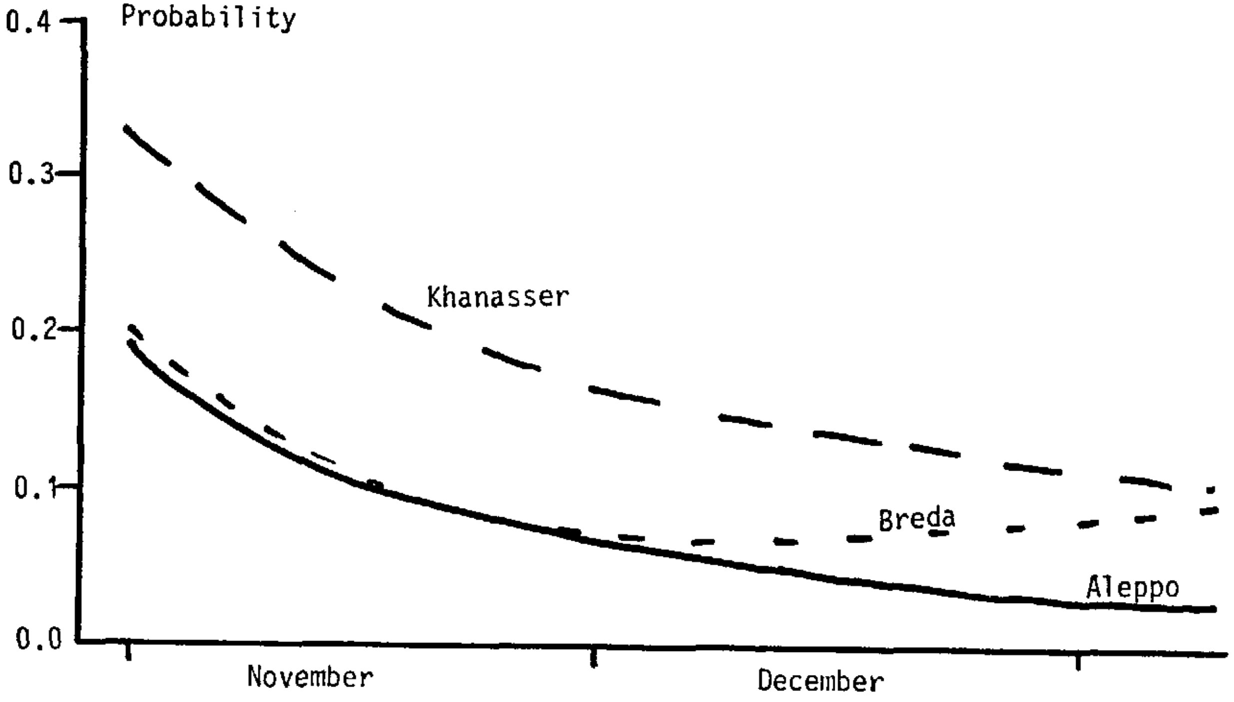


Figure 2b. The risk of receiving less than 5 mm of precipitation in the thirty days following crop germination at three sites in Northern Syria.

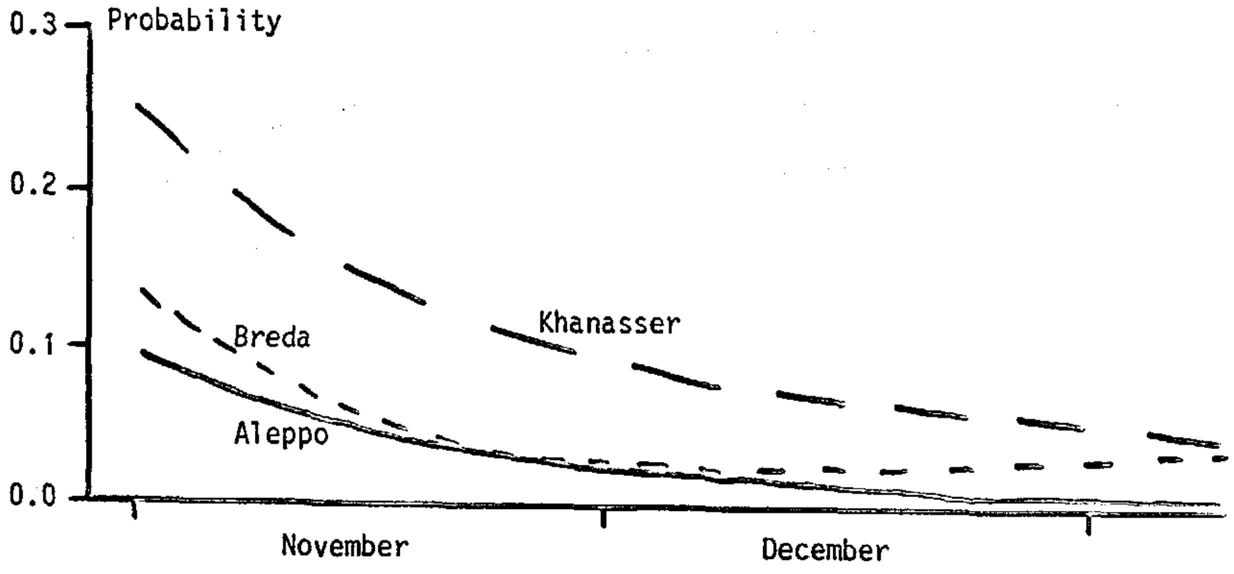


Figure 3. The probability of attaining specific seasonal precipitation totals at three sites in Northern Syria.

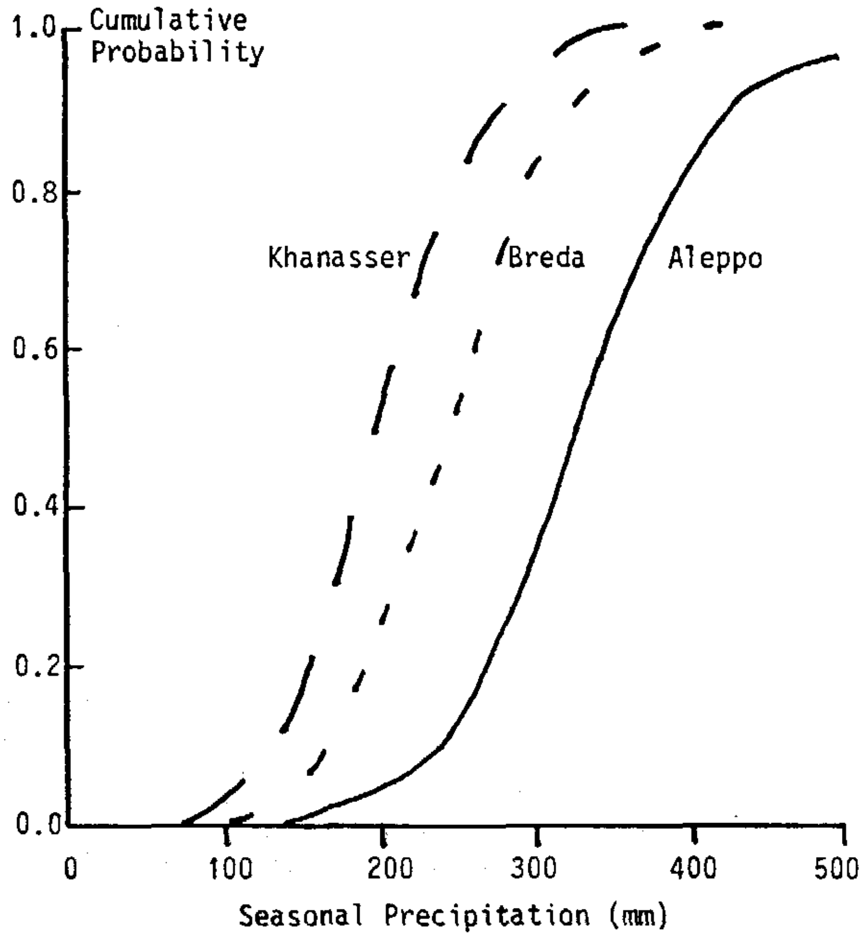
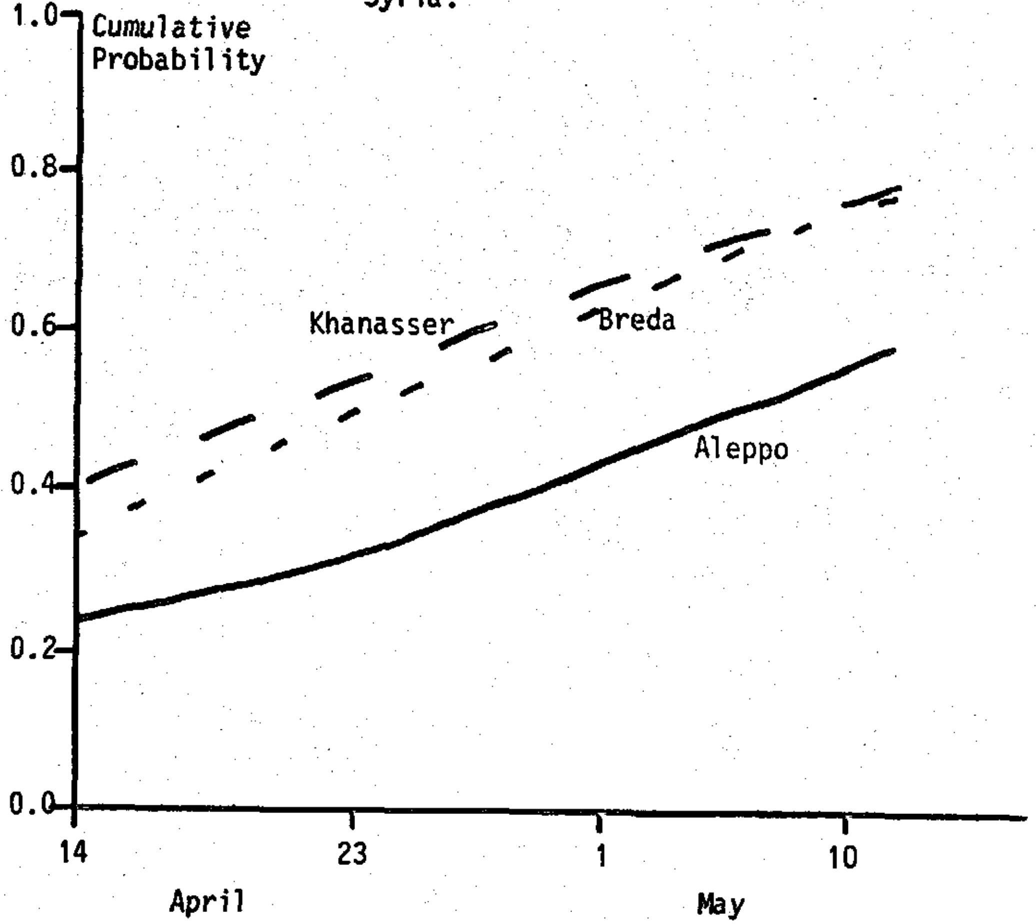


Figure 4. The probability of receiving less than 10 mm of precipitation within thirty days of the date on the time axis at three sites in Northern Syria.



ROTATIONS AND YIELD EXPECTATIONS IN BARLEY PRODUCTION IN SYRIA

By

Kutlu Somel

Revised

February 1984

Farming Systems Program
(ICARDA)

INTRODUCTION

A critical dimension of barley production appears to be the rotations practiced. In the Barley Survey conducted in 1981/83, in order to gain a better understanding about rotations, two specific questions were asked to farmers about the largest plot of barley: 1/

1. What crop was on the largest plot in 1980/81?

2. What was the usual crop rotation practiced on the largest barley plot?

It was expected that the answers to the first question could then be related, along with other things, to yields in 1981/82. This would have given fairly concrete evidence about the effects of different rotations. However, 1981/82 turned out to be a rather poor year for barley production due to adverse climatic conditions. Consequently, low yields were realized and in many cases fields were grazed. Until now, this has perevented us from establishing a meaningful correspondence between "crop on plot in 1980/81" and yields in 1981/82. However, it was possible to look at the effects of rotations through another perspective.

1/ Complete and detailed information about production practices, inputs and yields were sought for the largest barley plot.

This perspective uses information from the answers to the second question presented above and information utilized in deriving long-run yield expectations of barley producers.[1]

One point needs to be emphasized: the question about the usual crop rotation was asked in relation to the largest barley crop. Subsequently, in other parts of the barley survey questionnaires, questions were asked about expected yields in good, poor and normal years. However, these expected yields were asked in general terms and not in relation to the largest barley plot specifically.

If different crop rotations have different effects on yield levels and if farmers have different rotations on different plots, then the results of this paper have to be viewed with caution.[2]

This is because we will essentially be relating usual crop rotations on the largest plot to yield expectations related to the farm as a whole. We suspect that inter-plot differences on a farm are not that great to totally invalidate the results of this paper. However, as we have no supporting evidence we would like to recommend caution and a reasonable amount of healthy skepticism.

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[1] For details of this, cf. K. Somel, "Long Run Yield Expectation of Barley Producers in Syria," FSP/ICARDA, February 1983. (Mimeo).

[2] Caution is necessary if there are significant yield differences between plots in a farm due to other reasons.

The number of plots that farmers have can be considered as a basis for this skepticism:

a. Average number of barley plots are 3.05 in West Syria and 2.32 in Northeast Syria. The differences are significant at 2 percent.

b. Differences in the number of barley plots between zones are significant (at 10 %) only in West Syria; 2.87 for Zone 2, 2.79 for Zone 3 and 3.83 for Zone 4.

c. Only 10.9 percent of the farmers in the West have only one barley plot whereas 41.7 percent of the farmers in the Northeast have only one barley plot. Those who have two plots comprise 34.1 percent of the farmers in the West and 29.8 percent in the Northeast. The percentage of farmers who have four plots or less is 85.6 percent in the West and 92.9 percent in the Northeast.

The dominant rotations are barley-fallow (B-F), continuous barley (B-B) and barley-barley-fallow (B-B-F). The first two rotations essentially cover 76.8 percent of the barley producers in the sample but B-F is dominant in the West whereas B-B is dominant in the Northeast. (Table 2). We also checked whether the planting of barley on the largest plot in 1981/82 was consistent with the usual crop rotations on this plot. It was found that at least 16 farmers (10.5 %) were deviating from their declared crop rotations. (Table 3).

ROTATIONS AND YIELD EXPECTATIONS

In this section we will try to related yield expectations to rotations. Two points need to be emphasized in this respect:

a) The yields that occur in a given year may differ from expectations for such a year because expectations may suffer from random and systematic errors due to their subjective nature. Consequently, we should be careful in extending results about yield expectations to actual yields.

b) Numerous factors may influence the formulation of expectations such as the environment, input use, practices, etc. For the purposes of this paper, we will be looking at whether yield expectations differ between different rotations, ignoring the effects of these other factors. This does not mean that we do not recognize their importance and possible effects; they will be analyzed in future studies.

In results not presented here, it was found that the category of "Other" rotations was invariably a highly heterogeneous entity and it had considerably higher yields than the three dominant rotations of B-F, B-B and B-B-F. Consequently, we exluded this relatively atypical and non-uniform category in further analysis.

In Table 4, long run expected yields are presented by rotations. Tests of significance of yield differences between rotations were conducted only for the West, Northeast and total Syria (Northern). Tests were not conducted on a zonal basis in each regime due to the lower number of observations at this level.

The results indicate that in long run yield expectations,1/ significant differences exist between B-F and B-B-F and between B-B and B-B-F. The differences between the two dominent rotations of B-B and B-F are not significant. This, on the surface, appears to be not in conformity with the results of FSP trials.

1/ The number of observations in Table 4 are lower because not all farmers were able to give a distribution of good, poor and normal years.

In FSP trials, there is evidence of yield advantages of B-F rotations over continuous barley. However, the drier sites in which these trials have been conducted have a B-F rotation as the dominant practice rather than continuous barley.[1/] In other words, if common practices of farmers reflect the wisdom of experience, continuous barley has been found to be unsuitable for these areas.

The same principle, i.e., common practices can also be used in interpreting the results of the survey. Notice that B-F is dominant in the West and continuous barley is dominant in the Northeast.[2/] In other words, the exception of the rule is B-B in the West and B-F in the Northeast. It can be hypothesized that these exceptions can not survive unless they perform at least as good as the dominant practice. It is also possible that these exceptions may occur in environments more suitable to them. It is difficult to check for this at the level of generality of zones.

In conclusion then, yield expectations based on current technology and on different rotations indicate that an adaptation process may have taken place whereby different rotations have found their niches in ideal locations and perform quite satisfactorily as compared to the averages of dominant practices.

The challenge now is to find ways of improving the level and stability of agricultural production through technological change. This necessitates research on introducing viable practices, inputs and alternative rotations.

[1/] These sites are Breda and Khanasser. The three other sites are in higher rainfall areas which are fertile and barley is produced in more complex rotations.

[2/] Other factors of a socio-economic nature may be causing the dominance of continuous barley, also popularly known as "mining" barley.

TABLES

a. **Notation:**

$\bar{x}$: the average

s : standard deviation-presented in parentheses

n : number of observations

I : statistically not different from zero.

b. The results for significance of differences are based on F-tests from one-way analyses of variance.

c. Some percentages may not add up to 100 due to rounding.

Table 1. Percentage distribution of barley producers according to the crop on the largest barley plot in 1980/81.

	ZONE 2		ZONE 3		ZONE 4		N. SYRIA		N. SYRIA
	West	Northeast	West	Northeast	West	Northeast	West	Northeast	Total
Fallow	70.0	28.6	45.8	11.1	70.0	11.1	61.6	15.5	36.3
Barley	20.0	57.1	37.5	81.5	20.0	86.1	26.1	77.4	54.2
Other	10.0	14.3	16.7	7.4	10.0	2.8	12.3	7.1	9.5
n	30	21	24	27	15	36	69	84	153

Table 2. Percentage distribution of barley producers according to the usual rotation practiced on the largest barley plot in 1980/81.

	ZONE 2		ZONE 3		ZONE 4		N. SYRIA		N. SYRIA
	West	Northeast	West	Northeast	West	Northeast	West	Northeast	Total
Barley-Fallow	66.7	33.3	50.0	18.5	63.3	8.3	60.1	17.9	36.9
Barley-Barley	13.3	28.6	29.2	40.7	20.0	83.3	20.3	56.0	39.9
Barley-Barley-Fallow	10.0	33.3	8.3	40.7	16.7	8.3	10.9	25.0	18.6
Other	10.0	4.8	12.5	0.0	0.0	0.0	8.7	1.2	4.6
n	30	21	24	27	15	36	69	84	153

Table 3. Consistency of declared usual rotations with crop on largest barley plot in 1980/81 (number of farmers).

ROTATION	Barley-Fallow	Barley-Barley	B-B-F	Other	Total
<u>Crop Last Year</u>					
Fallow	50	0	6	0	56
Barley	7	59	17	1	83
Other	0	3	6	6	15
Total	57	61	29	7	153

Table 4. Average long run expected yields (kg/ha) according to the usual rotation practised on the largest plot.

		ZONE 2		ZONE 3		ZONE 4		N. SYRIA		N. SYRIA
		West	Northeast	West	Northeast	West	Northeast	West	Northeast	Total
Barley-Fallow	x̄	385.0	718.6	1107.0	801.5	524.0	700.0	588.5	750.0	646.3
	s							(379.5)	(258.1)	(345.8)
	n	11	5	5	5	6	2	22	12	34
Barley-Barley	x̄	1119.3	947.0	762.7	679.0	465.8	560.5	801.2	642.8	673.8
	s							(377.4)	(280.3)	(303.3)
	n	3	5	3	8	3	22	9	35	44
Barley-Barley-Fallow	x̄	1416.0	1323.9	448.5	874.1	841.3	526.1	975.4	924.4	940.6
	s							(794.9)	(396.3)	(534.6)
	n	3	4	2	8	2	3	7	15	22
Significance level of yield differences between:										
a. BF, BB and BBF								I	2 %	2 %
b. BF and BB								I	I	I
c. BB and BBF								I	1 %	2 %
d. BF and BBF								10 %	I	2 %

THE FERTILIZER (NP) AND WATER REQUIREMENTS OF BARLEY IN CYPRUS

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SUMMARY

Barley is a highly versatile crop grown in Cyprus for grain and straw, fresh forage, or hay production. It grows relatively fast during the winter, thereby reaching maturity before the onset of very dry conditions. Moreover, it suffers little from diseases and pests and, because of its fast growth, it smothers weeds, including wild oats. These merits have established barley as the major agronomic rainfed crop, which is grown on 90 % of the cereal acreage. Rainfall over the period October-April (the rainy season) is on average 300 mm, but varies considerably both in amount and in distribution. In two out of ten years, it will be higher than 375 mm, and in another two it will be less than 270 mm. The success of barley under these conditions has been shown to be due to its water requirement matching the average rainfall, i.e. it requires about 300 mm of water. The soils are calcareous (they contain 20-30 % $CaCO_3$) and are inhenrently deficient in N and P (they contain 0.1 % N and 1-5 ppm bicarbonate extractable P), but are well supplied with K (they contain 300 ppm exchangeable K). Therefore, N and P, but not K, must be supplied through fertilizing. One ton of barley sheaf (grain + straw) dry matter removes about 12 kg N. For continuous barley growing, which is presently the practice in Cyprus, 50-70 kg N and 15-20 kg P_2O_5/ha are applied and grain yields ranging between 2,500 and 4,500 kg/ha are obtained. Response to P was more pronounced in drier years, particularly if only a limited volume of soil was wetted in the early part of the season. The threshold value for P sufficiently appears to be 6 ppm bicarbonate-extractable P. Nitrogen invariably increased concentration of K in the straw linearly, whereas phosphorus, decreased K in barley forage when soil K was just sufficient. Nitrogen not used because of drought, remained in the soil and was available for the following crop. On the other hand, some excess of N did not appreciably reduce yields. To take best advantage of whatever rainfall occurs, adequate N and P should be applied. However, excessive N application must be avoided because, in addition to causing lodging, it increases K concentration in the straw and consequently depletes soil K

reserves faster, since straw in Cyprus is used as roughage. NO_3-N was found to accumulate in the soil under bare fallow. Such nitrogen accumulation may be more important than water conserved during the fallow year, since such water increased yield only if rainfall during the ensuing growing season was much below average.

INTRODUCTION

Barley has long been grown in Cyprus as the major rainfed fodder crop. It is a highly versatile crop harvested green (farras), cut from the boot through the milk stage for making hay, or left to mature and be harvested for grain and straw. Under the relatively mild winter temperatures of Cyprus (Fig. 1) barley grows faster than wheat and matures about three weeks earlier than wheat. Since spring rainfall is mostly insufficient, by virtue of its earlier maturation, barley produces more stable yields than wheat. Grown as a forage crop barley yields twice as much dry matter as vetch or peas (Hadjichristodoulou, 1973, 1976). Moreover, barley grown for hay provides more total digestible nutrients than barley grown for grain and straw (Cyprus Agricultural Research Institute, 1983). These considerations as well as the ready availability of wheat grain at reasonable prices on the world market, have prompted expansion of barley at the expense of wheat, particularly for the production of roughage (hay, straw) for a thriving livestock industry. Presently, almost 90 % of the area under rainfed cereals is cropped with barley under complete mechanization.

Traditionally, the most popular rotations for barley have been: barley-bare fallow, and barley-bare fallow-wheat. However, because of the urgent need to produce fodder from limited land, farmers presently grow barley on the same land year-after-year. They burn the stubble in late summer, if still present in burnable quantities following grazing by sheep, and immediately cultivate the field, mostly with tine cultivators. This produces a satisfactory seedbed for either seeding after the rains or in dry soil.

The soils used for growing barley, and other rainfed crops, are medium to five textured, calcareous (20-30 % $CaCO_3$), and low in organic matter (about 1 %), in N (less than 0.1 % total N) and P (1-5 ppm bicarbonate-extractable P), but are well supplied with K (about 300 ppm exchangeable K).

Fertilizers have long been readily available to Cypriot farmers at reasonable prices. Types containing N and P_2O_5 in a 1:1.5 ratio have all along been popular, and justifiably so, for basal application. Farmers also greatly value the use of farmyard manure in cereal growing, but the quantities available are limited and the cost is high. For continuous barley growing they apply up to 40 kg N, together with 60 kg P_2O_5, per hectare at seeding in early December and top dress another 20 to 40 kg N/ha at tillering, in early February, depending on rainfall. However, some farmers have recently started applying all the fertilizer at seeding.

Virtually all rainfall occurs from October to April, the period May-September being essentially rainless. Of the total rainfall, about 40 % occurs in December and January. Over most of the cereal growing area in five out of ten years total rainfall will be less than 330 mm and in two of these years it will be even less than 270 mm. On the other hand, in two out of ten years, it will be higher than 375 mm (Metochis, 1979). In addition to being low, rainfall is often erratically distributed, even in years when it is relatively high, with the result than cereals may still suffer water stress. Distribution may therefore have an overriding effect over that of total rainfall (Hadjichristodoulou, 1982). However, even under these conditions, low N and P in unfertilized soils are more limiting to cereal growth than water, a fact recognized long ago by Littlejohn (1946), who also concluded that the chief value of bare fallow lies in the accumulation of N, and possibly P, and not in water conservation. He also demonstrated that high yields (high for the mid 1930's, i.e. 2.5 tons of grain per hectare) could be produced by continuous cropping for at least 10 years, if adequate N and P fertilizer was applied. More recently, Loizides (1958) showed that, even after fallow, wheat and barley consistently responded to N, but the response to P was far less consistent.

EXPERIMENTAL AND RESULTS

(a) The NP Requirements of Barley Grown after Bare Fallow

Further to Loizides' (1958) experiments in the late 1940's - early 1950's, it was considered necessary in the late 1960's to undertake a new series of experiments with barley (the work also comprised wheat), since yields had reached higher levels as varieties and management had improved. These experiments were made in farmers' fields over the period 1968-1978, and their results have been reported by Krentos and Orphanos (1979) and Orphanos and Krentos (1980). The highlights of these results can be summarized as follows:

Despite long years of fertilizer use fields could be found, which were very low in bicarbonate-extractable P. In one such field, response to N was spectacularly conditional on adequacy of P and vice versa (Fig. 2). N fertilizing generally increased yields (Table 1), but such increases were rather modest (the fields had been under bare fallow during the season preceding the experiment). It must also be noted that yields were not appreciably reduced when excessive N was applied. However, concentration of N in the grain and the straw increased linearly with increasing N rate, and N fertilizing also increased linearly the concentration of K in the straw (Table 2).

The threshold value for response to fertilizer P appeared to be 6 ppm bicarbonate-extractable soil P in the plough layer. Response to fertilizer P was small when rainfall was high, but very pronounced when rainfall was low (Fig. 3), particularly if it fell in small installments in the early part of the season. Under such conditions only a shallow layer of soil was wetted and plants receiving P fertilizer grew markedly better, developed faster, and reached heading earlier than P deficient plants, which, however, did not exhibit any symptoms of P deficiency other than reduced growth.

(b) Yields and P Contents of Forage Barley Grown in a P Deficient Soil

This experiment was initiated at Athalassa in the 1980-1 growing season on a soil containing 3 to 5 ppm bicarbonate-extractable P, and 170 to 270 ppm exchangeable K, in the plough layer. The field was divided, on the basis of K content, into 10 blocks (replicates), which accommodated the combinations of three P treatments (0, 30, or 60 kg P/ha) and three K treatments (0, 240, or 480 kg K/ha). P was applied as triple superphosphate and K as potassium sulphate. A uniform N rate of 60 kg N/ha, split between seeding and tillering, was applied to all plots.

Athenais barley was grown in 1980-1 and 1981-2. Rainfall was close to average in 1980-1 but much below average in 1981-2 (Fig. 2). In 1982-3 (a year of very low rainfall) the plots were sown to vetch. Barley was cut at the milk stage to make hay. Yields were substantially increased by P, by almost 30 % in 1980-1 and 50 % in 1981-2 (a drier year), and such increase was curvilinear (Fig. 4). In contrast, K fertilizing did not influence yields (data not shown).

Phosphorus fertilizing slightly increased concentration of P in both the forage and the leaves but slightly decreased K concentration (Table 3). A similar, though not so marked, trend was also observed in our previous experiments.

At the end of three years of P fertilizing soil P remained unchanged in unfertilized plots but increased substantially and linearly with P application (Fig. 5).

(c) The Nitrogen and Water Relationships of Barley

This study was initiated in 1979 in the framework of a research programme coordinated by the International Atomic Energy Agency, and aimed to devise agronomic practices for more efficient use of fertilizer and water under semiarid conditions. It comprises a rotation trial in which barley is grown for grain production (continuously or after fallow) or forage production. Under each rotation treatment three rates of N (0, 30, or 60 kg N/ha) and two rates of P (0, or 20 kg P/ha) are tested. Soil water is monitored by neutron probe to a depth of 90 cm.

The experimental field had been under lucerne and other irrigated crops, which were liberally fertilized with both N and P. As a result, it contained a lot of P (50 ppm bicarbonate-extractabe P) and N (35 ppm NO_3-N) in the plough layer alone, which is quite atypical of barley fields.

Rainfall over two of the four growing seasons so far has been below average, particularly in early season (Fig. 6), to the extent that irrigation had to be applied in January 1982 and 1983 to rescue the crop. Because of drought, emergence was considerably delayed in the last three growing seasons, but the crop reached maturity on about the same date as with earlier emergence (Table 4).

The amount of water conserved in fallow plots (kept free of weeds as far as possible by cultivation) ranged from 25 to 75 mm (Fig. 7). Such conserved water increased yield only in 1982-3 when rainfall, including a 50 mm irrigation, was only 190 mm (Fig. 6). By contrast, in 1980-1 when rainfall was 300 mm, the water conserved under fallow during the preceding season (70 mm) did not increase yield.

Yields were satisfactory under the circumstances, e.g. in 1981-2 with only 260 mm of water, but with adequate rainfall in spring, yields of about 3.5 tons of grain per hectare were obtained (Fig.8). Fertilizer N did not affect yield except for a slight increase of forage yield in 1981-2 and a slight reduction in grain yield in 1982-3, the driest year (Fig. 8). Thus unfertilized plots produced 10 tons of grain and 20 tons of straw per hectare over four growing seasons, which contained a total of 390 kg N/ha of which 250 kg was in the grain and 140 kg was in the straw (cf. Fig. 8). When soil N was neither very low nor very high, one ton of sheaf (grain + straw) dry matter harvested removed 11.7 kg N (Fig. 9).

Barley cut at the milk stage for making hay produced virtually the same total dry matter yield as barley harvested for grain and straw (Fig. 8).

Nitrate-N was found to accumulate in the soil during the fallow year even when no fertilizer N was applied (Table 5).

Since rainfall was generally low, it was assumed thet there was no deep percolation of water, therefore any depletion of water from the 0-90 cm layer was considered to be due to water evapotranspired. Such evapotranspiration values when there was ample water in the soil were very close to values calculated according to Doorenbos and Pruitt (1977) from Class A pan evaporation (Figs. 10 and 11). Total evapotranspiration was around 300 mm, closely matching total rainfall (Fig. 12).

DISCUSSION

Under Cypriot conditions the uniqueness of barley as the best producer of grain, straw, hay and fresh forage (Hadjichristodoulou, 1973, 1976) appears to be mainly due to its growth cycle matching closely the rainfall pattern, i.e. it grows under the least possible water stress. Because it grows well during the cold winter months, and develops rapidly, at a time when evaporation is low, it uses water most efficiently. Additionally, it suffers little from diseases, and smothers weeds, including wild oats.

Fallowing has long proven its worth as a useful practice in cereal growing, but the reasons for this have not been always clear. In older times when machinery was not available, the farmer had, in a way, to fallow in order to cope with his land to his best benefit. There are at least three important advantages in fallowing, i.e. conservation of water, accumulation of N, and possibly of other nutrients, and better preparation of the seed bed. Which of the three will be the most important depends on local conditions.

The amount of water conserved during the fallow year depends to a considerable extent on keeping the soil free from weeds thereby reducing loss of water through transpiration. This is not always possible because the top soil is normally wet over the period December-March, and more than one cultivation may be required. It is also rather costly. Timely cultivations in 1981-2 permitted the highest conservation of water (75 mm), which represented one third of the season's rainfall. However, conserved water increased yield only in 1982-3 in which rainfall was much below average (190 mm). In any case, conserved water is known to be less effective than growing-season precipitation, e.g. in Canada it has been shown to be about one third as effective as growing-season precipitation (Bole and Pittman, 1980). This could conceivably be mainly due to the fact that drying of the plough layer (it is always the first layer to dry out or be wetted) deprives the crop of its vital nutrient supply, which resides mainly in this layer.

It has long been known that mineral N accumulates during the fallow year. This is clearly shown by the present results (Table 5) even though a more dense network of measurements would be desirable. Such accumulated N may be of crucial importance if fertilizers are in short supply, and this then may be the most important benefit from fallowing. Indeed, when fertilizers were relatively more costly in the 1940's, Cypriot farmers had "discovered" that applying only P to fallowed land was more profitable than applying only N (Loizides, 1958). Apparently, since soils were then very low in both N and P, and N was accumulating under fallow, P was becoming the most limiting factor, hence the marked response to fertilizer P. Moreover, they also "discovered" that P fertilizer was more important in years of low rainfall, whereas in years of high rainfall N fertilizer was more important, apparently because of the higher yield potential.

The marked differences in yield among unfertilized plots in the different experiments on fallowed land (Table 1) can be ascribed to varying residual N from previous applications by the farmers. This is clearly reflected in the 1973-4 experiment in which 3.7 tons/ha barley grain was produced without any fertilizer. The field was fertilized and sown in the preceding season by the farmer himself, but because of extreme drought (the worst drought on record) the crop hardly emerged, and dried up. The fertilizer apparently remained unused in the soil and was available for the following crop. The same conclusion can be drawn from the results of the rotation trial.

The marked response to fertilizer P under a combination of low available P and low rainfall is now well documented (Matar, 1977; Harmsen and Shepherd, 1983). This could explain the inconsistent responses to P obtained by Loizides (1958). In any case, P reserves of such soils will have to be built up gradually through applications of fertilizer.

In order to take best advantage of whatever rainfall occurs, particularly in years of high rainfall, adequate fertilizer must be applied. For nitrogen the norm of 11.7 kg N/ton of dry matter harvested (Fig. 9) should be widely applicable because it was obtained under adequate N supply, as suggested by Greenwood (1983). Since in Cyprus a slight excess of N does not reduce yields appreciably, and any unused N remains in the soil and is available to the following crop, one can modify his fertilizer practice in order to always have a level of fertility sufficiently high to take best advantage of rainfall. However, excessive N application to barley should be avoided for the additional reason that it increases K concentration in the straw (Table 2) and as this is harvested along with the grain, the soil is depleted of valuable K reserves.

Under semiarid conditions all N could be applied at seeding. In this way, not only application costs would be less, but also volatilization losses from topdressed N could be reduced, particularly when urea is used, of which losses of up to 30 % have been observed (Orphanos, unpublished data).

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Table 1. Effects of N and P fertilizing on grain and straw yields of Athenais barley (main effects of each nutrient over all rates of the other nutrient).

Year and Site	kg N/ha				kg P/ha		
	0	35	70	105	0	13	26
Grain Yield (tons/ha)							
1969-1970							
Lefkonico	2.38	2.47	2.36	2.32	2.23	2.45	2.47
Stylli	0.88	1.35	1.51	1.45	0.99	1.32	1.59
Koublia	1.03	0.97	0.84	0.84	0.54	0.97	1.25
1970-1971							
Angastina	1.50	2.18	2.28	2.33	2.08	2.11	2.03
Pyrga	2.25	2.27	2.56	2.20	2.19	2.26	2.52
Prastio	1.76	2.11	2.41	1.98	2.13	1.97	2.10
Stylli	0.60	1.47	1.95	2.07	1.40	1.51	1.66
Athalassa	2.32	2.69	2.66	2.74	2.52	2.66	2.64
1971-1972							
Angastina I	1.42	1.73	1.70	1.62	1.45	1.68	1.73
Angastina II	0.99	1.17	1.12	1.07	0.83	1.08	1.35
Pyrga	0.38	0.36	0.34	0.35	0.29	0.39	0.36
Palekythro	1.84	1.85	1.87	1.89	1.62	1.86	2.11
1973-1974							
Kythrea	3.73	3.65	3.56				
1977-1978							
Nissou III	0.62	0.86	1.21	1.21	0.79	0.92	1.22
Nissou IV	0.78	1.41	1.80	1.83	1.36	1.45	1.56

Table 1. (Contd.) Effects of N and P fertilizing on grain and Straw yields of Athenais barley (main effects of each nutrient over all rates of the other nutrient).

Year and Site	kg N/ha				kg P/ha		
	0	35	70	105	0	13	26
Straw Yield (tons/ha)							
1969-1970							
Lefkonico	3.00	3.27	3.43	3.24	2.98	3.18	3.56
Stylli	0.86	1.66	2.08	2.04	1.17	1.77	2.05
1970-1971							
Angastina	1.71	2.55	2.92	3.23	2.55	2.62	2.64
Pyrga	2.89	3.29	3.46	3.58	3.24	3.26	3.40
Prastio	1.88	2.80	3.58	3.27	3.05	2.73	2.87
Stylli	0.83	1.73	2.70	3.22	1.97	2.24	2.14
Athalassa	3.08	3.83	4.37	4.28	3.63	3.98	4.05
1971-1972							
Angastina I	1.42	1.74	1.92	1.89	1.62	1.80	1.81
Angastina II	1.20	1.57	1.64	1.53	1.16	1.55	1.74
Pyrga	0.77	0.97	1.03	1.05	0.80	1.04	1.03
Palekythro	1.79	1.79	1.76	2.02	1.69	1.86	1.96

Table 2. Concentration (% dry weight basis) of N in grain and straw, and of K in straw of Athenaís barley as influenced by *fertilized N*.

Year	% N								% K			
	Grain				Straw				Straw			
	0	35	70	105	0	35	70	105	0	35	70	105
1969-70 (4)*	1.75	1.91	2.12	2.29	-	-	-	-	-	-	-	-
1970-71 (4)	1.69	1.93	2.15	2.34	0.49	0.55	0.65	0.75	1.46	1.67	1.93	2.04
1071-72 (2)	1.81	2.05	2.25	2.38	0.41	0.48	0.51	0.59	1.88	21.4	2.22	2.45

* Figure in parenthesis indicates number of experiments.

Table 3. Concentration of N, P and K in barley forage cut at the milk stage, and in leaves sampled at heading (the leaf below the flag leaf) in two growing seasons (% DM basis).

	1980-1			1981-2		
	P_o	P_1	P_2	P_o	P_1	P_2
Forage						
N	1.49	1.41	1.55	1.65	1.45	1.49
P	0.17	0.19	0.21	0.14	0.15	0.18
K	1.57	1.49	1.44	2.20	2.03	1.84
Leaves						
N	4.24	4.13	4.22	4.25	4.42	4.48
P	0.27	0.27	0.28	0.22	0.22	0.28
K	1.98	1.90	1.89	2.71	2.32	2.17

(P_o: No P, P_1: 30 kg P/ha, P_2: 60 kg P/ha).

Table 4. Phenology of barley. Athalassa, 1979-83.

Growth Stage	Growing season			
	1979-80	1980-1	1981-2	1982-3
Seeding	1 Dec	30 Dec	11 Dec	26 Nov
Emergence	12 Dec	12 Jan	28 Dec	9 Jan
Second Leaf	31 Dec	20 Jan	10 Jan	
Third Leaf		2 Feb	20 Jan	
Tillering	28 Jan	12 Feb	25 Jan	30 Jan
Boot	13 Mar	22 Mar	22 Mar	
Heading	29 Mar	30 Mar	31 Mar	4 Apr
Flowering	3 Apr	3 Apr	3 Apr	
Milk	11 Apr	11 Apr	14 Apr	
Dough	24 Apr	25 Apr	28 Apr	27 Apr

Table 5. Concentration of nitrate-N in the top 45 cm soil layer sampled in late November, just before seeding. Underlined figures refer to plots fallowed over the season preceding soil sampling.

Plot No.	Crop rotation			ppm nitrate-N	
	1979-80	1980-81	1981-2	1980	1982
$\underline{N_oP_o}$					
5	Forage barley	Forage barley	Forage barley	12	8
8	Fallow	Grain barley	Fallow	$\underline{16}$	$\underline{39}$
22	Vetch	Grain barley	Vetch	21	6
34	Grain barley	Vetch	Grain barley	10	3
42	Fallow	Grain barley	Fallow	$\underline{25}$	$\underline{64}$
46	Fallow	Grain barley	Fallow	$\underline{36}$	$\underline{42}$
63	Fallow	Grain barley	Fallow	$\underline{33}$	$\underline{57}$
68	Forage barley	Grain barley	Forage barley	14	7
75	Grain barley	Forage barley	Grain barley	10	5
82	Grain barley	Grain barley	Grain barley	7	2
$\underline{N_2P_1}$					
2	Forage barley	Forage barley	Forage barley	17	15
10	Fallow	Grain barley	Fallow	$\underline{10}$	$\underline{37}$
21	Vetch	Grain barley	Vetch	24	13
32	Grain barley	Vetch	Grain barley	10	5
39	Fallow	Grain barley	Fallow	$\underline{26}$	$\underline{39}$
47	Fallow	Grain barley	Fallow	$\underline{39}$	$\underline{57}$
65	Fallow	Grain barley	Fallow	$\underline{27}$	$\underline{32}$
67	Forage barley	Grain barley	Forage barley	16	10
73	Grain barley	Forage barley	Grain barley	10	7
84	Grain barley	Grain barley	Grain barley	11	2

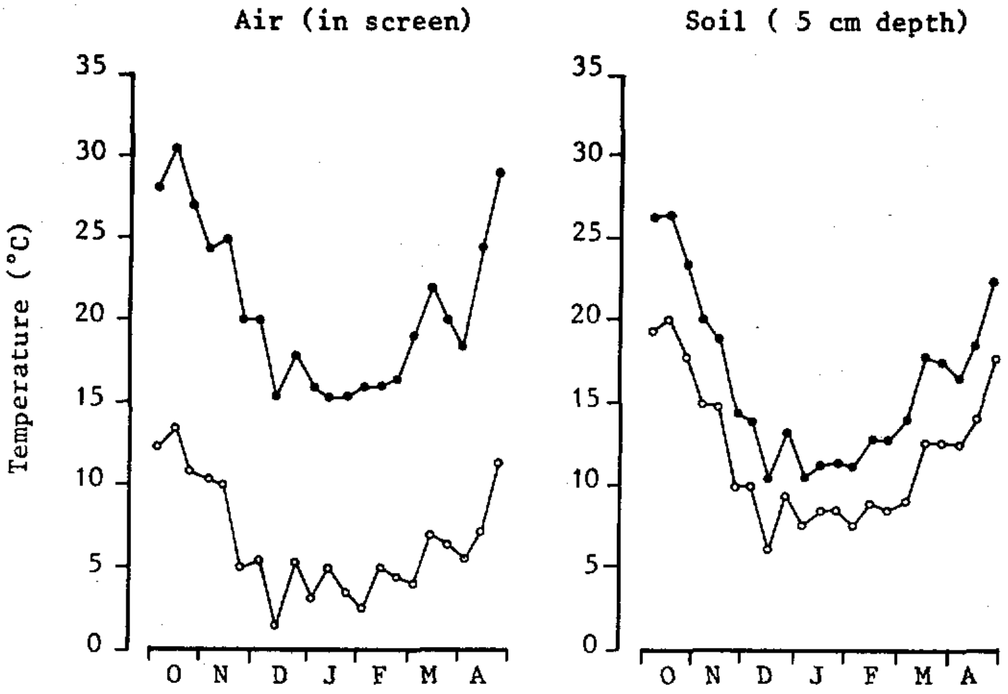

Fig. 1. Left: Maximum (●) and minimum (o) air temperatures

Right: Soil temperatures at 5 cm depth at 080:00 hrs (o) and 14:00 hrs (●).

(averaged over 10-day periods, Athalassa, 1980-1).

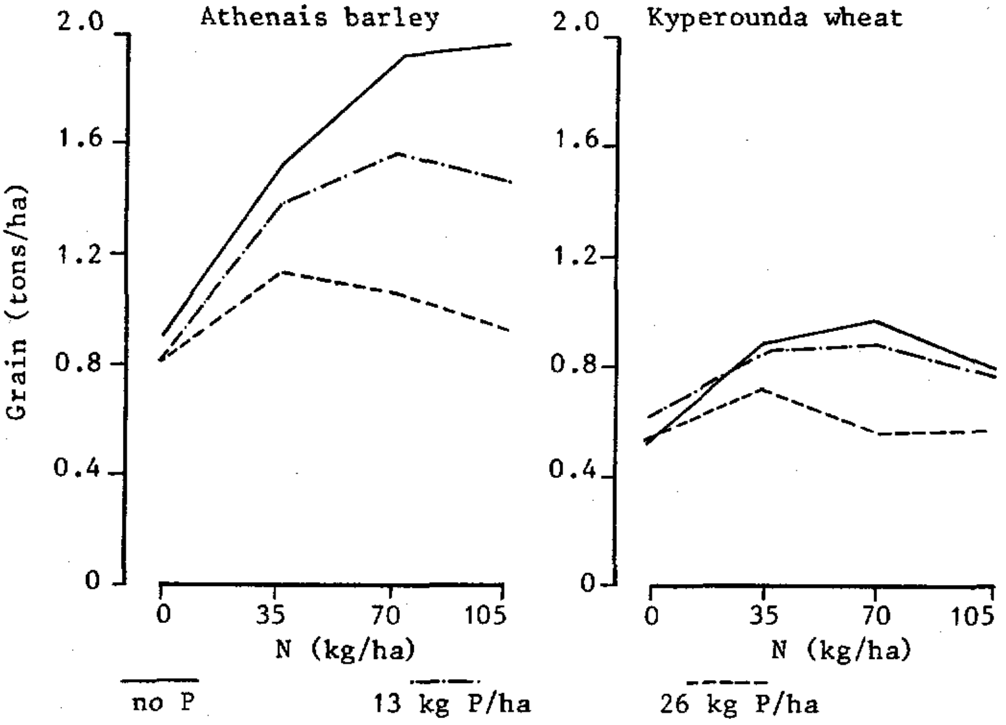

Fig. 2. Effects of N and P fertilizers on grain yield of Athenais barley (left) and Kyperounda wheat (right) at Stylli, 1969-70.

(140 mm rainfall; 1 ppm bicarbonate-extractable P).

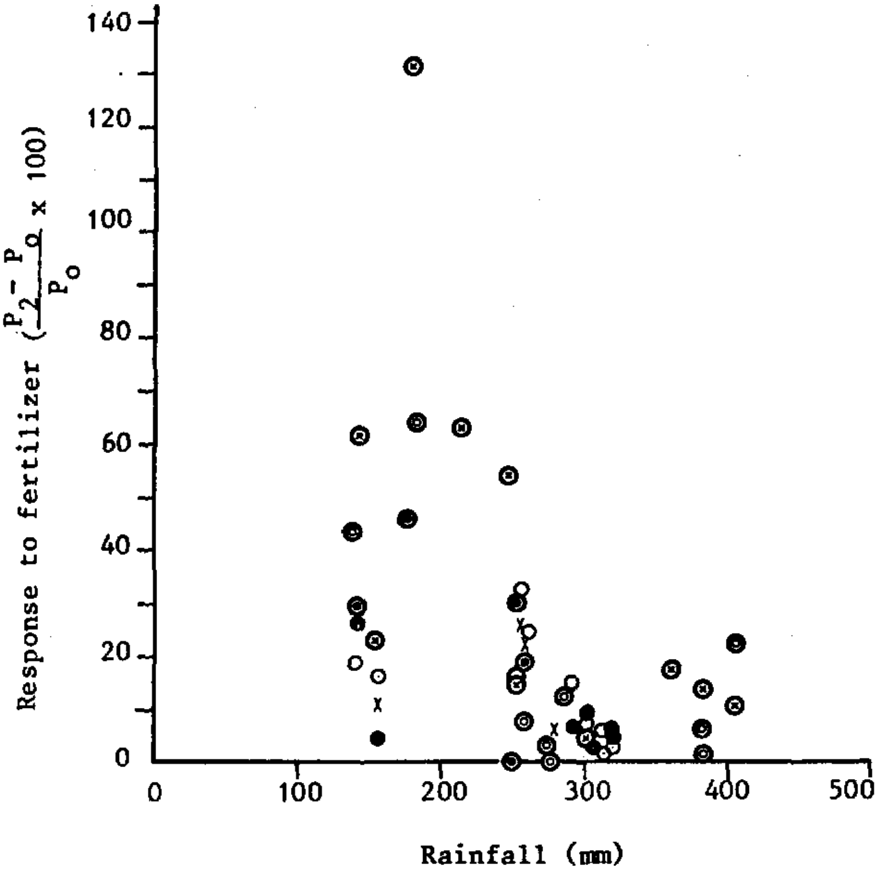

Fig. 3. Grain yield responses to P fertilizer by Athenais barley (x), Pitic 62 wheat (o) and Kyperounda wheat (●) in relation to rainfall.

(range of bicarbonate-extractable soil P 1-10 ppm; encircled symbols refer to soil P values less than 6 ppm)

P_o : no fertilizer P

P_2 : 26 kg P/ha

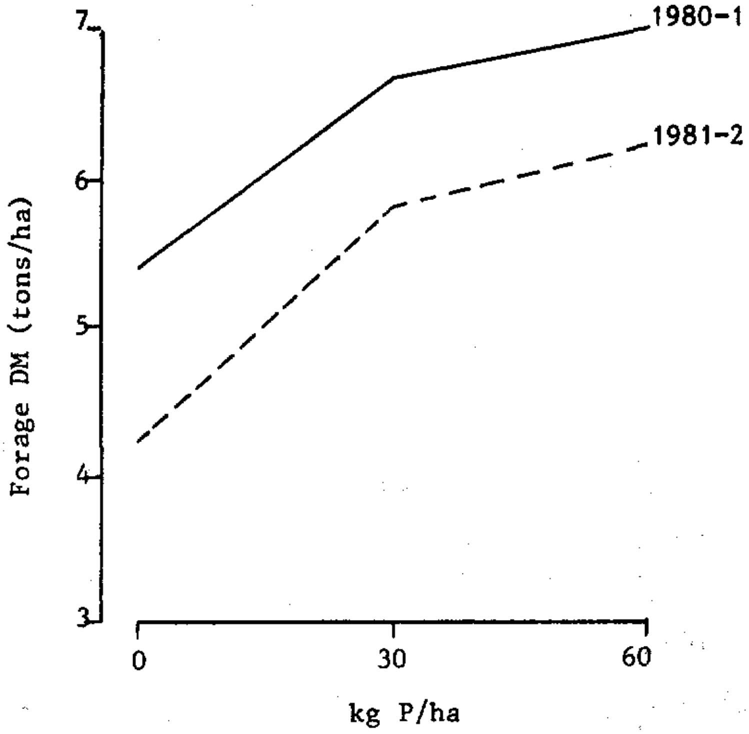

Fig. 4. Yields of Athenais barley forage cut at milk stage as influenced by P fertilizing (rainfall: 1980-1 300 mm, 1981-2 200 mm; the soil contained 3-5 ppm bicarbonate-extractable P; DM comprised 25-30 % of the fresh matter).

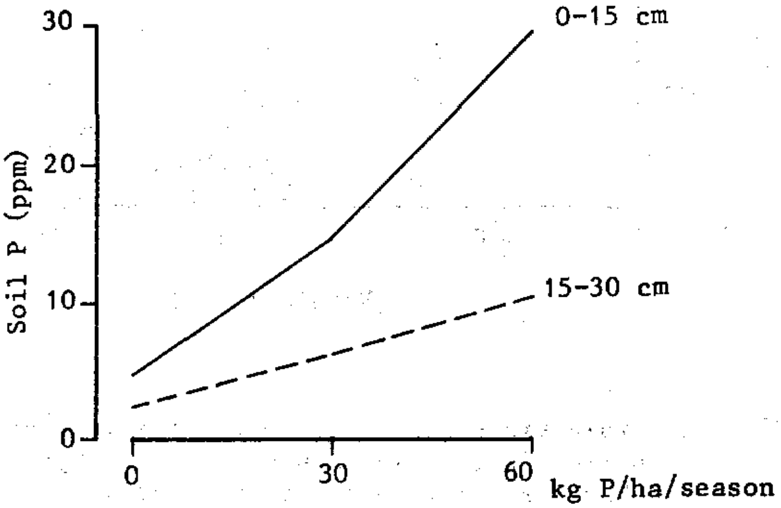

Fig. 5. Bicarbonate-extractable P in the 0-15 cm and the 15-30 cm layers of the soil at the end of the third season of fertilizer P application.

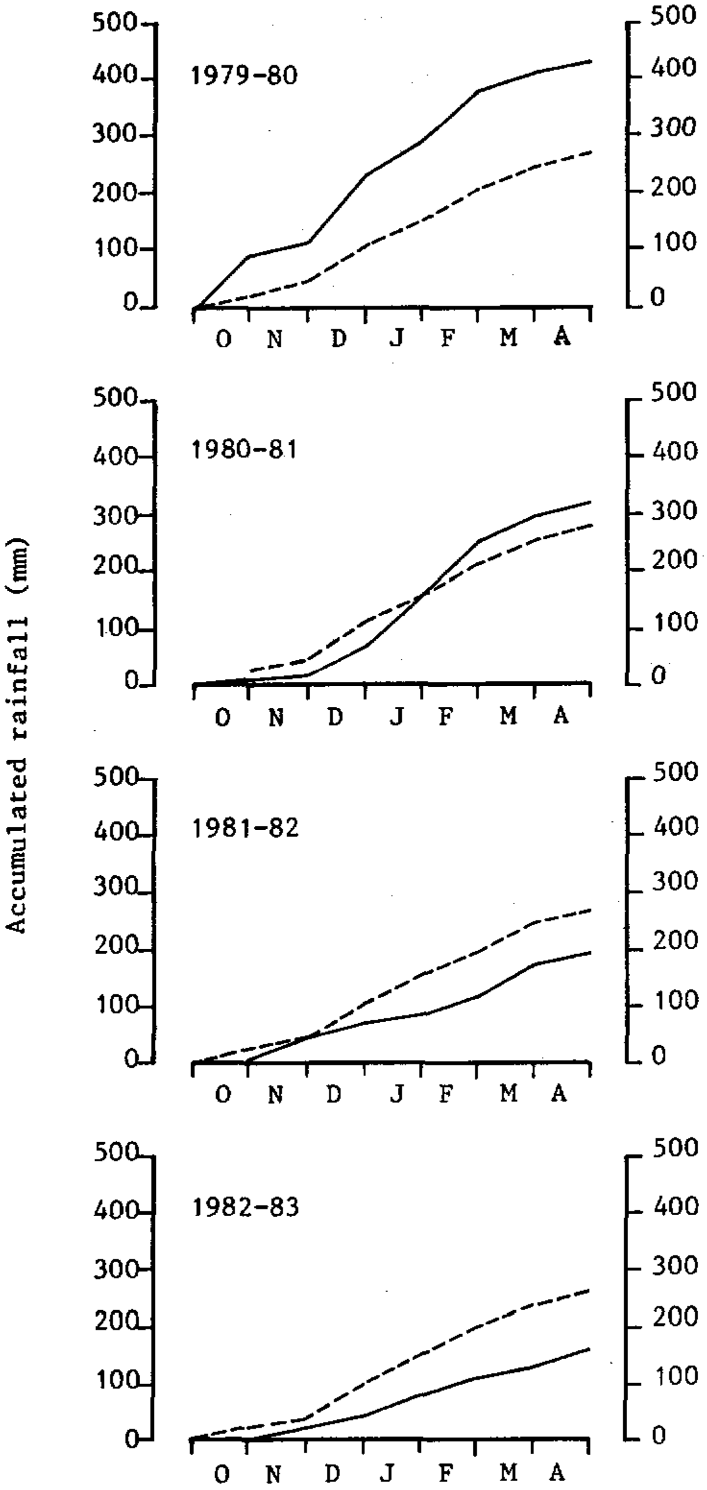

Fig. 6. Accumulated season's rainfall in four growing seasons (1979-83) at Athalassa. Broken lines represent the long-term average.

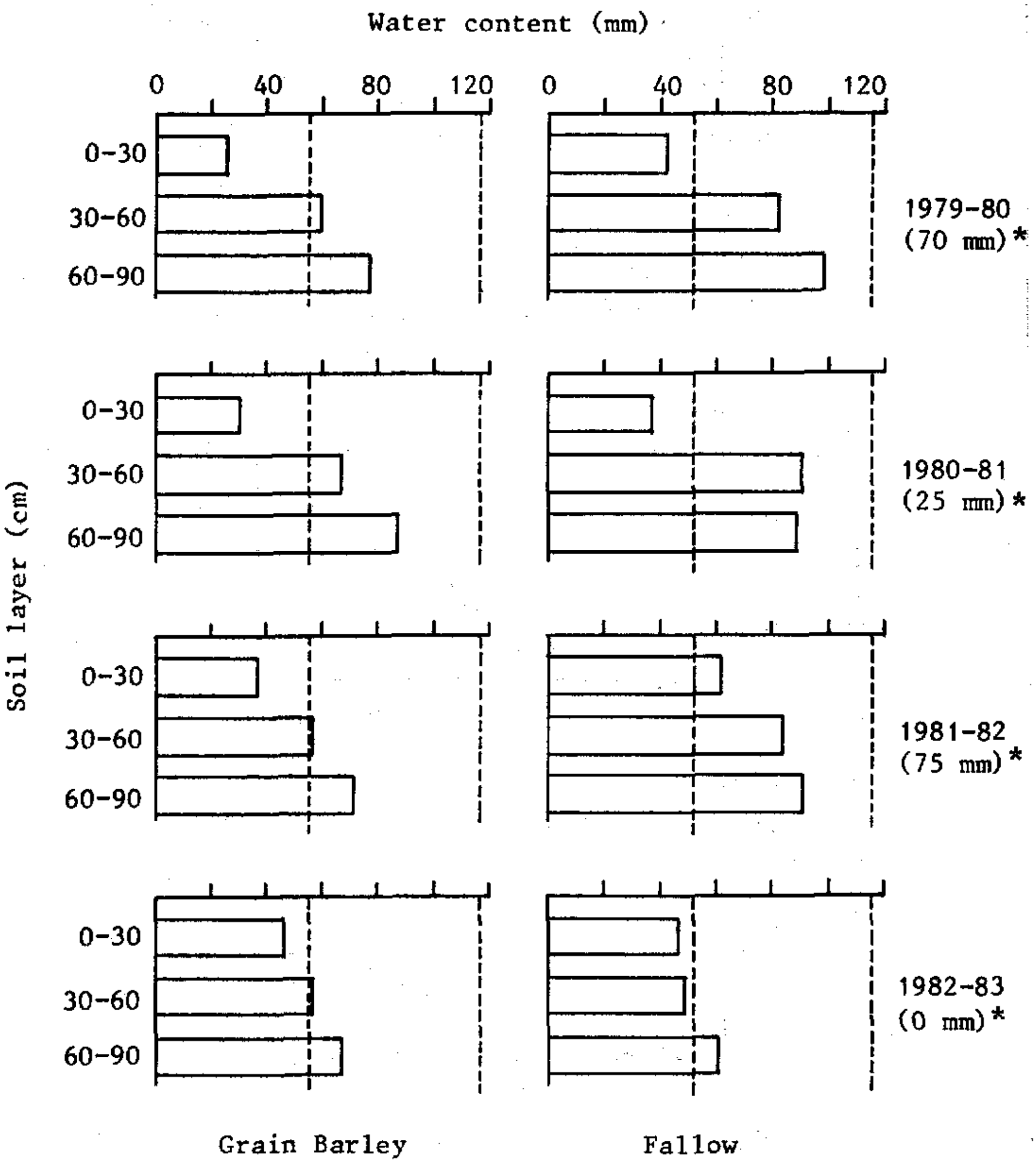

Fig. 7. Soil water profiles (in late autumn) of plots which grew grain barley (left) and of plots that were fallowed (right). Broken lines indicate the water contents of each 30 cm layer at field capacity and at 15-atm. percentage.

* water content differentials (mm) between the two sets of plots over the 0-90 cm profile.

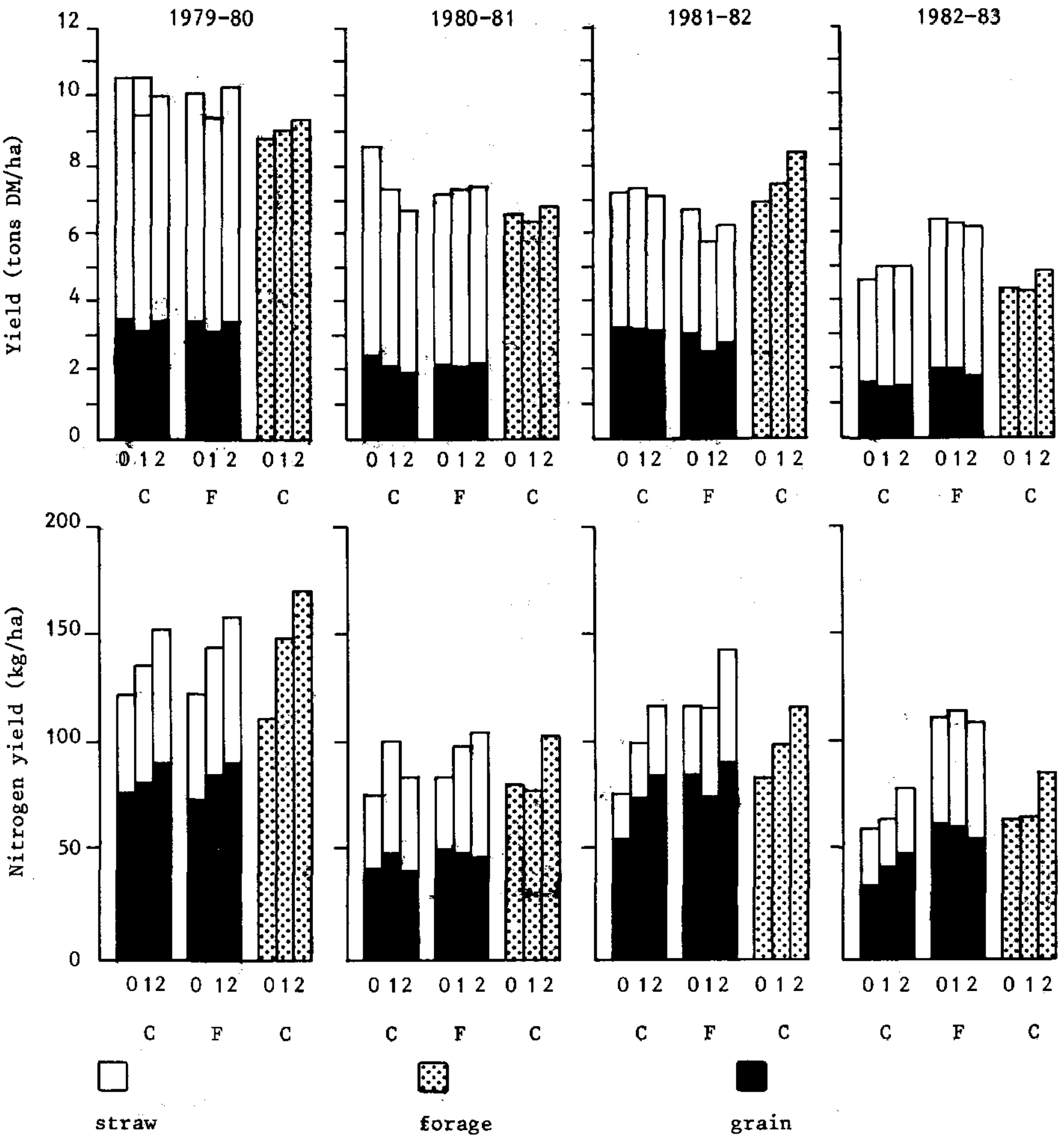

Fig. 8. Yields (air-dry matter) of barley grain, straw and forage (upper), and N yields (lower) under continuous cropping (C) or after fallow (F), with three N rates (P: no fertilizer N, 1: 30 kg N/ha, 2: 60 kg N/ha) in four growing seasons (1979-83).

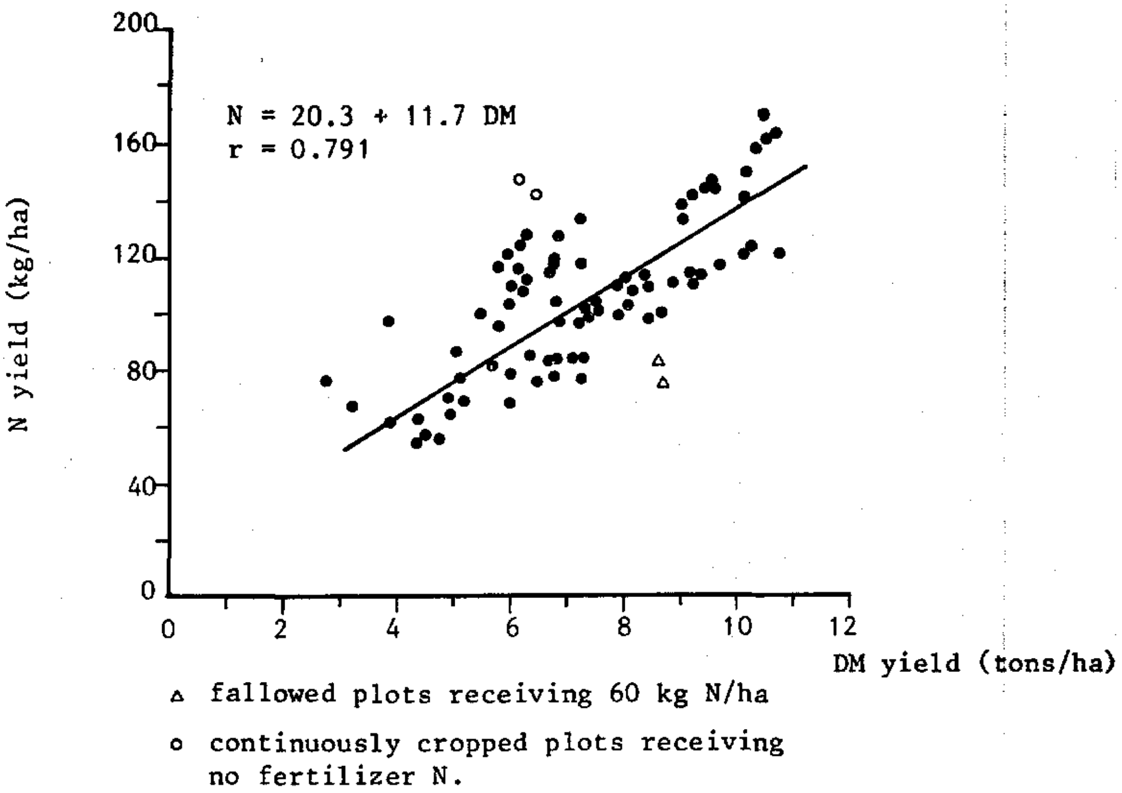

Fig. 9. Relationship between the harvested dry matter of barley (grain + straw) and its N content at Athalassa.

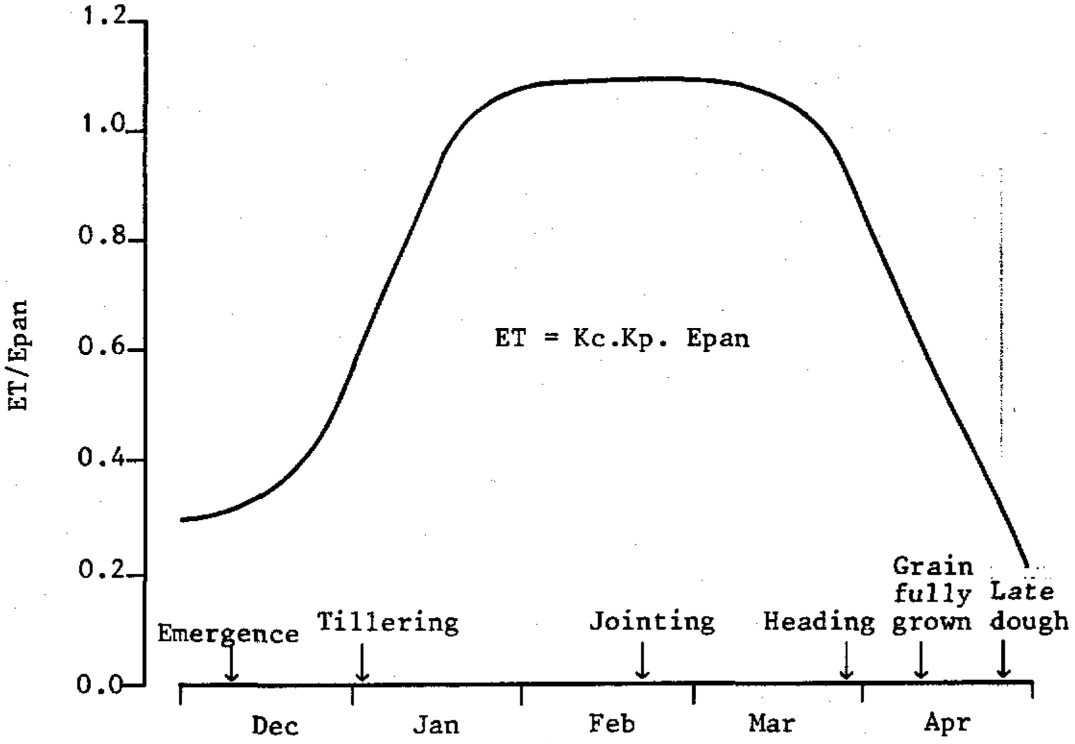

Fig. 10. Ratio of evapotranspiration (ET) over evaporation from the Class A pan (Epan) for barley at Athalassa. ET calculated according to Doorenbos and Pruitt as ET = Kc.Kp.Epan; Kp was around 0.85.

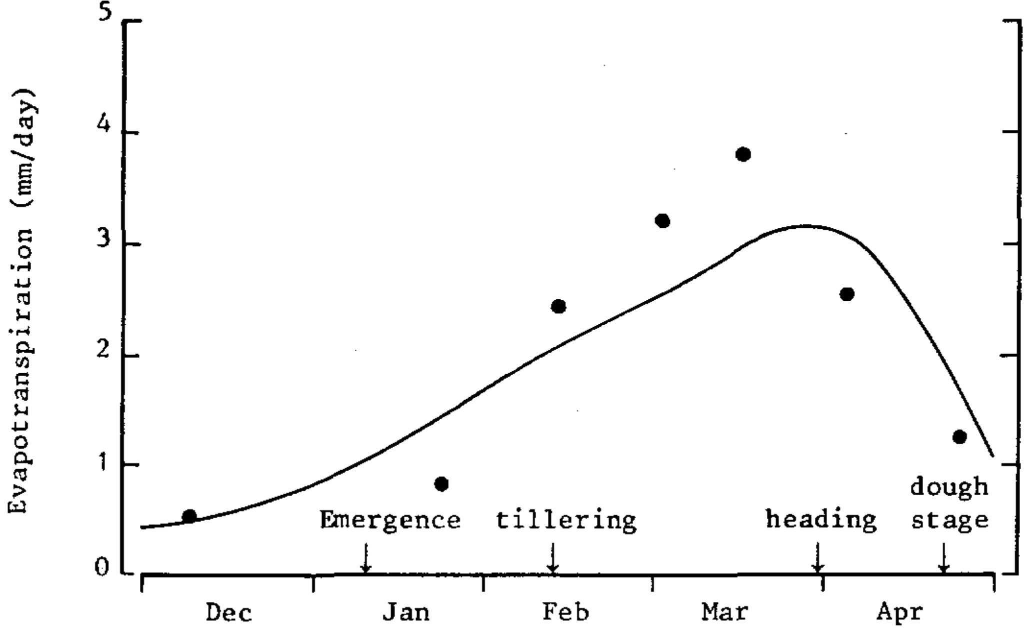

Fig. 11. Calculated potential evapotranspiration rates (solid line) for barley, and values determined from moisture depletion data (closed circles) obtained by neutron probe in a typical year, 1980-1, Athalassa.

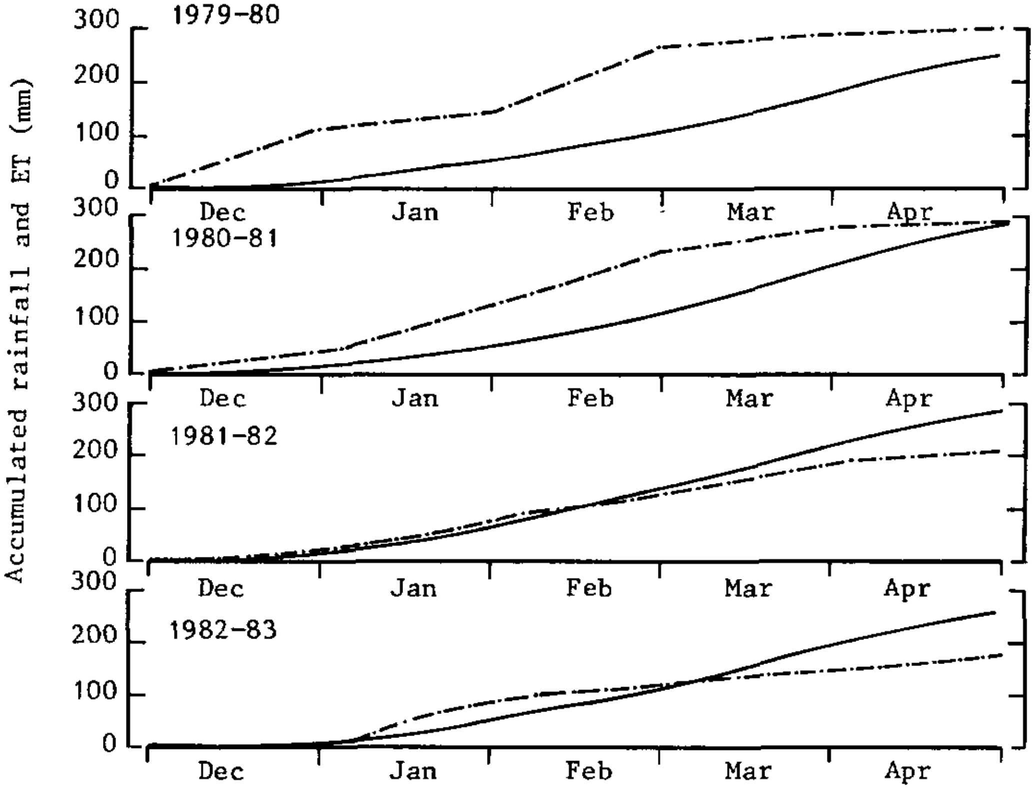

Fig. 12. Accumulated season's rainfall (broken lines) and calculated potential evapotranspiration of barley (solid lines) in four growing seasons at Athalassa. Rainfall in 1981-2 and 1982-3 includes supplementary irrigation of 50 mm and 40 mm, respectively.

BARLEY PRODUCTIVITY OF RAINFED SOILS AS RELATED TO SOIL, PRECIPITATION AND FERTILIZATION IN A PILOT AREA OF SYRIA

by

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BARLEY PRODUCTIVITY OF RAINFED SOILS AS RELATED TO SOIL, PRECIPITATION AND FERTILIZATION IN A PILOT AREA OF SYRIA

Introduction

The total cultivated area of the Arab Countries amounts to 50.6 million hectares, with more than 80 % of the area under rainfed agriculture.

Cereals occupy about 68 % of the main production of rainfed lands, with wheat and barley as the main cereal cultivated crops. Cereal production oscillates within large intervals from one year to the next. That could be to some extent due to change in total cultivated area; but it is mostly due to changes in yields of crops per unit area.

Available soil moisture has been considered as the most limiting factor affecting yields of crops. But other soil and management variables should not be underestimated. That would include soil nutrients availability, fertilizer use, weed, pest and disease control and the use of improved cultivars.

The understanding of the interrelationship between crop production in the rainfed area, climate, soil and management practices, has become of paramount importance to any agrotechnology transfer to increase crop production. The development of a reliable crop-soil-climate and technology model was found necessary to identify the management practices that will maximize production; to determine the factors that should be controlled to improve the potential productivity of rainfed soils and finally to create means of prediction on yields of crops and estimation of climatic risks on crop production.

The Arab Center for the studies of Arid Zones and Dry Lands initiated a regional project to study the cereal production of the rainfed soils of the Arab Countries as related to soil properties, climate and some management variables using a multiple regression computer program. It was started first in a pilot area in Syria in 1979-80; and then expanded since 1981-82, in addition to Syria, to three other Arab Countries, which are Algeria, Morocco and Jordan, as part of the Wheat and Barley Improvement Project financed by IFAD.

The present article summarizes the results obtained in the first three years of the project in the Pilot Area of Syria.

Materials and Methods

Selection of the Pilot Area:

A pilot area with different ecological conditions and different soil types was chosen, extending between the coastal plain, near the city of Tartous and the longitude line 35 and 53 M with an average annual precipitation of 900 mm; and the city of Palmyra with an average yearly precipitation of 150 mm and a longitude 38.13 . That would make a pilot area with about 200 kms long, with a width changing between 100 and 150 kms depending upon its location along the transect.

Selection of the Soil Sites:

In the pilot area, farmer's fields were selected, as representing different soil associations, according to their parent materials, climatic zones, topography and profile development. The main soil associations in the pilot area are mainly typic and vertic xerochrepts moderately fine, hyperthermic and chromoxererts, fine hyperthermic in the costal plain; and mainly lithic and typic xerochrepts in the western mountain range. But in the flat plateau of Homs and Hama the soil associations are mainly typic xerochrepts, calcic xerollic, xerochrepts and petrocalcic xerochrepts.

Differences in degree of surface stoniness, surface slope, soil depth and differences in farm management practices, such as type of rotations, crop cultivars, the level of fertilizer use, weed control were all considered in the choice of farmer's fields. Efforts were made to select sites and the farmer's fields representing the major types of farming system practised under the rainfed agriculture of the pilot area.

Although a good number of barley fields were chosen in an area above 400 mm rainfall, it was in the drier areas that the majority of barley fields were chosen.

Experimental Studies:

- At the farmer's fields:

Soil Studies

- A soil profile description according to USDA soil taxonomy system was carried out.
- Soil surface slope, percentage stoniness of surface coverage and or of soil volume in various horizons, and bulk density were measured.
- On soil samples of each horizon, laboratory determinations were carried out to measure the particle size distribution (Boyoucos method), pH of the saturated paste, total $CaCO_3$ % (Calcimeter method), the active $CaCO_3$ % (Drouineau Method), the cation exchange capacity (Na-acetate Method), exchangeable and soluble K (by NH_4-acetate extraction), the organic matter percent (Wakley and Black Method) and the available P (Olsen Method).

Productivity of Barley

Five square meters, chosen at random in the farmer's fields, were harvested at maturity for the determination of total weight of grain and straw separately, weight of 1000 kernels, average height of plants and degree of leaf infection by rust, infection by weeds and several other measurements.

Meteorological Measurements

The meteorological data for the sites were taken from the network of nearest available meteorological stations located in the pilot area. The only common measured factor at all stations was the daily precipitation. Consequently, the only climatic variable considered was *total precipitation (SON, total of September, October and November)* and the winter precipitation (DJ, December + January).

Computer Analysis

Barley yield components were related to various soil, climate and some management variables using a Linear Multiple Regression Computer Program written by Professor Issam Jano of the Syrian Atomic Energy Agency. The list of variables included in the present article is included in Table 1.

Fertilizer Experiments

During the first year of the study, it was found that the amounts of fertilizer used in the rainfed part of the pilot area were very limited in spite of the large potential response to N and P fertilizers. So it was decided to test the NP response of Barley along the climatic cross-section starting from the 1980-81 season and for three consecutive years.

There were five fertilizer treatments:

0 is the control plot with no addition of N or P fertilizers N_1, N_2, N_1P_1 and N_2P_2 are the four other treatments where: N_1 and N_2 are equivalent respectively to 150 and 300 kgs of NH_4NO_3 (33 % N) per hectare for sites with less than 400 mm average rainfall (arid). In such areas, the nitrogen fertilizer was added completely before sowing. 250 and 500 kgs of NH_4NO_3 was used at sites with more than 400 mm (humid), and N fertilizers were split in two applications, half before sowing and the other half at

tillering stage. P_1 and P_2 are equivalent respectively to 75 and 150 kgs of triple superphosphate per hectare for either arid or humid sites, and the whole amount was added before sowing. The treatments were run first in two replicates, and then in 4 replicates in following years.

Except broadcasting and distribution of NP fertilizers and harvesting of fertilized field plots, it was the farmer who carried out all other field operations. Nitrogen analysis of barley grains was carried out by the Kjeldahl Method.

Results and Conclusions

Linear Multiple Regression Equations:

In the three consecutive years, 1980, 1981 and 1982, it was consistently found that barley grain and straw yields grown in the climatic transect of the pilot area was related to precipitation more than to any other variable. However, soil depth comes next in importance to precipitation in its contribution to grain and straw yield variation. The average multiple correlation coefficient between soil and precipitation variables were included in Table (2). This kind of relationship between grain and straw yield and precipitation could be explained on the ground that barley crop is mostly concentrated in the drier part of the rainfed area of Syria, where any change in total precipitation in the growing season will be reflected directly on grain and straw yield variation. It is noticeable that the correlation coefficients between barley yields and early precipitation (SON) were of the same magnitude as between total precipitation in the growing season and yields. That would suggest that available soil moisture in soil profile prior to germination is an important factor affecting final barley yields.

Soil depth, which came next in importance to precipitation, will determine the maximum water storage capacity of soil and consequently will affect the precipitation water use efficiency by barley and the final yields (1).

The two other intrinsique soil properties which were found to affect barley crops were the cation exchance capacity (CEC) and the amount of available phosphorus. The CEC of soils is an indication of total available nutrient cations such as potassium, magnesium and others. Soil available P was found by many workers in the region to be an important nutrient specially under arid conditions. The barley area is an aridic zone where P is expected to be an important factor of growth and yields.

Some other soil variables were found to negatively affect yields of barley. Stoniness at the soil surface or in soil profile and the bulk density of soil were found to be negatively correlated with yields of barley. Calcium carbonate in soils had a depressive effect on yields of barley. This could be explained on the ground that high free lime levels in the soil may cause stunted growth as a result of P and micronutrient immobilization (3).

The results of the linear multiple regression computation relating grain and or straw barley yields for the three years 1980, 1981 and 1982 combined were grouped in Tables 3 and 4 respectively for various combinations of soil and precipitation variables. Regression equations YG1 and YS1 which relate grain and or straw yields to six soil variables (STONES, STONEP, SLOPE, BD, POROSITY and CALA) with the exclusion of precipitation can explain only 18 and 34 percent respectively of grain and straw barley yields variation.

Nine other soil and precipitation variables, as shown in Equations YG2 and YS2, could explain 58 and 80 percent of grain and straw barley yield variations. Consequently, when all the 15 soil and precipitation variables were considered, as shown in Equations YG3 and YS3, it could explain 75 and 83 percent of grain and straw yield variation.

Finally, when grain barley yields were related to 20 soil and precipitation variables, including the N and P fertilizer variables and interaction for the two seasons 1981 and 1982 combined as shown in Table 5, 91.4 percent of grain yield variation was accounted for. But from a practical point of view, a minimum number of data set of soil and environmental variables should be looked for to make prediction on yields; and that should be carried out in the near future.

Fertilizer Experiments

There was a great variability in main soil properties and environmental conditions where the fertilizer experiments were carried out in the pilot area during the three consecutive years 1981, 1982 and 1983. The results of experiments were grouped in Table 6. Calcium carbonate in soils ranged between 0 and 62.5 percent. The clay content ranged between 18 and 64.5 percent. Soil depth ranged between 25 cm and more than 1 meter; and the available P ranged between 6.3 and more than 27 parts per million. Total precipitation from September to end of April ranged between 156 and 854 mm.

It is obvious from Table 6 that response to N and P fertilizers was clear and significant in many of the barley experiments carried out in the area; but insignificant in several others. This could be expected, due to the large differences in soil properties of the sites, which could significantly affect barley response to fertilization.

The response to application of P deserved a special attention. Several important works carried out in the Mediterranean Region had shown previously that available P in soils is an important factor affecting yields of cereal and small grain legumes crops when grown under the arid or semi-arid conditions. Cooper (1) showed that P increases the rate of development of crop resulting in maturity of barley being advanced from one to two weeks. Thus the water use by crop is reduced by addition of P in spite of the more rapid development and higher values of the green area index. Harmsen, Krentos and Matar (2, 4, 5) suggested that P improves the root development, thus extending the soil volume for available water and nutrient.

The relative increase in barley grain yields as function of total precipitation was plotted in Fig. (1) for soil sites where available P before sowing was below 15.2 parts per million and total precipitation below 400 mm. It shows clearly that the relative response to P increases as the total precipitation decreases; in a way similar to results obtained earlier (1, 2, 4 and 5). The broad scattering of points on Fig. (1) could be due to differences in soil properties of sites which could have an effect on barley response to phosphate fertilization.

On the other hand, the increase in grain yield of barley due to addition of phosphate fertilizers as function of total precipitation was plotted in Fig. (2) for all sites where available P is below 15.2 parts per million. This figure shows that grain yield increase ranged between 0 and 45 kilogram grain per donum for sites where total precipitation was below 314 mm a year. However, it is obvious that a greater response to P fertilization was found in the more rainy part of pilot area. When soils are well supplied with N fertilizers the potential yields and total biomass expected in high rainfall areas become so large that low available P- soils will respond strongly to P fertilization as shown in Fig. (2). The humid sites included in Fig. (2) had an available P concentration in the soil before sowing below 7 parts per million.

The relative response of most sites to N fertilizers was quite significant and the best treatment for optimum yields was the NP treatment; however the application of N fertilizers to low-rainfall sites is a critical operation; and N fertilizers applied at seeding time could have a negative effect on yields if rainfall is delayed or scarce. However, from Table 6, it is clear that the response to NP fertilizers combined (NP-control yield) was greater in most cases to P fertilizers response alone (NP-N yields) and consequently, both nitrogen and phosphorus fertilizer use in such arid areas should be considered. The relative response to N and P fertilizers should be investigated more thoroughly and be related to main soil and environmental factors in order to obtain practical recommendations which farmers can adopt with confidence.

The results of N analysis of grain barley cultivars from the six fertilizer experiments carried out in the year 1982-83 were grouped in Table 7. In 4 out of 6 experiments nitrogen fertilizers and especially (N_2 or N_2P_2 treatments) had a positive and significant effect on grain N content. This kind of work needs further investigation.

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Table 1. List of Soil, Precipitation and Fertilization Variables included in the Regression Models of the Article.

Variable	Specifications
SD	Soil depth in cms.
STONE S	Stoniness % of the surface.
STONE P	Stoniness % volume of horizon A.
SLOPE	Soil surface slope %.
CALT	Total $CaCO_3$ %.
CALA	Active $CaCO_3$ (Drouineau).
CEC	Cation exchange capacity (meg/100 g).
SICLAY	(Slit + Clay) % of horizon A.
POTT	Total (soluble + exchangeable) K in horizon A. In parts per million.
PHOS	Available soil P (ppm) of horizon A.
BD	Bulk density in (gr/cm^3) of horizon A.
SAPR	Total precipitation from September through April (mm).
SON	Total precipitation from September to end November (mm).
DJAN	Total precipitation in December ÷ January (mm).
NADD	Nitrogen fertilizer added in kgs N/donum.
N^2ADD	Square of N fertilizer added in kg N/donum.
P ADD	Phosphate fertilizer added in kg P_2O_5/donum.
P^2ADD	Square of P fertilizer added in kg P_2O_5/donum.
N P	Product of N and P fertilizer added in kg/donum.
GRAIN	Grain barley yields in kg/donum.
STRAW	Straw barley yields in kg/donum.

Table 2. Multiple Correlation Coefficients (R) between Soil and Precipitation Variables with Grain and Straw Barley Yields during Three Consecutive Years 1980, 1981 and 1982.

Variables	(R)	
	Grain	Straw
DJAN	+ 0.53	+ 0.48
SAPR	+ 0.63	+ 0.60
SON	+ 0.57	+ 0.64
SD	+ 0.48	+ 0.57
CEC	+ 0.14	+ 0.29
PHOS	+ 0.16	+ 0.02
CALT	- 0.22	- 0.12
STONES	- 0.10	- 0.22
STONEP	- 0.11	- 0.29
BD	- 0.18	- 0.30

Table 3. Regression Models for Grain Yields of Local Barley Cultivars with their Respective Coefficients of Determination for the Three Years 1980, 1981 and 1982 Combined.

Grain Yield kg/1000 M^2	Regression Equations	R	R^2
Y_{G1}	= - 2.232 STONES - 3.556 STONEP + 10.81 SLOPE + 588.9 BD +16.04 POROSITY - 4.275 CALA - 1277.37	0.424	0.179
Y_{G2}	= - 0.0438 DJAN + 0.077 SAPR + 0.379 SON + 1.309 SICLAY + 1.586 SD - 0.0269 POTT - 0.5252 PHOS - 1.387 CALT - 0.2498 CEC + 12.3707	0.761	0.579
Y_{G3}	= - 0.2352 STONES + 0.4315 STONEP+ 6.215 SLOPE + 879.3 BD + 25.64 POROSITY + 5.426 CALA - 0.6818 DJAN + 0.5238 SAPR - 0.2016 SON - 0.4899 SICLAY+ 1.094 SD - 0.0264 POTT - 0.6911 PHOS - 1.945 CALT - 0.2362 CEC - 2388.7712	0.866	0.750

Table 4. Regression Models for Straw Yield of Local Barley Cultivar with their Respective Coefficients of Determination for the Three Years 1980, 1981 and 1982 Combined.

Grain Yield kg/1000 M^2	Regression Equations	R	R^2
Y_{S1}	= - 2.576 STONES - 0.9977 STONEP + 22.51 SLOPE +45.92 BD + 7.331 POROSITY- 3.02 CALA - 181.8154	0.579	0.336
Y_{S2}	= - 0.8621 DJAN + 0.2389 SAPR + 1.675 SON + 2.663 SICLAY + 0.2915 SD - 0.05375 POTT - 4.79 PHOS - 2.395 CALT + 1.705 CEC - 61.6953	0.892	0.795
Y_{S3}	= + 0.4349 STONES- 0.4935 STONEP + 5.468 SLOPE + 1708 BD + 47.88 POROSITY+ 12.91 CALA - 1.99 DJAN + 1.004 SAPR + 0.8166 SON + 0.3302 SICLAY + 2.834 SD - 0.0405 POTT - 5.884 PHOS- 5.018 CALT + 0.7935 CEC - 4641.574	0.913	0.834

Table 5. Regression Models for Grain Yields of Local Barley Cultivars with their Respective Coefficients of Determination for the Two Years 1981 and 1982 Combined with the Introduction of Fertilizer Variables and their Interactions.

Grain Yield kg/1000M^2	Regression Equations			R	R^2
Year 1981 + 1982	- 0.1392 STONES	- 0.7977 STONEP	+ 14.92 SLOPE		
	+15.22 BD	- 1.482 POROSITY	+ 15.41 CALA		
	+ 0.1077 DJAN	- 0.2589 SAPR	+ 0.8082 SON		
	+ 0.1939 SICLAY	+ 0.5797 SD	- 0.2087 POTT		
	+ 2.912 PHOS	- 4.305 CALT	- 4.206 CEC		
	+ 0.4311 NADD	- 0.0052 N^2ADD	+ 4.814 PADD		
	- 0.5278 P^2ADD	+ 0.1796 NP	+ 371.1579	0.956	0.914

Table 6. Effect of N and P Fertilizers on Grain and Total Harvest Barley Yields at Various Sites of the Pilot Area in 1981, 1982 and 1983.

Year	Site Name	Total Precip. mm	$CaCO_3$ %	Depth cm	Clay %	Avail.P ppm	Yield Components kg/donum	Fertilizer Treatment					Level of Significance
								0	N_1	N_2	N_1P_1	N_2P_2	
1980/1981	Okeirbat	155.6	13.5	35	36.	15.2	Grain	57.5	98.5	98.	114	108	.05
							Total Harvest	104.	231.	211.5	230.5	223.5	.05
1980/1981	Hassieh	170.	58	+100	18	9.4	Grain	101.5	68.	93.	95.5	112.5	-
							Total Harvest	250	199.5	292.	252.	263.	-
1980/1981	Manzoul	159.9	1	28	31	12.3	Grain	73	70.5	65.5	95	89.5	-
							Total Harvest	218	225.5	176.	231.5	258.5	-
1980/1981	Mokarram	266.1	3.5	25	22	9.5	Grain	116.5	168	161	179.5	223	.05
							Total Harvest	231.5	346.5	278.5	330.5	411	.10
1980/1981	Domeineh	223	8.3	43	24.	12.5	Grain	109	152	135.5	212.5	221.5	.01
							Total Harvest	275.5	341.5	300	417.5	461.5	.10
1981/1982	Kan-Shekoun	309	33	42	52	6.9	Grain	286.3	285	263.8	295	275.8	-
							Total Harvest	672	857	756.5	1031.5	942.	-
1982/1983	Firklos	200.4	49.5	60.	27.3	27.5	Grain	71.6	72.1	65.4	82.5	79.3	-
							Total Harvest	259	259.8	246.5	270	288	-
1982/1983	Mokarram	247.7	20.	29	44	7.0	Grain	70.7	117.5	116.1	128.3	150.9	.01
							Total Harvest	237	346.	346.8	392.3	476.	.01
1982/1983	Salamieh	265.6	27.5	95	45.8	8.	Grain	121.5	95.9	92.2	146.5	132.1	-
							Total Harvest	381.	346.1	336.2	443.4	407.3	-
1982/1983	Okeirbat	184.9	0.	27	60.	13.8	Grain	99.9	149.9	135.7	169.2	157.8	.05
							Total Harvest	256.5	444.3	473.3	470.5	451.0	.05
1982/1983	Morek	314	38	90	64.5	6.3	Grain	201.5	226.6	214.5	217.9	206.8	-
							Total Harvest	594.	673.8	621.	665	788	-
1982/1983	Tel Kalakh	853.5	0	87	48.8	2.5	Grain	99.	149.9	135.7	169.2	157.8	.01
							Total Harvest	256.5	444.3	473.3	470.5	451.	.01
1982/1983	Omel-Izam	392.5	0.	28	23	7.8	Grain	78.8	146.2	172.5	146.5	217.5	.01
							Total Harvest	303.2	505.	629.	625.2	730.5	.01

Table 7. Effect of N and P Fertilizers on Nitrogen Content (%) in Barley Grain in Different Sites of Syria during 1982-1983 Season.

Site Name	Total Precip.	Variety	Fertilizer Treatments					Level of significance	LSD .01	LSD .02
			0	N_1	N_2	N_1P_1	N_2P_2			
Firklos	200.4	Arabi Aswad	3.07	2.89	3.29	3.24	3.18	-	-	-
Mokarram	247.7	Arabi Abiad	2.19	2.40	3.14	2.42	2.73	**	0.64	0.46
Salamieh	265.6	Arabi Abiad	3.07	3.50	3.35	3.20	3.02	-	-	-
Okeirbat	184.9	-	1.99	2.00	2.73	2.04	2.60	*	0.84	0.60
Morek	314.0	Six rows	2.79	2.81	3.02	2.30	3.17	**	0.41	0.29
Tal Kalakh	853.3	-	2.59	3.55	3.68	2.72	3.60	**	0.87	0.62

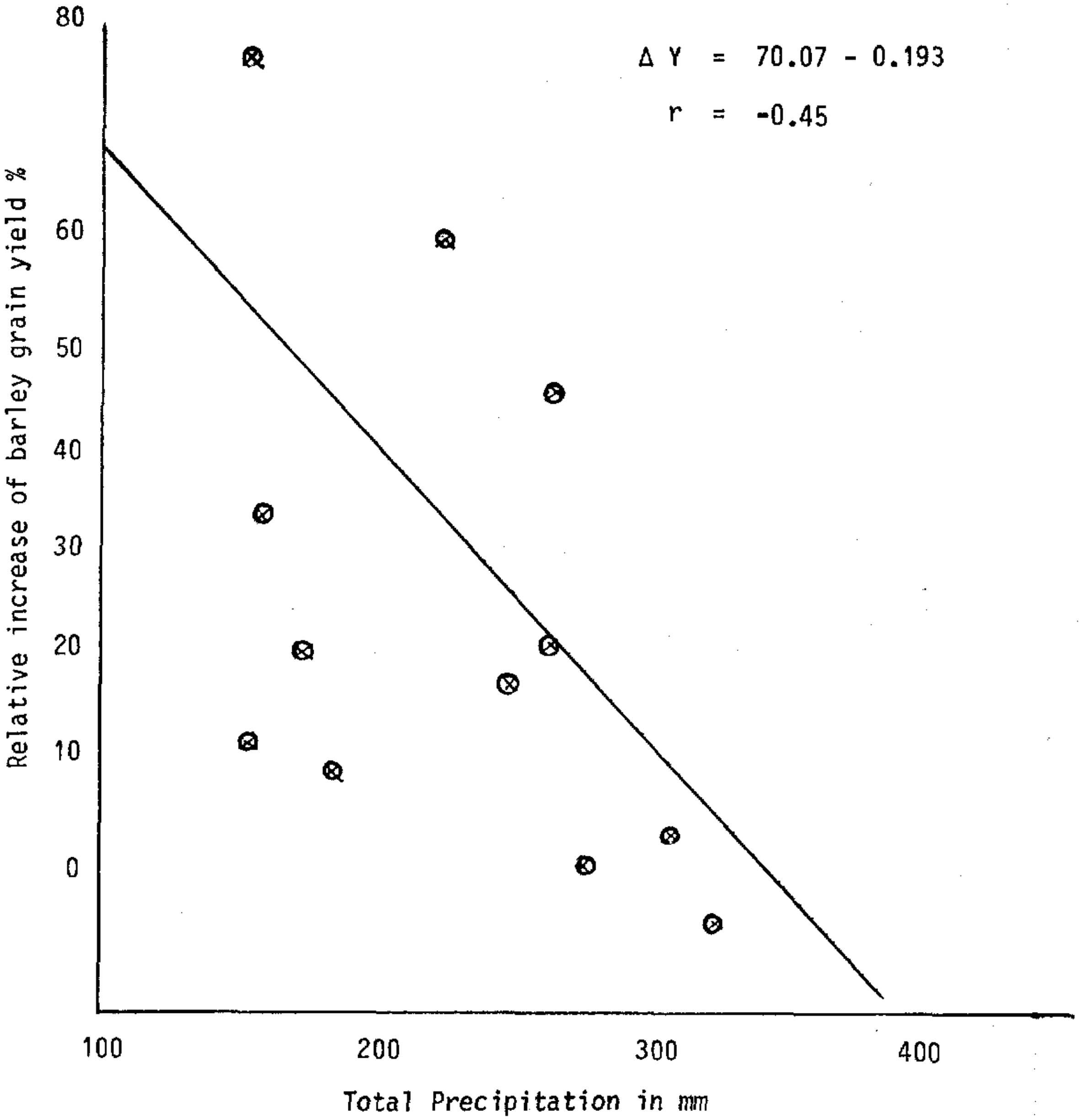


Figure 1 Relative response to phosphate fertilization of Barley as function of total precipitation in growing season in various sites of Syria

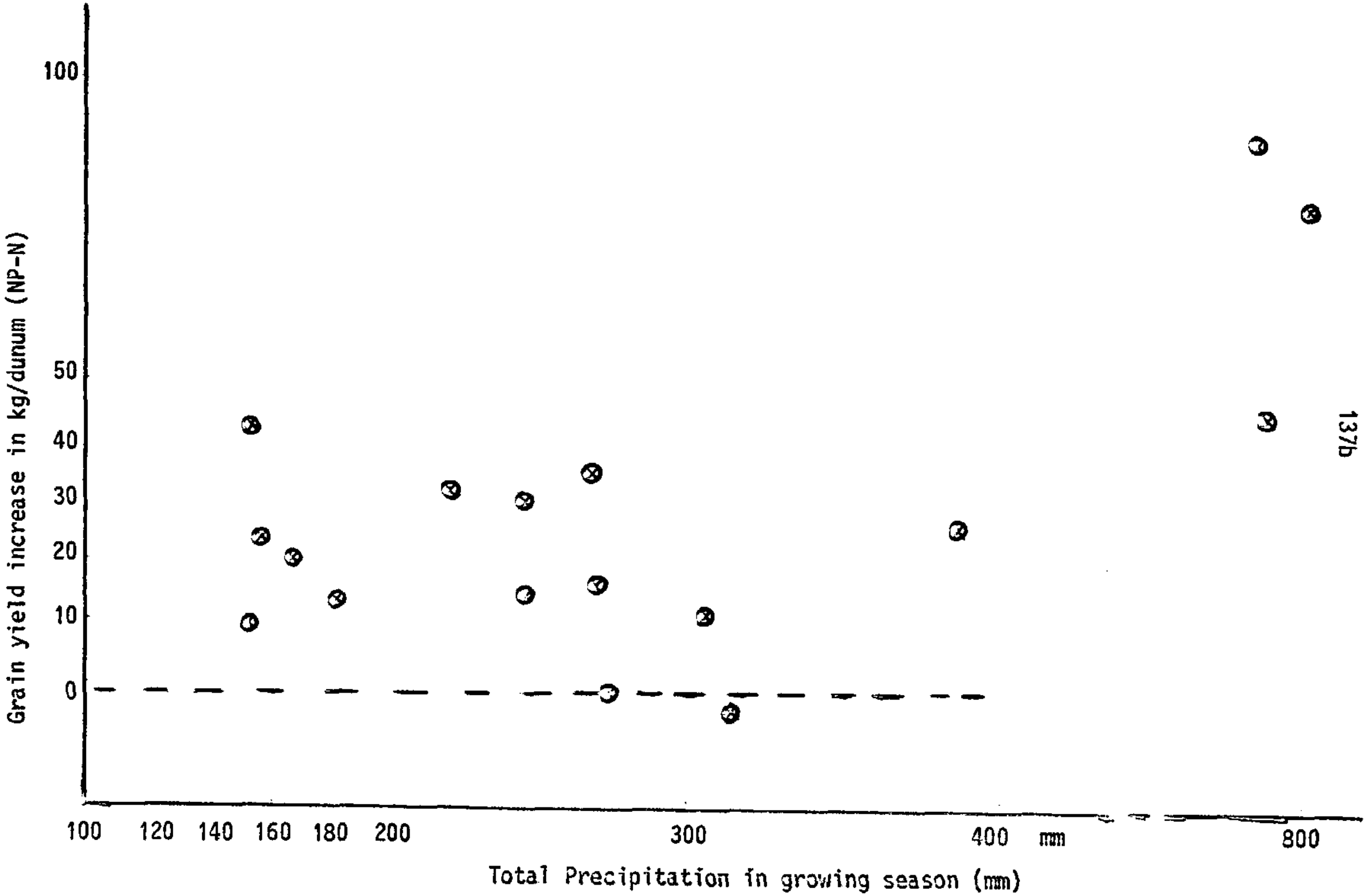


Figure 2. Grain barley yield increase due to addition of phosphates as function of precipitation in various sites of Syria.

1. Introduction

Soil Fertility and Plant Nutrition Section has initiated a study on 1974/75 to assess the response levels of the Syrian soils to phosphate application, and a series of fertilizer experiments have been conducted on some of Syria's economically important crops of which wheat crop is one. This study aimed to elaborate on the following points:

1. To assess the absorbable phosphorus content of different types of soils (estimated according to Olsen method) in all Syria Provinces.

2. To determine response levels to phosphate fertilizer of wheat grown on different types of soils, in terms of:

    a. the absorbable phosphorus level at which wheat crop does or does not respond to phosphate application, and

    b. the economic rate of application based on the actual or effective content of absorbable phosphorus in the soils.

Intensive experimentation has been conducted to define the transformation of phosphorus in soils, particularly in calcareous soils. The phosphorus balance (total phosphorus applied to the soil minus the quantity extracted by the crop and the quantity lost with drainage water) calculated by some of these studies indicates that a considerable proportion of the phosphorus applied to the soil does not become available to the crop as it is transforned to either in organic or to organic but unsoluable compounds (phosphorus fixation). Hence P quantity used by the crop constitutes only a very small proportion of the total quantity applied.

Phosphorus fixation in the soil poses two problems practically.

- The first related to P quantity which effectively remain available in the soil for absorbation by plants' roots.
- The second is related to the assessment of absorbable P level that must be maintained in the soil.

Arview, J.C., 1967, found that the aqueous solution of phosphate, in the presence of Calcium Carbonate, transforms to Dihydro Calcium phosphate which firstly precipitates, then transforms to Tri-Calcium phosphate. This transformation process is strongly affected by temperature. However, the relationship between the results of soil analysis in terms of its P content and the response to phosphate fertilizer depends on the method of phosphorus extraction from the soil. Extraction solution differes from one method to another. According to Olsen, 1954, with extraction solution of pH=8.5 the following responses to phosphate was recorded:

- If soil content of absorbable phosphorus is less than 6 PPM phosphorus application would have significant responses.
- A probable response to phosphorus application is expected in soils of 6-12 PPM of absorbable phosphorus content.
- The response to phosphorus application is nil on soils of absorbable P content of more than 12 PPM.

Based on phosphorus extraction method by Sodium Bicarbonate solution, Bingham, 1962, gave limits for crops with low, moderate or high requirements of phosphorus. He defined borders where phosphorus is insufficient, response to phosphorus is probable, or no response for some crops of low requirement of phosphorus. Bingham considered wheat one of phosphorus low requirement crops, and a soil content of 4 PPM absorbable is not enough for the crop, the response is probable at 5-7 PPM and nil at soil content of more than 8 PPM absorbable P.

2. Methods and Materials

2.1 Location

The locations of the experiment were selected according to the following procedure. For each province, ten soil samples representing different groups of soils were analysed and the absorbable phosphorus contents were estimated. Based on these contents (ranging from 3 to 14.5 PPM) locations of variable contents were selected. Then, another soil analysis was conducted for the selected locations just before planting in order to re-assess the effective levels of phosphorus contents prior to fertilizer application. Later on, another soil sampling and analysis was carried out after harvesting the crops to define the effect of different application rates of phosphorus on basic P contents of the soils.

2.2 Experimental Design

- Five levels of phosphorus application (with one level of N application for all the treatments) were studied. The treatments were distributed on completely randomized plots with three replicates.
- Plot area was 20 m² (8 x 2.5 m).
- Wheat variety Cite Siros was grown in all provinces except Dar'aa and Sweida where the variety grown was Hourani.
- Nitrogen fertilizer (in the form of Calcium Nitrate) was applied before planting at the rate of 80 kg/ha of N.
- Super mono phosphate was applied before planting at the rates of 0, 30, 60, 90, and 120 kg/ha of P_2O_5.
- Sowing rates were 110 kg/ha for Cite Siros and 120 kg/ha for Hourani.

3. Results

- Seasonal rainfall and the dates of major agricultural operations for each location are presented in Table 1.

- Table 2 shows the analysis results of soil samples taken before fertilizer application. The following measurements were recorded for each sample: pH and electric conductivity of the saturated soil phase by using pH and Ec equipment. The organic matter was estimated according to the Dichromate method, the total Calcium Carbonate by the Calcimeter method, the active Calcium Carbonate by Drouineau method, the total N by Kjeldahl method, the exchangeable K by flame spectrophotometer, and the mechanical analysis of the soil was assessed by using the Hydrometer method without removing Calcium Carbonate.

Available phosphorus was estimated according to Olsen method.

- The results of post-harvest sampling and analysis of soils are shown in Table 3.

- Table 4 shows yields and yield responses to phosphate fertilizer of different treatments.

- The economic rate of application for each experiment was calculated within the limits that statistical analysis results permit. The following prices were considered:

kg of Super mono phosphate = 34 SP
kg of Wheat = 49 SP

Regression equations of yield with respect to phosphorus application are listed in Table 5 where,

$\hat{Y}$ = Yield (kg/ha)
P = P_2O_5 (kg/ha)

Discussion of Results

Rainfed wheat response to phosphate fertilizer was studied in 22 trials (18 for Cite Siros variety and 4 for Hourani). The soils of trials' locations were greatly varied in terms of physical and chemical characteristics.

1. Organic matter can be considered less than moderate in all locations with the exception of trial No. (13 and 16) where it was relatively good.

2. Soil contents of Calcium Carbonate and active Calcium Carbonate -- major factors in phosphorus fixation process especially in Calcareous soils -- varied widely within the sample. The contents were as follows:

   1.5 - 7 % in experiments No. 1, 2, 6, 7, 13, 16, 19, 20 and 21.
   11 - 40 % in experiments No. 2, 4, 5, 8, 12, 14, 17, 18 and 22.
   40 - 75 % in experiments No. 9, 10, 11, 15.

3. Due to the low level of organic matter in most of the sampled soils, the total N contents were also small. Exception to this was the case of locations No. 13 and 16. In these two locations the yields of control treatment (Po) were higher than normal yields. This most likely due to positive response of wheat to N fertilizer applied homogeneously to all trial plots.

4. Most soils were rich in exchangeable K element with the exception of locations 10, 11 and 13 (moderate level of K), and locations 1, 12 and 15 (low level of K).

5. Soil content of absorbable phosphorus varied widely in the sample and the locations were selected to reflect this variation in order to achieve the objectives of the study.

6. The relationship between soil content of absorbable phosphorus (P/PPM) and crop response to phosphate application was estimated, where it was possible, by regression equations of yield calculated from the results of statistical analysis after compensating P value by the economic rate of phosphorus application. In cases where equation calculations were not possible the economic rate of application was estimated from production increase of the treatment over the control treatment provided that the increase was big enough to cover the cost of fertilizer applied.

7. The statistical analysis for results of 22 experiments indicates the following points:

   - Wheat response to phosphate application was significant in 11 experiment and it was possible to calculate the economic rate of P application under such conditions.
   - Yield responses to phosphate were unsignificant in 7 experiments, and the statistical analysis data did not allow the calculation of equation which relates yields to applied phosphorus.
   - Wheat did not respond to phosphate in 4 experiments.

8. Figure 1 shows the relationship between soil content of absorbable phosphorus defined as P/PPM (X axis) and yield response to phosphate (Y axis). It is obvious (in the Figure) that on soils of 4-6 PPM phosphorus content wheat responsed positively to phosphate application. The response varied according to soil type, it was higher in non-calcareous soils (experiment No. 12) and lower in the Calcareous soils (experiments No. 4, 11 and 13).

Summary

1. Wheat crop responded positively to phosphate application in 11 experiments. The economic rate of application ranged between 33 and 94 kg/ha of P.

2. The responses were non-significant in 7 experiments.

3. There was no response in 4 experiments.

4. At a given level of P the response to phosphate application varied with respect to soil type. Generally speaking we can say that at 4-6 PPM soil content of absorbable phosphorus the response was obvious, and as this content increased over 9 PPM the response was almost nil.

5. The relationship between soil content of absorbable phosphorus and rainfed wheat response to phosphate application is weak and statistically not significant. However, this response declines as soil content of absorbable phosphorus increases.

Table 1. Rainfall, Dates of Major Agricultural Operations.

Trial No.	Location	Dates of N and P Application	Sowing Date	Rainfalls mm	Harvest Date
1	Homs-Hawleh	16/12/1974	16/12/1974	478.5	25/6/1975
2	Hama-Mesyaf	2/ 1/1975	2/ 1/1975	395.6	3/6/1975
3	Hama-Kafr Zeita	8/ 1/1975	8/ 1/1975	395.6	10/6/1975
4	Hama-Kafr Bahem	2/12/1974	2/12/1974	343.4	2/6/1975
5	Aleppo-Azaz-Alqimeh	13/11/1974	13/11/1974	410	12/6/1975
6	Aleppo-Azaz-Mohamed Maradi	14/11/1974	14/11/1974	410	14/6/1975
7	Idleb-Harem	3/12/1974	3/12/1974	559.4	9/6/1975
8	Idleb-Ma'arah	28/12/1974	28/12/1974	383.5	7/6/1975
9	Lattakia-Yougousneh	17/11/974	17/11/1974	1313.0	22/5/1975
10	Lattakia-Khalali	28/11/1974	28/11/1974	1313.0	24/5/1975
11	Lattakia-Bir Abd	27/11/1974	27/11/1974	974.9	26/5/1975
12	Lattakia-Qaroujeh	18/11/1974	18/11/1974	974.9	27/5/1975
13	Tartous-Sheikh Badr	31/12/1974	31/12/1974	1423.4	17/6/1975
14	Tartous-Safita	29/11/1974	29/11/1974	1318.4	2/6/1975
15	Tartous-Thawra	28/11/1974	28/11/1974	1039.2	18/5/1975
16	Tartous-Dreikish	4/12/1974	4/12/1974	1280.5	3/6/1975
17	Hassakeh-Melkieh	5/12/1974	5/12/1974	566.8	18/6/1975
18	Hassakeh-Kamishli	4/12/1974	4/12/1974	405.3	30/6/1975
19	Dar'a-Nowa	14/12/1974	15/12/1974	N.R.	10/6/1975
20	Suwida-Shahba	1/ 1/1975	1/ 1/1975	200	3/6/1975
21	Suwida-Lakhd	5/ 1/1975	5/ 1/1975	200	23/6/1975
22	Suwida-Shahba	17/12/1974	17/12/1974	216.6	8/6/1975

N.R. = Not recorded.

Table 2. Soil analysis results of samples (0-25 cm) taken from the trial locations prior to fertilizer application.

No.	pH	% of Soil Dried by Air				Absorbable	Exchangeable
		Organic Matter	Calcium Carbonate	Effective Calcium	Total N	P PPM	K PPM
1	7.3	1.13	1.0	2.9	0.10	62.0	30
2	7.9	1.57	2.0	2.6	0.10	6.0	473
3	7.6	1.01	37.0	16.4	0.08	6.5	323
4	7.7	1.45	14.0	6.5	0.10	13.0	633
5	--	0.63	14.0	5.9	0.08	8.0	593
6	--	1.40	4.0	5.9	0.08	5.0	320
7	8.0	1.60	7.0	3.6	0.11	5.0	400
8	7.5	1.01	31.5	14.8	0.06	6.0	458
9	7.6	1.89	41.5	16.4	0.13	13.0	393
10	8.0	1.60	51.5	14.4	0.10	7.5	160
11	7.9	2.26	42.5	16.4	0.14	14.0	250
12	--	0.91	11.0	4.5	0.06	5.0	130
13	--	3.15	3.5	3.6	0.19	12.0	230
14	--	2.39	39.0	4.5	0.12	7.0	365
15	--	1.26	75.0	16.2	0.05	7.0	15
16	--	3.30	1.5	0.06	0.20	4.5	500
17	--	1.76	20.0	7.9	0.10	4.0	508
18	--	1.44	28.5	12.8	0.09	4.0	480
19	--	0.69	4.0	1.98	0.08	3.0	490
20	7.7	1.57	1.5	2.97	0.08	8.5	375
21	7.9	0.82	1.5	3.9	0.07	4.5	630
22	--	0.82	26.0	13.9	0.05	5.0	538

Table 3. Absorbable phosphorus contents of soils samples taken from the fertilizer treatments after harvest.

No.	First Analysis (Before planting)	Second Analysis (after harvest)					Differences Between the First and the Second Analysis				
		Po	P1	P2	P3	P4	Po	P1	P2	P3	P4
1	62.0	57.5	50.5	60.0	63.0	70.5	-4.5	-11.5	-2.0	+1.0	+8.5
2	6.0	6.5	23.5	30.0	38.0	67.5	+0.5	+17.5	+24.0	+32.0	+61.5
3	6.5	5.0	16.5	10.0	38.5	38.5	-1.5	+10.0	+3.5	+32.0	+77.0
4	13.0	6.5	39.0	23.5	39.0	43.0	-6.5	+26.0	+10.5	+26.0	+30.0
5	8.0	6.0	8.5	18.5	16.0	20.0	-2.0	+0.5	+10.5	+8.0	+12.0
6	5.0	4.5	17.0	12.5	24.0	16.0	-0.5	+12.0	+7.5	+19.0	+11.0
7	5.0	6.5	9.5	11.0	16.0	13.0	+1.5	+4.5	+6.0	+11.0	+8.0
8	6.0	7.5	15.0	21.5	15.0	32.0	+1.5	+9.0	+15.5	+9.0	+26.0
9	13.0	3.0	1.5	16.0	21.5	18.0	-10.0	-11.5	+3.0	+8.5	+5.0
10	7.5	*	5.0	11.5	11.5	53.0	-7.5	-2.5	+4.0	+4.0	+45.5
11	14.0										
12	5.0										
13	12.0	14.0	20.0	27.0	34.0	50.0	+2.0	+8.0	+15.0	+22.0	+38.0
14	7.0	7.5	10.0	21.5	19.5	19.5	+0.5	+3.0	+14.5	+12.5	+12.5
15	7.0	8.5	15.0	6.5	9.5	7.5	+1.5	+8.0	-0.5	+2.5	+0.5
16	4.5										
17	4.0										
18	4.0										
19	3.0										
20	8.5										
21	4.5	5.0	22.5	12.5	5.0	62.0	+0.5	+18.0	+8.0	+0.5	+57.5
22	5.0	7.5	9.5	8.0	11.0	5.0	+2.5	+4.5	+3.0	+6.0	0

* Negligible amount.

Table 4. Effect of phosphate application on the yields of rainfed wheat (kg/ha).

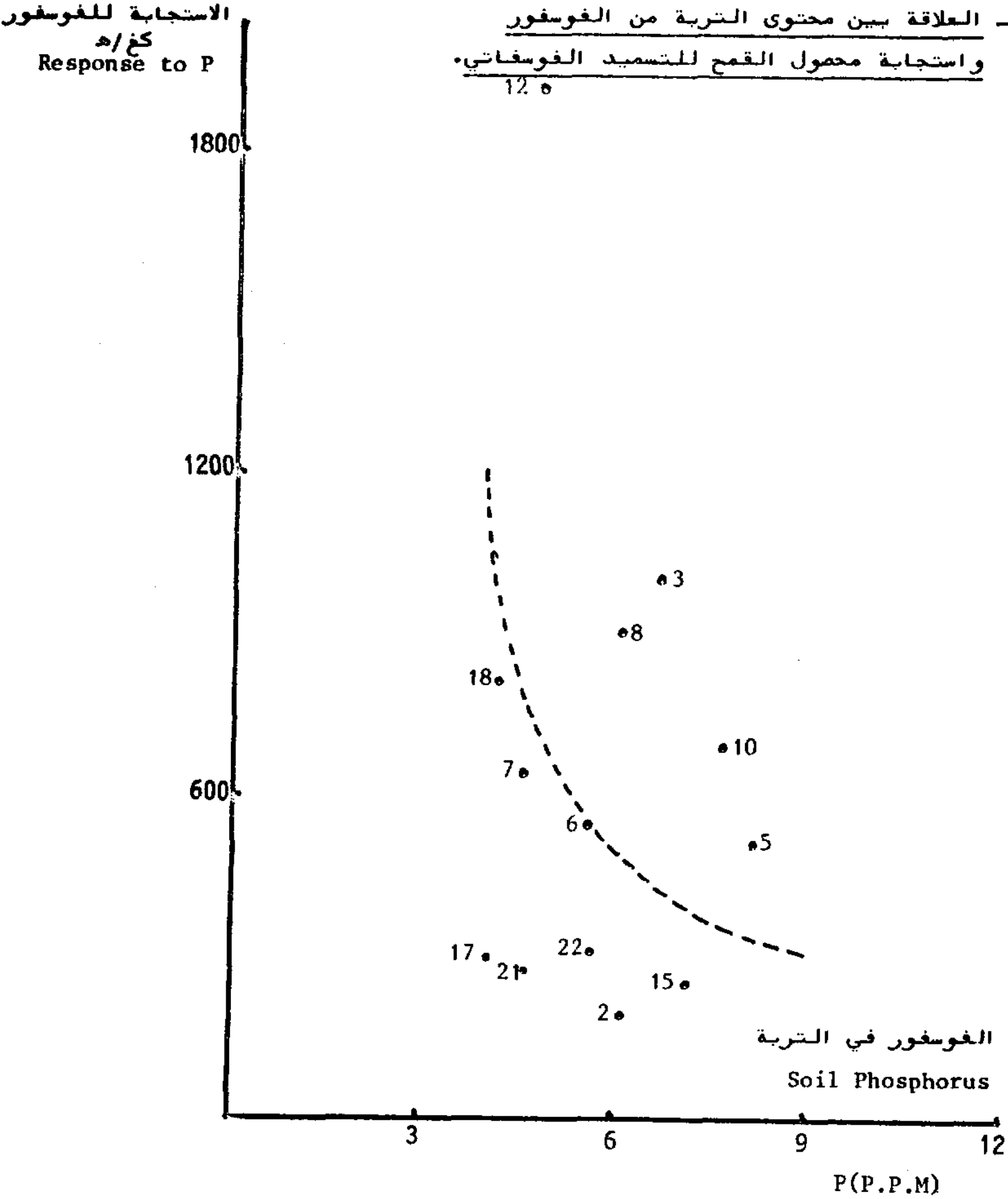
	Yields According to Treatments					Yield Increase Over non Fertilized Treat. (Po)				L.S.D.		Coefficient
No.	Po	P1	P2	P3	P4	P1	P2	P3	P4	1%	5%	of Variance
1	1758	1458	2267	2750	2600	-300	509	992	842	--	--	Inaccurate
2	1792	1925	2067	2125	2125	133	275	333	333	201	138	3.6
3	3591	4233	4383	4575	4758	642	392	984	1167	260	179	2.1
4	3333	2975	3400	3225	3292	358	-67	-108	-41	771	530	8.7
5	2125	2958	2875	2375	2667	833	750	250	542	1030	708	14.5
6	1916	3042	2500	2308	2266	1126	584	392	350	460	316	6.9
7	1516	1710	1917	2417	1907	194	401	901	391	294	202	5.6
8	1846	2140	2567	2907	2069	294	721	1061	223	931	640	14.1
9	1933	1366	1516	1450	1058	-567	-417	-483	-875	--	--	Inaccurate
10	2525	3642	3425	3250	3375	1117	900	725	850	1837	1262	20.6
11	2300	1958	2295	2441	2608	-342	-5	141	308	852	586	13.3
12	590	1878	2166	2545	2561	1288	1576	1955	1971	1635	1124	Inaccurate
13	2217	2333	2517	2483	1967	116	300	266	-250	1437	987	22.8
14	2600	2366	2533	2067	1833	-234	-67	-533	-767	--	--	Inaccurate
15	4667	5833	4267	5500	4667	1166	-400	833	0	--	--	Inaccurate
16	1433	3433	3333	4167	1233	2000	1900	2734	-200	--	--	Inaccurate
17	2833	3167	3167	3083	2833	334	334	250	0	889	611	10.8
18	2667	3000	3500	2667	2833	333	833	0	166	1518	1043	19.0
19	1300	1336	1550	1726	1816	36	250	426	516	403	277	9.5
20	1167	1250	1000	750	583	-83	-167	-417	-584	--	--	Inaccurate
21	1700	1950	2033	2100	1583	250	333	400	-117	738	507	14.3
22	1583	1867	2033	1800	1750	284	450	217	167	271	186	5.5

Table 5. Regression equations of yield with respect to phosphorus and the economic application of phosphate fertilizer.

No.	Soil Content of Phosphorus P PPM	Regression Equation of Yield with respect to Phosphorus	Economic Application of P_2O_5 kg/ha	Observations
1	62.0	--	--	No effect of Phosphorus
2	6.0	$\hat{Y} = 1783 + 6.221\ P - 0.02775\ P^2$	38	--
3	6.5	$\hat{Y} = 3648 + 17.250\ P - 0.06944\ P^2$	95	--
4	13.0	--	--	Unsignificant Effect
5	8.0	$\hat{Y} = 2285 + 15.953\ P - 0.11905\ P^2$	50	--
6	5.0	$\hat{Y} = 2129 + 18.775\ P - 0.15738\ P^2$	46	--
7	5.0	$\hat{Y} = 1436 + 15.558\ P - 0.08835\ P^2$	65	--
8	6.0	$\hat{Y} = 1728 + 26.393\ P - 0.18624\ P^2$	60	--
9	13.0	--	--	No effect of Phosphorus
10	7.5	$\hat{Y} = 2704 + 22.853\ P - 0.1541\ P^2$	61	--
11	14.0	--	--	No effect of Phosphorus
12	5.0	$\hat{Y} = 683 + 38.230\ P - 0.19050\ P^2$	89	--
13	12.0	--	--	Unsignificant Effect
14	7.0	--	--	No effect of Phosphorus
15	7.0	$\hat{Y} = 4882 + 10.317\ P - 0.09524\ P^2$	33	--
16	4.5	--	--	Unsignificant Effect
17	4.0	$\hat{Y} = 2855 + 11.627\ P - 0.09920\ P^2$	38	--
18	4.0	--	--	Unsignificant Effect
19	3.0	--	--	Unsignificant Effect
20	8.5	--	--	Unsignificant Effect
21	4.5	--	--	Unsignificant Effect
22	5.0	$\hat{Y} = 1600 + 11.047\ P - 0.08465\ P^2$	41	--

Relationship between Soil Content of P and the Response of Rainfed Wheat to Phosphate Fertilizer.

منحنى بياني رقم ١- العلاقة بين محتوى التربة من الفوسفور واستجابة محصول القمح للتسميد الفوسفاتي.



DRYLAND BARLEY PRODUCTION IN NORTHWEST SYRIA:

III. Response to fertilizer application

by

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1. Introduction

Many of the soils in the Mediterranean environment are deficient in plant--available nutrients (Jackson, 1977; Sillanpää, 1982). Application of fertilizers under such conditions may increase yields significantly, even though potential yields under rainfed conditions are determined by available moisture in low--rainfall area's (FAO, 1969; Harmsen et al, in press). Increased levels of available nutrients may enhance root development and early vegetative growth, which may result in increased water use efficiency by the crop (Cooper, in press; Cooper et al, in press). Research conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA) has confirmed that there exists a considerable potential for increasing yields of cereal crops under rainfed conditions, through the use of nitrogen and phosphorus fertilizers, and improved crop management (FAO, 1969; Cooper, in press; Harmsen et al, in press).

The objective of this paper is to discuss some of the factors that limit yields in dryland barley production in Syria. Some results of experiments conducted at experimental sites and in farmer's fields will be presented.

2. Factors limiting yields of dryland barley crops

The potential yield of a particular crop may be defined as the maximum yield that can be obtained under a given set of environmental conditions, that cannot be controlled by the farmer. Potential yields under irrigated conditions would be determined by crop genetic factors, and environmental factors, such as daylength, radiant energy and temperature. Under rainfed conditions, in arid and semi-arid regions, potential yields are generally determined by moisture available to the crop.

Actual yields in farmer's fields are usually lower than the potential yields under those conditions. Factors that may limit yields under farmer's conditions, include the incidence of weeds, pests and diseases, poor plant establishment, nutrient deficiencies, damage caused by rodents, birds etc. It is usually difficult, if not impossible, to determine which factor actually limited crop yield in a farmer's field. This is because different factors may limit growth rates of crops at different stages during the growing season. For example, available moisture or low temperatures may limit growth rates early in the season, then nutrients may become limiting, later on pests or diseases, whereas at the end of the season moisture or temperature may again become limiting. Other factors do not directly affect crop growth rates, but tend to depress yields. For example, grazing of the crop (sheep, camels) tends to depress final crop yields, whereas weeds compete with the crop for moisture and nutrients, and thus tend to depress crop yields. Factors such as crop rotation, tillage methods, seed quality, time and method of sowing, and seeding rate, may affect crop establishment and the effective length of the growing season, and therefore affect yields.

Matar (1981) showed that yields of cereal crops in farmer's fields along the Tartous-Palmyra transect were highly correlated with rainfall (positive) and the incidence of weeds (negative), and with factors that affect plant stand establishment and the soil water balance, such as stoniness, slope, soil depth, soil texture and bulk density of the soil. The available-nutrient status of the soil did not appear to be highly correlated with crop yields.

In this connection, two points may be mentioned:

(1) Even in nutrient-deficient soils, that is, in soils that are unable to supply the crop with sufficient nutrients to sustain potential growth, yields are not necessarily limited by available nutrients. Therefore, application of fertilizers to correct nutrient deficiencies does not necessarily increase yields under farmer's conditions. Other factors, such as available moisture, low temperatures, pests or diseases may be more limiting than available nutrients. Application of fertilizers (in particular nitrogen) under such circumstances may acutually depress yields. For example, application of nitrogen fertilizer in a dry year may depress yields due to haying off of the crop. Application of nitrogen may also create conditions favourable for the development of pests or diseases, due to enhanced vegetative growth, or may result in a strong development of weeds.

The fact that little or no response to fertilizer is obtained, does not imply, however, that the soils were not deficient in nutrients. It highlights the importance of other factors in the system, and of interactions between the factors that affect yields, such as nutrient-moisture and nutrient-weed interactions. It may be concluded that in order to increase yields under rainfed farming conditions, nutrient deficiencies have to be corrected, but the application of fertilizers has to be part of a carefully designed package, in which other yield determining factors, and their interactions, are considered.

(2) Even if available nutrients, rather than available moisture, are limiting actual growth rates during most of the season, yields tend to increase with higher rainfall. This is because in a season with above-average rainfall, and a favourable rainfall distribution, the effective availability of nutrients is likely to increase. Moisture penetrates deeper into the soil, thus increasing the volume of soil accessible to the rooting system. An early start of the rains may lengthen the growing season, and create more favourable conditions for early vegetative growth, also because average temperatures are higher in November, than in December on January. A better root development and a higher microbiological activity in the soil may result in an increased availability of soil nutrients. Late rains allow the crop to take up nutrients from the surface horizon, where nutrient availability (in particular phosphorus) may be higher than in subsurface horizons. Therefore, yields are likely to increase with higher rainfall, but his does not imply that available nutrients would not be a major limiting factor.

In most of the barley producing area in Syria, rainfall is the main variable determining differences in yields between seasons. For example, barley yields in Syria in the period of 1969-1980, ranged from 97 (1973) to 1310 kg grain/ha (1980), with an average of 711 (± 379) kg grain/ha (MAAR, 1977, 1980). It may be assumed that the fluctuations in barley yields between seasons (Figure 1) mainly reflected differences in rainfall conditions between seasons. A linear regression of mean barley yields in all of Syria on estimated rainfall in the major barley producing areas (weighted average proportional to the area under barley in each province) resulted in the following regression equation for the period 1969-1980:

$$GY = 0.0036(R-151) \qquad n=12,\ r^2=0.78$$

where GY denotes grain yield (kg/ha), R denotes rainfall (mm/season), n is the number of seasons, and r^2 is the coefficient of variation (Harmsen and Anderson, in preparation). Hence, barley yields tended to increase with higher rainfall (Figure 2), even though nutrient deficiencies were probably a major yield limiting factor in rainfed barley production in Syria.

Agronomy experiments conducted in Syria, as part of a joint research program between ICARDA, ACSAD and ARC-Douma, have shown that grain yields of cereal crops increased with rainfall across locations, and tended to increase with fertilizer application at each individual location. For example, a linear regression of grain yields in fertilized plots at 17 locations in Syria (1981-82 season) resulted in the following regression equation:

$$GY = 0.0150(R-100) \qquad n=17,\ r^2=0.73$$

and for grain yields in unfertilized plots the following regression equation was obtained:

$$GY = 0.0089(R-118) \qquad n=17,\ r^2=0.56$$

Hence, yields tended to increase with rainfall (Figure 3), but the increase was more pronounced under fertilized conditions (15 kg grain/ha per mm of rainfall) than under unfertilized conditions (8.9 kg grain/ha per mm of rainfall). At each individual location, yields tended to increase with application of fertilizer, from about 770 kg grain/ha at 200 mm of rainfall, to about 1990 kg grain/ha at 400 mm. This illustrates that application of fertilizer may significantly increase yields, and thus water-use efficiency, even under low-rainfall conditions.

3. Yield functions and fertilizer use efficiency

The yield of cereal crop (Y) may be described as :

$$Y = f\ (X_1,\ X_2,\ \ldots\ldots)$$

where f denotes the yield function, and X_1, X_2, .. denote variables such as available moisture and nutrients, temperature, pests, diseases, weeds, soil conditions and management factors.

Under experimental conditions, the yield function can often be simplified, because many of the factors limiting yields in farmer's fields, are controlled in experimental plots. In fertilizer-response trials, weeds, pests and diseases are usually controlled, unless they are factors in the experiment. Most experimental fields are on deep soils, free of stones, and on nearly flat land, such that these soil factors do not contribute to yield differences between different locations. Crop management (seeding rate, row spacing, sowing method) are usually uniform among different locations, and if the experimental sites are at approximately the same altitude, temperature conditons are likely to be similar between different locations as well. Under such conditions, most of the variation in yields between locations will be due to differences in available moisture (θ), and in available nitrogen (N) and phosphorus (P). Hence, the yield function reduces to:

$$Y = f\ (\theta,\ N,\ P)$$

where it is assumed that N and P are factors in the experiment, and that one crop variety is used as the indicator crop.

In variety-testing trials, the yield function would take the form:

$$Y = f\ (\theta,\ V)$$

where V denotes variety, and where it is assumed that sufficient fertilizer is applied to correct nutrient deficiencies. For example, a linear regression of grain yields of barley, durumwheat and breadwheat (average of all varieties for each crop) in the 1981-82 farmer's field verification trials, on estimated rainfall during the growing season, resulted in the following regression equation:

$$GY = 0.0145(R-153) \qquad n=49,\ r^2=0.78$$

Hence, 78% of the observed variation in yields of cereal crops between locations, could be explained by estimated seasonal rainfall (from nearby meterological stations) for those locations (Figure 4).

Moisture available to the crop during the growing season (θ), depends on the moisture status of the soil at the start of the season (e.g., moisture carried over from fallow), on the amount, distribution and intensity of rainfall, on climatic variables, such as temperature and relative humidity, on crop factors, such as stand establishment and rooting pattern, and soil factors, such as slope, soil depth, permeability, and water-holding capacity. In most fertilizer or variety trials, the moisture balance is not studied, and only rainfall during the season is recorded. Because rainfall is one of the major factors determining plant-available moisture, θ may be replaced by the total seasonal rainfall (R) in the yield equation. Obviously, this is a rather rude approximation, but Figure 4 shows that for the conditions of those experiments, the approximation is acceptable. On the other hand, in the experiments reported by Matar (1981), plant-available moisture could not be replaced by seasonal rainfall because of the variability in soil conditions (slope, depth, texture, bulk density) between fields.

The water-use efficiency of a crop (WUE) may be defined as the partial derivative of the yield function with regard to available moisture:

$$WUE = \frac{\partial f}{\partial \theta}$$

or with regard to rainfall:

$$WUE = \frac{\partial f}{\partial R}$$

where WUE is in kg/ha per mm of available moisture, or rainfall. The factors that determine WUE for barley crops in rainfed agriculture, have been discussed recently (Cooper, in press).

The nitrogen-use efficiency of a crop (NUE) may be defined as:

$$\mathrm{NUE} = \frac{\partial f}{\partial N}$$

and the phosphorus-use efficiency by :

$$\mathrm{PUE} = \frac{\partial f}{\partial P}$$

In fertilizer experiments, plant available nitrogen is made up of available nitrogen in the soil (Ns) and nitrogen applied as fertilizer (Nf). Similarly, plant-available phosphorus is made up of Ps and Pf. In order to test the efficiency of fertilizer application, it is useful to define fertilizer-use efficiencies:

$$\mathrm{NFE} = \frac{\partial f}{\partial Nf}$$

where NFE denotes the nitrogen fertilizer-use efficiency, and:

$$\mathrm{PFE} = \frac{\partial f}{\partial Pf}$$

where PFE denotes the phosphorus fertilizer-use efficiency (kg grain or dry matter per kg of nutrient applied). Fertilizer-use efficiencies usually decrease with increasing level of soil nutrients and with increasing level of fertilizer applied.

In fertilizer trials, nutrients are applied in discrete quantities, e.g., N_0, N_1,.. for nitrogen, and P_0, P_1, .. for phosphorus. For such trials, fertilizer-use efficiencies are usually calculated from the approximate equations :

$$\mathrm{NFE} = \frac{\Delta Y}{\Delta N}$$

for nitrogen, and:

$$\mathrm{PFE} = \frac{\Delta Y}{\Delta P}$$

for phosphorus, where ΔY denotes the difference in yield between two fertilizer treatments, and ΔN or ΔP the difference in nutrients applied. Usually the lower level of fertilizer application is taken as zero, and only one nutrient is varied between treatments. Hence, for nitrogen :

$$\mathrm{NFE} = \frac{Y(N_1,P_1) - Y(N_0,P_1)}{N_1 - N_0}$$

and for phosphorus:

$$\mathrm{PFE} = \frac{Y(N_1,P_1) - Y(N_1,P_0)}{P_1 - P_0}$$

It is important to note that fertilizer-use efficiencies depend on the levels of soil nutrients, on the level of fertilizer applied, and on the levels of other nutrients applied.

4. Regression models for yield analysis

The yield functions presented in the previous section are not very suitable for the analysis of the results of fertilizer trials, because the functional relationships between the relevant variables are usually not known. Instead, the results of fertilizer trials may be analyzed by means of regression analysis of yields on one or more variables.

To this end, it may be assumed that the yield function can be approximated by the product of functions of the individual variables:

$$f(R,N,P) = f(R)\ f(N)\ f(P)$$

As a further simplification it may be assumed that $f(x_i)$ can be approximated by a power series:

$$f(x_i) = a_0 + a_1 x_i + a_2 x_i^2 + \ldots\ldots = \sum_n a_n x_i^n$$

where a_n denotes a coefficient, and x_i a variable in the yield equation. Hence, the yield equation can be written in the approximate form:

$$f(R,N,P) = (\Sigma\, a_n\, R^n)(\Sigma\, b_n\, N^n)(\Sigma\, c_n\, P^n)$$

In regression analysis, the summation is usually limited to n=1 (linear) or n=2 (quadratic). The linear approximation would thus become:

$$f(R,N,P) = (a_0 + a_1\, R)(b_0 + b_1\, N)(c_0 + c_1\, P)$$

Plant-available nitrogen (N) may be distinguished in soil-nitrogen (Ns) and fertilizer-nitrogen (Nf):

$$b_1 N = b_{11}\, N_s + b_{12}\, N_f$$

similarly for plant-available phosphorus:

$$c_1P = c_{11}\,P_s + c_{12}\,P_f$$

such that the linear approximation of the yield function may be written as:

$$f(R,N,P) = (a_0 + a_1\,R)\,(b_0 + b_{11}\,N_s + b_{12}\,N_f)\,(c_0 + c_{11}\,P_s + c_{12}\,P_f)$$

Hence, even a simple linear approximation of the yield function, already results in a regression equation with 18 terms, whereas the quadratic approximation results in regression equation with 108 terms. Obviously, there is a limit to what a computer can handle, and therefore the quadratic equation is usually simplified in that only linear interactions between nutrients are considered, that is, only terms of the form N_sN_f, N_sP_s, N_sP_f, etc. This would result in a modified quadratic regression equation with 45 terms.

A simple linear regression model was used to study the effect of application of nitrogen fertilizer (N_f) and phosphorus fertilizer (P_f) on grain yield of cereal crops (GY). Experimental sites were characterized by seasonal rainfall (R), nitrate-nitrogen in the soil, down to 1.20 m depth (N_s), and Olsen-extractable phosphorus in the 0-20 cm layer of the soils (P_s). The square of the multiple correlation coefficient ($\bar{R}^2$), adjusted for degrees of freedom, was used as a measure for the explanatory power of the regression equations. Regression analyses were carried out at the Harry S. Darling Computer Center at Tel Hadya, using a computer program called CRISP.

The trials analyzed, were unreplicated NxP trials with 5 N levels and 5 P levels. Hence, 25 grain yields were obtained for each location. The results for 17 location in Syria (82-83 season) may be summarized as follows (I=intercept):

$$GY = I + aN_f + bN_s + cP_f + dP_s \qquad (\bar{R}^2 = 0.35)$$
$$GY = I + aN_f + bN_s + cP_f + dP_s + eR \qquad (\bar{R}^2 = 0.70)$$
$$GY = I + aN_f + bN_s + cP_f + dP_s + eR + \text{interaction terms} \qquad (\bar{R}^2 = 0.79)$$

Rainfall had the most significant effect on grain yield, followed by soil nitrogen and soil phosphorus. A modified quadratic model could explain 80-90% of the variation in grain yields across locations (Harmsen and Anderson, in prep.).

Regression equations of the type presented here, could be useful in the interpretation of the results of fertilizer experiments, and as a basis for fertilizer recommendations. It has to be emphasized, however, that equations of this type would only apply to situations where soil conditions and crop management do not differ significantly between locations, and where factors such as weeds, pests and diseases are not limiting yields.

5. SNP trials

Seed rate x nitrogen x phosphorus (SNP) trials, have been conducted during 3 seasons (1979-1982) at 5 sites in Aleppo Province: Jindiress, Kafr Antoon, Tel Hadya, Breda, and Khanasser. The results of these trials have been reported for each season individually (ICARDA 1981a, 1981b, 1982). One of the objectives of these trials was to relate the productivity of Beecher barley to soil and climatic conditions, as a basis for the generalization of the results of these trials. The results of an analysis of yield responses of Beecher barley to applied nitrogen and phosphorus, across sites and seasons, have been presented recently (Harmsen et al., in press). The results of the analysis of variance of a number of selected treatments in the trials, showed that site was the factor which had the most significant effect on yield, followed by nitrogen, year, and phosphorus. The site x year and site x N interactions were also highly significant (0.1%).

During the 1982/83 season, the SNP-trials were replaced by factorial trials (2^5-trials), in which 5 factors (nitrogen, phosphorus, weed control, variety and seed rate) were considered at two levels. The responses to phosphorus fertilizers during 3 years of SNP-trials and 1 year of 2^5 trials are summarized in Table 1. The parameters listed in Table 1 include the grain yields in plots that received no phosphorus, GY_0, and the phosphorus-fertilizer efficiencies, PFE, in kg grain/kg P_2O_5. Because of changes in the design of the trials in the course of 4 years, it was not possible to be entirely consistent in the presentation of the results. The grain yields in unfertilized plots refer to P_0=0 kg P_2O_5/ha and N_1=20 (residual trials) to 60 kg N/ha. The phosphorus-fertilizer efficiencies refer to P_0=0 and P_1=45-60 kg P_2O_5/ha, at N_1=20 to 60 kg N/ha.

The data in Table 1 illustrate the order of magnitude of the responses to phosphorus fertilizer at sites with different rainfall conditions in Aleppo Province. The direct response to phosphorus application was positive at all sites, and averaged 4.3 kg of grain/kg P_2O_5 applied, for 4 sites and 4 seasons. At Jindiress, Kafr Antoon and Breda, the PFE tended to decrease with increasing GY_0 (Mitscherlich behaviour), suggesting that phosphorus was indeed the major factor limiting yields, in plots that received nitrogen fertilizer. The fluctuations in GY_0 between seasons reflect variation in climatic conditions. At the wetter sites, Kafr Antoon and Jindiress, the yields in the 1982/83 season were lower, but the PFE higher than in previous seasons (Cooper effect).

The residual effects of phosphorus in the first season (all sites) and the second season (Breda and Khanasser) following the application of phosphorus, were generally positive. During the 1980/81 season the direct response to phosphorus fertilizer (4.8 kg grain/kg P_2O_5), averaged over 4 sites, was in fact slightly lower than the residual response (5.3 kg grain/kg P_2O_5). Averaged over 2 seasons and 4 sites the direct response was slightly higher (4.3) than the residual response (3.0 kg P_2O_5/ha). Although the data in Table 1 are approximative, they clearly show that phosphorus was a significant factor in determining yields under the conditions of the experiments.

The data in Table 2 also show the decline in yields, observed at all sites, if barley crops were grown continuously. This is further illustrated in Figure 5, which shows that barley yields at Breda and Khanasser declined quite steeply in the second or third year of continuous barley.

6. On-farm trials (farmer-managed trials)

The significance of phosphorus as a factor affecting barley yields under experimental conditions, was fairly well established in 1981, after two seasons of SNP-trials. Under farmer's conditions, however, poor stand establishment, weeds, unfavourable soil conditions, and other factors may affect yields, and therefore it was decided to start a new series of experiments, at the farmer's level of management. Starting in the 1981/82 season, simple agronomy trials have been conducted in farmer's fields near Breda and Khanasser, in which 2 factors were considered: variety (Beecher barley and Arabic Aswad) and phosphorus fertilizer (0 and 50-60 kg P_2O_5/ha). The objectives of these trials were to (1) compare the performance of Beecher barley and Arabic Aswad under experimental conditions and under farmer's management, and (2) compare the responses to phosphorus fertilizer under experimental and farmer's conditions.

The results of two years of on-farm trials are summarized in Table 2. It can be seen that the phosphorus fertilizer use efficiencies for Beecher barley, averaged over two seasons, compared well with the mean values for Beecher barley at Breda and Khanasser experimental sites (1981-83), listed in Table 1: 7.5 and 7.3 at Breda, and 2.7 and 3.1 kg grain/kg P_2O_5 at Khanasser, for farmer's fields and experimental sites, respectively. This is further illustrated in Figure 6, where yields in fertilized plots (GY_p) are plotted against yields in unfertilized plots (GY_o). The broken line represent the relationship:

$$GY_p = GY_o$$

that is, no response to phosphorus fertilizer. It can be seen that in only 4 out of 28 farmer's fields, yields in fertilized plots seemed to be lower than yields in unfertilized plots. In all other fields, fertilized yields were higher. The solid line in Figure 6 represents the linear regression curve of GY_p on GY_o:

$$GY_p = 0.156 + 1.16\ GY_o \qquad n=36,\ r^2=0.84$$

Hence, the effect of phosphorus application tended to increase with higher yields, suggesting that the lowest yields were limited by factors other than phosphorus. It can further be seen from Figure 6 that grain yields at Breda and Khanasser experimental sites, in the 81/82 and 82/83 seasons (large stars) were in the same range as yields in farmer's fields, whereas yields at the experimental sites in the preceding two seasons tended to be higher (small stars), probably due to more favourable climatic conditions.

It may be concluded that phosphorus increased yields of barley crops significantly during the 81/82 and 82/83 growing seasons, and that results obtained at experimental sites and in farmer's fields were in close agreement.

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II. Rainfall-yield relationships
III. Responses to nitrogen fertilizer.
IV. Responses to phosphorus fertilizer.

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Table I. Grain yields in unfertilized plots (t/ha) and phosphorus-fertilizer efficiencies (kg grain/kg P_2O_5) in SNP-trials and 2^5 trials.

جدول ١ – محصول الحبوب في القطع غير المسمدة (طن/هكتار) ، وكفاءة السماد الفوسفوري (كغ حبوب /كغ P_2O_5) في تجارب SNP وتجارب 2^5 .

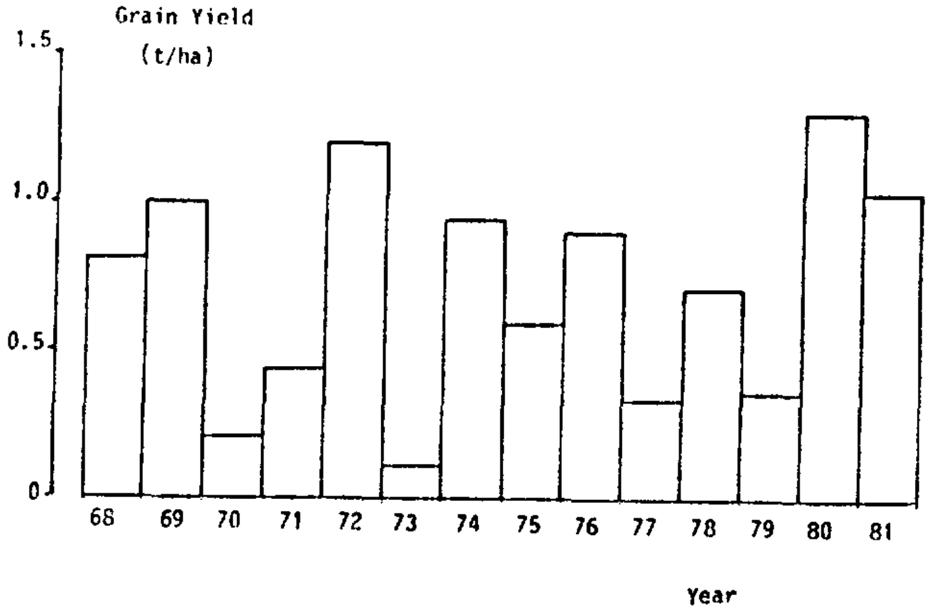
Site الموقع	Season السنة	Direct Response الاستجابة المباشرة		1st yr resid. بقايا السنة الاولى		2nd yr resid. بقايا السنة الثانية	
		GY(P_o)	PFE	GY(P_o)	PFE	GY(P_o)	PFE
Jindiress	1979/80	2.99	3.2				
	1980/81	3.58	1.8	1.66	4.2		
جنديرس	1981/82	2.97	3.5	1.38	-0.2		
	1982/83	1.61	7.3				
	80-82	3.28	2.65	1.52	2.0		
Kafr Antoon	1979/80	3.59	5.3				
	1980/81	4.16	4.5	2.17	5.3		
كفر انطون	1981/82	3.44	4.1	1.54	-1.1		
	1982/83	1.66	7.5				
	80-82	3.80	4.3	1.86	2.1		
Breda	1979/80	1.89	5.4				
	1980/81	1.80	7.2	0.64	4.0		
بردة	1981/82	1.51	4.1	0.44	3.4	0.15	2.0
	1982/83	0.52	10.4				
	80-82	1.66	5.7	0.54	3.7		
Khanasser	1979/80	1.93	13.9				
	1980/81	1.27	5.7	0.51	7.5		
خناصر	1981/82	0.77	3.3	0.39	1.1	0.17	2.7
	1982/83	0.89	2.9				
	80-82	1.02	4.5	0.45	4.3		

Table 2. Yields of barley in unfertilized plots (P_0) and in plots where 50 (1981/82) or 60 (1982/83) kg P_2O_5/ha was applied (P_+), in trials conducted in farmer's fields during two seasons (1981-83).

الموقع Location	الموسم Season	رقم التجربة Trial No.	شعير بيجر Beecher Barley				عربي أسود Arabic Aswad			
			(حب) Grain		(قش) Straw		(حب) Grain		Straw (قش)	
			P_0	P_+	P_0	P_+	P_0	P_+	P_0	P_+
Breda بردة	1981/82	1	508	973	671	975	774	647	1191	715
		3	584	536	605	532	516	431	594	476
		4	595	799	967	1133	796	910	1082	1236
Breda	1982/83	1	1010	1647	1352	2137	533	1065	637	1532
		2	690	1361	1085	1569	851	953	1113	1202
		3	518	1031	829	1292	878	1174	1170	1790
		4	615	1107	812	1778	882	913	1114	1337
Khanasser خناصر	1981/82	5	159	163	443	309	46	217	222	298
		6	70	120	215	335	170	144	295	215
		7	668	771	1269	1170	831	973	970	1148
Khanasser خناصر	1982/83	1	693	1055	1165	1243	951	1593	1454	2418
		2	1099	1451	1351	1986	1315	1750	1348	2148
		3	980	1002	1306	1481	1005	1316	1375	1620
		4	368	521	529	1168	459	1237	554	1588
Breda برده	1981-83		646	1065	903	1345	747	870	986	1184
Khanasser خناصر	1981-83		577	726	897	1099	682	1033	888	1348
Br. + Kh.	1981/82		431	560	695	742	522	554	726	681
Br. + Kh.	1982/83		747	1147	1054	1582	359	1250	1096	1704
Br. + Kh. برده خناصر	1981-83		611	896	900	1222	715	952	937	1266

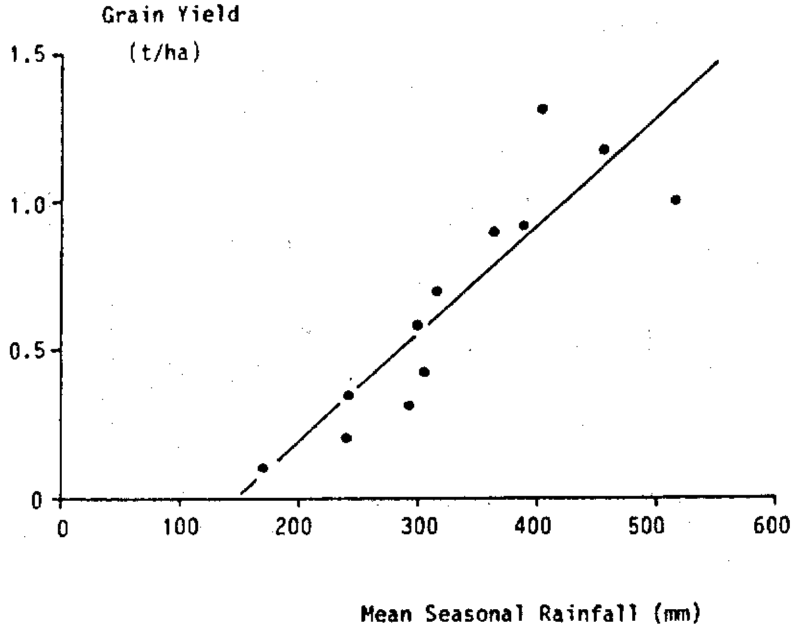
جدول ٢ – محصول الشعير في القطع غير المسمدة (P_0) وفي القطع المسمدة ب ٥٠
(٨٢/١٩٨١) او ٦٠ (٨٣/١٩٨٢) كغ سماد فوسفاتي (P_2O_5) بالهكتار.
(P_+) في التجارب المطبقة على حقول المزارعين خلال الموسمين
(٨٣-١٩٨١).

Figure 1. Average grain yields for rainfed barley in Syria, for the period 1968-1981 (MAAR, 1977 and 1980; FAO Production Yearbook, Vol.35, 1981, FAO, Rome).



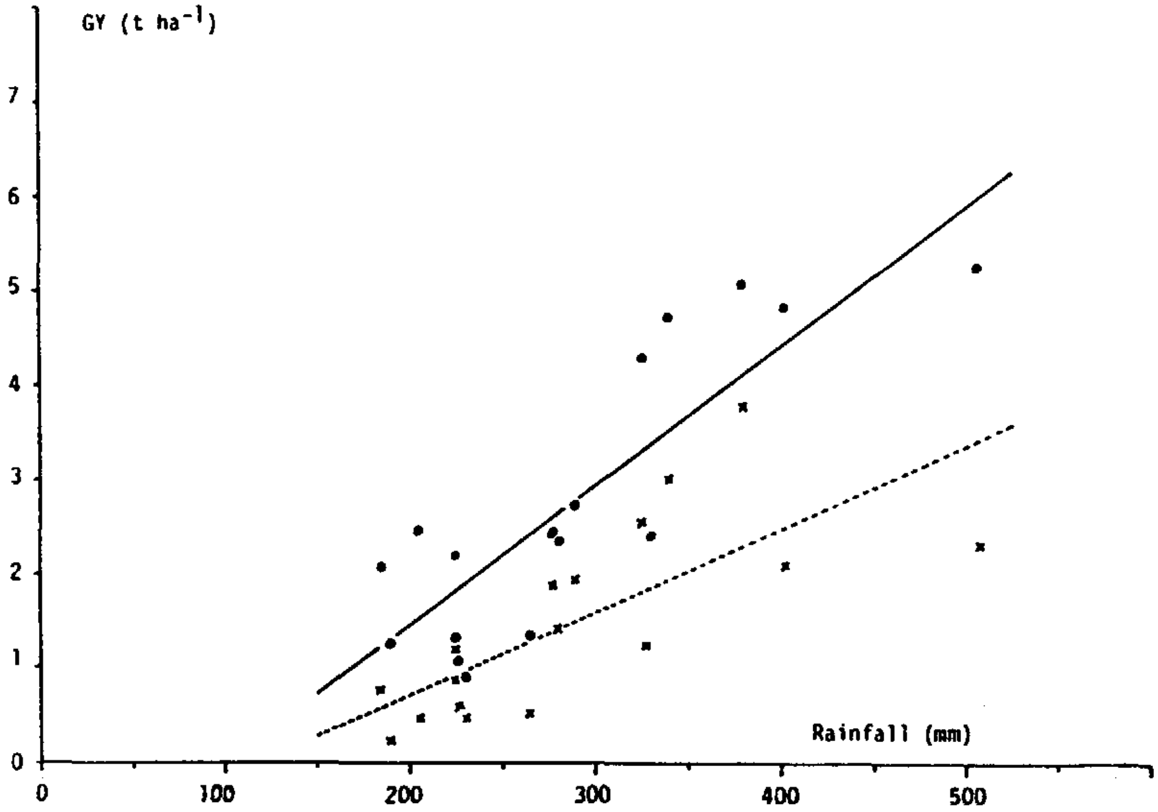
شكل ١ – متوسط محصول الحبوب للشعير البعل في سوريا لفترة ١٩٦٨–١٩٨١ (وزارة الزراعة والاصلاح الزراعي ١٩٧٧، و ١٩٨٠، النشرة السنوية لمنظمة الاغذية العالمية رقم ٣٥ عام ١٩٨١، روما).

Figure 2. Average grain yields of rainfed barley in Syria plotted against estimated seasonal rainfall in the barley producing area of Syria.



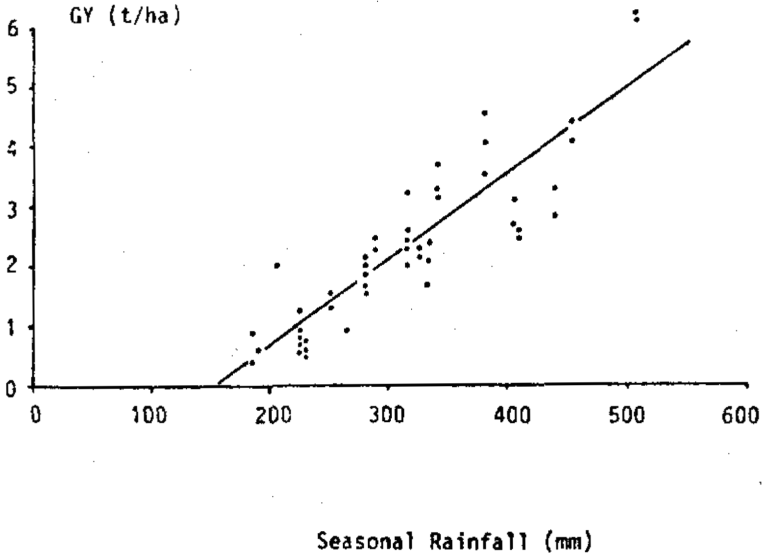
<u>شكل ٢</u> ـ متوسط انتاج الشعير البعل في سوريا موقع بالمقارنة مع معدل الامطار الموسمية المقدرة في اماكن انتاج الشعير في سوريا.

Figure 3. Average yields of cereal crops at 17 locations in Syria (1982/83) in fertilized plots (●) and unfertilized plots (x).



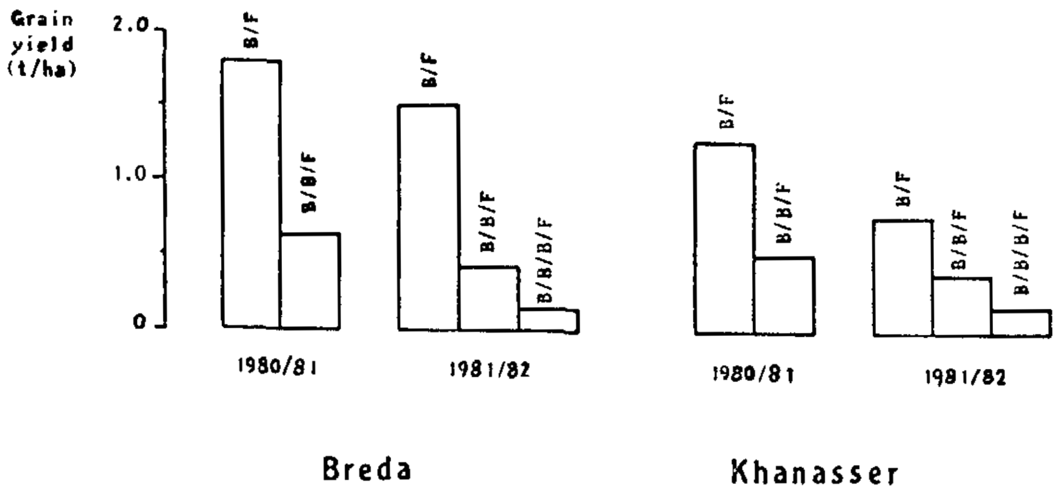
شكل ٣ – متوسط انتاج الحبوب في ١٧ موقع في سوريا (٨٣/١٩٨٢) في القطع المسمدة (●) والقطع غير المسمدة (x).

Figure 4. Grain yields of cereal crops grown under rainfed conditions at 24 locations in Syria (variety verification trials, 1982/83), plotted against estimated seasonal rainfall.



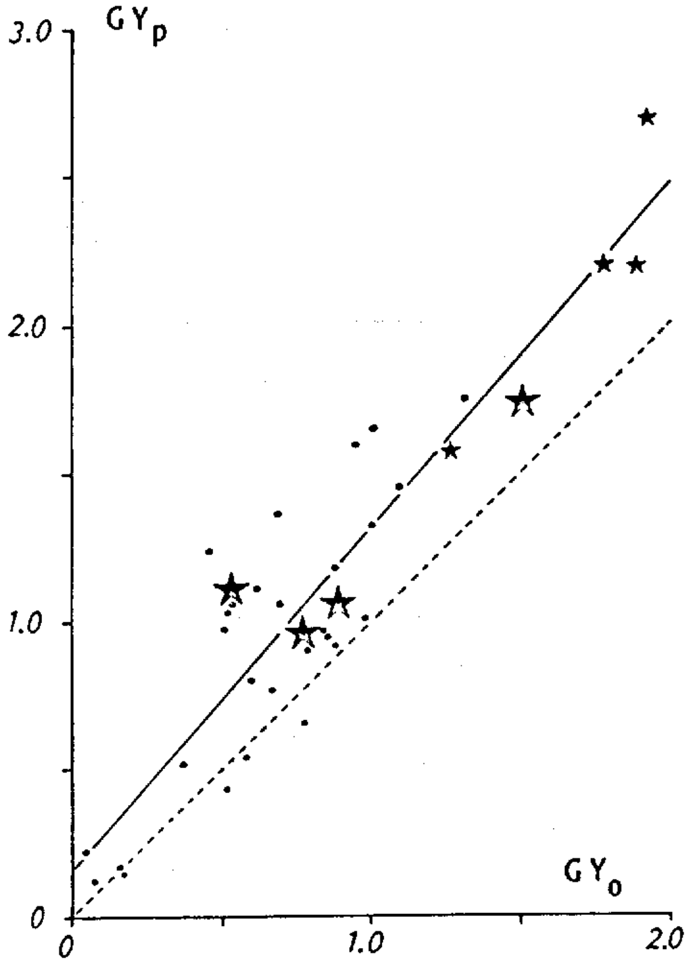
شكل ٤ – انتاج محاصيل الحبوب البعلية في ٢٤ موقع في سوريا (تجارب الاصناف ، ١٩٨٢/٨٣) موقع بالمقارنة مع معدل الامطار الموسمية المقدرة .

Figure 5. The effect of crop rotation on grain yield of barley crops at Breda and Khanasser (B= barley, F= fallow).



شكل ٥ – تأثير الدورات الزراعية على انتاج الحبوب في محصول الشعير في بردة وخناصر (B = شعير ، F = بور)٠

Figure 6. Grain yields of barley in fertilized plots (GY_p) in farmer's fields (dots) and at Breda and Khanasser experimental sites (stars) plotted against grain yields in unfertilized plots (GY_o).



شكل ٦ – انتاج الشعير في القطع المسمدة (GY_p) في حقول المزارعين (نقط). وفي محطتي تجارب بردة وخناصر (نجوم) موقع بالمقارنة مع انتاج المحصول بالقطع غير المسمدة (GY_o).

EFFECT OF PHOSPHATE FERTILIZER ON ROOT GROWTH OF BARLEY AND ITS EFFECT ON MOISTURE EXTRACTION

by

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EFFECT OF PHOSPHATE FERTILIZER ON ROOT GROWTH OF BARLEY AND ITS EFFECT ON MOISTURE EXTRACTION

Introduction

Phosphate applications to barley are known to modify both shoot and root growth. However, it is only comparatively recently that experiments have determined that the root growth is directly modified by the concentration of phosphorus rather than simply reflecting the overall growth and phosphate status of the shoot. Studies with barley (Hackett, 1968)[1/] and semi-arid grasses (Christie, 1975)[2/] show that, in young plants, the principal effect of increasing phosphate supply is to increase the length of the primary lateral roots and to increase the number and length of nodal roots. Moreover, in both studies there were significant interactions between varieties and phosphate nutrition.

Where phosphate is supplied to roots in localized bands rather than mixed uniformly throughout the rooting medium (as occurred in the previous experiments cited above), localized modifications to roots occur and, in particular, the number and length of lateral roots is increased (Drew and Saker, 1978)[3/]. Phosphate, then, whether uniformly or unevenly distributed, increases the overall size of root systems largely by increasing the length and numbers of the lateral roots.

In all of these studies, though, the plants were kept well supplied with water. In dryland regions, water supply is clearly restricted and a number of questions is raised:

- Does adding phosphate fertilizer increase the size of the root system of crops or are the results cited earlier appropriate only to young plants grown in well-watered conditions?
- Does application of fertilizers change the amount of water extracted and the pattern of water use?
- Is there any evidence that different varieties respond differently to applications of fertilizer?

This paper presents results from experiments conducted during the last two years at sites in N.W. Syria. On the basis of the results, some preliminary answers are offered to the questions asked above.

Sites, Crops and Methods

Details of the soils, sites and methods are given by Gregory et al. (1984)[5/].

For both the 1981/82 and 1982/83 growing seasons, barley was sown at Jindiress (mean rainfall 475 mm; actual Nov-May 324 mm and 344 mm respectively) and Breda (mean rainfall 275 mm; actual Nov-May 319 mm and 254 mm respectively).

In 1981, Beecher barley was sown in mid-November at both sites. Three fertilizer treatments were studied: zero fertilizer (Z), 60 kg P_2O_5/ha (P), and 60 kg P_2O_5/ha with 60 kg N/ha (NP). Phosphate (triple superphosphate) was drilled with the seed together with 20 kg N/ha (as ammonium nitrate) where appropriate; the remaining N was top-dressed in mid-March.

In 1982, Beecher and Arabic Abiad varieties of barley were sown either with zero fertilizer (Z) or N and P fertilizer. At Jindiress, 60 kg P_2O_5 and 60 kg N per ha was applied at sowing with an additional 40 kg N/ha as a spring top-dressing. At Breda, 60 kg P_2O_5 and 20 kg N per ha was applied at sowing followed by a 20 kg N/ha top-dressing in the spring.

Water use by the crops was monitored with a combination of the neutron probe and gravimetric sampling in the surface layers. Shoot growth was measured regularly by destructive sampling and root growth was measured twice in 1982 (early stem elongation and anthesis) and thrice in 1983 (as 1982 plus maturity). Disturbed cores of soil in 15 cm increments were obtained using a hand-operated Jarratt auger sampling with one edge of the auger touching the row position. Roots were washed from the soil and separated from other organic debris. Length was estimated by counting interactions with a 1 cm grid (Tennant, 1975)[4/] before drying at 70°C and weighing.

Results and Discussion

1. Root growth

Table 1 compares the effects of fertilizer on the total length of roots produced at the two sites in the two years. The following points emerge:

(a) Additions of fertilizer have consistently increased the total length of the root system.

(b) Insufficient treatments exist to distinguish satisfactorily the separate effects of N and P alone. In 1981/82 the addition of P alone increased total length significantly ($P < 0.1$) at the first sampling and adding N produced no further growth whereas at anthesis, P alone had no significant effect but the addition of N produced longer root systems ($P < 0.01$). Given the apparent change in effects of N and P with time, it is impossible to state whether the effects observed in 1982/83 were due to N or to P.

(c) Although root length was influenced only slightly by site in 1981/82 (when rainfall was similar at both sites), in 1982/83 root length at Jindiress was consistently longer than that at Breda.

(d) At Breda, there was little root growth between anthesis and maturity. At Jindiress there was growth where fertilizer was applied and this occurred throughout the soil profile but particularly in the upper 30 cm.

The effect of fertilizer on the distribution of roots within the soil profile is shown in figures 1 and 2. The following points emerge:

(a) In both years, the depth of rooting at Jindiress was some 15-30 cm deeper than at Breda corresponding to the slightly deeper wetting of the soil profile.

(b) Fertilizer applications generally increased root length to a depth of 45-60 cm; below 60 cm, there was little or no effect of fertilizer.

(c) There were differences between sites in the distribution of roots with a marked accumulation of roots in the surface 0-15 cm at Breda . This was most pronounced in 1981/82 when about 75 % of the root length at Breda was located in the top 15 cm of soil irrespective of treatment. Even in 1982/83 52 % of root length was in the surface 15 cm at Breda compared with 33 % at Jindiress.

Table 1 and Figure 3 together show that while the total mean root length produced by the two varieties was similar between anthesis and maturity, its distribution was different. Arabic Abiad generally had a lower root length in the surface layer and more roots below 30 cm than Beecher.

2. Water extraction

Table 2 shows that in 1981/82, fertilizer had little effect on the total amount of water used but in 1982/83, application of fertilizer consistently increased the total amount of water used (a mean increase of 6 %). Arabic Abiad also consistently used more water than Beecher.

Figrues 4 and 5 show the profiles of water recharge and water use measured in the two years. In 1981/82 water recharge was restricted to about 1 m at both sites but more rain at Jindiress in 1982/83 allowed re-wetting to 1.8 m; fertilizer had little effect on the depth of re-wetting or on the depth of subsequent water extraction.

These profiles of water use together with the root distributions allow the comparison of the amounts of water extracted with the quantity of roots present. Figure 6 shows the comparison obtained for the two sites and seasons; fertilizer treatments are not identified separately. The following points emerge:

(a) Although there is a good deal of scatter in the points, the relation is generally asymptotic with no clear distinction between sites or seasons.

(b) At root densities greater than about 1.2 cm/cm^3, increasing root length has no effect on the amount of water extracted; all of the water stored in the soil is available to the roots.

(c) At root densities less than about 1.2 cm/cm^3, the amount of water extracted is related to the root density.

3. Growth and Water Use

Other papers at this workshop and elsewhere (e.g. Cooper, 1983)[6/] show that crop growth and ultimately grain yield are related to the quantity of water transpired. Figure 6 suggests that any practice that increases root densities in the range 0-1.2 cm/cm³ should increase the amount of extractable water.

In 1981/82, although root densities were increased by application of fertilizer there was no corresponding increase in the amount of water extracted. However, in 1982/83, root densities were increased as was the amount of water extracted (Table 3). Table 3 also shows that Arabic Abiad, which had a greater root length at depth, than Beecher, also extracted more water than Beecher.

Table 4 shows the shoot dry matter and grain yields achieved by the crops in both years. Clearly yields are higher at Jindiress than at Breda and are generally higher where fertilizer is applied. Applying fertilizer may change the balance between evaporation and transpiration (e.g. Cooper, 1983)[6/] or increase the total quantity of water used or both.

Conclusions

On the basis of the experimental work conducted during the last two years, the following tentative answers are offered to the questions posed in the introduction.

(a) Applications of fertilizer do increase the overall size of the root system particularly in the upper 60 cm. The results show here do not enable separation of the independent effects of N or P.

(b) Fertilizer had no effect on the total amount of water extracted in one year and only a small effect (26 mm at Jindiress and 10 mm at Breda) in the second year. The pattern of water use may be affected by fertilizer particularly if root length in the range 0-1.2 cm/cm^3 is increased.

(c) Root growth and shoot growth of different varieties may respond differenctly to the applications of fertilizer but these effects are small in comparison with the main effects of site and fertilizer.

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جدول رقم (١): الطول الاجمالي للنظام الجذري (كم/م٢) للشعير المسمد وبدون تسميد.

Table 1. The total length of the root system (km/m²) of barley grown with and without fertilizer.

Site الموقع	جنديرس JINDIRESS (36°23'N, 36°41'E) خط عرض خط طول							بـــرده BREDA (35°55'N, 37°10'E) خط عرض خط طول						
Year السنة	1981/82			1982/83				1981/82			1982/83			
Variety الصنف	بيشر Beecher			بيشر Beecher		عربي ابيض Arabic Abiad		بيشر Beecher			بيشر Beecher		عربي ابيض Arabic Abiad	
Fertilizer السماد	Z	P	NP	Z	NP	Z	NP	Z	P	NP	Z	NP	Z	NP
وقت اخذ العينات Sampling time														
اوائل فترة استطالة الساق Early stem elongation	9.0	10.4	11.3	4.7	7.7	5.3	10.9	5.4	7.7	8.7	1.3	2.0	1.4	3.9
الازهار Anthesis	11.0	11.1	14.2	8.2	9.2	9.2	9.4	10.5	11.7	16.2	4.0	7.2	5.0	7.7
النضج الفزيولوجي Maturity	غير مقاس not measured			7.7	13.3	9.6	15.8	غير مقاس not measured			5.0	7.8	5.3	4.9

Table 2. Effects of site and fertilizer on total seasonal water use by barley. Evapotranspiration (mm).

Site	Treatment	1981/82	1982/83	
		Beecher	Beecher	Arabic Abiad
JINDIRESS	Z	323	333	344
	P	308	–	–
	NP	316	356	372
BREDA	Z	225	227	236
	P	227	–	–
	NP	232	240	243

جدول رقم (٢): تأثيرات الموقع والسماد على اجمالي استعمال الشعير الموسمي للماء بتبخر ـ نتح (ملم).

الموقع	المعاملة	٨٢/١٩٨١	٨٣/١٩٨٢	
		بيشر	بيشر	عربي ابيض
جنديرس	بدون سماد	٣٢٣	٣٣٣	٣٤٤
	سماد فوسفاتي	٣٠٨	–	–
	فوسفات + آزوت	٣١٦	٣٥٦	٣٧٢
برده	بدون سماد	٢٢٥	٢٢٧	٢٣٦
	سماد فوسفاتي	٢٢٧	–	–
	فوسفات + آزوت	٢٣٢	٢٤٠	٢٤٣

جدول رقم (٣): رطوبة التربة القابلة للاستخلاص تحت محصول الشعير في موقعين من شمال سوريا للموسم ١٩٨٢/٨٣ (سم/١٥ سم على اعماق مختلفة).

Table 3. Extractable soil moisture under barley at two locations in N. Syria. 1982/83. (cm/15 cm depth interval).

شرائح العمق (سم) Depth Interval (cm)	جنديرس JINDIRESS				برده BREDA			
	B+	Bo	A+	Ao	B+	Bo	A+	Ao
0- 15	2.49	2.49	2.49	2.49	2.46	2.09	2.65	2.23
15- 30	2.80	2.49	2.70	2.69	2.00	1.71	2.16	1.93
30- 45	2.43	2.00	2.38	2.53	1.76	1.41	1.76	1.49
45- 60	2.22	1.74	2.18	2.17	1.35	1.00	1.25	1.30
60- 75	1.93	1.52	1.97	1.83	0.60	0.46	0.41	0.87
75- 90	1.49	1.32	1.77	1.47	0.10	0.0	0.10	0.31
90-105	1.22	1.08	1.53	1.24	-	-	-	-
105-120	1.00	0.99	1.40	1.06	-	-	-	-
120-135	0.68	0.78	1.18	0.82	-	-	-	-
135-150	0.42	0.63	0.90	0.57	-	-	-	-
150-165	0.20	0.40	0.59	0.08	-	-	-	-
165-180	0.08	0.13	0.28	-	-	-	-	-
اجمالي مقطع التربة Profile TOTAL	16.96	15.57	19.37	16.95	8.27	6.67	8.33	8.13

Table 4. Effects of fertilizer on yields. Dry weight (t/ha).

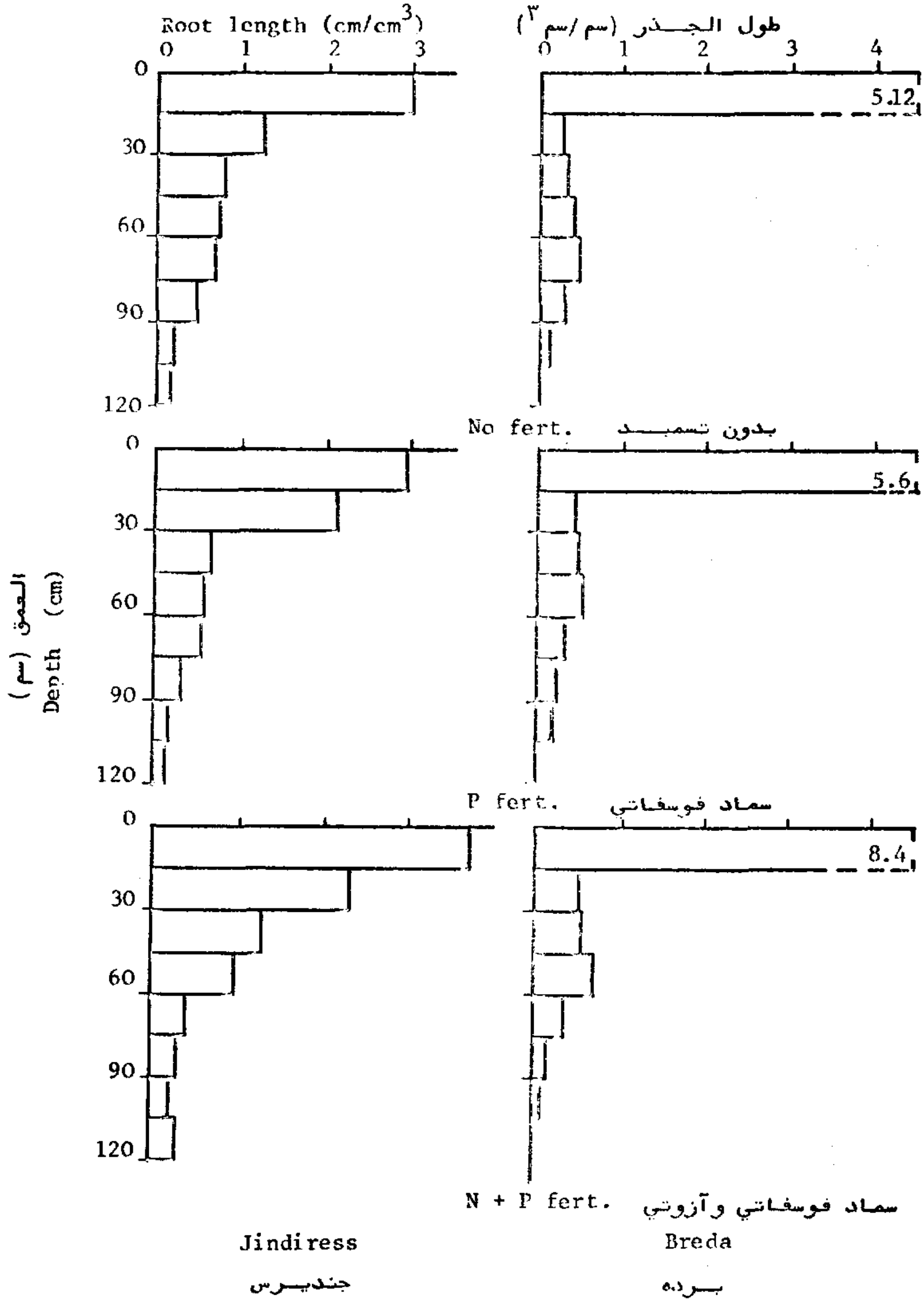
Site	Treatment	1981/82		1982/83			
				Beecher		Arabic	Abiad
		Shoot weight	Grain weight	Shoot	Grain	Shoot	Grain
JINDIRESS	Z	4.35	1.44	6.61	3.05	5.99	3.17
	P	4.56	1.49	-	-	-	-
	NP	8.66	2.93	10.99	4.69	8.78	4.40
	L.S.D. (5%)	0.63	0.26	1.79	0.81	1.79	0.81
BREDA	Z	3.89	1.32	2.01	0.90	3.24	1.67
	P	5.70	2.17	-	-	-	-
	NP	6.18	2.22	3.40	1.49	3.66	1.58
	L.S.D. (5%)	1.01	0.41	0.69	0.37	0.69	0.37

جدول رقم (٤): تأثيرات السماد على معدلات الغلة للشعير الحب وللمادة الجافة (طن/هكتار).

الموقع	المعاملة	٨٢/١٩٨١		١٩٨٣/١٩٨٢			
		وزن الحب	وزن الاشطاءات	بيشر		عربي ابيض	
				اشطاءات	حب	اشطاءات	حب
جنديرس	بدون سماد	٣٥ر٤	٤٤ر١	٦١ر٦	٠٥ر٣	٩٩ر٥	١٧ر٣
	سماد فوسفاتي	٦٥ر٤	٤٩ر١	—	—	—	—
	فوسفات + آزوت	٦٦ر٨	٩٣ر٢	٩٩ر١٠	٦٩ر٤	٧٨ر٨	٤٠ر٤
	اقل اختلافا مؤكدة (٠٥/٠)	٦٣ر٠	٢٦ر٠	٧٩ر١	٨١ر٠	٧٩ر١	٨١ر٠
برده	بدون سماد	٨٩ر٣	٣٢ر١	٠١ر٢	٩٠ر٠	٢٤ر٣	٦٧ر١
	سماد فوسفاتي	٧٠ر٥	١٧ر٢	—	—	—	—
	فوسفات + آزوت	١٨ر٦	٢٢ر٢	٤٠ر٣	٤٩ر١	٦٦ر٣	٥٨ر١
	اقل اختلافا مؤكدة (٠٥/٠)	٠١ر١	٤١ر٠	٦٩ر٠	٣٧ر٠	٦٩ر٠	٣٧ر٠

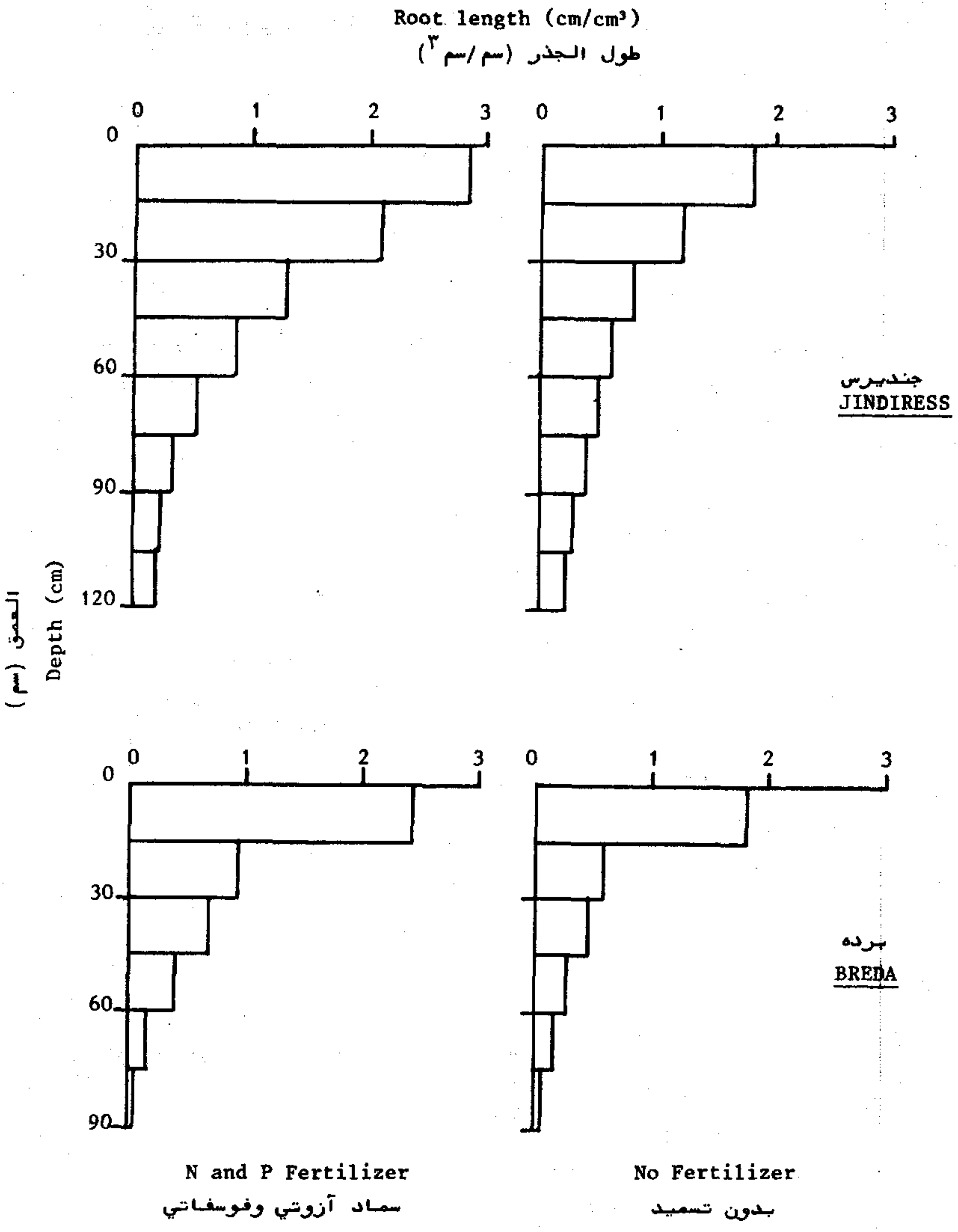
شكل رقم (١) تأثيرات السماد علي نمو الجذور (موسم ١٩٨١/٨٢)۔
نتائج العينات المأخوذة عند الازهار

Figure 1. Effects of fertilizer on the growth of roots 1981/82.
Anthesis results.



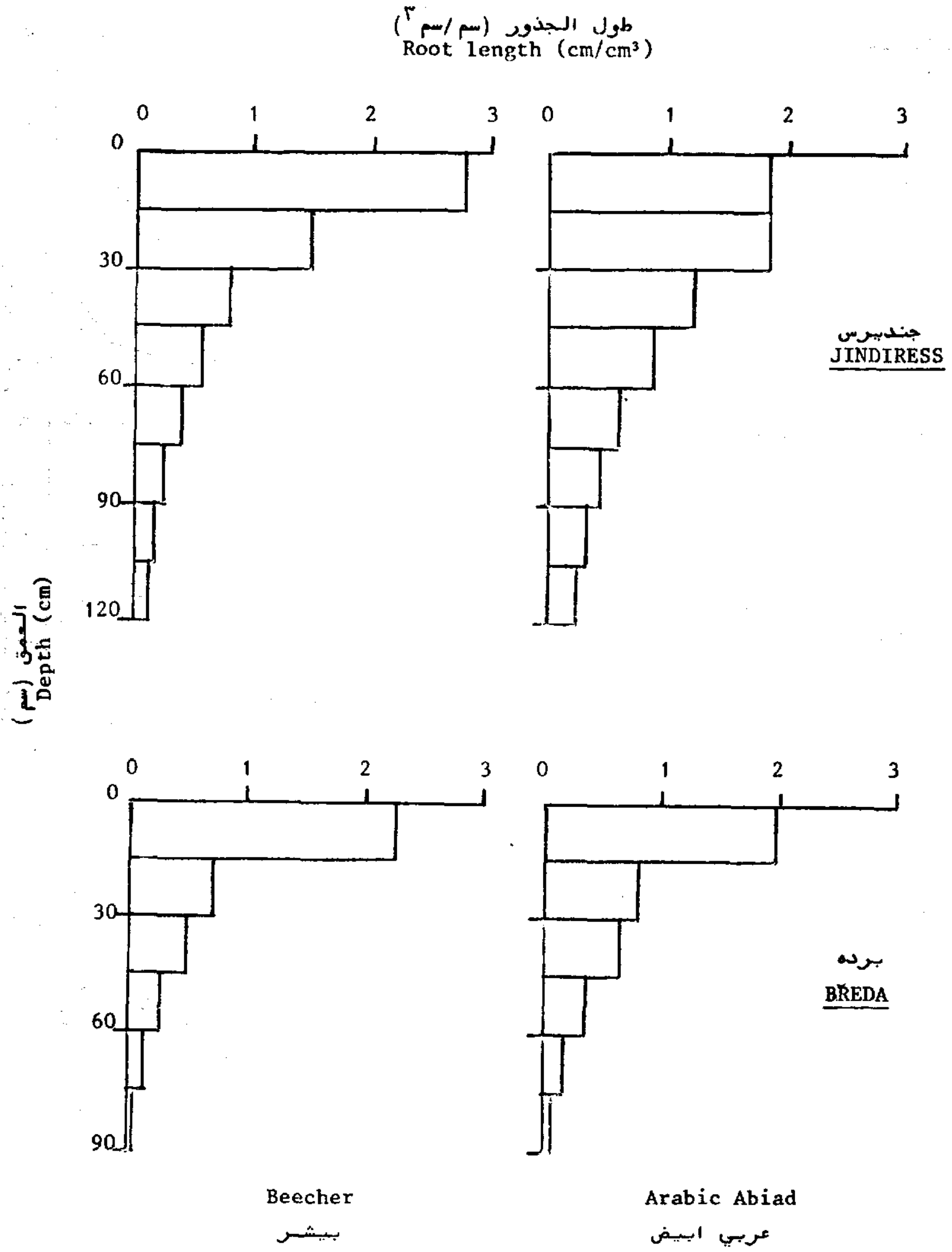
شكل رقم (٢): تأثيرات السماد على طول الجذور (موسم ١٩٨٢/٨٣).
النتائج هي متوسطات القياسات عند الازهار
وعند النضج لصنفين من الشعير.

<u>Figure 2.</u> Effects of fertilizer on the growth of roots 1982/83. The results are the means of anthesis and maturity measurements of two varieties.



شكل رقم (٣) : الاختلافات في نمو النظام الجذرى بين صنفي الشعير.
النتائج عبارة عن متوسطات القياسات عند الازهار
وعند النضج للمحاصيل المسمدة وغير المسمدة.

Figure 3. Varietal differences in the growth of root systems. The results are the means of anthesis and maturity measurements of crops with and without fertilizer.



شكل رقم (٤): تغييرات محتوى التربة من الماء تحت محاصيل الشعير (الموسم ١٩٨١/٨٢).
القياسات هي (١) عند البذار ، (٢) المحتوى او المخزون الاقصى ، (٣) عند النضج.

<u>Figure 4.</u> Changes in water content beneath barley crops 1981/82. Measurements at (1) sowing, (2) maximum recharge, and (3) maturity.

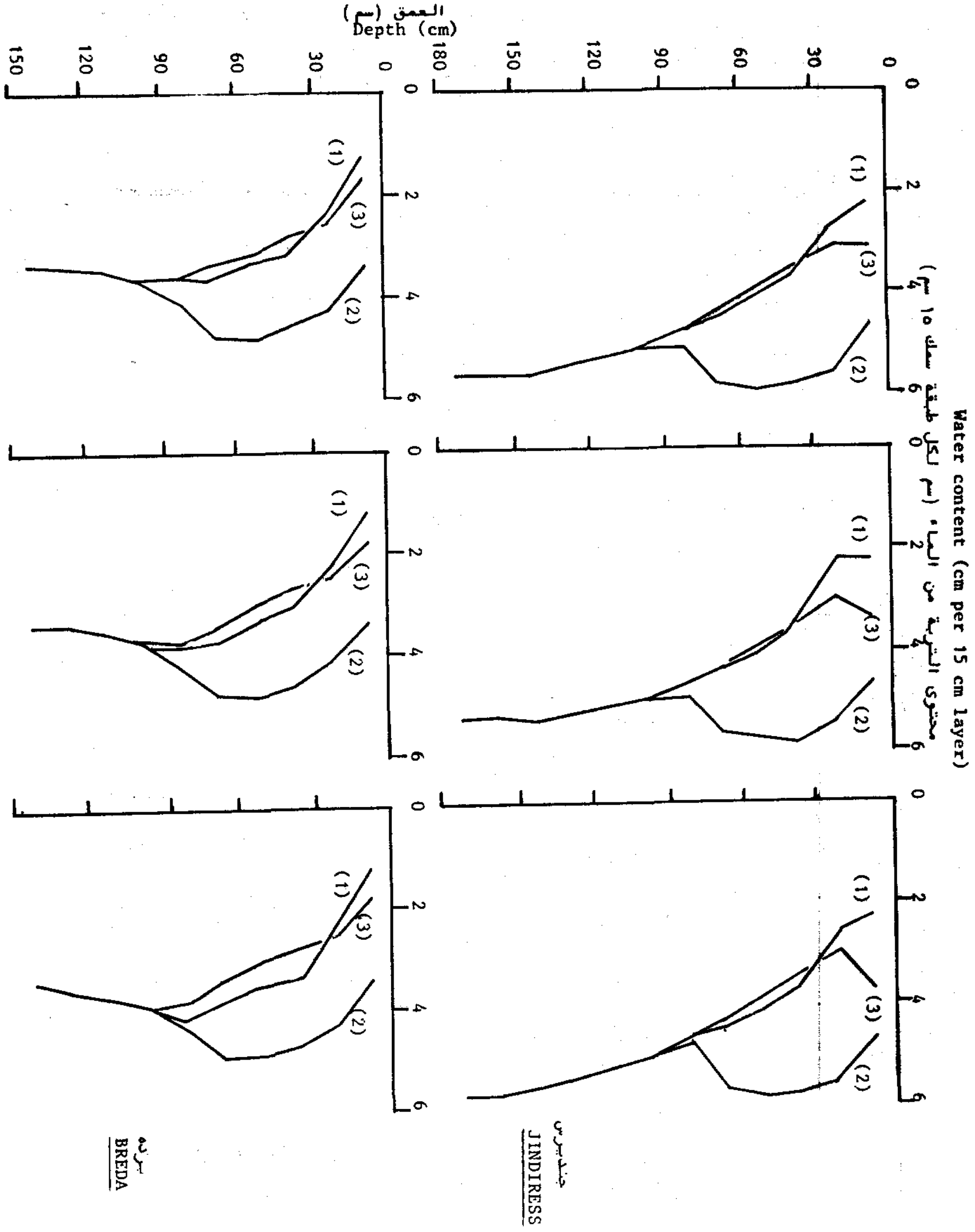
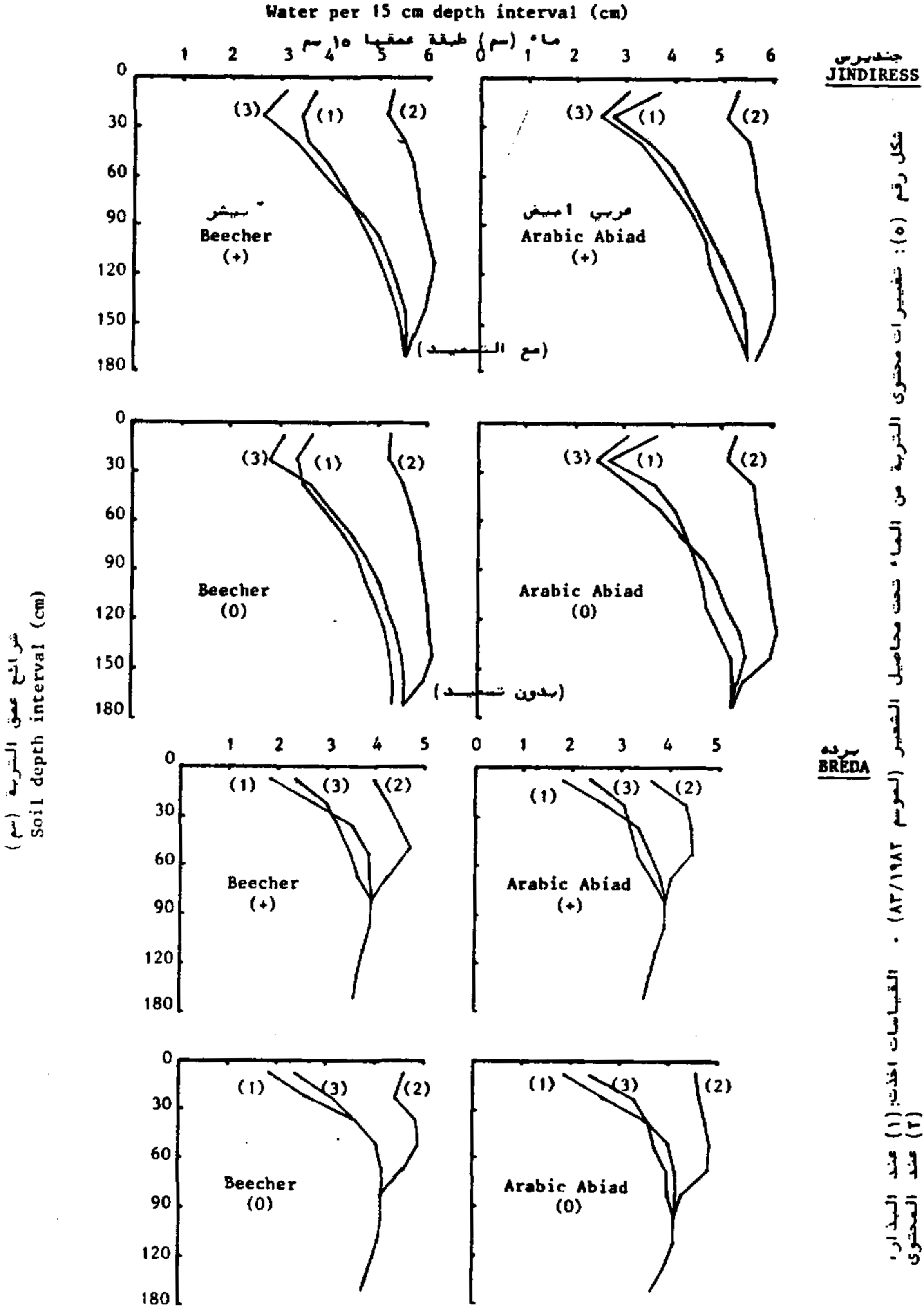


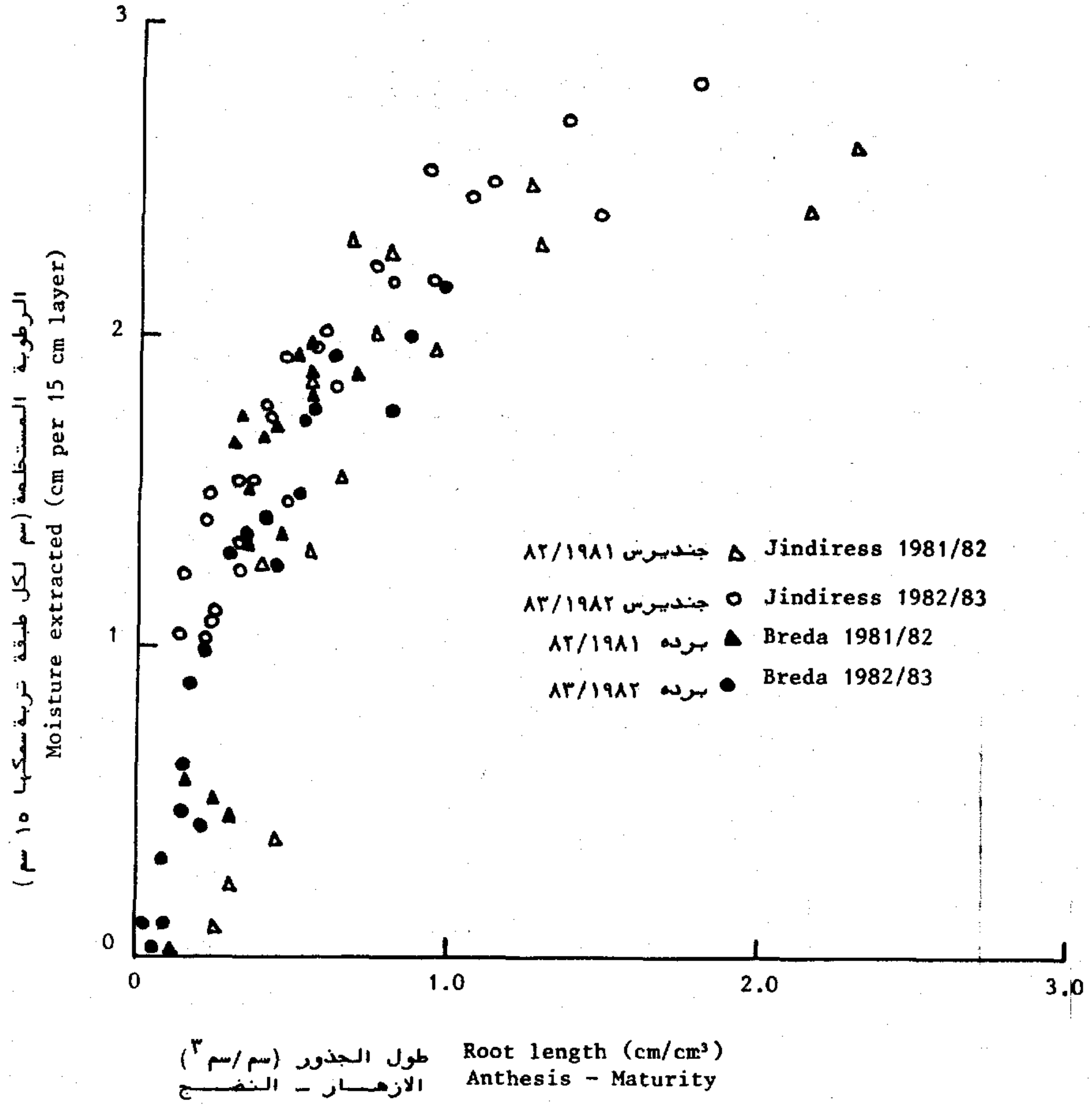
Figure 5. Changes in water content beneath crops of barely 1982/83. Measurements at (1) sowing, (2) maximum recharge, and (3) maturity.



شكل رقم (٥): تغيرات محتوى التربة من الماء تحت محاصيل الشعير (الموسم ١٩٨٢/٨٣) . القياسات اخذت (١) عند البذار، (٢) عند المحتوى الأقصى او المخزون الأقصى (٣) عند النضج.

شكل رقم (٦): العلاقة بين الماء المستخلص وطول الجذور.

Figure 6. Relation between water extracted and root length.



THE EFFECT OF FERTILIZER ON WATER USE AND WATER USE EFFICIENCY OF BARLEY IN DRYLAND REGIONS

by

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Farming Systems Program
ICARDA

March 1984

THE EFFECT OF FERTILIZER ON WATER USE AND WATER USE EFFICIENCY OF BARLEY IN DRYLAND REGIONS

Introduction

Other papers presented in this workshop have shown that in many dryland barley growing areas, defficiencies of soil nitrogen and phosphorus occur which can greatly reduce grain and straw yields. As a result of these defficiencies, pronounced and economic responses to fertilizer, especially phosphate are often observed, even at quite low levels of application.

However, it is also clear that in the very regions that barley is grown, rainfall totals and seasonal distribution show marked year to year variation. It is also apparent that in such areas, farmers, being well aware of this variation, are very cautious about adopting a management practice which they feel might further add to the instability of their crop production systems.

Therefore, in looking at the potential for fertilizer use on barley in such areas, some important questions need to be answered:

- Does the increased dry matter and grain yield production resulting from fertilizer application result in greater moisture use?

- How does enhanced growth resulting from fertilizer application affect the pattern of moisture use?

- How does fertilizer application affect the water use efficiency (WUE) of the barley crop in terms of kg-dry matter (or yield) produced per millimetre of crop evapotranspiration?

- Does fertilizer application increase or decrease the chances of crop failure in very dry years?

Some results are presented from barley/moisture use trials conducted over the last three years at two typical barley growing areas in N.W. Syria. In the following sections, these results are examined and discussed, and based on these results, tentative answers to these questions are offered.

Results and Discussions

1. Yields, water use and water use efficiency data for barley (variety Beecher) are presented in Table 1. These results illustrate the effect of fertilizer application at two locations in N.W. Syria over the last three years. In all trials the barley was grown in a barley/fallow rotation which predominates in N.W. Syria. The following points are clear:

   (a) Fertilizer has produced large increases in total dry matter (between 1060 and 3700 kg/ha) and grain yield (between 540 and 960 kg/ha) at both locations in all three years.

   (b) In spite of this enhanced crop production, total crop evapotranspiration (E_T) has not been increased.

   (c) Water use efficiency of the crop has been increased dramatically in all instances. These increases range from 35 to 104%, with a mean value of 71%.

Table 1 Yield (kg/ha), water use (mm) and water use efficiency of barley (variety Beecher) grown with and without fertilizer 1/ at two locations in N. Syria over three years.

	BREDA (35°55'N, 37°10'E)						KHANASSER (35°45'N, 37°32'E)					
	1980/81		1981/82		1982/83		1980/81		1981/82		1982/83	
Seasonal Rainfall (mm):	299		324		284		251		263		296	
	No Fertilizer	Plus Fertilizer	No Fert.	Plus Fert.	No Fert.	Plus Fert.	No Fert.	Plus Fert.	No Fert.	Plus Fert.	No Fert.	Plus Fert.
Total Dry Matter Production (kg/ha)	3840	7540	4540	6130	2010	3400	3100	4980	1330	2390	1530	2660
Grain Yield (kg/ha)	1620	2580	1320	2220	900	1490	1350	2200	376	917	730	1270
Evapotranspiration Germ. - maturity (mm)	234	225	231	231	224	235	229	221	210	210	242	238
Water Use Efficiency of Total Dry Matter kg/ha/mm	15.4	33.5	19.7	25.5	9.0	14.5	13.5	22.5	5.3	11.4	6.3	11.2
% Increase in W.U.E.	104		35		61		67		81		77	

1/ Fertilizer Application:
1980/81 90 kg/ha P_2O_5 and N
1981/82 60 kg/ha P_2O_5 and N
1982/83 60 kg/ha P_2O_5 and 20 kg/ha N

Triple Super Phosphate and Ammonium Nitrate Fertilizer were used.

2. Fertilizer application does not affect the total crop evapotranspiration, but does alter the seasonal pattern of moisture use. This is illustrated in Figure 1 for two seasons at Breda, 1980/81* and 1982/83, which received similar rainfall totals, but contrasted in their length of growing season. The following points are clear:

   (a) During the early growth period, from between 50-80 days, depending on the rainfall distribution and temperature, when green area index is small, fertilizer has no effect on crop evapotranspiration.

   (b) As green area index increases, and fertilizer effects become more pronounced, higher rates of E_T are observed in fertilized crops than in the control. This effect persists until anthesis. In the post anthesis period, this effect is reversed, and the unfertilized control crop maintains higher rates of E_T.

   (c) Fertilizer has considerably enhanced the rate of crop development. This effect is due to phosphate fertilizer. Nitrogen fertilizer has, in anything, the opposite effect, and tends to delay maturity.

   The patterns in Figure 1 are presented on a calendar basis. However, since phosphate fertilizer increases the rate of crop development, a clearer picture is obtained if crop evapotranspiration is related to particular development stages. This is simply

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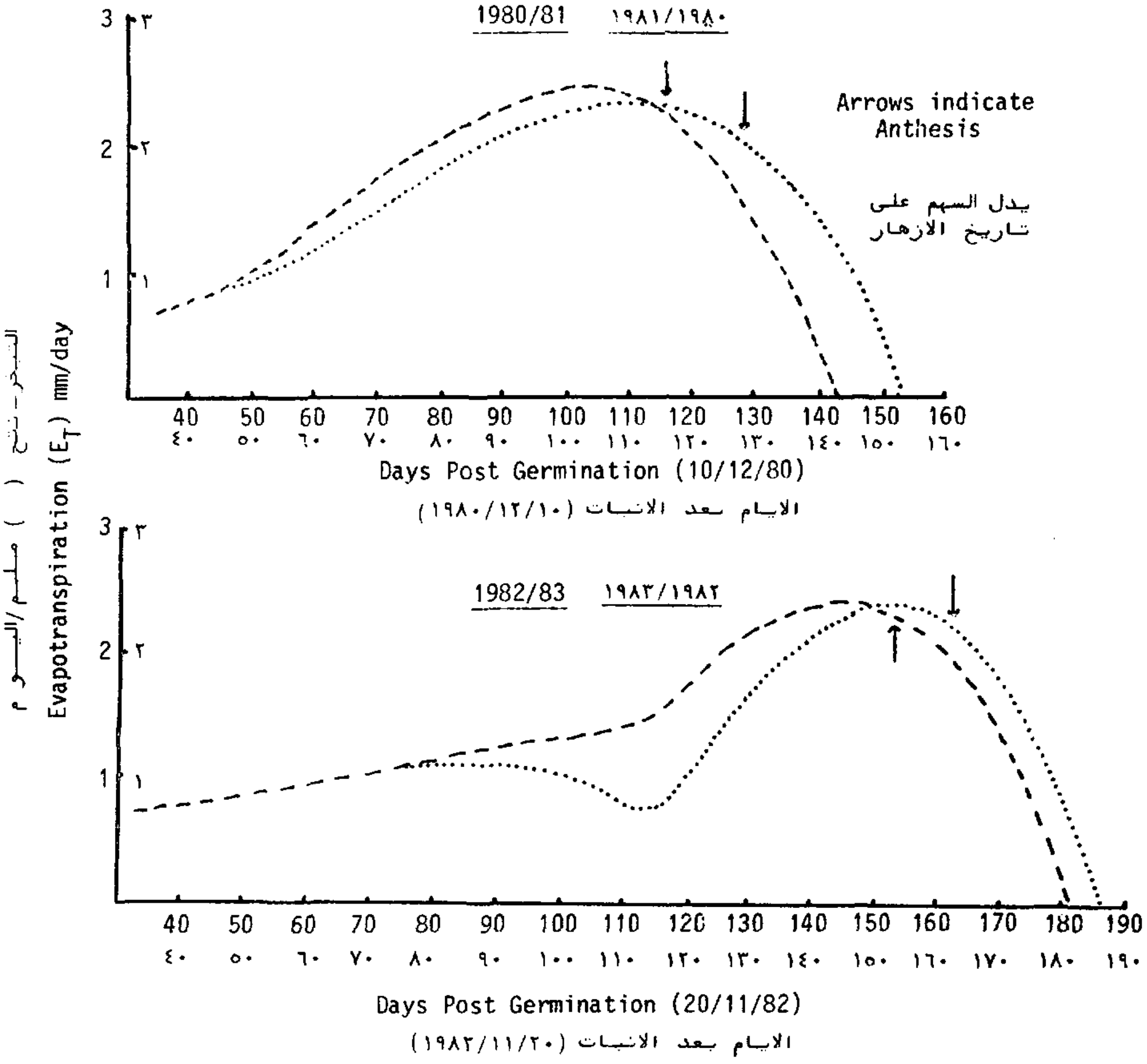
* Note: The results presented in sections 2 and 3 for 1980/81 at Breda are from a different trial on barley water use to that reported in Table 1. In this trial, the fertilizer barley received 60 kg/ha of P_2O_5 and N as opposed to 90 kg/ha.

Figure 1 Seasonal variation in daily rates of evapotranspiration of barley (variety Beecher) with (---) and without (...) fertilizer at Breda, N.W. Syria.

الرسم البياني ١: التغيرات الفصلية لمعدلات التبخر-نتح لمحصول الشعير (صنف بيتشر) بوجود (- - -) وعدم وجود (...) السماد فى شمال غرب سوريا - برده



illustrated in Table 2 for the two sets of data in Figure 1, by considering the periods germination to anthesis, and anthesis to physiological maturity.

Examination of these data indicate that moisture use by barley during given physiological periods is not greatly affected by fertilizer application, and that mean daily rates of E_T during these periods are very similar for fertilized and control treatments in a given year. There is a trend in these, and other results not reported here, for moisture use during the period anthesis to maturity to be increased by fertilizer application. During this period, barley crops are largely surviving on moisture stored in the profile, and it has been showed that fertilizer application increases root length densities of barley, and hence its ability to extract soil moisture.

3. It is important to consider how it is possible to achieve these large increases in production without corresponding increases in E_T as indicated in Table 1 and Table 2.

Crop evapotranspiration (E_T) consists of two components, crop transpiration (T) and evaporation from the soil surface under the crop (E_{SC}) thus:

$$E_T = T + E_{SC}$$

Recently (Cooper et al, 1983)[1/] a simple technique has been developed which enables us to split measured crop evapotranspiration into its two components utilizing field measurements of E_T, crop green area index (GAI), and evaporation from an uncropped bare soil adjacent to

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[1/] Cooper, P.J.M., J.D. Keatinge and G. Hughes (1983). Crop evapotranspiration - a technique for calculation of its components by field measurements. Field Crops Research 7, 299-312.

Table 2 Crop evapotranspiration during two development stages (variety Beecher) with and without added fertilizer at Breda, N.W. Syria, 1980/81 and 1982/83.

Year:	1980/81				1982/83			
Development Period:	Germ. - Anthesis		Anthesis - Mat.		Germ. - Anthesis		Anthesis - Mat.	
Treatment:	Barley +	Barley o	Barley +	Barley o	Barley +	Barley o	Barley +	Barley o
Days post germination	0 - 115	0 - 128	115 - 146	128 - 153	0 - 153	0 - 162	153 - 178	162 - 183
E_T (mm)	180	192	36	28	198	192	37	32
E_T (mean daily rate) mm/day	1.56	1.50	1.16	1.12	1.29	1.19	1.42	1.52

جدول ٢ التبخر-نتح للمحصول اثناء مرحلتي تطور الشعير (صنف بيتشر) باضافة او عدم اضافة السماد في برده شمال - غرب سوريا، ٨١/١٩٨٠ و ٨٣/١٩٨٢.

السنة :	١٩٨١/١٩٨٠				١٩٨٣/١٩٨٢			
فترة التطور :	الانبات - الازهرار		الازهرار - النضج		الانبات - الازهرار		الازهرار - النضج	
المعاملة :	شعير مسمد	شعير غير مسمد	شعير مسمد	شعير غير مسمد	شعير مسمد	شعير غير مسمد	شعير مسمد	شعير غير مسمد
الايام بعد الانبات	٠ – ١١٥	٠ – ١٢٨	١١٥ – ١٤٦	١٢٨ – ١٥٣	٠ – ١٥٣	٠ – ١٦٢	١٥٣ – ١٧٨	١٦٢ – ١٨٣
E_T (ملم)	١٨٠	١٩٢	٣٦	٢٨	١٩٨	١٩٢	٣٧	٣٢
E_T (معدل المتوسط اليومي) ملم/اليوم	١ر٥٦	١ر٥٠	١ر١٦	١ر١٢	١ر٢٩	١ر١٩	١ر٤٢	١ر٥٢

the trial area (E_S). This technique has been tested on data obtained from a barley fertilizer trial at Breda in 1980/81 (see Figure 1 and Table 2), and the results are presented in Figure 2 which illustrates the following points:

(a) T values are very low during the early winter priod, reflecting the low GAI of the crop. During this period E_{SC} accounts for nearly 100% of E_T.

(b) In spring as GAI increase, T values increase and reach maximum values just before anthesis. Due to shading of the soil surface by the crop, E_{SC} values fall correspondingly.

(c) T values reach higher levels in the fertilized crop (2.0 mm/day) than in the unfertilized control (1.7 mm/day), reflecting the different GAI's.

(d) In the post anthesis period, as soil moisture reserves are depleted, and GAI values fall due to leaf senescence, T values fall and reach zero at physiological maturity. During this period, E_{SC} values increase. It should be noted that in this year, the soil surface under the crop was rewetted by atypical late rains, thus during a more normal year such a pronounced increase in E_{SC} would not be expected.

It is clear from Figure 2 that although fertilizer has had little effect on Total E_T, it has not only altered the pattern of seasonal variation in E_T, but has also changed the relative amounts of E_T lost as T and E_{SC}. Summation of the daily rates of T and E_{SC} indicate that in the control plot, with a total E_T of 220 mm, 137 mm (62%) was lost as E_{SC} whereas only 83 mm (38%) was used in transpiration. However, in the fertilized plots, with a total E_T of 216 mm, 108 mm (50%) was actively used in transpiration.

Such detailed analyses has not been conducted for all our barley/moisture use trials, but approximate calculations can be made for the data in Table 1 based on the assumption of a seasonal transpiration efficiency (TE) value of 44 kg/ha/mm.[1/] Such calculations indicate that as much as 76% of E_T can be used as T for high yielding barley crops (7540 kg/ha T.D.M.) whereas as little as 14% is used for very poor crops (1330 kg/ha T.D.M.). As would be expected, there are clear relationships between the % E_T used as T and the crop yield, and also with the maximum GAI achieved by the crop. These are illustrated in Figure 3.

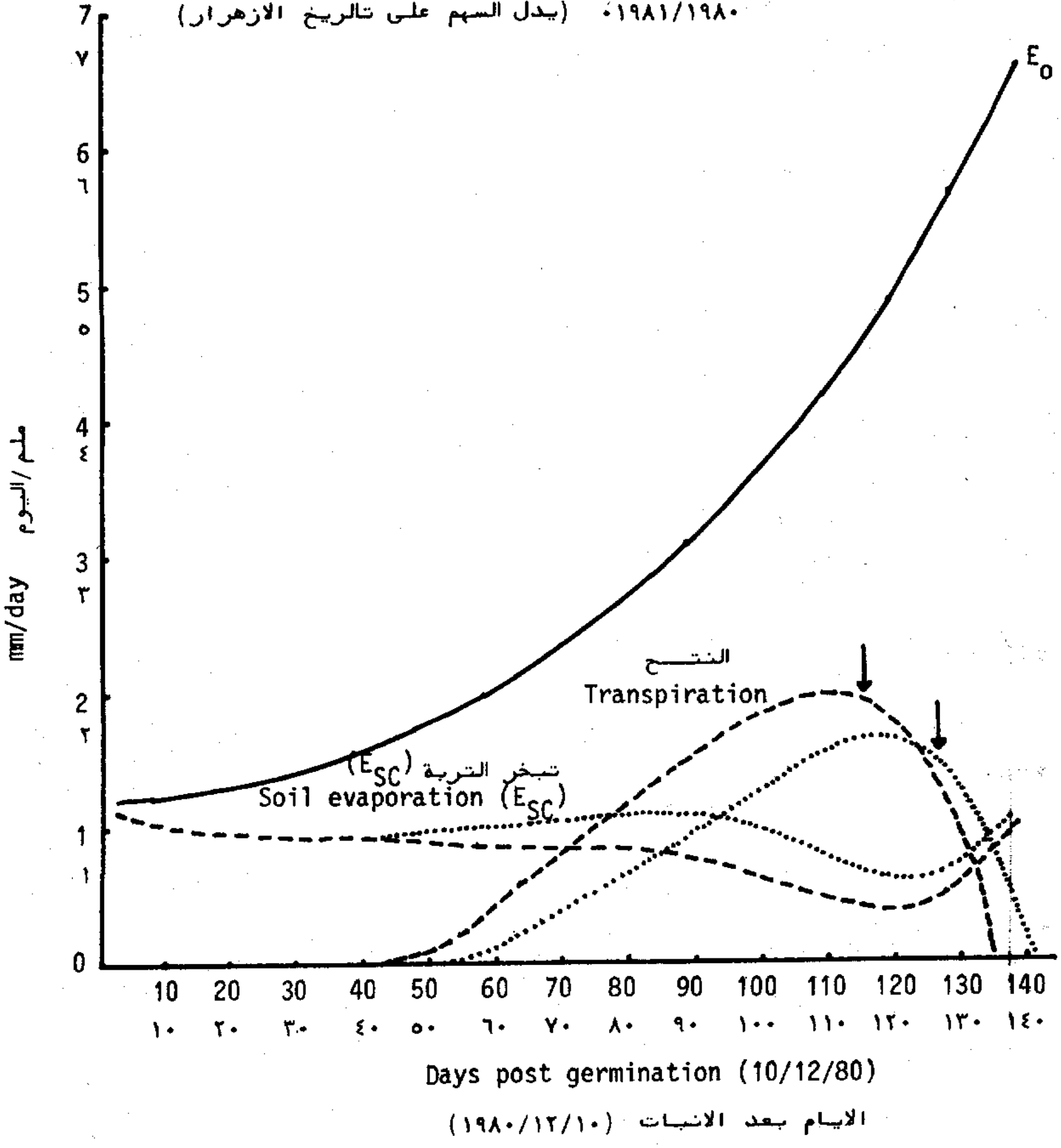
Conclusions

Based on this summary presentation of three years' studies on water use by barley crops in dry areas, the following conclusions can be made in answer to the questions posed in the introduction.

1/ Derived from combined results of Cooper et al., 1983 and those of Fischer, R.A., 1981 in Plant & Soil, 58, 249-278.

Figure 2. Seasonal variation in rates of E_o, T and E_{SC} for barley at Breda with (---) and without (...) added fertilizer, 1980/81. (Arrows indicate date of anthesis.)

الرسم البياني ٢: معدل التغيرات الفصلية لـE_o ، T وE_{SC} للشعير في برده
باضافة (ـ ـ ـ) او عدم اضافة (...) السماد،
١٩٨٠/١٩٨١. (يدل السهم على تالريخ الازهرار)



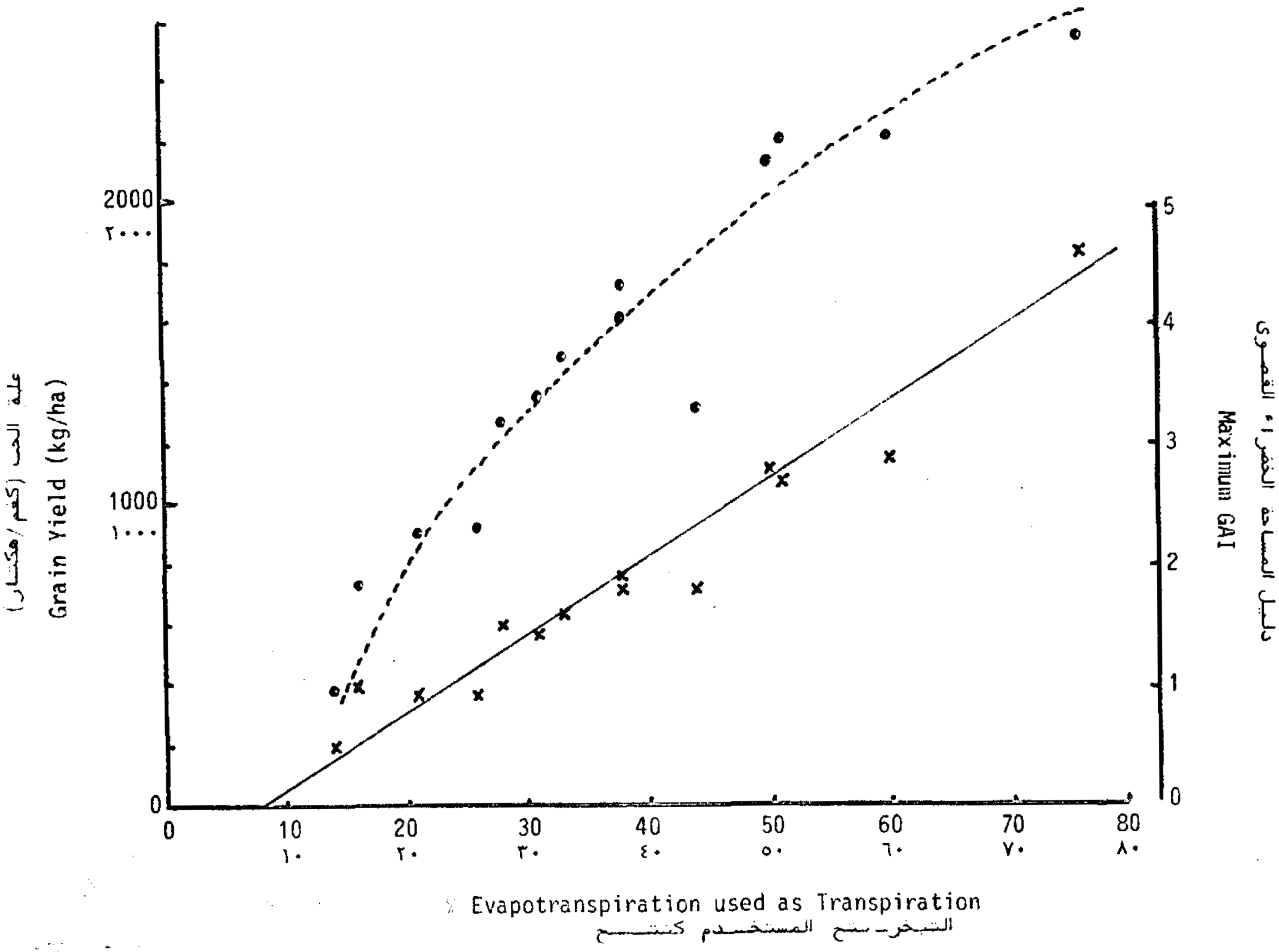


Figure 3 The relationship between % E_T used as T and (a) grain yield (●---●), (b) maximum GAI (x—x).

الرسم البياني رقم ٣ العلاقة بين النسبة المئوية للتبخر-نتح E_T المستخدمه كنتح T وغلة الحب (●---●) ودليل المساحة الخضراء القصوى (x—x).

(a) The greater crop production resulting from fertilizer application does not result in increased total evapotranspiration (E_T) but has significant effects on the relative amounts of water lost through soil evaporation (E_{SC}) and crop transpiration (T).

(b) Phosphate fertilizer enhances the rate of crop development, and thus also affects the pattern of crop evapotranspiration when expressed on a calendar basis. However, when specific developmental periods are considered, fertilizer has only small effect on moisture use. Fertilized crops do tend to use more moisture during grain filling, and this is probably due to the ability of a more prolific root systems to extract moisture from the drying soil moisture profile.

(c) As a result of this negligible effect on total evapotranspiration, coupled with increased dry matter production, dramatic increases in WUE are achieved, both for total dry matter production and for grain yield.

(d) A very dry year has not yet been experienced. However, these results indicate that, because of the enhanced rate of development resulting from phosphate fertilizer, coupled with the greater dry matter production at the cost of no extra moisture use, in dry years the use of phosphate fertilizer is unlikely to increase the chance of crop failure. Indeed, it may even have the opposite effect. For instance, in a barley trial during the 1982/83 season at Ghrerife, near Breda, (230 mm of rainfall), the application of 45 kg/ha P_2O_5 and 20 kg/ha N increased the grain yield of Beecher barley by 60% from 840 to 1340 kg/ha.

COMBINED ANALYSIS
OF
MULTIPLE SEASON-MULTIPLE LOCATION SEED RATE-NITROGEN-PHOSPHORUS TRIALS

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February 1984

I. Introduction

The Seed rate - Nitrogen - Phosphorus (SNP) trials were held at FSP/ICARDA during the three cropping seasons between 1979/80 and 1981/82, as part of the UNDP funded Soil, Water and Nutrient (SWAN) project. The trials were held at the five sites of Jindiress, Kafr Antoon, Tel Hadya, Breda and Khanasser. These sites are located across the rainfall transect and lie within a radius of 100 km.

This study uses the set of data from the SNP trials that pertain to drilled Beecher barley (with weed control). This data set is supplemented by data related to drilled Beecher barley (with weed control) from the 2^n trials conducted by FSP in 1982/83 in Breda, Khanasser and Ghrerife. The complete data set consists of 880 observations. The distribution of observations at each location and year, as well as the total cropping season rainfall is given in Table 1.

The SNP trials have been analysed for each location and year.(Somel 1983a). This study attempts to analyse the results in a combined manner with the objective of analysing how the responses to the experimental factors change with climatic conditions.

II. The Analysis

The SNP trials sites were chosen in order to observe the effects of different levels of rainfall. However, the sites differ in other aspects as well. As can be expected, the distribution of rainfall during the cropping season, other climatic factors, soils, available nutrient levels, etc. also differ between the locations. Furthermore, some of these factors, mainly the climate related ones, change between seasons too.

Table 1. Rainfall (mm) at the trial sites.

Sites	1979/80	1980/81	1981/82	1982/83	Long Term Average
Khanasser	291	246	263	295	214
n	102	32	34	8	
Breda	298	292	324	285	278
n	102	32	34	8	
Tel Hadya	425	373	338	-	342
n	110	32	34		
Kafr Antoon	452	467	397	-	438
n	110	32	34		
Jindiress	488	472	350	-	479
n	102	32	34		
Ghrerife	-	-	-	232	-
n				8	

Source: FSP Files.

Notes : n indicates the number of observations.

The experimental factors in the SNP trials were:

S : Seed rate, kg/ha,

N : Nitrogen fertilizer, in kg of pure N/ha

P : Phosphorus fertilizer, in kg of pure P_2O_5/ha.

The standard season and location specific analysis would relate the experimental variables to an independent variable, for example,

Y = grain yields, in kg/ha.

This relationship is specified in a quadratic form with interactions:

$$\begin{aligned} Y = a &+ bS + cN + dP \\ &+ eSN + fSP + gNP \\ &+ hS^2 + kN^2 + lP^2 \end{aligned}$$

Can we now systematically and quantitatively analyse the effects of an environmental factor on the responses to the experimental factors? In other words, how do the responses change between locations and seasons as climatic conditions change?

In order to answer this question, we conducted a combined analysis of the whole data set and included total cropping season rainfall as a variable.

R = cropping season rainfall, mm.

It is clear that while we do this, we are abstracting from the effects of other factors such as soils, available nutrients, other climatic factors, etc. This does not mean we deny their effects. As a first exercise, we hypothesized rainfall to be the climatic factor that changes responses between locations and seasons. This can be improved upon with further information on other factors. However, it will be observed that rainfall is a powerful variable. In any case, the whole exercise can be viewed from a methodological perspective and critically evaluated with respect to its potential application under other circumstances.

The specification of the regression implies that the responses to the experimental factors change with the level of rainfall:

$$\begin{aligned} Y = a &+ bS + cN + dP + b'RS + c'RN + d'RN \\ &+ eSN + fSP + gNP + e'RSN + f'RSP + g'RNP \\ &+ hS^2 + kN^2 + lP^2 + h'RS^2 + k'RN^2 + l'RP^2 \\ &+ mR + oR^2 + pR^3 \end{aligned}$$

The relationship is specified in the third order for rainfall because this specification fits the observations at the lower range of rainfall better. In any case, the predictions of the regression should be constrained to the 225-490 mm range of rainfall. As with any other regression, the reliability of the predictions decreases as we move away from the means of the independent variables. The estimated regression is as follows:

$$\begin{aligned} Y = \underset{a}{18145.3} &+ \underset{(11\ \%)}{20.4\ S} - \underset{(21\ \%)}{20.5\ N} + \underset{a}{76.9\ P} \\ &- \underset{(15\ \%)}{0.95\ RS} + \underset{b}{0.09\ RN} - \underset{a}{0.18\ RP} \\ &+ \underset{(20\ \%)}{0.145\ SN} - 0.215\ SP + 0.085\ NP \\ &- \underset{(21\ \%)}{0.0004\ RSN} + \underset{(12\ \%)}{0.0005\ RSP} - 0.0002\ RNP \\ &+ 0.014\ S^2 - \underset{(12\ \%)}{0.165\ N^2} - \underset{a}{0.510\ P^2} \\ &- 0.00007\ RS^2 + 0.00022\ RN^2 + \underset{a}{0.00128\ RP^2} \\ &- \underset{a}{198.7\ R} + \underset{a}{0.068\ R^2} - \underset{a}{0.0069\ R^3} \end{aligned}$$

R-squared = 0.7042 F(21,858) = 97.3 a n = 880

The significances of the coefficients are indicated as a = 1%, b = 5%, c =10%. In some other cases, the significance level of some coefficients are given in actual percentages in parentheses.

One can observe how responses to experimental factors will change with rainfall by looking at the partial derivatives of the estimated regression. Let us look at the cases of nitrogen and phosphorus.

In order to facilitate analysis, we have taken the seed rate as 100 kg/ha, a rate approximately equal to the average seed rate used by farmers.

1. (a) The response to nitrogen is given by:

$$\frac{\partial Y}{\partial N} = -20.4 + 0.085\ P - 0.330\ N + 0.05\ R - 0.0002\ RP + 0.00044\ RN$$

The value of this response will depend on the values of N, P and R. However, the response will be positive within the range of values of the experimental factors and observed rainfall levels.

(b) How the response to nitrogen changes with rainfall is given by:

$$\frac{\partial^2 Y}{\partial N \partial R} = 0.05 - 0.0002\ P + 0.00044\ N$$

This will be positive within the range of the values of the experimental factors. In other words, the response to nitrogen will increase with rainfall. This is an expected result. For *example, at N = 35 and P = 60, each mm of rainfall will increase* yields (the response to N) by 53 grams.

2. (a) The response to phosphate is given by:

$$\frac{\partial Y}{\partial P} = 55.4 + 0.085\ N - 1.02\ P - 0.13\ R - 0.0002\ RN + 0.00256\ RP$$

Again, the value of this response will depend on the values of R, N and P. Within the range of values of the experimental factors, the response to P will be positive upto the rainfall level of 398 mm.

(b) How the response to phosphate changes with rainfall is given by:

$$\frac{\partial^2 Y}{\partial P \partial R} = -0.13 - 0.0002\ N + 0.00256\ P$$

In order for the response to phosphate to increase with rainfall, phosphate has to be applied at least around 50 kg/ha. For example, at N = 35, phosphate has to be applied at rates over 54 kg/ha.

III. Probability Analysis and Predicted Response Surfaces

Another interesting use of the model is to predict response surfaces for given rainfall levels. For example, using the example of Breda, which has exhibited an average rainfall of 283.6 mm (for the last 19 years for which data are available) the predicted response surface is:

$$\begin{aligned} Y = {} & \underset{a}{670.1} + \underset{c}{6.6}\ S + 5.4\ N + \underset{a}{26.0}\ P \\ & + 0.037\ SN - \underset{c}{0.067}\ SP + 0.028\ NP \\ & - 0.004\ S^2 - \underset{a}{0.104}\ N^2 - \underset{a}{0.147}\ P^2 \end{aligned}$$

Using 1983 prices, we can calculate economically optimum fertilizer levels with seed rate at 100 kg/ha. [1/]

N = 35 kg/ha $\quad$ P_2O_5 = 59 kg/ha

[1/] *These prices are as follows:*

Barley grain = 820 SL/ton
Triple Super Phosphate = 1160 SL/ton
Ammonium Nitrate (33%N) = 955 SL/ton
These imply relative (to barley grain) prices of pure N = 3.529 and pure P_2O_5 = 3.075.

If one makes these fertilizer recommendations based on the economical optimum under average rainfall conditions, what would the yields, based on these recommendations, be under different rainfall levels?

In order to answer this question, we use the frequency or probability distribution of rainfall. We use the example of Breda again in Table 2.

Table 2. Frequency distribution of rainfall and predicted yields for Breda.

Frequency (%) [a.]	Rainfall (mm) [b.]	Predicted Yields (kg/ha) [c.]			
		N+P+	NoP+	N+Po	NoPo
5	112.5	200 [d.]	200	200	200
5	137.5	200	200	200	200
5	162.5	200	200	200	200
5	187.5	200	200	200	200
21	262.5	1934	1719	1176	1029
26	287.5	2224	1966	1553	1352
5	312.5	2621	2320	2038	1783
5	337.5	3063	2719	2566	2258
5	362.5	3484	3096	3074	2712
11	412.5	4006	3532	3769	3301
5	462.5	3673	3113	3611	3035
Averages	283.6	2131	1885	1689	1477

Notes: a. Source: FSP Files. Does not add up to 100 due to rounding.

b. Mid-points of rainfall ranges.

c. N+ = 35 kg/ha, P+ = 59 kg/ha.
No = Po = 0 kg/ha.

d. Assumes that 200 kg/ha is the grain equivalent of grazeable dry matter when crop failure occurs.

In Table 2, we observe that there is a discrete set of rainfall levels less than 200 mm with a probability of approximately 20 %. This observation corresponds with farmers' expectations of crop failures in at least 20 % of the years. (Somel, 1983b, p. 9). The yield predictions of the response surface for Breda are replaced for those cases of rainfall less than 200 mm by a yield of 200 kg/ha. This approximates the grazing threshold which is that level of yield below which it would not pay the farmer to harvest and the mature crop is allowed to be grazed by sheep. (Nordblom, p. 8ff). The figure of 200 kg/ha is actually below the grazing threshold of 235 kg/ha estimated from the results of a barley survey in Syria in 1981/82. (Mazid and Hallajian, p. 10).

While the recommendations can not eliminate the crop failures at such low levels of rainfall, expenditures on fertilizers will be recovered approximately 80 % of the time. 1/

In the particular case of an environment like Breda, losses in poor years can be minimized by a risk management type recommendation. This would be the recommendation that while phosphate be applied at planting, nitrogen can be split-applied or top dressed. Given that farmers are inclined to implement recommendations in steps (i.e. by components), such an approach would enhance gradual adoption. 2/ The final adoption and diffusion process would depend on the attitudes of farmers towards risk as well as other social and biological factors.

1/ The grain equivalents of recommended input levels are:
35 kg N/ha = 124 kg/ha barley
59 kg P_2O_5/ha= 180 kg/ha barley.
While these appear to be recoverable expenditures, possible differences between farmers' yields and scientist controlled experimental yields may change results. The testing stage of FSR with on-farm research.

2/ Adopting the economically optimum fertilizer levels implies a rate of return of 215% under average conditions. Adopting phosphate first implies a 227% rate of return and following by nitrogen fertilizer implies an additional 198% rate of return.

IV. Conclusions

The combined analysis presented here, can be used in several ways. In the present study we illustrated these with the data from the SNP trials:

a. It is possible to predict response surfaces for different environmental conditions.

b. It is possible to find optimum levels of inputs based on average (or any other) conditions. Subsequently, it is possible to evaluate how the associated yields will perform under different environmental conditions.

c. If probability distributions of environmental conditions are available, probability distributions of yields for given recommendations of inputs can be obtained.

Such an analysis will allow a more thorough and efficient assessment of response surfaces. Subsequently, in the experimental and testing stages of FSR, 2^n trials, incorporating optimum levels of inputs contrasted with traditional levels, can be used to effectively illustrate the advantages of technological developments.

The approach developed here is considerably less sophisticaed than a crop modeling effort. Hence, it does not require the skills necessary for crop modeling. Knowledge of standard regression techniques is adequate. However, it is highly possible that the approach may tax the memory limits of small computer hardware.

The model is somewhat more complex than estimating simple regressions for each site in each year. However, the environmental variation in the rainfed areas poses complex problems for agricultural production and research. Seeking simple answers to complex problems in complex environments may end up producing inadequate solutions.

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