PN-AAN-997
ISN 32805

PROJECT REPORT No.3

SOIL WATER AND NUTRIENT RESEARCH-1979-80

by the
Farming Systems Research Program

The International Center for Agricultural Research in the Dry Areas
(ICARDA)

Oct. 1981

This report appears in ICARDA's Project Report publication series. For details of other ICARDA publications, please write to

Training and Communications Program
ICARDA, P.O.Box 5466, Aleppo, SYRIA.
Telex 31206 SY.

PREFACE

This Project Report has been prepared by staff of the Farming Systems Research Program at ICARDA. It describes in detail the work carried out in the first full season of the Program's "Soil Water and Nutrients"(SWAN) project which is funded jointly by the United Nations Development Program (UNDP) and ICARDA. The report is intended as a comprehensive account of the first year's work; it is expected that subsequent reports will focus on different aspects of the Project.

The report is presented in ten Chapters. Following the Introduction, Chapter 2 gives a brief description of the five sites that have been chosen for the experimental work and includes information on climate and soil characteristics.

The project results of the 1979/80 season are reported in Chapters 3 to 7. Chapters 3, 4 and 5 discuss the research on barley, legumes and wheat with particular reference to water-use and nitrogen supply. The work described in Chapter 5 is being conducted in cooperation with the University of New England. The results of the agronomic research are presented in Chapter 6 and soil fertility is discussed in Chapter 7.

Chapter 8 includes work in the Center that is being done on biological nitrogen fixation even through this research is not actually in the project. Much progress has been made in this area and it is summarised in this Chapter.

Chapter 9 calls attention to the new developments that have been started by the crop physiologist. This area will receive much more attention as the project develops. The final chapter includes a summary of research results and discusses implications for future research requirements.

Contributors to this report include the following ICARDA staff:

Peter Cooper	- soil physicist, SWAN Project
Alister Allan	- agronomist, SWAN Project
Karl Harmsen	- soil chemist, SWAN Project
Dyno Keatinge	- plant physiologist, SWAN Project
David Nygaard	- Program Leader, Farming Systems Research Program
Mohan Saxena	- agronomist, Food Legume Improvement Program
Rafiqul Islam	- microbiologist, Research Support Group.

TABLE OF CONTENTS

		Page
CHAPTER 1.	INTRODUCTION	1
	1.1 Project highlights-1979/80	1
	1.2 Experimentation in 1979/80	2
CHAPTER 2.	DESCRIPTION OF RESEARCH SITES	5
	2.1 Climatic record 1979/80	6
	2.2 Soil classification	6
	2.3 Figure 2.1 and Table 2.1	10
CHAPTER 3.	THE EFFECT OF NITROGEN SUPPLY ON GROWTH, WATER USE AND YIELDS OF BARLEY (CV.BEECHER) AT FIVE LOCATIONS IN NORTHERN SYRIA.	
	3.1 Introduction	12
	3.2 Materials and methods	13
	3.3 Results	15
	3.4 Summary	26
	3.5 Figures 3.1 to 3.24 & Tables 3.1 to 3.16	28
CHAPTER 4.	WATER USE OF LENTIL AND FABA BEAN AT TEL HADYA.	
	4.1 Introduction	58
	4.2 Materials and methods	58
	4.3 Results	59
	4.4 Summary	62
	4.5 Figures 4.1a to 4.4b & Tables 4.1 to 4.4	65
CHAPTER 5.	QUANTIFICATION OF SOIL WATER, TEMPERATURE AND NITROGEN LIMITATION TO WHEAT YIELDS.	
	5.1 Introduction	70
	5.2 Results	71
	5.3 Climatic data collation	74
	5.4 Plans for 1980/81	75
	5.5 Conclusions	75
	5.6 Figures 5.1 to 5.5 & Tables 5.1 to 5.4	76

Page

CHAPTER 6. AGRONOMY TRIALS.

6.1 Introduction 85
6.2 Materials and methods 85
6.3 Results 87
6.4 Summary and conclusions 93
6.5 Tables 6.1 to 6.22 94

CHAPTER 7. SOIL FERTILITY RESEARCH.

7.1 Introduction 116
7.2 Treatments selected for sampling 116
7.3 Methods for soil analysis 118
7.4 Results 121
7.5 Summary 128
7.6 Figures 7.1 to 7.31 130

CHAPTER 8. BIOLOGICAL DINITROGEN FIXATION STUDIES.

8.1 Introduction 161
8.2 Nodulation survey, and collection, isolation and evaluation of rhizobial strains 163
8.3 Strains for specific situations 165
8.4 Protection of nodules from insect damage by insecticide use 166
8.5 Methods of inoculant production and use 167
8.6 Effect of agronomic factors on the magnitude of symbiotic dinitrogen fixation 167
8.7 Summary and conclusions 169
8.8 Tables 8.1 to 8.12 172

CHAPTER 9. CROP PHYSIOLOGICAL STUDIES.

9.1 Introduction 182
9.2 Methodology 182
9.3 Research outline 1980/81 184

CHAPTER 10. OVERVIEW OF RESEARCH FINDINGS.

10.1 Introduction 186
10.2 Highlights of research and implications 187
10.3 Conclusion 191

APPENDIX I A SHORT DESCRIPTION OF SOIL PROFILES AT BRIDA, KHANASSER, KAFR ANTOON, JINDIRESS AND TEL HADYA.

CHAPTER 1

INTRODUCTION

The importance of climate, soil nutrients and soil moisture as determinants of agricultural productivity in rainfed agriculture in the Middle East is widely recognised. However, the interactions among these factors and the way they determine crop growth and, subsequently, yields, are not clearly understood. These interactions are complex,and a better understanding of them is vital if ICARDA is going to increase agricultural production in the region. A soil water and nutrient project (SWAN) has been established in the Farming Systems Program at ICARDA to investigate these relationships. The first year's field experiments were conducted in the 1979/80 cropping season and this first annual report presents the results of this research.

The general goals of the SWAN project are to increase crop production by improving the efficiency of use of a limited soil water and nutrient supply in the rainfed agricultural sector in the region. To achieve these goals intensive research is required on the availability and use of soil nutrients and soil moisture, on the potential for biological nitrogen fixation and on the possibility of improving crop management and crop rotations.

This research is being carried out as an integral part of complementary studies in ICARDA on farming systems, crop improvement, agroeconomic surveys and livestock research. The multidisciplinary research approach that has been adopted is considered to be necessary if the results and understanding obtained by scientists in each discipline are to be used to explain the complete farming system and if the results obtained in one location are to be meaningfully extrapolated to other locations in the region.

1.1. Project highlights - 1979/80

This project was developed by the staff of the Farming Systems Program in the summer of 1978 and submitted to the United Nations Development Program (UNDP) for funding. The project began in January 1979. One of the first tasks was to organise a meeting of international scientists, specializing in soil moisture and soil nutrient research. This workshop was to review the state of knowledge of this subject and to recommend research priorities and goals for the project, and equally important, to give practical guidance on how these goals might be achieved.

The workshop was held in Aleppo in January 1980, and was attended by 35 scientists from twelve countries, many from countries in the region. The proceedings of this meeting are now available in a book entitled Soil Water and Nitrogen in Mediterranean-Type Environments (Martinus-Nijhoff Publishers, 1981).

Staff development began by recruiting a soil physicist whose arrival was followed by that of an agronomist in early 1979. After the cropping season started in the autumn of 1979, a soil chemist was added to the project which allowed some soil sampling of the experimental plots at harvest time. An agro-climatologist/crop physiologist has joined the team for the 1980/81 cropping season. A social science input will be important to the project as it progresses and currently there are social scientists in the Farming Systems Program working on complementary projects. A microbiologist is the only remaining vacancy and candidates are being actively sought for this position. The support staff for the project currently numbers 17 persons.

The project received, beginning in 1980, additional financial support from the OPEC Special Fund. This money was used to develop the soil chemistry laboratory at Tel Hadya and generally support soil fertility research.

1.2. Experimentation in 1979/80

Much of the effort of the first year was devoted to locating and employing staff, developing office and laboratory facilities and purchasing equipment. While substantial progress was made in all of these areas it was also important to formulate a research approach to achieve the objectives of the project. This approach needed to be flexible enough to adapt to the expected increases in staff, yet specific enough to allow the development of an experimental program for the 1979/80 season. Particular care was taken to complement rather than duplicate the research efforts of the other programs and to concentrate on issues that would help guide the general direction of research in the Center and give priorities to research activities. The team, at that time a soil physicist and an agronomist, decided that the initial thrust of the project should be designed to explain the basic relationships among the factors involved.

The research was designed to take advantage of the steep rainfall isohyet gradient that characterises Aleppo province. Thus, the experimentation was conducted at five sites, four off-station sites and one at Tel Hadya, ICARDA's principal research station. Each site

has a different average annual rainfall which covers the range of precipitation zones, from 200 to 600 mm, that are specified in the ICARDA mandate. The soils, climate and management of the sites are described in detail in Chapter 2.

Research at these sites will need to be conducted over a period of several years in order to have sufficient data to identify management practices for different climatic zones. These practices would aim to minimise the probability of crop failure in dry years yet increase crop productivity and consequently farmers incomes in average and wet years. The sites are sufficiently large to allow the inclusion of new research activities of the incoming scientists and yet not so large as to inhibit the development of additional research activities by project members at other locations in Syria and the ICARDA region. For example, a simulation model is being developed to use the data being generated by the project to predict crop performance under a range of agronomic inputs at locations outside Syria for which relevant climatic and soil data are available.

Therefore, the experimental work for 1979/80 was designed with several immediate objectives in mind. They are:

1) to study changes in soil moisture levels throughout the year under the major crops and fallow, within traditional rotation systems,

2) to determine the moisture use patterns of these crops, to establish the relationship between these patterns and the growth of the crop, and to obtain final total dry matter and grain yields,

3) to study the effect of different agronomic practices (such as plant population, method and time of sowing, fertilizer application) on water use and yields, and

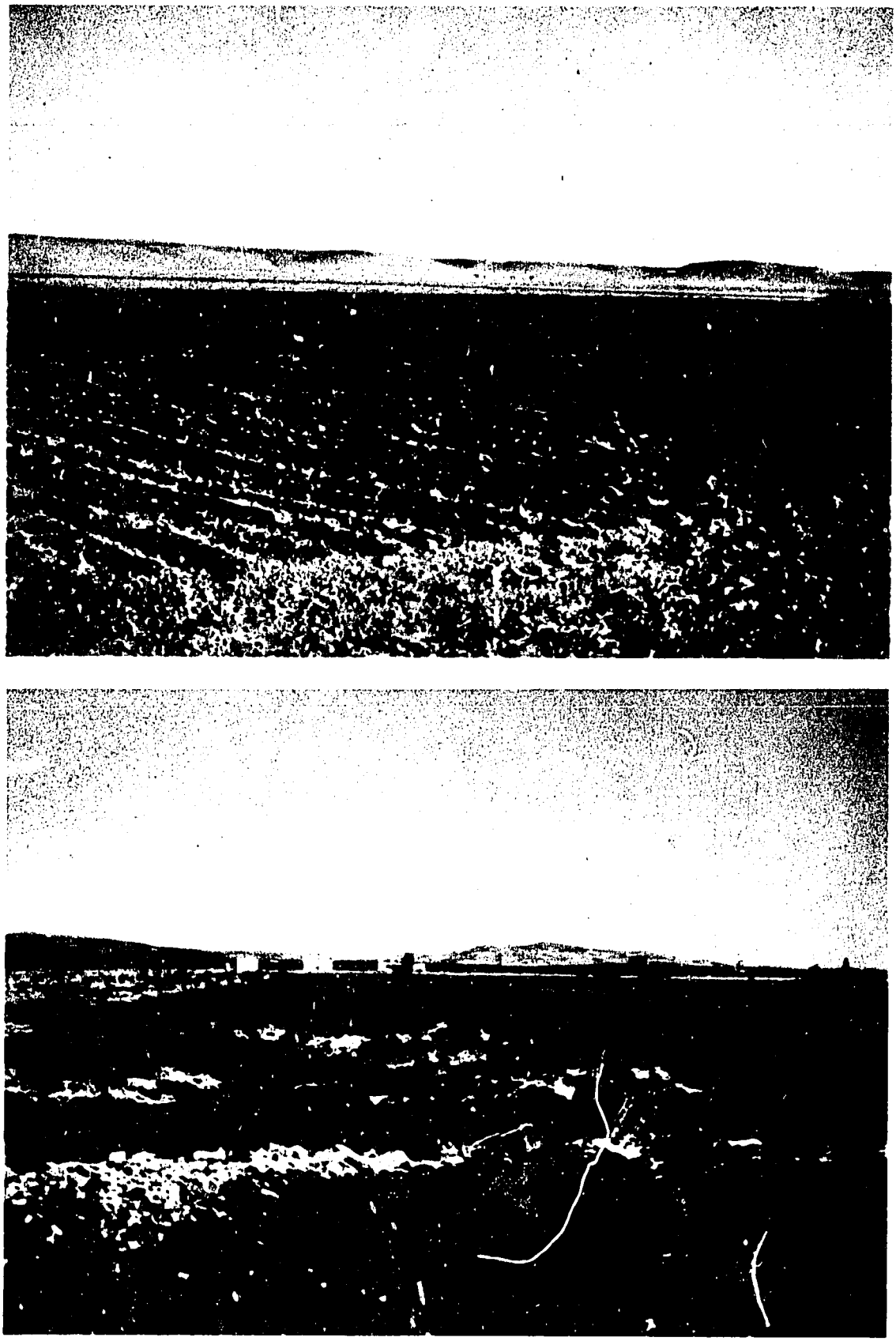
4) to understand the interaction between the effect of the agronomic variables on crop water use and the environment.

Although only a small research team was present at the beginning of the 1979/80 season, an effort was made to study as many ICARDA crops as possible. These included barley, bread wheat, lentil and faba bean. The concentration in the first year on soil moisture studies and agronomic practices was due to the interests of the specialists involved.

There were several basic experiments conducted in the 1979/80 season. Three experiments concentrated on soil moisture use; one on moisture use of barley under different levels of nitrogen applications, one on water use by faba beans and lentils and the third on the effect of water availability, temperature and nitrogen on three cultivars of bread wheat. Agronomic experiments included treatments of seed rate, sowing method, date of planting and nitrogen and phosphate applications. The results of these experiments are presented in the next several chapters.

The addition of new staff members and the acquisition of more research equipment will enable us to obtain a more comprehensive set of data in the 1980/81 season and should enable us to substantially expand the interpretation of the results and observations of this report.

Before closing this introduction, a word of caution to the reader is in order. This report presents the results of only the first experimental season in 1979/80. Although many results are discussed below, this is one season's work undertaken in a year with higher than average and well distributed rainfall. Therefore, care must be taken in interpreting these results and one cannot draw firm conclusions. As more research is conducted and we gain more confidence in interpreting the data, hopefully recommendations for increasing agricultural production in the region will emerge.



Contrasting soils at Khanasser (a) and Kafr Antoon (b) (See Appendix 1) prior to planting. (Note: white material in foreground at Kafr Antoon is substratum material removed from profile pit).

CHAPTER 2

DESCRIPTION OF RESEARCH SITES

This chapter describes in some detail the five research sites that were chosen for the specific experimentation relating to the SWAN project. Aleppo is ideally located for this research as it is in the middle of a very steep rainfall isohyet gradient, where average rainfall ranges from 600 to 200 mm per year.

The five sites, Tel Hadya and four off-station sites, are all located within an 80 km radius of Aleppo in different rainfall zones. The off-station sites have been established at Jindiress (550 mm mean rainfall), Kafr Antoon (450 mm), Brida (250 mm) and Khanasser (200 mm) (see Figure 2.1). This land has been leased for an initial five year period from either the Syrian Government or private land owners. In addition a similar site has been established at the ICARDA experiment station (350 mm).

Each site consists of 10 hectares of uniform flat land with soil depth greater than 2 m. The sites are divided into four 2.5 ha blocks which are managed on a rotational basis typical of the zone. At the wetter sites (Jindiress and Kafr Antoon) a typical three course rotation of cereal/lentil/summer crop rotation is employed. An additional year has been introduced into the rotation at all sites when a uniform crop with no fertilizer is grown after the experimental year to help remove or study residual effects of previous treatments. Thus, at the wetter sites the rotation is cereal experiments/uniform cereal/ lentil/ summer crop and at the drier sites it is cereal experiments/ uniform barley/uniform barley/fallow. Similar adjustments are made for land which is utilised for legume crop experiments.

In the 1979/80 season, a simple meteorological station was set up at each site and rainfall, pan evaporation, screened air temperature and relative humidity were recorded on a daily basis. These data are summarised and presented in this chapter. In the current 1980/81 season these meteorological stations are being upgraded to include the measurement of incoming radiation and daily wind run.

Soil pits were dug at each location and the profile was described and the soils classified. The results of this work are also presented in this chapter.

2.1. Climatic record 1979/80

The meteorological data obtained from the five experimental sites is summarised in Table 2.1. These data were used to calculate such variables as evapotranspiration and crop moisture use efficiency (see Chapters 3 and 4). However, due to a delay in equipment delivery at the beginning of the cropping season, the data record is incomplete at all sites except Tel Hadya.

The seasonal variation in the parameters measured follows the Mediterranean environmental type. However, three aspects of the season's data were exceptional and these should be taken into consideration when reviewing the crop production results.

1) Seasonal precipitation totals were significantly higher at the three drier sites than would be expected from the available long term averages (1951-73). At Tel Hadya and Khanasser increases of 31.6 and 21.9 percent respectively were experienced (see Table 2.1).

2) The distribution of precipitation within the season proved to be highly amenable to crop growth. Heavy storms occurred approximately one week prior to the anthesis of barley at all sites (end of March) and thus considerably delayed the development of moisture stress in the sensitive post anthesis growth phase. Weekly precipitation totals of 70.2 and 52.4 mm were recorded at Jindiress and Khanasser that week, and these represent more than a fivefold increase over the long term average precipitation for these sites for this period.

3) Very low temperatures were experienced at all sites in midwinter. Weekly average air temperatures in early January were often 6°C lower than the long term norm of approximately 8°C. As a result, significant amounts of frost damage were observed in the barley trials and more severe damage was reported by other ICARDA scientists in winter faba beans and chickpeas. An exceptional minimum temperature of -14°C was reported once at Kafr Antoon.

2.2. Soil classification

The soils at Khanasser, Brida, Tel Hadya, Kafr Antoon and Jindiress were studied by a consultant (Dr. P. Buringh, professor of tropical and subtropical soils at the Agricultural University of Wageningen, The Netherlands) to ICARDA during the period of October 19 to 23,

1980. During this period, six soil pits were studied and described, two at Tel Hadya, and one on each of the off-station sites.

All soils were classified according to the soil mapping units of the Soil Map of the World, scale 1:5,000,000, Vol. I (FAO/UNESCO, Paris, 1974), the new American system of soil classification (Soil Taxonomy , USDA Soil Survey Staff, Washington, 1975), and the new French system (ORSTOM, Paris, 1979). In addition, a few of the older names, which may still be in use, were given.

The soils in the Aleppo region are characterised by an aridic soil moisture regime, and thermic soil temperature regime, typical for a Mediterranean climate, which is transitional to a temperate-continental climate. Parent material of most soils is clay or heavy clay, mainly of colluvial origin, with montmorillonitic clays as the main clay minerals. All soils are calcareous or highly calcareous, often with accumulation of lime at shallow depth. All soils studied have a subangular blocky structure in the surface layer due to self-mulching. In the experimental fields, most soils are at least 80 to 120 cm thick overlying a substratum consisting of limestone, gypsum or heavily cemented sand. Shallow soils can be found outside the experimental fields.

The soils at the two drier sites, Brida and Khanasser, are quite similar. These were both classified as Calcic Xerosols (FAO), or Typic Calciorthids (USDA). However, the soil at Brida would be a Carboxysol vertique sur carbonates (ORSTOM) and at Khanasser a Carboxysol haplique sur gypse (ORSTOM). In older systems of soil classification the soils could have been classified as Reddish Brown Soils (USA), Brown Steppe Soils or Sierozems (France), Semidesert Brown Soils or Gray Cinnamonic Brown Soils (USSR).

Taxonomically, these soils are characterised by the presence of an ochric epipedon and cambic horizon. The cambic horizon differs in structure from surrounding soil material and has a more intensive colour. Also there is redistribution of lime at 40-60 cm depth (calcic horizon). The substratum consists of lime-rich sandy material at Brida, and highly gypsiferous material at Khanasser. The colours of the moist top soils are reddish brown in Brida (5YR 4/4) and yellowish brown (5YR 4/6) at Khanasser. The slightly lighter colours at Khanaser point to a less intensive rubefaction as a result of the lower rainfall at this site.

The structure of the soil at Brida is prismatic below the surface horizon, and is angular blocky at Khanasser. The soil aggregates contain many fine pores and varying number of fine roots. The relatively high porosity of the soil aggregates is a favourable characteristic

for agriculture, since it allows for a rapid infiltration of rainwater and an even distribution, so that a relatively large proportion of the stored soil moisture would be available to the plants.

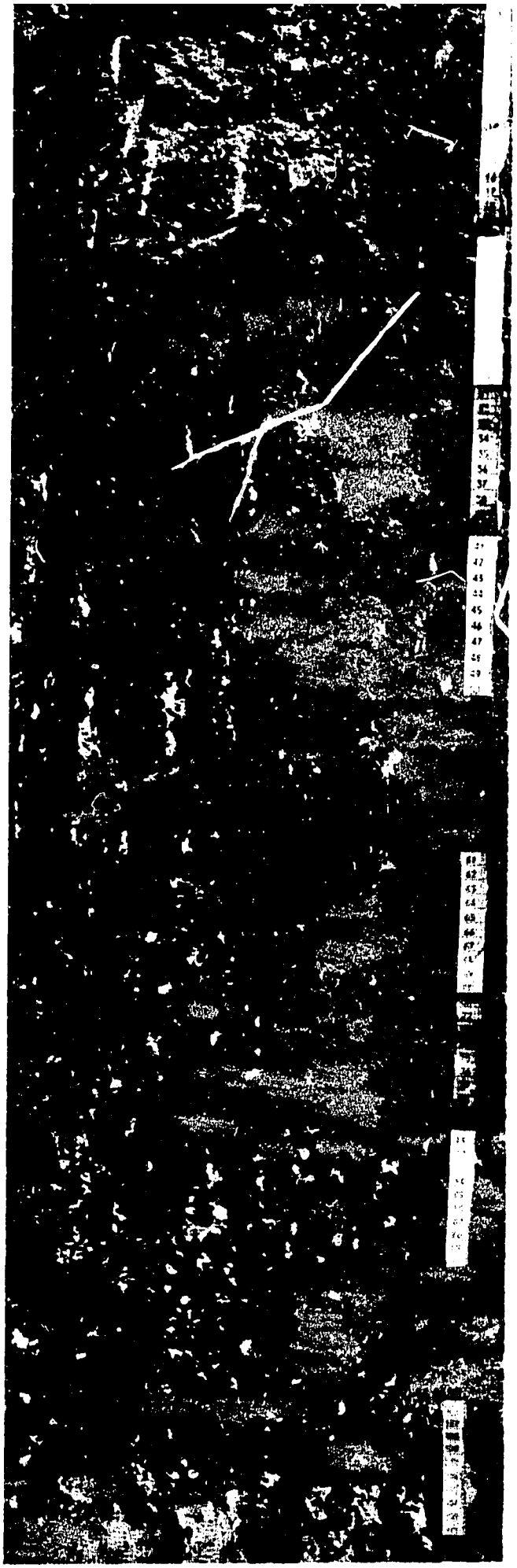
The soils at Tel Hadya are Luvisols which are transitional to Vertisols (cracking soils, with slickensides at depth). The soil in Block B-4 (south of the hill) was classified as Vertic (calcic) Luvisol (FAO) and in Block C-17 (north of the hill) as Chromic Luvisol (FAO). In the USDA-system they would be Chromoxerertic Rhodoxeralf and Calcic Rhodoxeralf, respectively, and in the ORSTOM-system Rhodo-Ferbisialsol, carboxique. In older systems of soil classification the soils could have been classified as Terra Rossa (USA), Red Mediterranean Soil (France), or Red-Yellow Earth (USSR).

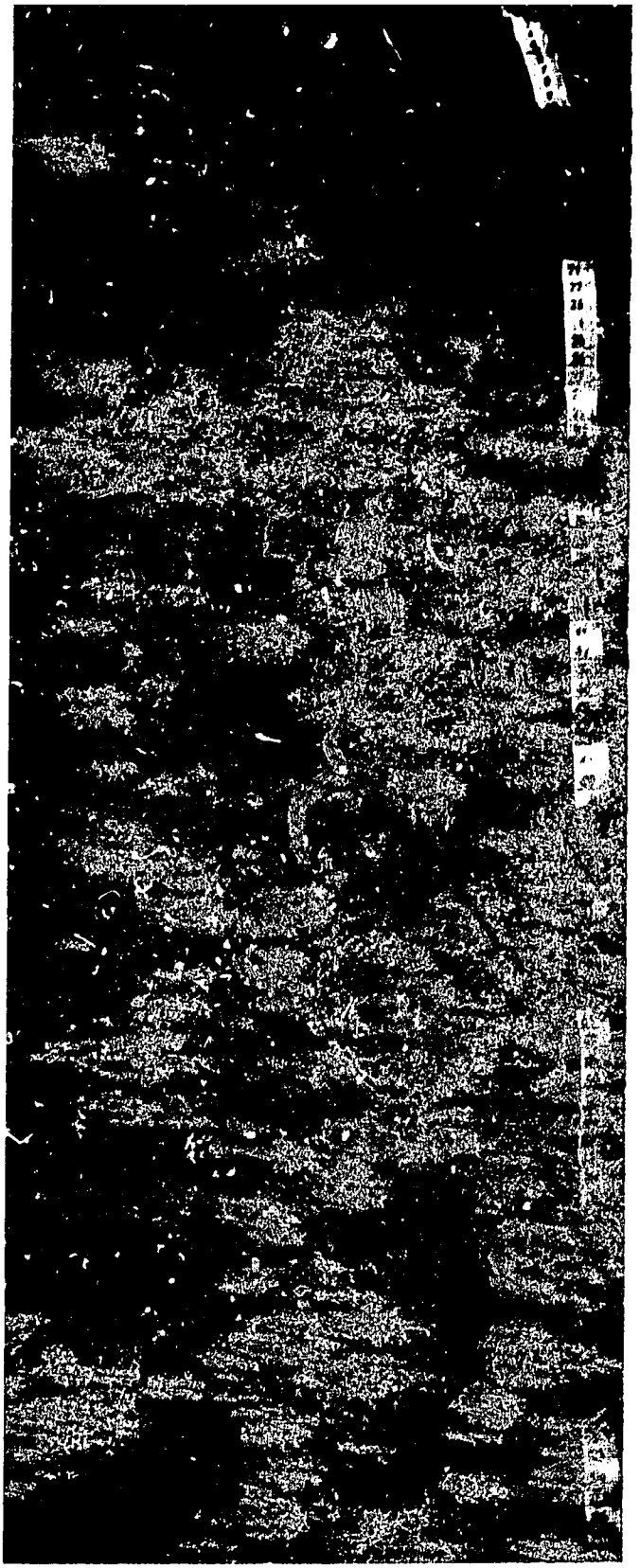
Taxonomically, the soils are characterised by an ochric epipedon, an argillic horizon, a calcic horizon, and slickensides at depth. The substratum consists of weathered limestone. The more reddish colours of the Tel Hadya soils, as compared to the drier sites, probably result from the formation of hematite and possibly goethite. The higher rainfall at Tel Hadya favours the formation of smectitic clay minerals (montmorillonite).

The structure of the Tel Hadya soils is angular blocky near the surface, and prismatic below. The soil aggregates are covered with clay coatings, which transform into pressure skins and slickensides at depth. The aggregates contain few fine pores and the roots generally are on the surface of the structural aggregates. These characteristics are not very favourable for agriculture, since infiltrating rainwater would largely follow the cracks, and infiltration into structural aggregates will be slow because of the surface coatings. Also, soil moisture stored in the aggregates will be less available to the crop than in the case of Brida and Khanasser, since the roots do not penetrate the aggregates to such an extent.

The soils, at Kafr Antoon and Jindiress are quite similar and were both classified as Chromic Vertisols (FAO), Palexerollic Chromoxererts (USDA), or Smecti-Bisialsols, vertique (ORSTOM). In older systems of soil classification they would have been classified as Grumusol (USA), Vertisol (France), or Cinnamonic-brown Earth, or Takyr (USSR).

Taxonomically, the soils are characterised by an ochric epipedon, the occurrence of deep cracks in polygonal patterns, slickensides, prismatic structure and wedge-shaped structural aggregates at depth. The substratum consists of weathered limestone and glauconitic minerals. There is not a pronounced calcic horizon, probably because of the rather intensive churning of the soil. Clay minerals are probably mainly of the smectitic-type.

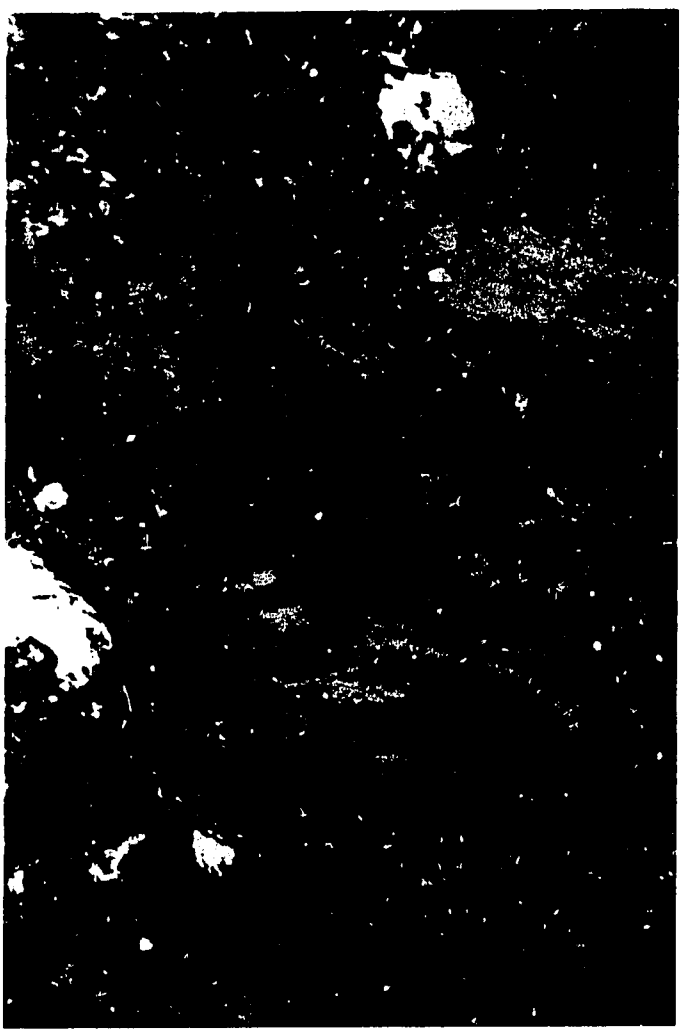




Soil profile at Brida. (See Appendix 1, soil 1 for classification and profile description).

Soil profile at Tel Hadya. (See Appendix 1, soil 3 (south) for classification and profile description).

Deep cracks in polygonal pattern and surface mulching at Jindiress (See Appendix 1, soil 5). Typical also at Kafr Antoon and Tel Hadya.



Slickenside at (a) Kafr Antoon and (b) Jindiress. Note roots running across aggregate surfaces in plate (b).

The structure of the soils is coarse subangular blocky near the surface and coarse to very coarse prismatic below. The structural aggregates contain few fine pores, and roots, in particular in the B-horizon, follow the surfaces of the aggregates. Early in the season, the internal drainage of the soils will be good because of the deep cracks. However, some rainwater may be lost due to deep drainage. Infiltration of rainwater in soil aggregates will be slow because of the pressure skins and slickensides on the aggregates, and therefore the distribution of soil moisture might be uneven. Soil moisture stored in the aggregates will only be partly available to the crop, since the roots penetrate the aggregates to a limited extent only. Also, part of the moisture in the soil aggregates will be taken up by the swelling clay minerals and thus become largely unavailable to the crop.

The churning of the soil would result in a more even distribution of plant nutrients throughout the profile than in non-churning soils. However, the relation between total nutrient contents and plant-available contents in soils is rather complicated, and plant-available contents of nutrients generally are more dependent on physico-chemical conditions in the soil than on total contents of nutrients.

The self-mulching properties of the top soil would prevent extensive losses of soil moisture in early spring, and thus are favourable for agriculture.

A more detailed description of the soil profiles is given in Appendix (I).

Fig. 2.1 ALEPPO PROVINCE

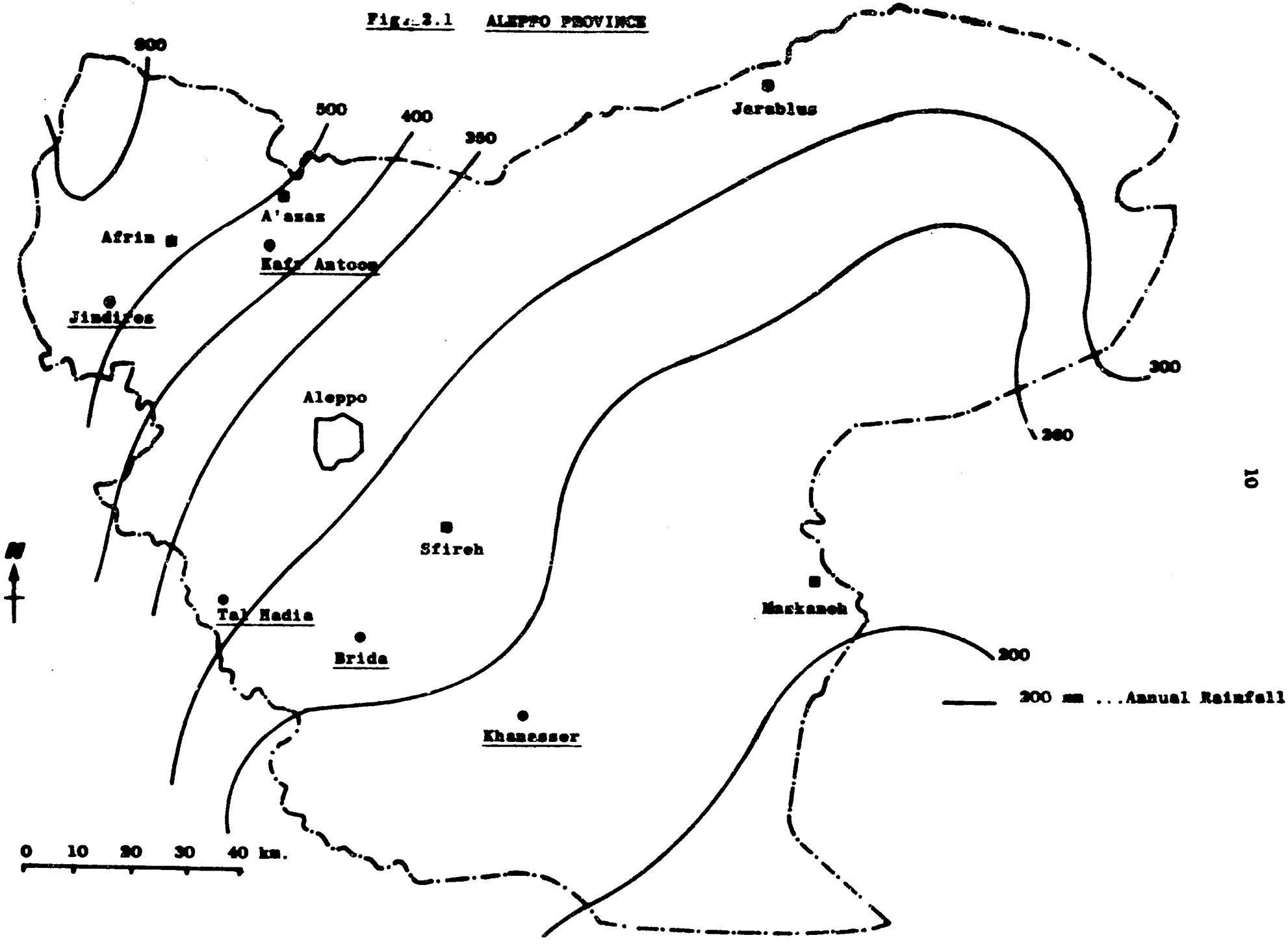


Table 2.1

Summary of Meteorological Data From Five Experimental Sites

(1979-1980)

Weekly Period	JINDIRES				KAFR ANTOON				TAL HADIA				BRIDA				KHANASSER			
	T	RH	R	E_o	T	RH	R	E_o	T	RH	R	E_o	T	RH	R	E_o	T	RH	R	E_o
	°C	%	mm	mm/d	°C	%	mm	mm/d	°C	%	mm	mm/d	°C	%	mm	mm/d	°C	%	mm	mm/d
25/10-31/10	na	na	na	na	na	na	na	na	18.5	79	15.2	2.9	na	na	na	na	na	na	0.0	na
1/11- 7/11	na	na	na	na	na	na	20.7	na	17.1	77	39.9	2.7	na	na	20.0	na	na	na	26.0	na
8/11-14/11	na	na	na	na	19.2	78	0.9	na	15.3	71	2.4	2.7	na	na	2.9	na	na	na	7.3	na
15/11-21/11	na	na	na	na	20.0	68	2.1	na	15.5	61	0.0	3.6	14.7	77	0.0	na	na	na	0.0	na
22/11-28/11	na	na	na	na	18.0	73	5.6	na	14.4	64	8.8	2.3	13.0	74	7.4	na	na	na	5.4	na
29/11- 5/12	10.8	81	12.4	1.8	13.0	83	14.3	na	10.5	76	14.4	1.8	9.6	83	0.0	na	na	na	0.6	na
6/12-12/12	10.2	78	2.5	1.8	7.8	85	5.0	1.8	10.1	79	0.4	1.5	9.6	86	8.9	na	9.0	90	28.4	na
13/12-19/12	9.5	80	36.6	1.3	7.2	84	26.4	1.1	10.0	80	35.5	1.2	9.0	86	26.4	1.4	9.0	84	9.2	1.0
20/12-26/12	6.4	81	3.4	1.2	4.8	77	0.0	0.7	7.5	77	6.2	1.3	5.3	88	4.4	0.8	5.0	90	6.8	0.9
27/12- 2/01	1.4	85	18.2	1.3	-1.2	86	14.0	0.7	3.0	87	24.6	1.1	1.1	86	14.0	0.5	-1.0	86	10.4	0.5
3/01- 9/01	6.1	85	42.4	1.3	3.7	90	51.8	0.6	6.7	85	26.6	1.3	6.4	87	19.6	1.1	5.0	88	7.6	1.6
10/01-16/01	3.4	75	4.5	1.1	1.5	71	4.6	1.4	6.6	74	0.4	0.9	4.5	78	2.6	1.0	4.0	83	1.8	0.5
17/01-23/01	1.2	74	0.8	1.8	0.5	63	1.6	1.4	4.9	77	9.8	1.0	4.0	81	7.4	1.2	4.0	86	8.0	0.9
24/01-30/01	2.1	77	19.6	1.6	-1.6	72	17.2	1.4	4.3	75	12.2	1.3	1.8	80	8.0	1.6	3.0	80	7.4	1.6
31/01- 6/02	1.3	66	2.0	2.0	-0.2	60	0.0	1.4	4.1	59	0.0	1.9	2.1	69	0.7	1.6	3.0	69	0.6	1.6
7/02-13/02	8.6	64	8.8	2.8	6.4	67	12.1	2.8	9.8	64	9.0	2.7	8.6	72	5.0	2.9	7.0	73	3.4	2.9
14/02-20/02	7.5	74	27.3	1.8	5.6	78	14.6	1.8	8.2	75	10.0	1.8	7.0	81	11.2	1.9	6.0	82	6.7	2.2
21/02-27/02	5.7	74	15.8	2.8	5.5	72	25.4	2.1	8.2	71	17.1	2.0	7.4	73	14.8	2.2	7.0	80	15.1	1.7
28/02- 5/03	5.1	86	28.0	1.2	3.8	86	25.2	1.5	6.9	76	16.7	1.8	7.6	84	13.3	2.0	6.0	82	6.4	2.4
6/03-12/03	8.9	69	9.8	3.0	5.9	72	8.4	3.2	11.0	63	6.5	3.3	11.2	73	16.4	3.2	9.0	73	12.8	3.5
13/03-19/03	9.7	78	23.6	2.4	7.6	79	17.6	3.1	10.9	65	19.2	3.2	9.4	79	11.4	3.1	7.9	74	4.8	3.5
20/03-26/03	11.7	76	2.0	3.7	12.0	78	3.0	3.4	13.5	69	5.0	3.8	13.0	73	4.0	3.8	10.4	83	5.3	3.2
27/03- 2/04	12.8	80	70.2	4.0	9.8	82	80.8	3.9	14.0	76	59.6	3.4	13.7	74	43.4	3.4	13.0	75	52.4	5.0
3/04-9/04	15.6	70	13.0	4.1	14.3	72	14.6	4.0	15.4	67	3.0	4.6	14.7	72	4.0	4.2	16.0	72	4.6	4.7
10/04-16/04	11.2	76	9.0	4.3	9.4	72	8.0	4.5	12.2	61	5.1	5.6	12.2	65	1.2	4.5	10.5	68	6.8	5.4
17/04-23/04	15.1	63	7.6	5.2	13.5	67	6.4	5.0	16.0	50	1.3	5.9	15.7	57	0.0	5.6	14.5	60	0.0	6.6
24/04-30/04	13.5	74	6.8	5.6	11.9	76	7.0	5.6	16.0	57	16.3	7.9	16.0	65	9.0	6.0	14.8	65	14.0	6.0
1/05- 7/05	16.5	69	1.2	5.9	15.8	67	1.6	5.4	18.2	51	0.4	7.2	18.5	59	0.0	6.8	16.5	57	0.0	7.8
8/05-14/05	17.5	66	1.8	6.0	16.2	67	3.4	5.5	18.3	53	9.8	7.4	18.1	58	12.3	6.4	18.9	54	4.8	7.5
15/05-21/05	20.9	51	0.0	6.9	22.0	50	0.0	7.5	21.0	29	0.2	9.3	21.2	46	0.0	8.3	22.0	36	0.4	12.1
22/05-28/05	21.6	47	0.0	7.6	22.6	49	0.6	9.3	21.6	31	0.0	11.6	20.4	47	0.0	10.9	22.7	38	0.0	14.5
29/05- 4/06	26.2	39	0.0	9.5	25.8	42	0.0	12.0	25.6	30	0.4	12.4	24.0	42	0.0	12.8	27.1	34	1.0	16.1

CHAPTER 3

THE EFFECT OF NITROGEN SUPPLY ON GROWTH, WATER USE AND YIELD OF BARLEY (CV. BEECHER) AT FIVE LOCATIONS IN NORTHERN SYRIA.

3.1. Introduction

In our first season's research, the agronomic studies conducted on our four off-station sites and Tel Hadya concentrated on barley (cv. Beecher) as the most widely grown crop in the region. In addition, barley is the only crop where one variety could be recommended for the whole 200-600 mm rainfall transect. These agronomic studies are described in detail in Chapter 6 and included studies on the following crop management factors: seed rate, date and method of seeding, effect of timing of nitrogen application and effect of phosphorus application.

It was decided to concentrate most of the detailed soil moisture studies on one aspect of this wider agronomic program, and in our first season the effect of nitrogen supply on the growth, water use and yield of barley was chosen as the most appropriate. In addition, parallel studies were conducted on the moisture dynamics under fallow land at the same five locations.

The major objectives of this study are:

a) to study the interaction between nitrogen supply, crop growth, water use and yield under a range of environment conditions on different soil types;

b) to utilise the data in the crop growth/water use model which is being developed in conjuction with the University of New England (see Chapter 5);

c) to provide a broad basis of understanding of soil moisture dynamics and crop water use on which to base future work, and

d) to identify problems and solutions associated with the Neutron Scattering technique for soil moisture measurement within the region.

3.2. Materials and methods

3.2.1 Treatments

Four rates of nitrogen fertilizer (ammonium nitrate) were chosen to correspond to those utilised in the agronomic trials reported in Chapter 6. They were 0, 20, 40 and 60 kg/ha of nitrogen. These treatments are referred to as B_0, B_{20}, B_{40} and B_{60}. The nitrogen was applied in a split dressing, 20 kg/ha being applied at planting with the seed, and the remainder being broadcast by hand at the start of stem extension. A uniform dressing of triple super phosphate (60 kg/ha P_2O_5) was applied, mixed with the seed, at planting.

Each treatment was replicated three times at each site in a randomized block design and a bare fallow plot was included in each block.

3.2.2 Plot management

The trial was laid down at each site adjacent to the main agronomy trials utlising a plot size of 12.5 x 10.5 m. Two moisture accession tubes were installed in each plot (see Section 3.2.3).

Beecher barley was planted with an Öyjord plot drill at a seed rate of 120 kg/ha in 17.5 cm rows at Jindiress (24 November 1979), Kafr Antoon (5 November), Tel Hadya (21 November), Brida (9 November) and Khanasser (11 November). Nitrogen and phosphorus were drilled with the seed as described in Section 3.2.1 and nitrogen was topdressed by hand on the dates 12/2, 30/1, 3/2, 29/1 and 5/2/80 respectively. Weeds in the barley plots were controlled by spraying with 'Faneron' at Tel Hadya and Kafr Antoon, and by hand weeding at Jindiress. No weeding was necessary at Brida or Khanasser. Weed control in the fallow plots was achieved by timely cultivations in early spring.

The crop was harvested by hand on the dates of 28/5, 31/5, 23/5, 17/5 and 21/5/80 respectively. An area of 1.5 m^2 was harvested around each moisture accession tube for grain yield analysis, and a further 2.0 m row length from each plot for total biological yield and harvest index analysis.

3.2.3. Installation of moisture accession tubes

Six access tubes per treatment (2 per plot) were installed to a depth of 1.80 m using a Giddings Hydraulic Auger mounted on a four wheel drive pick up truck. The tubes were installed in Sept/Oct 1979, before final seed bed preparation. Care was taken to ensure that the tubes were vertically placed and fitted tightly into the augered hole. Wheel marks of the vehicles were removed by hand hoe, and the final seed bed preparation was done with a tractor mounted set of spike-toothed harrows which were able to pass over the access tubes. This procedure ensured a uniform seed bed around each tube unaffected by the installation procedure. The crop was drilled over the tubes, the tyres of the planter passing either side of the tube. Subsequent germination and crop growth was uniform, indicating that the care taken to cause as little soil disturbance as possible around the tubes produced the desired results.

3.2.4. Field calibration of the neutron probe

Additional access tubes were installed at each site for field calibration of the Neutron Probes. Calibration was conducted throughout the season in wet and dry soils to provide a good spread of points. The calibration was done according to the Probe manufacturer's recommended procedure and is presented in Fig. 3.1, one calibration line being used for all five sites in the first season.

3.2.5. Soil moisture recording

Wallingford IH-2 Neutron Probes were used to monitor soil moisture changes at 15 cm intervals to a depth of 180 cm. The 0-15 cm depth interval was sampled with a volumetric soil sampler (2 samples/plot/sampling date) and the percent moisture by volume was determined gravimetrically by oven drying at 105°C for 24 hours.

During the winter months, access tubes were monitored as frequently as the soil surface conditions allowed. Plots were not entered when the soil surface was wet in order to avoid damage to plants and the soil surface. During spring and early summer, moisture was recorded approximately every 10 days. To avoid crop damage and soil compression around the tubes during early growth, portable raised aluminium frames were used by operators. Once crops became too high, wooden planks, laid between rows, were used when and if necessary.

The Giddings Hydraulic Auger being used for installation of moisture access tubes at Tel Hadya. (a) 44 mm diameter and hole being augured to depth of 2 m.
(b) Hydraulic auger being used to press in the access tube.

Soil moisture being measured in a Beecher barley crop at Khanasser. The crop received 60 kg/ha P_2O_5 & 20 kg/ha N and yielded 3360 kg/ha grain.

Uniform lentil crop being drilled at Kafr Antoon The trial area can be seen in the background.

3.2.6. Determination of crop moisture use

Utilising the counts obtained with the neutron probe and the calibration curve in Fig. 3.1, the percent moisture by volume was calculated for each 15 cm depth. This was converted to "centimeters of moisture per depth interval" which were then summed to provide an estimate of the total centimeters of moisture within the 0-180 cm soil profile for each accession tube. Crop evapotranspiration (E_t) or soil evaporation (E) for a given period were calculated according to the following equation:

$$E_t \text{ or } E = P - \Delta M - D - R \quad \ldots\ldots\ldots \quad (1)$$

where :
- P = precipitation occurring within period.
- ΔM = change in total moisture in 0-180cm profile.
- D = drainage below 180 cm.
- R = run-off from the soil surface.

No direct measurement of R or D was made. However, during the growing season, there was no evidence that the component R was significant within these trials where the land utilised was flat. Drainage below 180 cm depth (D) did occur in some treatments at the three wettest sites, Jindiress, Kafr Antoon and Tel Hadya. During such periods, estimates of E_t or E were used to derive the drainage component D (see Equation 1).

3.2.7. Plant growth studies

Plant samples (1m row length/plot) were taken from treatments B_0 and B_{60} periodically throughout the growing season. Plant and tiller number counts were made and the samples were divided into stem, green leaf, rachis, awn, grain and dead plant material components. Dry matter of each component was determined by oven drying at 80°C for 24 hours. During the grain filling period, grain number and grain weight measurements were made to follow the increase in 1000 grain weight.

3.3 Results

The Mediterranean environment is climatically typified by cool winter months (October-March), warm spring months (April-May) and hot summer months. During the cool winter months, when most of the annual precipitation occurs, precipitation (P) exceeds crop evapotranspiration (E_t) and soil evaporation (E). During this period moisture recharge

within the soil profile occurs. As air temperatures, radiation levels and canopy development increase in spring, accompanied by a decrease in precipitation levels, crop evapotranspiration exceeds precipitation and net moisture discharge occurs in the soil profile. During this period, crops are largely dependant on stored soil moisture to complete their growth cycle. This typical period of profile discharge allows the research worker to examine in detail the effect of different crop management practices on (a) the ability of the crop roots to extract soil moisture from within discrete soil horizons and (b) the depth from which moisture is extracted.

The results of this study are presented in this context. In Section 3.3.1 - 3.3.4 profile recharge and discharge are described under both fallow and barley treatments. In Section 3.3.5 and 3.3.6, the effect of nitrogen application on the barley crop's ability to extract moisture is examined, both with respect to rooting depth and discrete soil moisture.

Utilising Equation 1, the treatment effect on the seasonal pattern of E_t and E is presented in Section 3.3.7, and the results of the crop growth studies are given in Section 3.3.8 - 3.3.9. In the final Section, 3.3.10, the treatment effect on final harvest data is presented and is related to crop moisture use utilising the concept of water use efficiency.

3.3.1 Moisture recharge under fallow

Profile recharge of the 0-180 cm profile under fallow are given in Figures 3.2 ab-3.6 ab. Figures (a) describe the net changes in total moisture in the profile (ΔM), whereas figures (b) give a more detailed picture of the changes in moisture at discrete depth intervals with time.

At the three wettest sites, Jindiress, Kafr Antoon and Tel Hadya, the recharge front (the depth to which the current season rainfall has penetrated) moved steadily down the profile. Following the heavy rains in late March and early April, the recharge front went through the bottom of the 180 cm profile and drainage losses (D) in Equation (1) had to be estimated. This was done by utilising E/E_o ratios (E_o is the potential evaporative demand as measured by a Class A pan) for preceeding periods.

At the two drier sites, Brida and Khanasser, profile recharge occurred during December and early January, but this was followed by a period of discharge until the heavy rains in late March and early April when further recharge occurred. At these two sites, recharge was much

less and the recharge front did not extend beyond 120 cm depth. A summary of the moisture budget under fallow during profile recharge at the five sites is given in Table 3.1. These data demonstrate the much greater efficiency of moisture storage at the three wetter sites where approximately 50 percent of the rainfall was stored compared with the two drier sites where only about 20 percent was stored. This is of course dependant upon the balance between P and E since during the winter months there appears to be little difference in accumulated E_o values across the five sites, and E/E_o ratios are remarkably similar except at Kafr Antoon. This lower E/E_o value at Kafr Antoon is thought to be associated with a particularly strong self mulching soil characteristic noted both during field visits and profile description.

3.2.3 Moisture discharge under fallow

Following the date of maximum recharge, continuous profile discharge was recorded under fallow at all sites (see Figures 3.2a - 3.6a). However, during May and early June soil cracks developed around the access tubes at all sites, and results obtained after these cracks had formed indicated increased moisture loss at depth. An example of this can be seen from the data obtained at Jindiress (see Fig. 3.7a) where cracking was most severe and occurred in the period 7-25 May. When the cracks were filled by cultivation, the moisture loss in the subsequent period (25 May-18 June) was much reduced. Such soil cracking in fallow land is usually controlled by farmers with timely cultivations, thus in this study only the results obtained prior to soil cracking are considered valid and these are presented in Figures 3.7a - 3.11a. In these figures the dotted line indicates the moisture distribution at the start of the season, and the shaded area represents moisture stored from the 1979/80 rains prior to soil cracking.

At the three wettest sites (Figs. 3.7a - 3.9a), moisture loss occurred at all depths due to both slow drainage at depth and evaporation from surface horizons. In a separate study at Tel Hadya (see Chapter 5), where soil cracking in fallow plots did not occur, the results indicate that upward movement of moisture occurred in the top 75 cm of the profile, and that slow drainage from deeper horizons continued throughout the summer. Thus, although considerable moisture from the 1979/80 rains was still stored in the profile prior to soil cracking (15.5, 11.0, 9.0 cms of water in the 0-180 cm profile at Jindiress, Kafr Antoon and Tel Hadya respectively), it is impossible to assess both the proportion remaining at the start of the 1980/81 cropping season, and its distribution in the profile.

At the two driest sites, moisture loss was confined to the depth of penetration of the recharge front in the 1979/80 season. This appeared to be largely due to upward movement of water resulting from surface evaporation, although there was evidence of a small accumulation of moisture in the 90-120 cm horizon, presumably due to drainage from the horizons above. Prior to soil cracking, 3.68 and 2.14 cms of water was stored in the 0-180 cm profile from the 1979/80 rains at Brida and Khanasser respectively. For the same reasons as given above it is impossible to assess how much of this stored moisture would still be present at the start of the 1980/81 season.

A summary of the moisture budget under fallow during the profile discharge period is given in Table 3.2. In calculating the values for surface evaporation and drainage during this period, moisture losses in the profile above 75 cm are attributed to surface evaporation, and below 75 cm to drainage. This assumption is based on results in Chapter 5 and will be verified in the 1980/81 season by utilising soil moisture tensiometers.

3.3.3 Moisture recharge under barley

During November, December and January, when crop leaf area and transpiration were small, evapotranspiration (E_t) was dominated by evaporation from the soil surface, and thus profile recharge under barley was very similar to that under fallow (see Figs. 3.2a - 3.6a).

At the two wettest sites (Jindiress and Kafr Antoon, see Figs 3.2a - 3.3a) maximum recharge occurred following the heavy rains in late March and early April, and at this point the recharge front was approaching the "bottom" of the 0-180 cm profile, (see Figs 3.2b - 3.3b). During this period, (1-17 April, 1980 for Jindiress, 31 March and 16 April for Kafr Antoon) drainage below 180 cm was recorded in one or two access tubes in each treatment. E_t values for these periods were calculated from tubes which were not draining. Once net discharge occurred, from mid-April onwards, E_t values were calculated utilising information on rooting depth of the crop (see 3.3.5). It was only at these two wettest sites, where recharge continued during periods of rapid crop growth and high transpiration rates, that treatment effects of nitrogen application on recharge pattern were observed.

At the three driest sites, Tel Hadya, Brida and Khanasser, maximum profile recharge under barley occurred in January. During February and March, irregular profile recharge and discharge occurred. Following the heavy rains in early April, continuous profile discharge occurred at all three sites.

3.3.4 Moisture discharge under barley

Rapid profile discharge occurred at all sites following the heavy rains in early April, and continued until crop physiological maturity at the end of May (see Figs 3.2a - 3.6a and 3.7a - 3.11a). During this discharge period, the effect of enhanced crop growth resulting from nitrogen application on the profile discharge was apparent at all sites.

It was also apparent (see Figs 3.7a - 3.9a) that at the three wettest sites moisture loss was occurring at depth due to slow drainage. In order to separate drainage from evapotranspiration it was necessary to estimate the maximum depth of moisture extraction by barley roots. This could have been achieved by the use of field tensiometers and the determination of the "zero flux plane" of soil hydraulic potential. However, during periods of rapid profile discharge, tensiometers have to be read frequently and this was not feasable at the off-station sites.

However, the ICARDA environment is characterised by this period of rapid profile discharge during spring and early summer as crops mature, and dependant upon this, a method has been designed to determine moisture extraction depths utilising neutron probe data only. This is described in detail in the Section 3.3.5.

3.3.5 The effect of nitrogen application on moisture extraction patterns during profile discharge.

A detailed examination was made on the moisture data collected during the period of rapid profile discharge to determine the effect of nitrogen application on the moisture extraction pattern of barley roots. This period approximately covered crop anthesis to maturity. The results of these analyses are presented in Figs 3.7ab - 3.11ab and Table 3.3 - 3.7. The analysis is done in three stages and depends upon the assumption that at any given site within any one depth interval the soil physical properties are similar between treatments. Since the trial area at each site was small (51 x 47.5 m) and since the results are the mean of six tubes/treatment randomly distributed, such an assumption is reasonable.

This three stage analysis is described below. As an example, reference is made to Figs 3.9 and Table 3.5 which contain the data for Tel Hadya.

Stage 1. The moisture profiles on successive logging dates are plotted for the period concerned (see Fig. 3.9a). This gives a broad indication as to the depth of root extraction and the amount extracted from discrete layers. One might conclude from this that at Tel Hadya, barley without nitrogen application extracted moisture from as deep as the 120-135 cm interval, whereas the application of 60 kg/ha of nitrogen has promoted rooting down to the 165-180 cm depth interval. However, it is not certain at this stage whether moisture loss from deeper horizons is due to root uptake or slow drainage. Discharge under fallow at Tel Hadya shows that moisture is being lost from deeper horizons, and this certainly was not due to root uptake.

Stage 2. The same data is replotted (see Fig. 3.9b) showing the temporal change in moisture content for each individual soil horizon, indicating the moisture content at the start of the period. These lines are then carefully examined to identify points at which a clear discontinuity in the slope of the line occurs. When looking for these points attention is paid to the period during which the crop is reaching physiological maturity and water uptake is ceasing. For both B_0 and B_{60} data at Tel Hadya such discontinuities are well defined down to the depths of 120-135 cm (B_0) and 135-150 cm (B_{60}) (marked with arrows). Reference to the fallow data shows no such discontinuities and provides strong support for the hypothesis that the discontinuities occur at the point when moisture extraction by roots ceases in that horizon.

Stage 3. The total amount of moisture (mean of 6 tubes/treatment) lost from each horizon during the study period is then tabulated for each treatment (including fallow). Treatment means allow one to compare the moisture lost from discrete depth intervals in different treatments. A "t" statistic comparing the means is calculated and the level of significant differences between various treatments is indicated. For example, Table 3.5 shows that B_0 lost more moisture than fallow from all depth intervals down to 120 cm, whereas B_{60} lost more than fallow to a depth of 150 cm. Comparisons between B_0 and B_{60} indicate the depth intervals from which greater moisture uptake occurred as a result of N application.

This analysis was carried out for B_0 and B_{60} at all five sites, and a summary of the results are given in Table 3.8.

Stage 1 of the analysis gives a greater depth of moisture extraction depth than Stages 2 and 3 which show generally good agreement. In Stage 1 we are unable to differentiate between root uptake, slow drainage and upward movement of water in response to hydraulic gradients. In Stage 2, estimates of maximum depth of moisture extraction depend on identifying a discontinuity in rate of moisture loss from a given horizon at the time the crop approaches physiological maturity, and Stage 3 depends upon a comparison between moisture loss from a given horizon in the possible presence and definite absence of roots. More reliance is placed on the last two stages.

The application of 60 kg/ha of nitrogen significantly increased total moisture uptake during this period of rapid profile discharge. Tables 3.3 - 3.7 show that this is true at all sites except Brida. Only at Kafr Antoon, Tel Hadya and Khanasser did nitrogen have a significant effect on depth of moisture extraction. At the two driest sites, Brida and Khanasser, rooting depth appeared to be mainly limited by the depth of the recharge front. Since both these sites were under fallow during the preceeding 1978/1979 season this would suggest that there was little if any available moisture conservation at depths greater than 75 cm from the previous season's rains.

At Jindiress, the wettest site, crop dry-matter production and final yields were lower than might have been expected (see Section 3.3.10). However, there was a clear response to nitrogen in both total biological yield and grain yield, and more moisture was used. It is not clear why this nitrogen response was not reflected in greater rooting depth as at Kafr Antoon and Tel Hadya.

3.3.6 The effect of nitrogen application on extractable moisture by barley.

A common concept in moisture use studies is that of available moisture. Available moisture is usually defined as that held between field capacity (1/3 atmospheric pressure) and wilting point (15 atmospheric pressure). This concept is useful in describing soil moisture characteristics, but it does not indicate the amount of moisture available for crop uptake. The problem arises from the limits set by field capacity and wilting point. Firstly, a crop can take water from a horizon which is temporarily above field capacity (i.e. draining), and secondly the amount of moisture available to a crop in a given horizon before permanent wilting occurs will depend on the proliferation of roots within that horizon and the rate of atmospheric evaporative demand.

Thus "available water" within a soil is a variable factor and depends upon the interaction between soil type, crop species, profile recharge status, crop management, crop performance and atmospheric demand. Extractable moisture is defined as the difference between the highest moisture value recorded within a given depth interval and that recorded at harvest. Maximum depth of moisture extraction, (Section 3.3.5) determines the depths considered. Data in Figure 3.12 show the effect of the application of 60 kg N/ha to a barley crop on the extractable moisture within discrete depth intervals at five sites.

The data demonstrate clearly that nitrogen application of 60 kg/ha has not only increased the depth of moisture extraction (at three out of five sites), but has had a marked effect on the crops ability to extract moisture within all depth intervals at all five sites. The application of 60 kg N/ha has caused an increase in extractable moisture of 22.4, 25.5, 37.5, 12.4 and 16.2 mm at Jindiress, Kafr Antoon, Tel Hadya, Brida and Khanasser respectively.

3.3.7 Crop moisture use

Equation 1 was used to calculate crop moisture use. The data on accumulated moisture use are presented in Table 3.9 - 3.13, the seasonal variation in E_t are shown in Figs. 3.13a - 3.17a, and the seasonal variation in the E_t/E_o ratio are given in Figs. 3.13b - 3.17b.

There was very little difference between accumulated evapotranspiration from bare fallow and barley until the end of January except at Kafr Antoon which was sown first and where the barley showed much more rapid early growth and canopy development than the other four sites. At Kafr Antoon evapotranspiration from the cropped land was greater than from fallow from December onwards.

Differences in water use due to nitrogen application became apparent in February and increased steadily as the season progressed. At all sites, increasing the rate of nitrogen application resulted in an increase in moisture use.

Figures 3.13a - 3.17a show that the seasonal variation in rate of evapotranspiration of barley was related to the pattern of evaporative demand (E_o) up until and just after crop anthesis when maximum rates of evapotranspiration were reached. Beyond this, as leaf senescence increased and the crop neared physiological maturity, rates of evapotranspiration fell markedly.

During early crop growth the E_t/E_o ratio (the ratio of actual crop evapotranspiration to evaporative demand of the atmosphere) is dominated by the soil evaporation component which in turn is related to the frequency of soil wetting. As the canopy develops, and crop ground cover increases, transpiration becomes the dominant component and in the absence of moisture stress conditions E_t/E_o ratios of unity are expected when crop ground cover reaches 100 percent. The seasonal variation in the E_t/E_o ratios are presented in Figs 3.13b - 3.17b. The E_t/E_o ratio increased with increasing crop ground cover and reached maximum values around anthesis. At none of the sites did crop evapotranspiration ever fully satisfy the evaporative demand, the maximum values recorded at each site being 0.94, 0.90, 0.96, 0.80 and 0.70 for Jindiress, Kafr Antoon, Tel Hadya, Brida and Khanasser respectively. This may be due to overestimation of E_o by the Class A pan during hot dry weather, or due to partial stomatal closure during certain periods of the day. Certainly, where nitrogen was applied at 60 kg/ha, complete ground cover was achieved at anthesis at all sites, and thus in the absence of moisture stress values of E_t/E_o approaching unity would have been expected. At another study conducted at Brida (reported elsewhere, where greatly enhanced crop growth was observed to be associated with ant's nests), complete crop ground cover was achieved much earlier in the season and E_t/E_o values just greater than unity were observed during the period 11/Feb. - 11/March.

3.3.8 Crop growth studies

Studies were conducted on treatments B_0 and B_{60} at all sites, and the results are presented in Figs 3.18 abc - 3.33 abc. These results are summarised in Tables 3.14 and 3.15. Figs 3.18a - 3.22a show that at all sites (except Khanasser), the application of nitrogen caused a marked increase in dry matter production. This was reflected in leaf, stem and head weights. The maximum dry weights for each of these components are given in Table 3.14.

Application of nitrogen resulted in greater tillering at all sites (Figs 2.18b - 2.22b), but later tiller depth reduced the magnitude of this effect. The effect of nitrogen on tillering and tiller survival interacts strongly with seeding rate, phosphate application and site, which is discussed in Chapter 6.

The rate of increase in grain weight is shown in Figs 3.18c - 3.22c. The increase in grain weight was linear at all sites until growth ceased abruptly at physiological maturity. Nitrogen application had no significant effect on either the rate of increase of grain weight or the final grain weight, although field observations suggested

that nitrogen application delayed maturity by a few days. The rates of increase in grain weight at the five sites were estimated by the usual linear regression technique and were found to be 1.35 (Jindiress), 1.36 (Kafr Antoon), 1.37 (Tel Hadya), 1.33 (Brida) and 1.57 (Khanasser) g/1000 grains/day. Graphical analyses of Figs 3.18c - 3.22c indicated that barley reached physiological maturity at 38, 40, 34, 35 and 35 days post anthesis respectively at the five sites.

3.3.9 Crop growth rate and grain number

Data collected from within ICARDA's region and also from other contrasting agroclimatological zones clearly show that the final grain yield of cereal crops is largely dependant on the grain number. Under extremely adverse conditions during grain filling, grain weight may also be a significant component. Much interest has been centred on identifying the physiological mechanism which determines the number of viable grains produced. Recently it has been suggested that competition between plant components for assimilate during the period in which grain numbers are determined may be the controlling mechanism. For example, strong positive correlations have been found in maize between the crop growth rate ($g/m^2/day$) during the period of grain number determination and the final number of grains filled at harvest. Such a relationship supports the hypothesis that high rates of assimilate production during this period lessen the competition between the developing ear and other plant components, thus allowing more viable grain sites to develop.

However, since grain site initiation and development are temperature controlled processes, the rate at which these processes occur during a given period of calendar time will depend upon the mean temperature experienced by the plant. Thus, in examining the competitive effect for assimilate supply it is more pertinent to express crop growth rates in terms of thermal time rather than calendar time. Calendar time can be converted to thermal time using the concept of Growing Degree Days (GDD) thus:

$$GDD = (\bar{T} - T_o) \times D$$

where $\bar{T}$ is the mean temperature during a period of D days and T_o is the physiological base temperature of the crop. Thus, with a knowledge of the mean air temperature during the period considered and the physiological base temperature of the crop, crop growth rates ($g/m^2/day$) can be converted to thermal growth rates ($g/m^2/GDD$).

In the present study the mean crop growth rate of Beecher Barley (B_o and B_{60}) during the period of rapid stem elongation at the five sites was obtained by graphical analyses of Figures 3.18a - 3.22a. Thermal growth rates were computed assuming a value of 0^oC for T_o and by utilising the screened air temperature data from each site. The relationships

between crop growth rates, thermal growth rates and final grain number were examined. The results are presented in Table 3.15 and Figure 3.23. The regression of final grain number on crop growth rate was significant (R^2= 0.61) but replacement of crop growth rate by the thermal growth rate parameter explained even more of the variation in final grain number (R^2= 0.83).

If subsequent studies verify this relationship within the Aleppo Province, where daylength differences between sites are negligible, it may be necessary to consider growth rates in units of g/m^2/photothermal time before the relationship could be expanded for the wider region that ICARDA serves.

3.3.10 Final harvest anaylyses and water use efficiency

The harvest data are presented in Table 3.16 together with total evapotranspiration data and derived water use efficiency. Detailed statistical analysis was not carried out, but a simple randomized block ANOV was done, and the f-values for treatment effects are given. An analysis of nitrogen response, and its interaction with other crop management factors is made in Chapter 6. The results in this trial indicate that there is a significant biological yield and grain yield response to nitrogen application at four of the five locations. Nitrogen application had no significant effect on harvest index or grain weight.

Water use efficiency is considered in terms of both total biological yield and grain yield. Nitrogen application has increased the water use efficiency at all sites except Khanasser. The greatest increase in water use efficiency occurred at Brida and Jindiress where the nitrogen response was the greatest.

The relationship between total moisture use and total biological yield and grain yields are presented graphically in Figs 3.24 ab. A unique relationship appears to exist between total biological yield and evapotranspiration for each site. The complexities of these relationships are not clear, although we believe that the different nutrient status of these soils may be a factor, and that nitrogen is unlikely to be the only nutrient involved. In our first season's work evidence was obtained that phosphorus deficiencies may be as widespread and as severe as nitrogen deficiencies.

The relationship between grain yield and evapotranspiration is presented in Fig. 3.24b. In contrast to the relatonship in Fig. 3.24a, unique relationships for each site do not appear to exist. A general relationship does exist between grain yield and evapotranspiration for four of the sites, but the results from Khanasser do not fit this relationship.

It is not clear why such high grain yields were obtained at Khanasser in comparison to the low evapotranspiration recorded, but it may be due to the high mineral nitrogen levels in the soil profile (see Chapter 7). This observation, plus the increased water use efficiency at other sites due to nitrogen application, suggests that improved crop nutrition can increase water-use efficiency considerably. A study of evapotranspiration by barley at Brida showing enhanced growth associated with ants nests supports this conclusion. These ants are a harvesting species which collect surface organic matter into their nests. Soils tests, plant analyses, nutrient trials and nutrient pot trials all indicated greater soil nitrogen and phosphorus availability in the nests. The grain yield obtained from the study areas was 369 g/m^2, and the moisture use was 285 mm, giving a water use efficiency of 1.29 $g/m^2/mm$. This is very close to the values obtained at Khanasser, and considerably better than the value of 0.96 $g/m^2/mm$ obtained at Brida with 60 units of N and P_2O_5/ha.

3.4 Summary

(1) Nitrogen application gave a significant response in both total biological yield and grain yield of barley at four out of five sites. This response was reflected in all plant components. Increases in grain yield were associated with increases in grain number rather than grain size. Grain yields could be closely related to the thermal growth rate achieved by the plant during the phase of linear crop growth prior to anthesis.

(2) Nitrogen application on Barley plots increased water use but not in proportion to the increased total biological yield and grain yield. Therefore, water use efficiency (WUE) increased significantly with nitrogen application.

(3) Nitrogen application increased the "extractable" water availability for crop uptake. This was reflected by both an increase in the extractable water within a given discrete soil horizon, presumably due to greater root proliferation, and also an increase in maximum depth of moisture extraction.

(4) Relationships were established between total crop moisture use and total biological yield, but these appeared to be unique for each site. Soil chemical analyses suggest that the different soil fertility levels of each site (N and P) may be largely responsible for the lack of a general relationship for all sites. A more general relationship was found between total moisture use and grain yield at four of the sites. Data from the driest site Khanasser, where very high WUE's were obtained, did not fit this general relationship. Very high levels of mineral nitrogen were found at this site.

(5) In general, the results showed that improved crop nutrition gave rise to greatly improved crop performance and water use efficiency. These studies will be continued and expanded in the coming season.

Table 3.1. Moisture Budget under Fallow during Profile Recharge

(mm)

1979/1980

Site	Period	Rainfall in period	Moisture stored in 0-180 cm profile	Drainage below 180 cm (D)	Surface evapo-ration E	Accumul-ated E_o	E/E_o
Jindiress	27/11-17/4	359	181	14	164	312	0.53
Kafr Antoon	12/11-16/4	348	153	65	128	346	0.37
Tel Hadya	22/11- 9/4	279	122	17	140	286	0.49
Brida	10/11-10/4	226	48	0	178	322	0.55
Khanasser	14/11-13/4	200	44	0	156	284	0.55

Table 3.2. Moisture Budget under Fallow during Profile Discharge

(mm)

1979/1980

Site	Period	Rainfall in period	Total Moisture loss in period 0-180 cm	Surface evapo-ration E	Drainage below 180 cm (D)	Accumul-ated E_o	E/E_o
Jindiress	17/4- 7/5	16	27	33	10	110	0.30
Kafr Antoon	16/4-31/5	19	43	47	15	294	0.16
Tel Hadya	9/4-25/5	33	32	59	6	334	0.18
Brida	10/4-17/5	21	26	47	0	215	0.22
Khanasser	13/4-21/5	24	34	58	0	286	0.20

Table 3.3. Moisture Loss from Discrete Depth Intervals under Barley and Fallow at Jindiress during Profile Discharge Period 17/4-7/5/80 (cm)

Depth (cm)	Fallow	Barley 0 kg N/ha	Barley 60 kg N/ha	T - Test Value@		
				B_0.v.F.	B_{60}v.F.	B_{60}.v.B_0
15- 30	0.41	0.79	0.97	4.60***	7.63***	ns
30- 45	0.21	0.66	1.02	7.71***	7.76***	3.57**
45- 60	0.22	0.64	1.01	7.40***	8.77***	4.07**
60- 75	0.23	0.56	1.01	5.80***	9.36***	7.00**
75- 90	0.23	0.46	0.72	3.75**	8.23***	4.27**
90-105	0.21	0.42	0.36	3.71**	2.75*	ns
105-120	0.17	0.23	0.24	ns	ns	ns
120-135	0.11	0.18	0.17	ns	ns	ns
135-150	0.08	0.11	0.12	ns	ns	ns
150-165	0.04	0.07	0.07	ns	ns	ns
165-180	0.06	0	0.07	ns	ns	ns
TOTAL	1.97	4.12	5.76	6.91***	9.33***	3.89**

@ * P > 0.05 ** P > 0.01 ***P > 0.001

Table 3.4. Moisture Loss from Discrete Depth Intervals under Barley and Fallow at Kafr Antoon during Profile Discharge Period 16/4-20/5/80 (cm)

Depth (cm)	Fallow	Barley 0 kg N/ha	Barley 60 kg N/ha	T - Test Value@		
				B_0.v.F.	B_{60}.v.F.	B_{60}.v.B_0
15- 30	0.74	2.34	2.49	7.59***	12.57***	ns
30- 45	0.44	1.93	2.21	12.32***	18.58***	ns
45- 60	0.32	1.78	2.03	13.26***	16.36***	ns
60- 75	0.21	1.42	1.65	11.12***	10.59***	ns
75- 90	0.19	1.05	1.23	7.64***	13.53***	ns
90-105	0.22	0.73	0.79	5.61***	5.63***	ns
105-120	0.12	0.59	0.90	4.75**	4.88**	ns
120-135	0.09	0.34	0.53	2.39*	3.84**	ns
135-150	0.14	0.27	0.35	ns	5.73***	ns
150-165	0.17	0.25	0.21	ns	ns	ns
165-180	0.22	0.25	0.16	ns	ns	ns
TOTAL	2.86	10.95	12.55	16.65***	14.12***	2.37*

Table 3.5. Moisture Loss from Discrete Depth Intervals under Barley and Fallow at Tèl Hadya during Profile Discharge Period 9/4-13/5/80 (cm)

Depth (cm)	Fallow	Barley 0 kg N/ha	Barley 60 kg N/ha	T - Test Value@		
				B_0.v.F.	B_{60}.v.F.	B_{60}.v.B_0.
15- 30	0.64	2.09	2.42	9.84***	19.20***	2.41*
30- 45	0.44	1.42	1.87	10.11***	12.00***	ns
45- 60	0.33	1.27	1.53	5.19***	10.47***	ns
60- 75	0.15	1.10	1.22	6.26***	11.77***	ns
75- 90	0.15	0.89	0.96	4.91***	10.34***	ns
90-105	0.18	0.66	0.83	6.97***	11.66***	2.86*
105-120	0.13	0.39	0.78	2.38*	11.19***	3.73**
120-135	0.13	0.24	0.60	ns	8.77***	4.72**
135-150	0.12	0.11	0.35	ns	5.09***	ns
150-165	0.10	0.10	0.12	ns	ns	ns
165-180	0.09	0.00	0.07	ns	ns	ns
TOTAL	2.46	8.27	10.75	11.33***	15.96***	3.05**

Table 3.6. Moisture Loss from Discrete Depth Intervals under Barley and Fallow at Brida during Profile Discharge Period 10/4-17/5/80 (cm)

Depth (cm)	Fallow	Barley 0 kg N/ha	Barley 60 kg N/ha	T - Test Value@		
				B_0.v.F.	B_{60}.v.F.	B_{60}.v.B_0.
15- 30	0.72	1.19	1.27	4.65***	5.93***	ns
30- 45	0.82	1.34	1.41	5.44***	7.53***	4.06**
45- 60	0.62	1.29	1.36	7.68***	9.81***	ns
60- 75	0.41	0.61	0.62	3.01*	2.94*	ns
75- 90	0.10	0.10	0.20	ns	ns	ns
90-105	- 0.16	- 0.03	0.03	ns	ns	ns
105-120	- 0.08	0.00	0.00	ns	ns	ns
120-135	0.00	0.01	0.00	ns	ns	ns
135-150	0.00	0.00	0.00	ns	ns	ns
TOTAL	2.43	4.51	4.89	5.87***	5.93***	ns

@ * P>0.05 ** P>0.01 *** P>0.001

Table 3.7. Moisture Loss from Discrete Depth Intervals under Barley and Fallow at Khanasser during Profile Discharge Period 13/4 - 21/5/80(cm)

Depth (cm)	Fallow	Barley 0 kg N/ha	Barley 60 kg N/ha	T - Test Value[d]		
				B_0.v.F.	B_{60}.v.F.	B_{60}.v.B_0.
15- 30	0.77	1.09	1.16	5.54***	5.16**	ns
30- 45	0.57	1.00	0.92	6.34***	5.55***	ns
45- 60	0.48	0.65	0.78	ns	3.35**	ns
60- 75	0.31	0.36	0.55	ns	3.16**	ns
75- 90	0.18	0.05	0.26	ns	ns	ns
90-105	0.03	0.00	0.07	ns	ns	ns
105-120	- 0.11	- 0.03	0.03	ns	ns	ns
120-135	- 0.06	- 0.01	0.00	ns	ns	ns
135-150	0.00	- 0.03	0.00	ns	ns	ns
150-165	0.00	0.00	0.00	ns	ns	ns
165-180	0.00	0.00	0.00	ns	ns	ns
TOTAL	2.16	3.08	3.74	ns	ns	3.75*

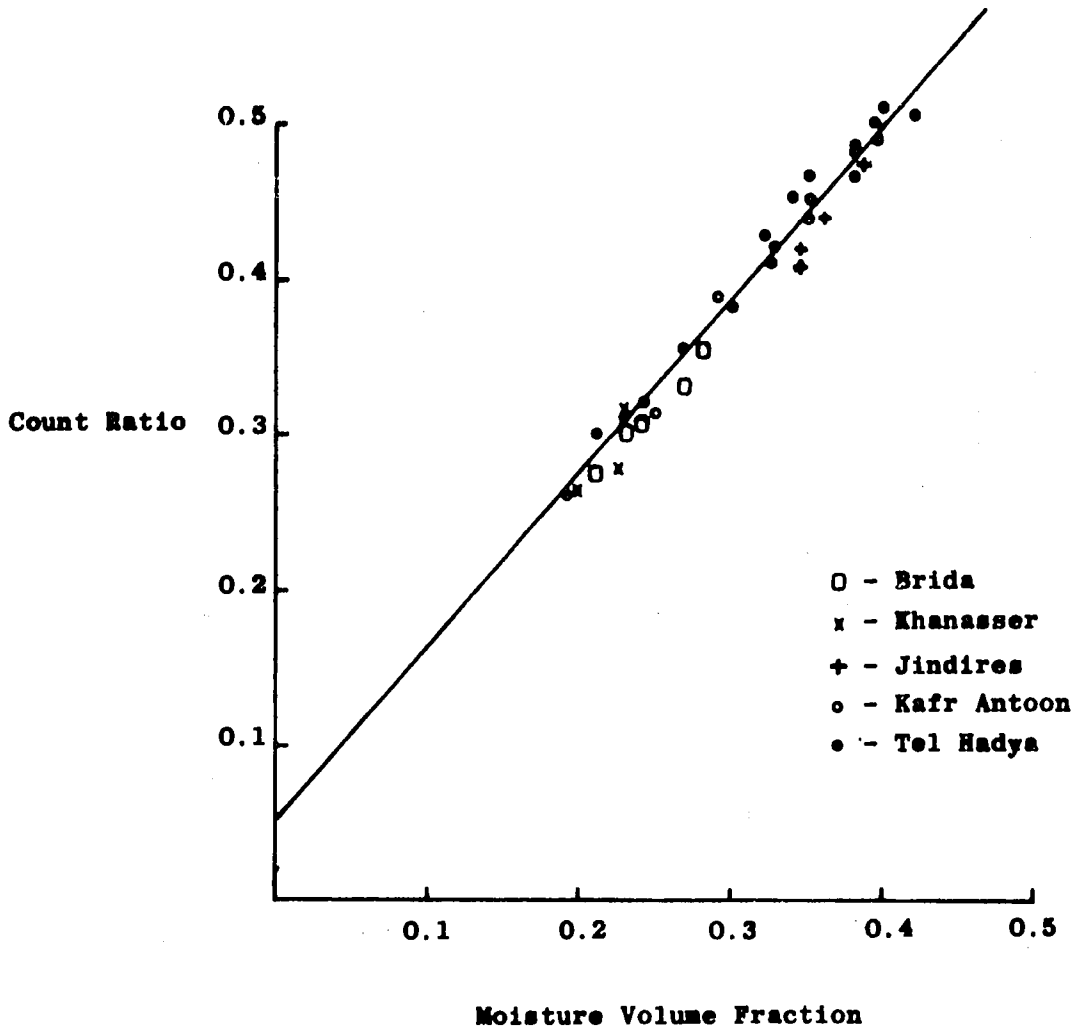
Table 3.8. The Effect of Nitrogen Application on Maximum Extraction Depth as Determined by Three Stage Analyses

Maximum depth of water extraction estimated in 3 stages (cm)

Site	Stage 1		Stage 2		Stage 3	
	B_0	B_{60}	B_0	B_{60}	B_0	B_{60}
Jindiress*	165	150	105	105	105	105
Kafr Antoon	180	180	120	150	135	150
Tel Hadya	135	180	135	150	120	150
Brida	105	90	75	75	75	75
Khanasser	90	105	60	75	45	75

* Due to rapid moisture loss from fallow resulting from deep cracking, the analysis in Stage 3 covers the period 17/4 - 7/5/80 only.

Fig. 3.1 **Field Calibration Curve for 5 Sites 1979/80**



$$MVF = 0.88\ CR - 0.04 \quad (r = 0.987)$$

$$(R^2 = 0.97)$$

Fig. 3.2a **Recharge/Discharge Pattern at JINDIRESS**

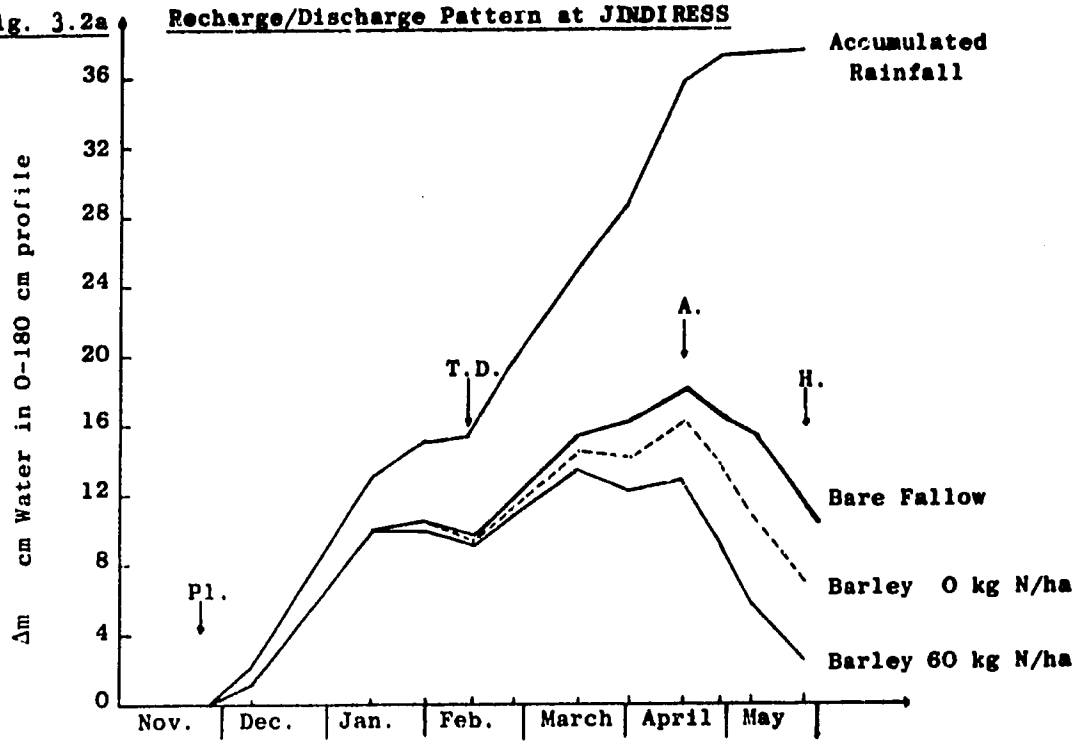


Fig. 3.2b **Soil Profile Recharge (cm Water/Interval)**

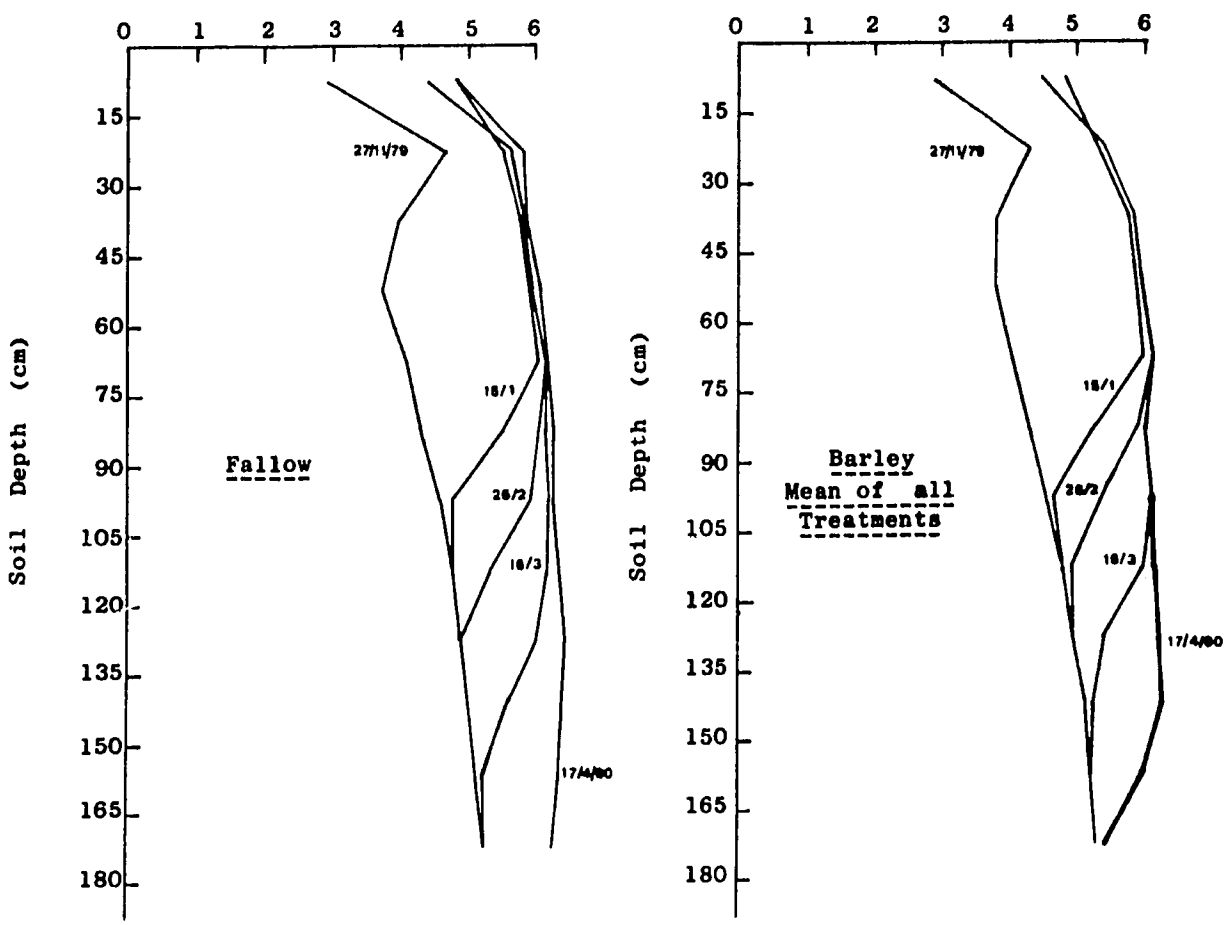


Fig. 3.3a

Recharge/Discharge Pattern at KAFR ANTOON

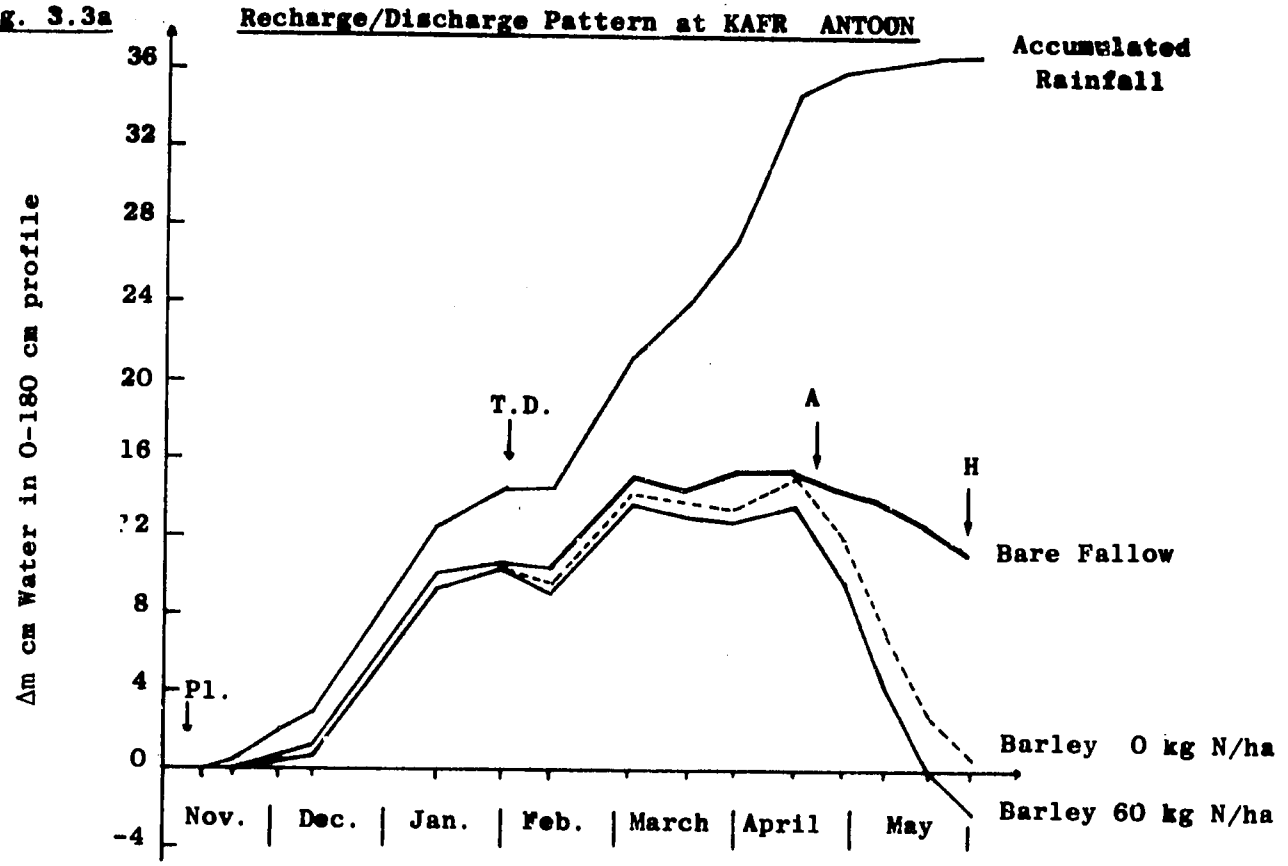


Fig. 3.3b

Soil Profile Recharge (cm Water/Interval)

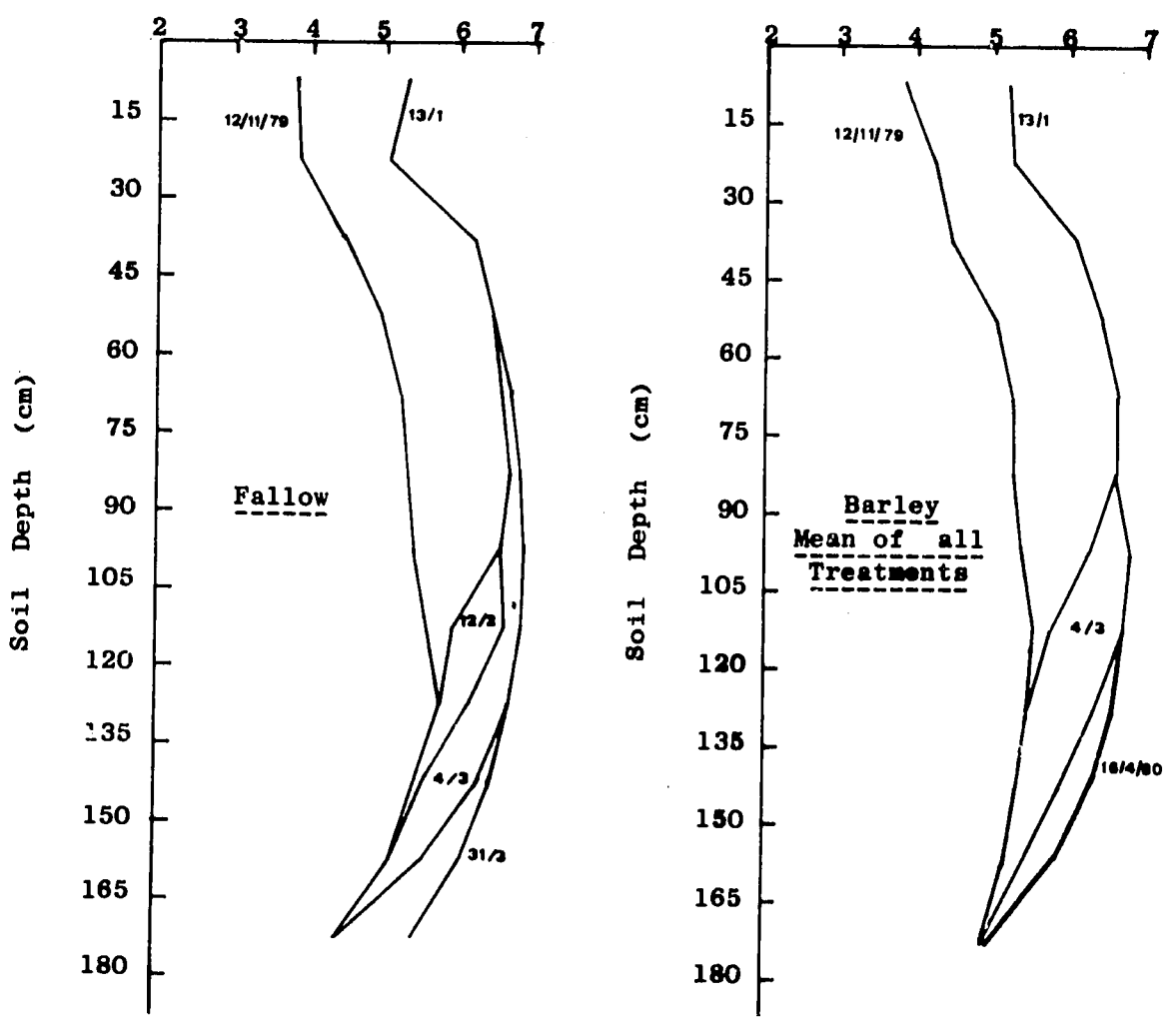


Fig. 3.4a

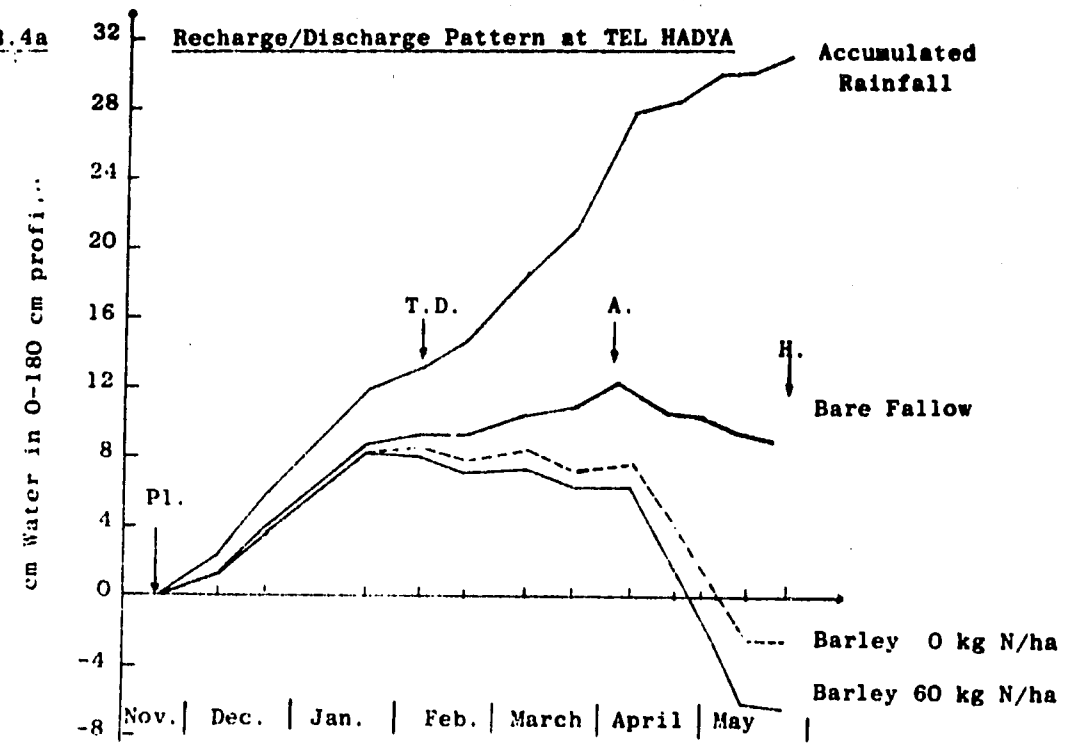


Fig. 3.4b

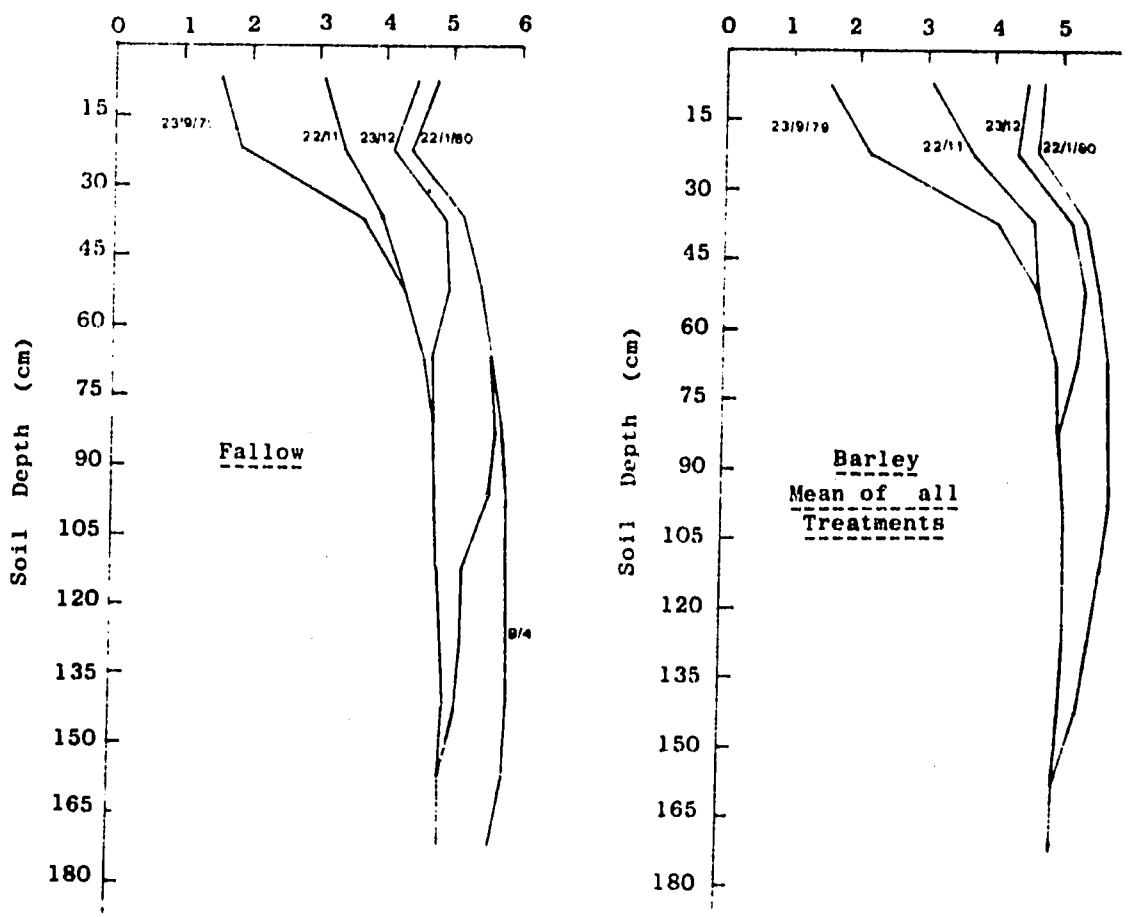


Fig. 3.5a

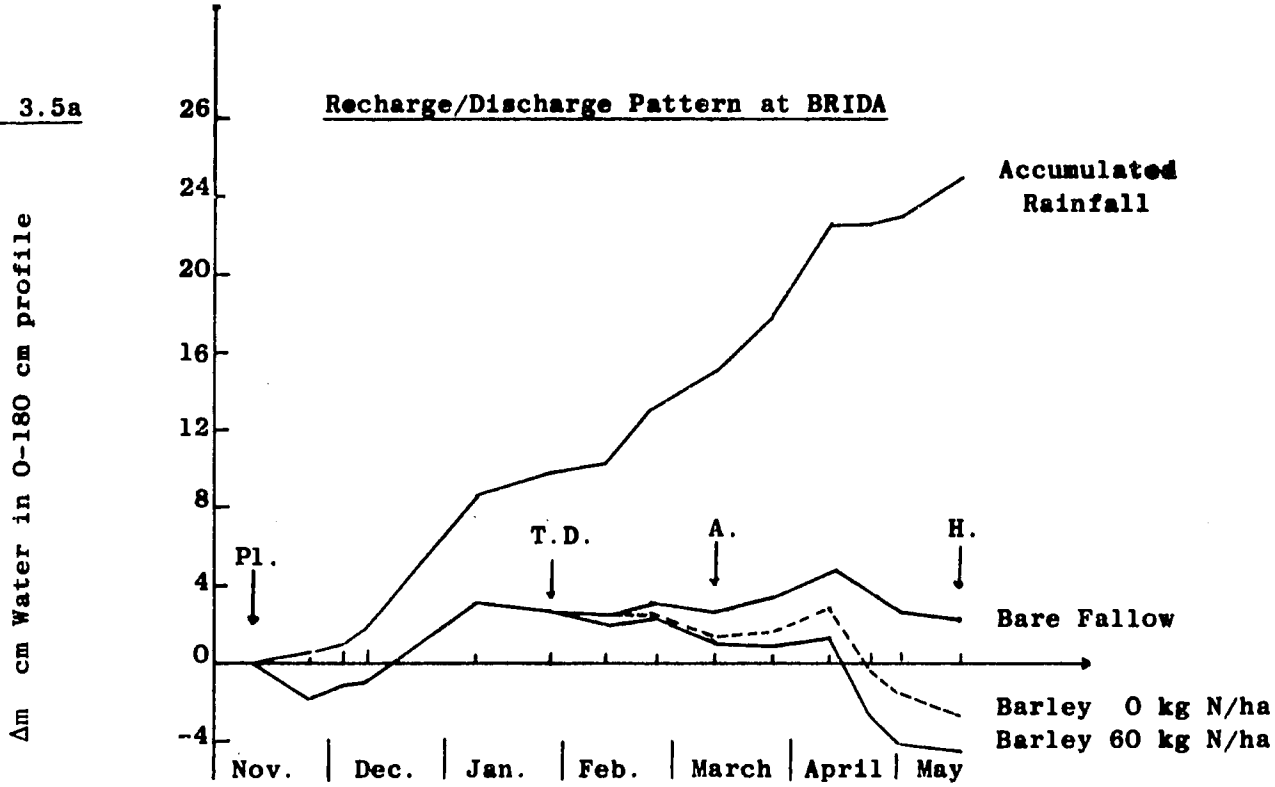


Fig. 3.5b

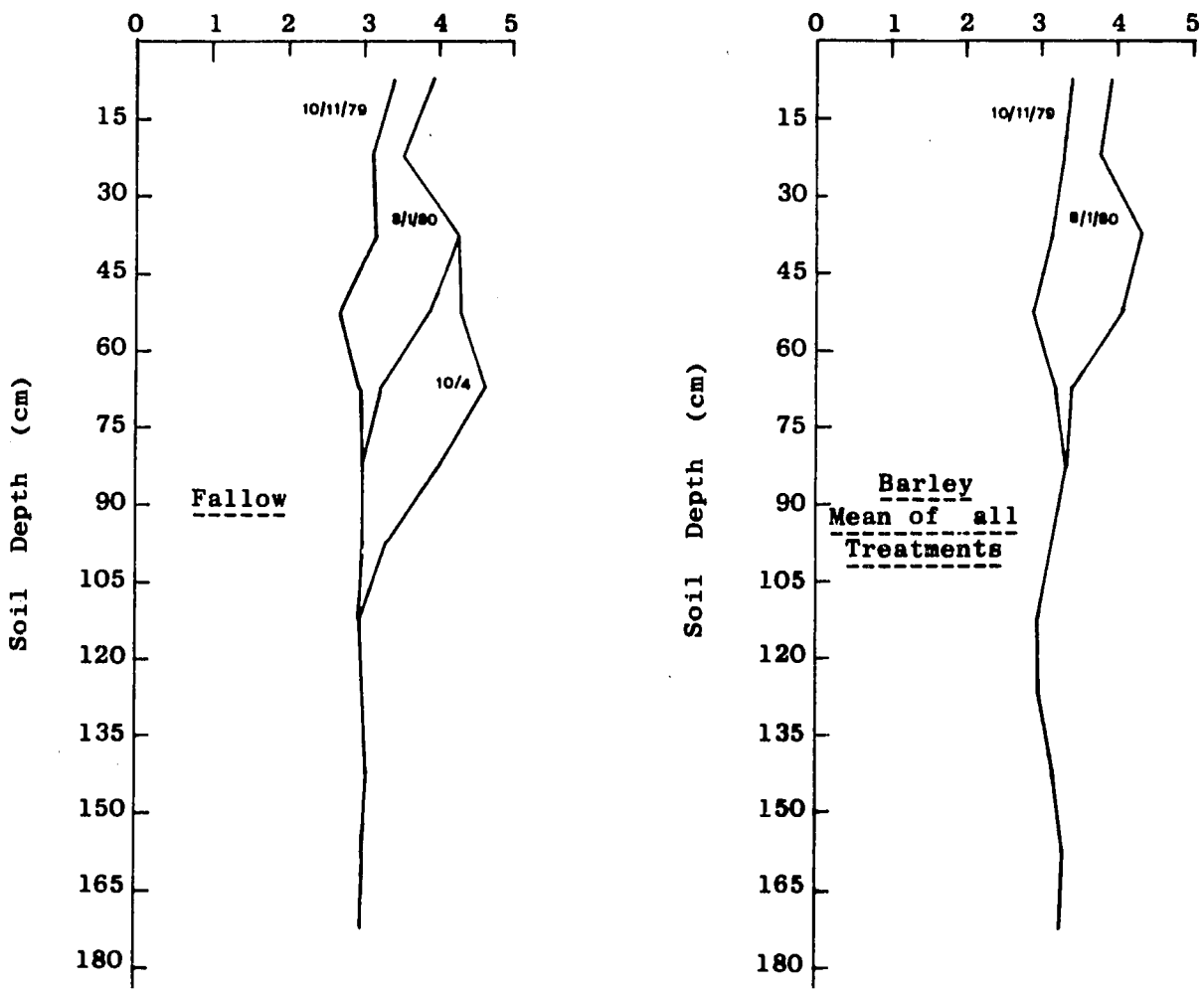


Fig. 3.6a

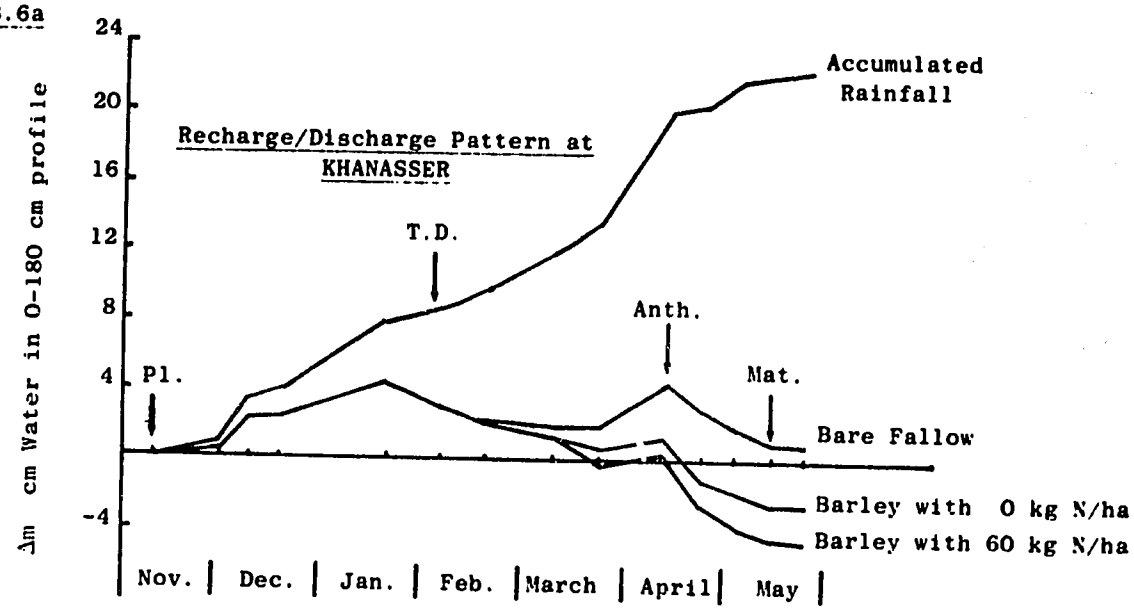


Fig. 3.6b

Soil Profile Recharge (cm Water/Interval)

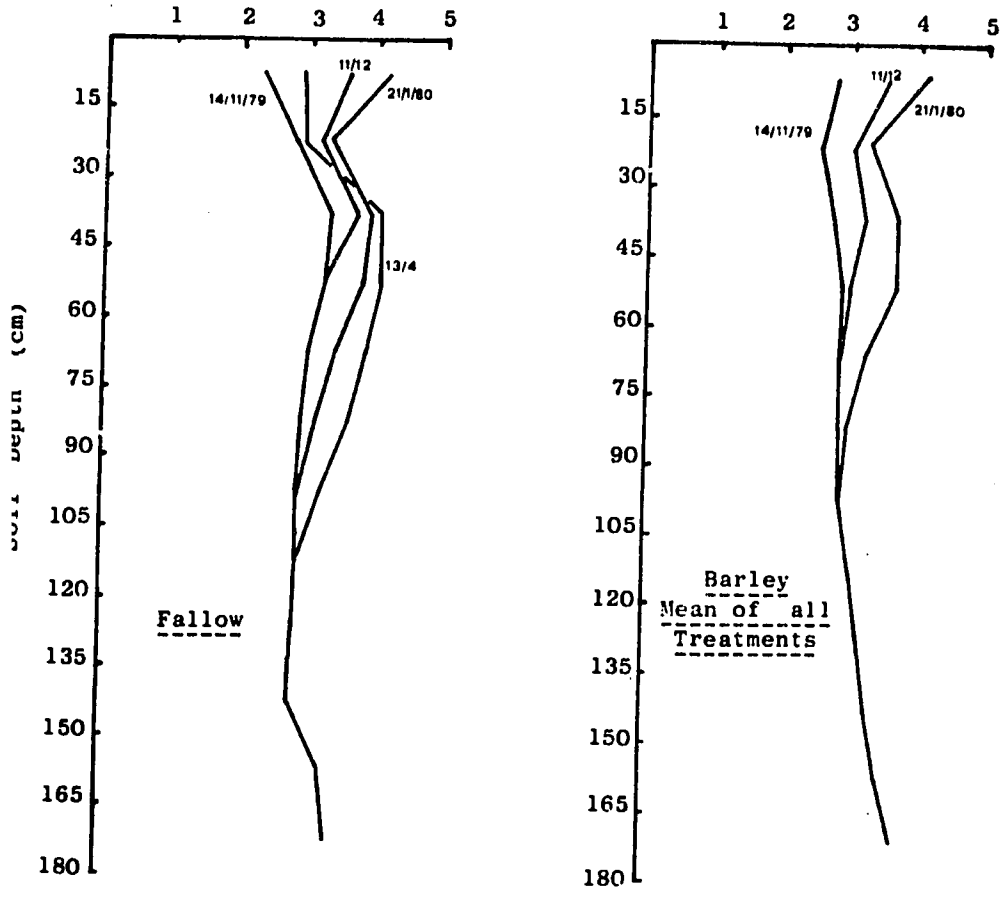


Fig. 3.7a **Pattern of Profile Discharge at JINDIRESS under Fallow and Barley 1979/80**

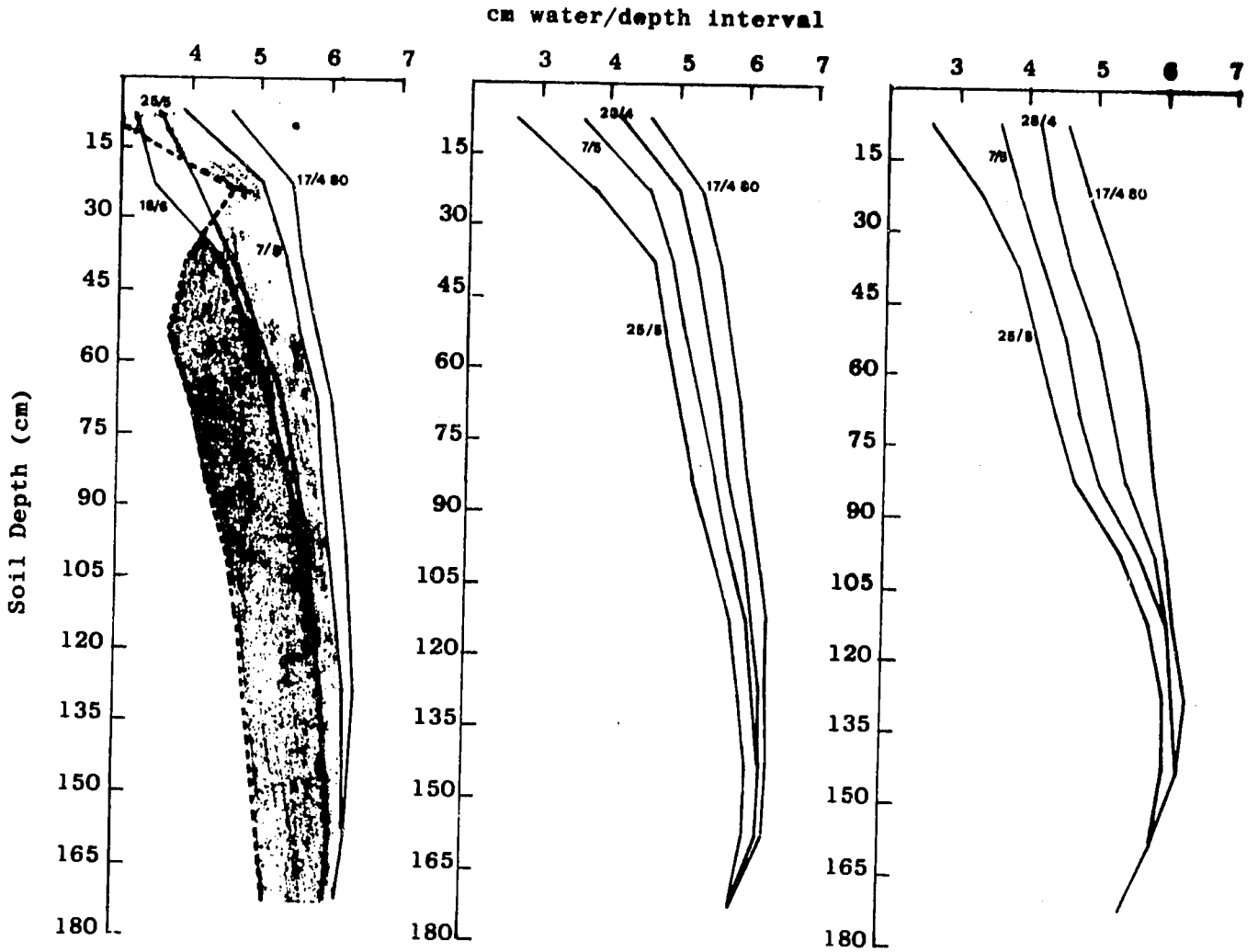


Fig. 3.7b Change in Moisture in Discrete Depth Intervals with Time

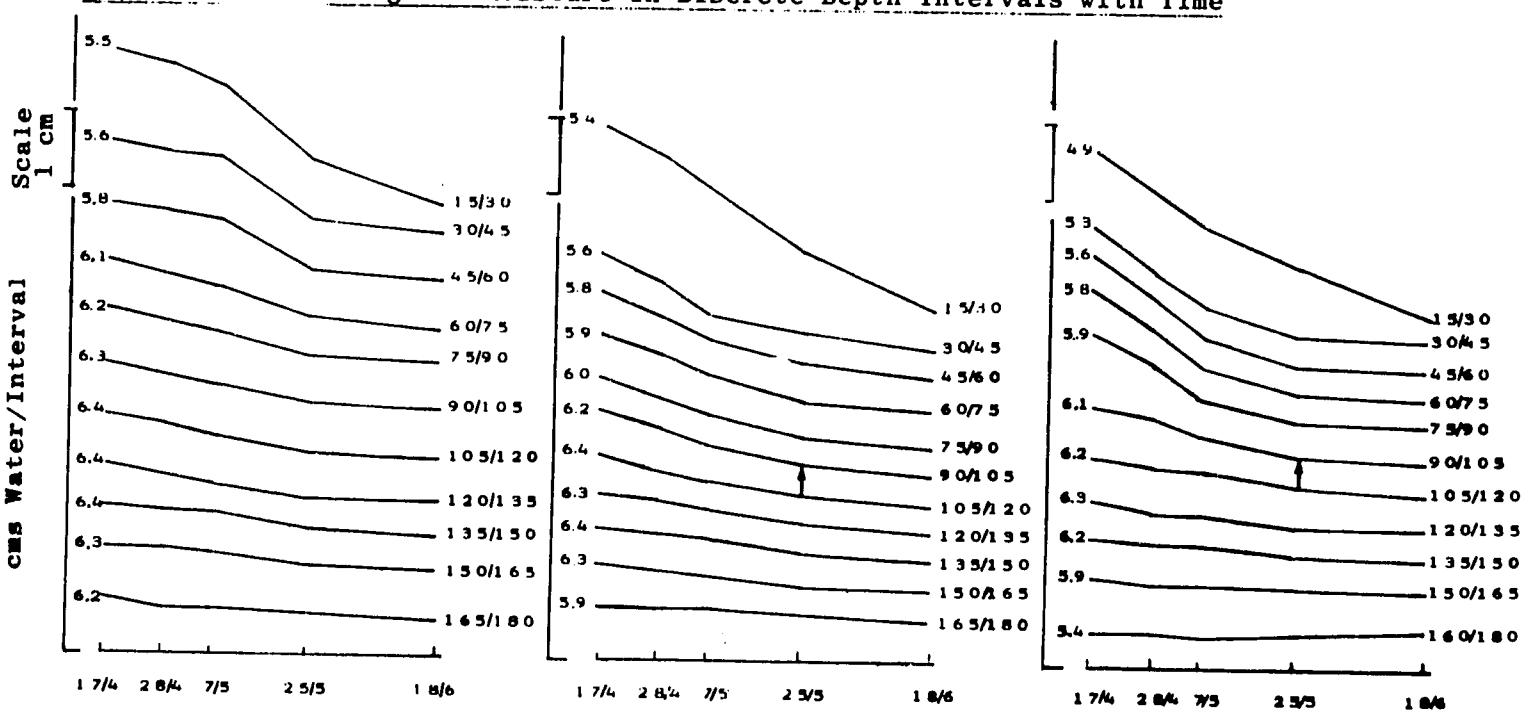


Fig. 3.8a **Pattern of Profile Discharge at KAFR ANTOON under Fallow and Barley 1979/80**

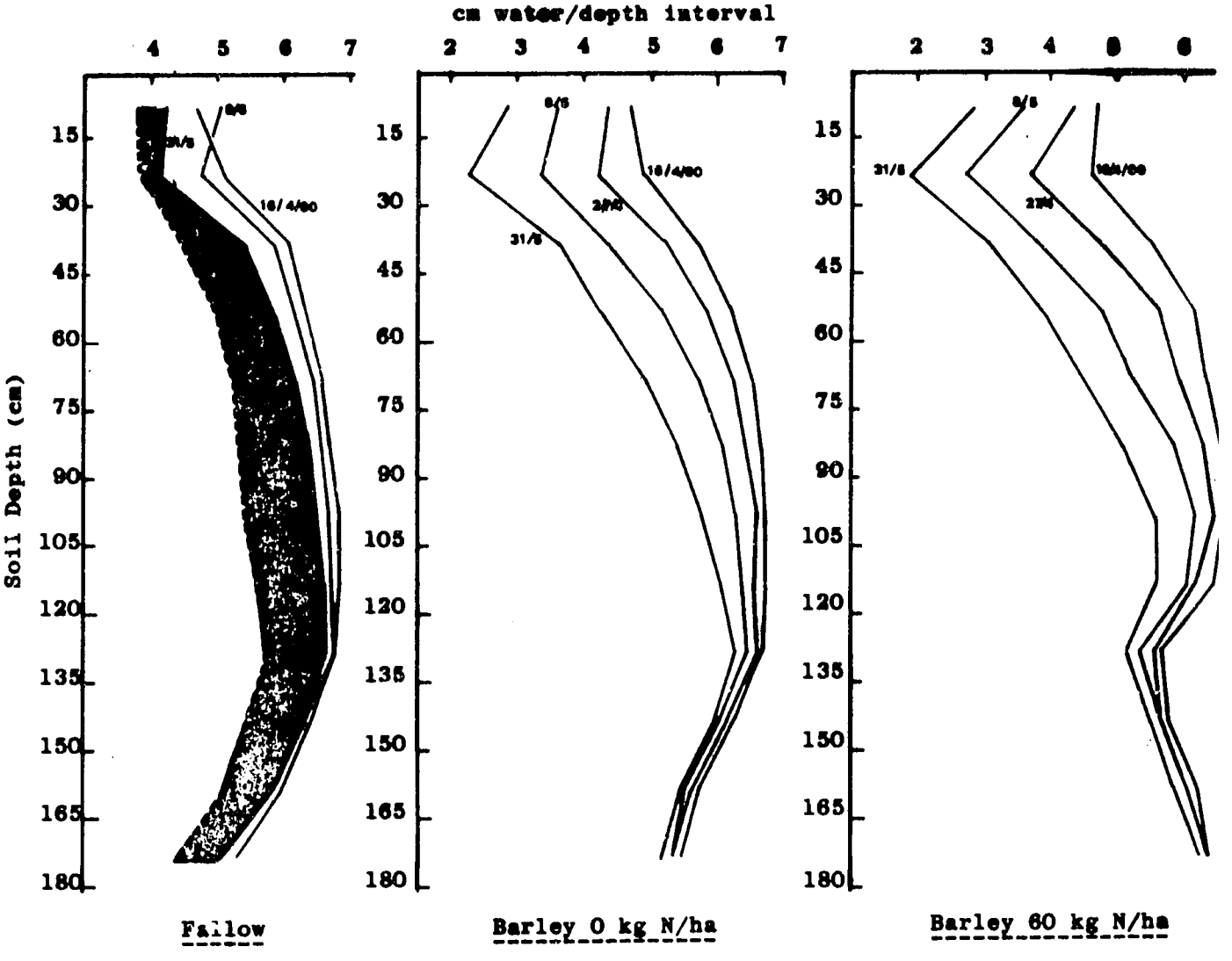


Fig. 3.8b **Change in Moisture in Discrete Depth Intervals with Time**

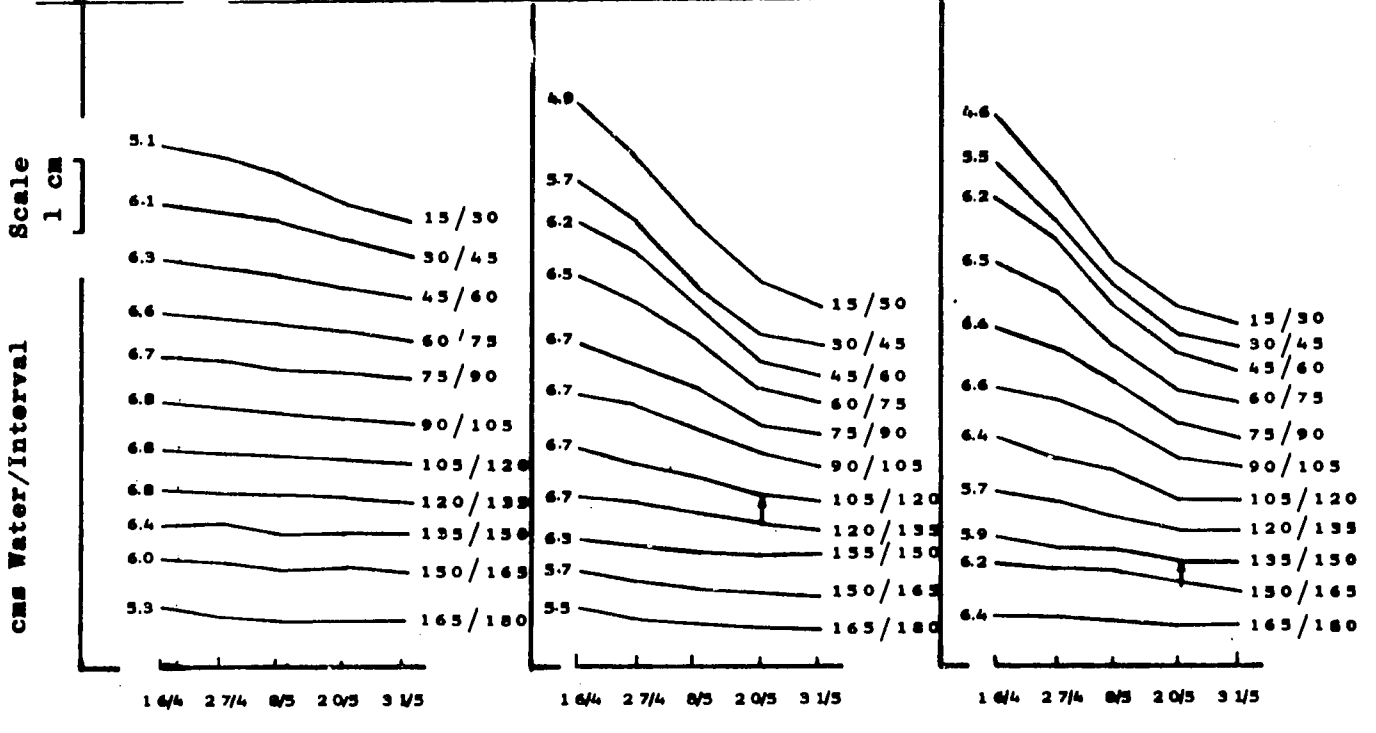


Fig. 3.9a **Pattern of Profile Discharge at TEL HADYA under Fallow and Barley 1979/80**

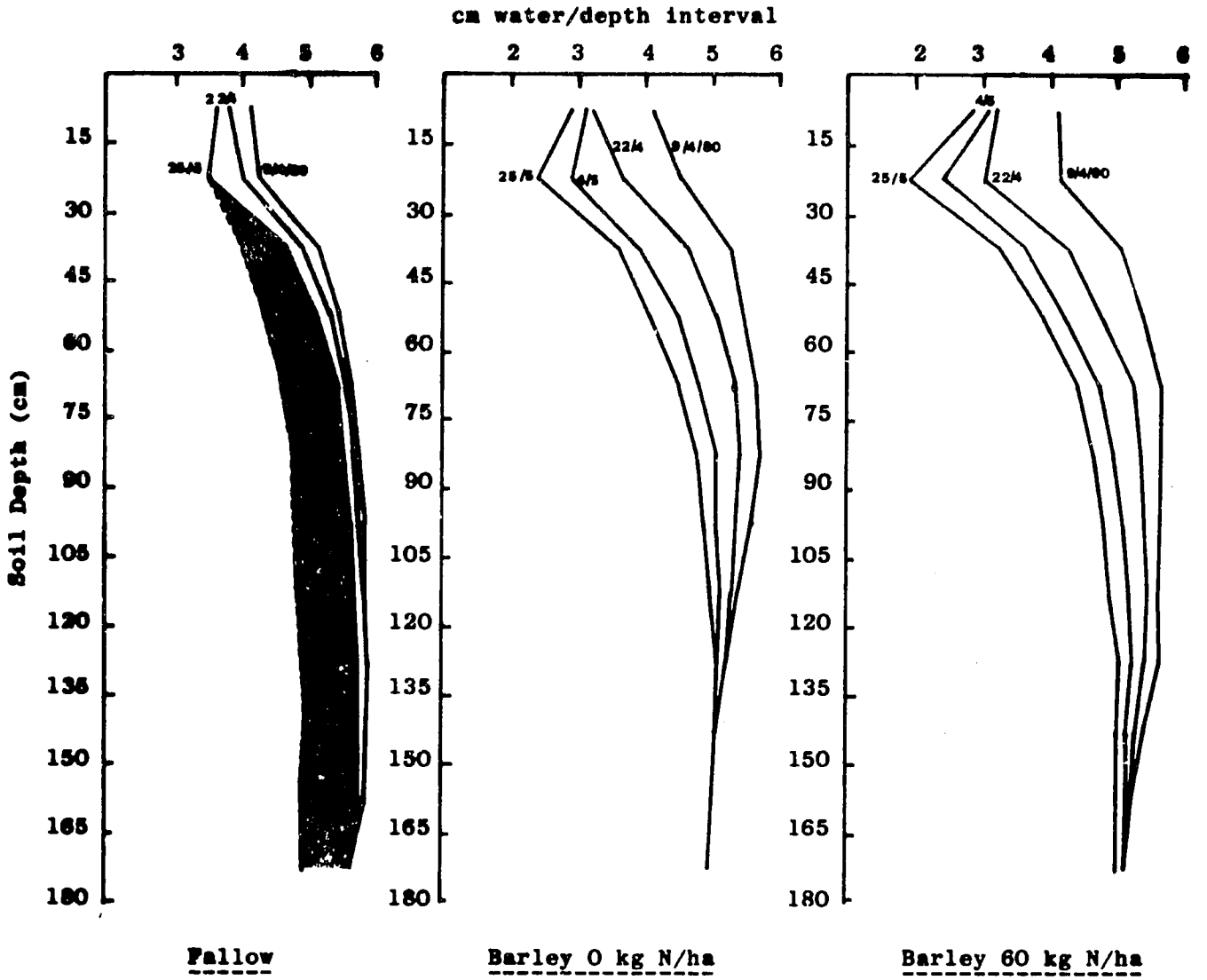


Fig. 3.9b **Change in Moisture in Discrete Depth Intervals with Time**

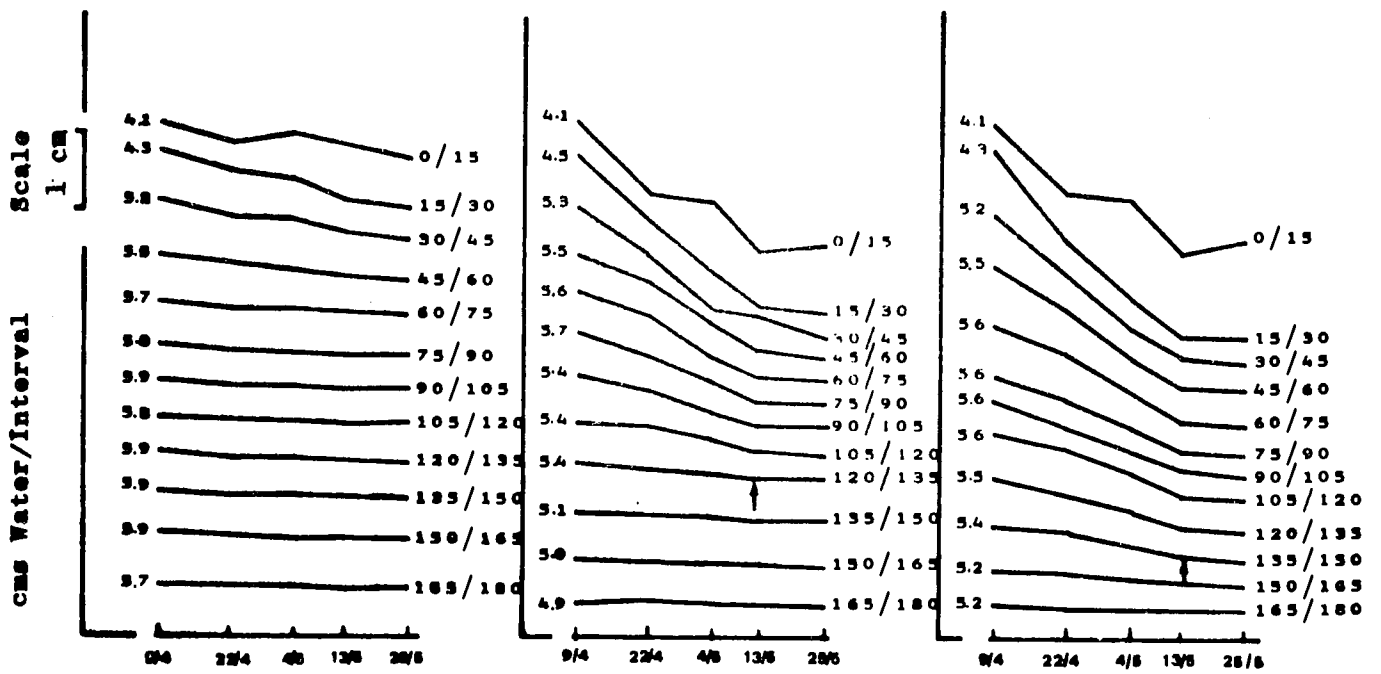


Fig. 3.10a **Pattern of Profile Discharge at BRIDA under Fallow and Barley 1979/80**

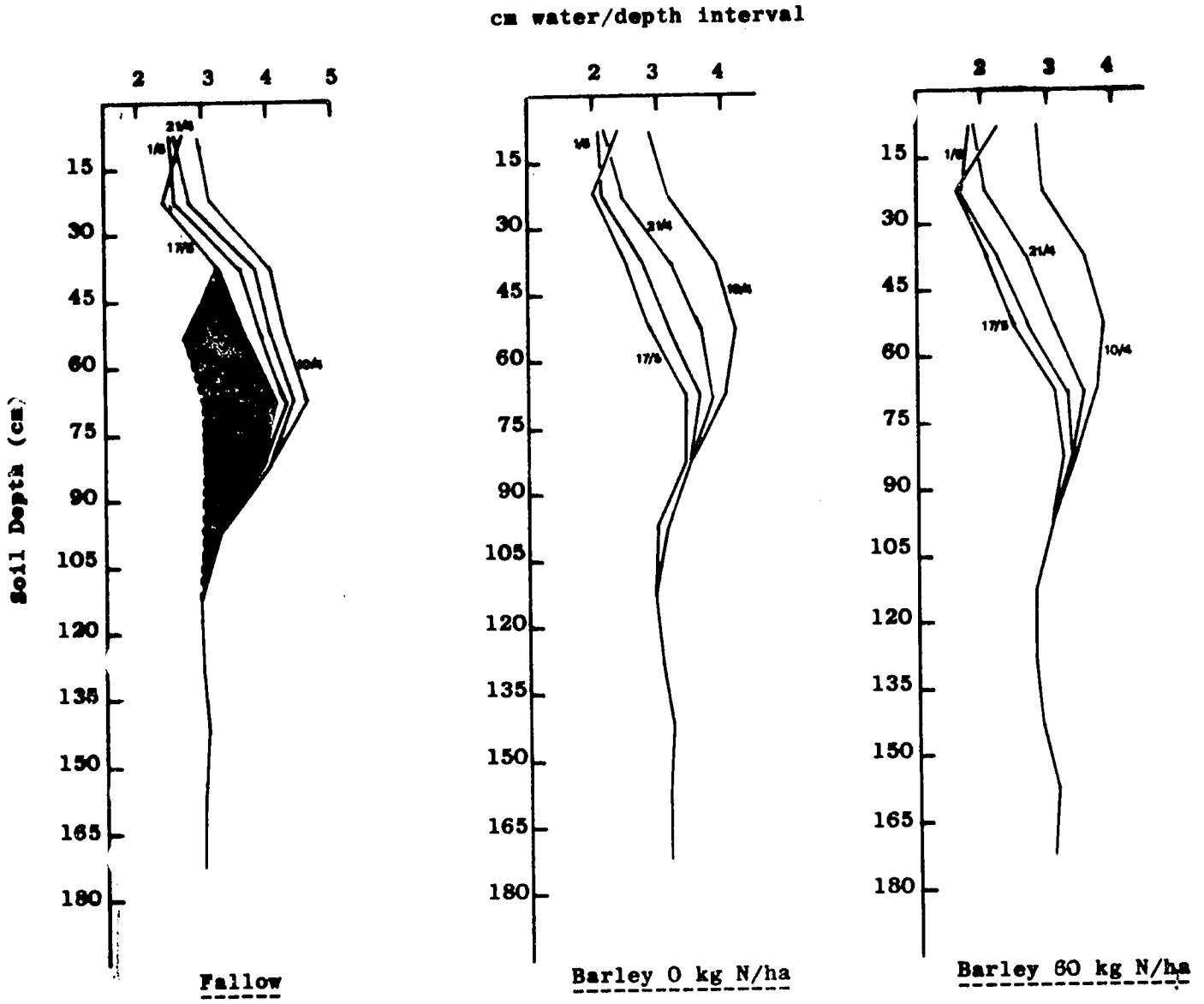


Fig. 3.10b **Change in Moisture in Discrete Depth Intervals with Time**

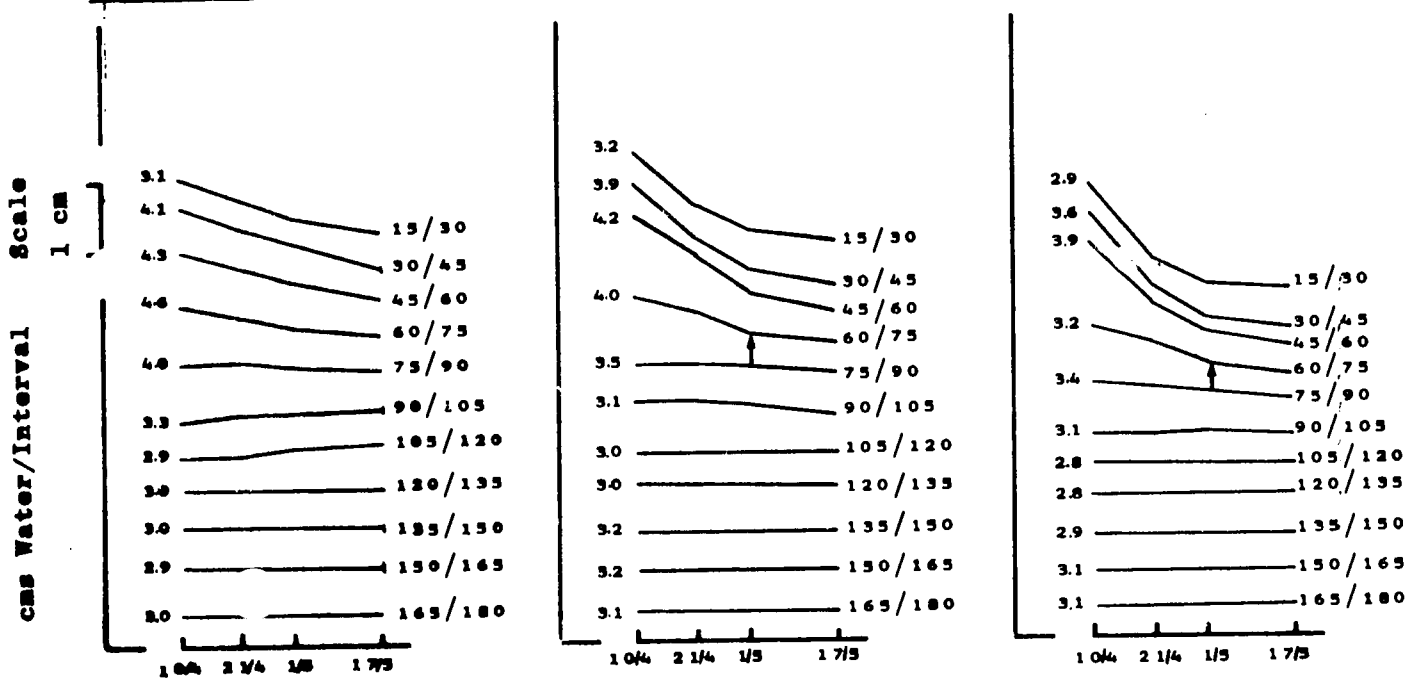


Fig. 3.11a Pattern of Profile Discharge at KHANASSER under Fallow and Barley 1979/80

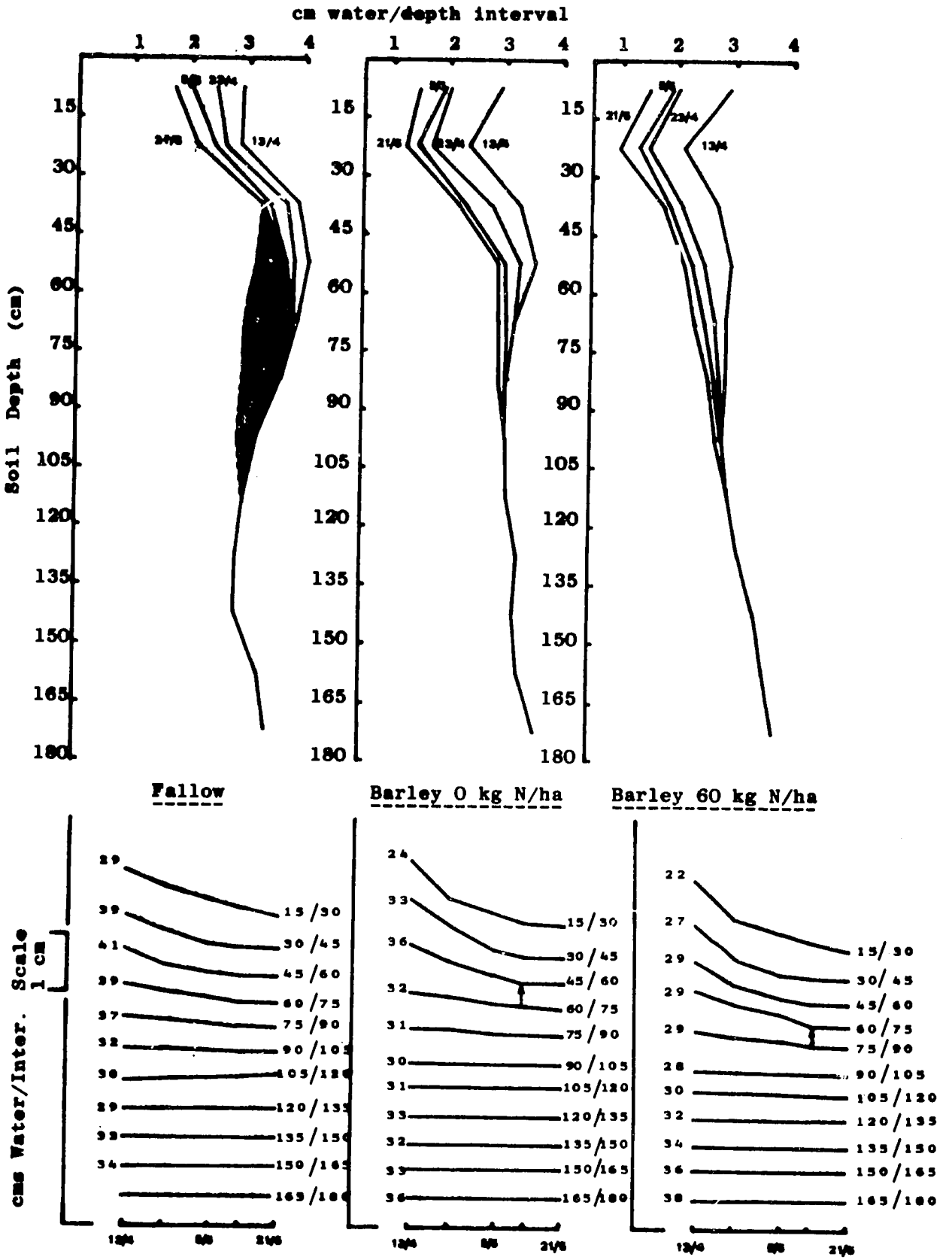
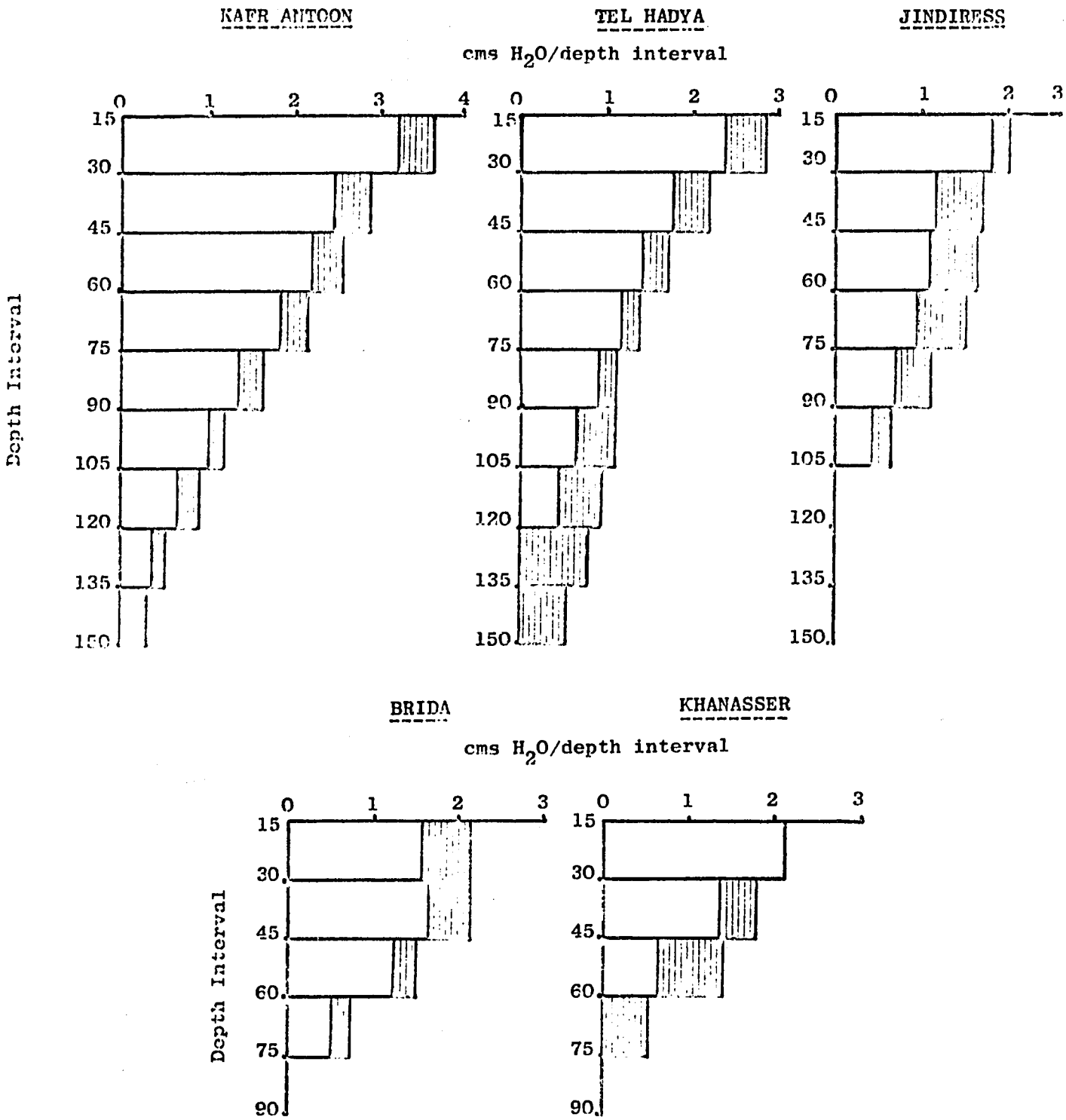


Fig. 3.11b Change in Moisture in Discrete Depth Intervals with Time

Fig. 3.12 The Effect of 60 kg N/ha on Extractable Moisture by Barley Within Discrete Depth Intervals at 5 Locations



Stippled blocks represent the increase in extractable moisture due to nitrogen application.

Table 3.9 Accumulated Water Use by Barley & Fallow
JINDIRESS 1979/80 (mm)

	9/12	15/1	31/1	26/2	16/3	1/4	17/4	28/4	7/5	25/5
F	10	31	46	77	96	124	164	198	197	-
B_o	9	28	44	81	105	144	198	234	259	292
B_{20}	10	31	49	91	121	162	221	261	290	324
B_{40}	10	31	49	91	120	163	223	265	298	332
B_{60}	10	31	49	88	118	164	232	277	309	342
E_o	18	63	88	151	190	240	312	367	422	536

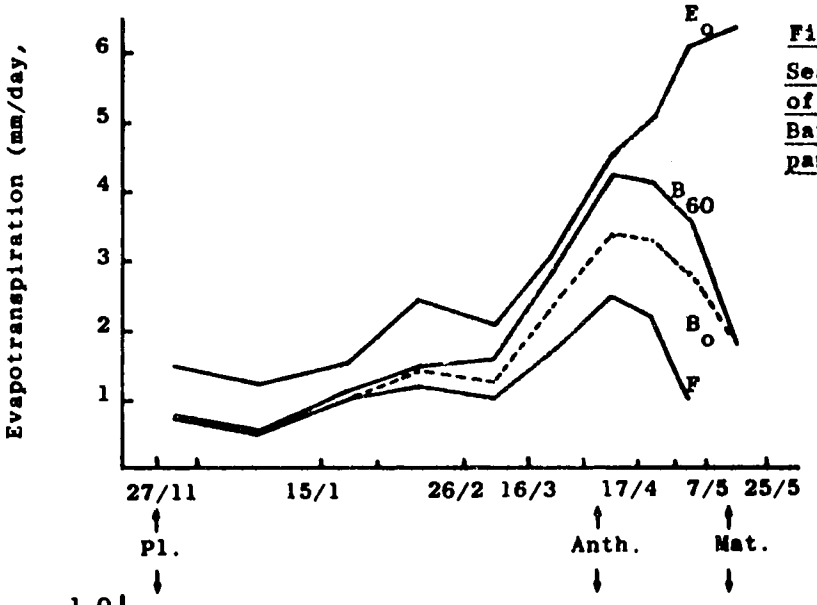


Fig. 3.13a
Seasonal Variation in Rate of Evapotranspiration by Barley, Fallow and Class A pan E_o (mm/day).

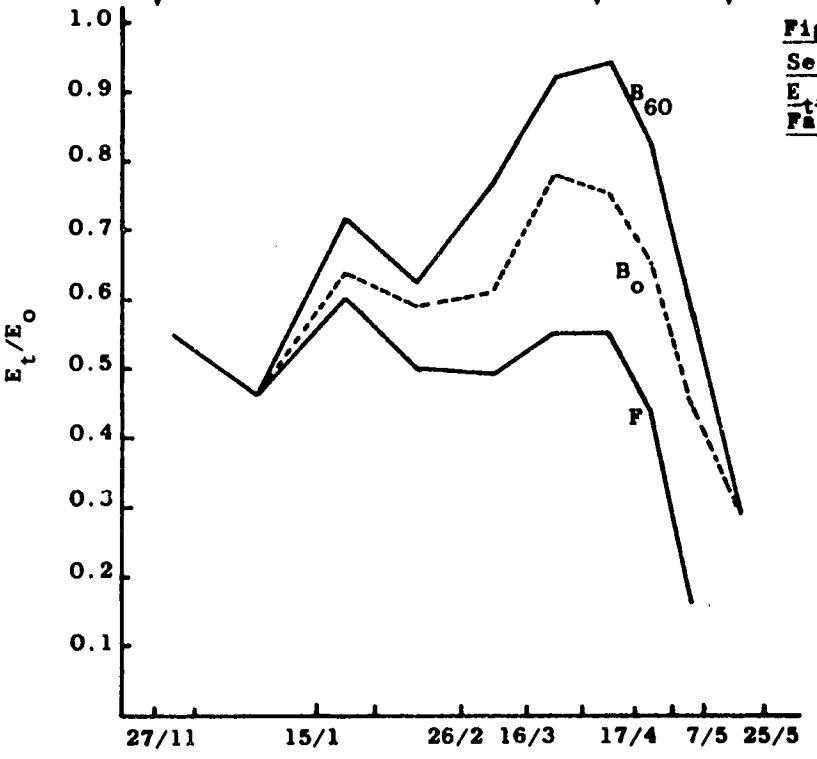


Fig. 3.13b
Seasonal Variation in E_t/E_o ratio of Barley-Fallow.

Table 3.10 Accumulated Water Use by Barley & Fallow
KAFR ANTOON 1979/80 (mm)

	20/11	2/12	11/12	13/1	30/1	12/2	4/3	19/3	31/3	16/4	27/4	8/5	20/5	31/5
F	6	12	15	23	30	39	58	80	97	128	142	148	163	175
B_o	7	16	21	31	39	49	72	104	136	198	243	288	333	352
B_{20}	7	15	20	32	42	52	75	110	141	203	247	301	345	335
B_{40}	7	15	20	32	42	52	77	110	142	208	255	310	350	370
B_{60}	7	15	20	32	42	53	76	112	143	211	262	318	365	383
E_o	27	56	70	108	127	152	189	232	269	346	403	467	547	640

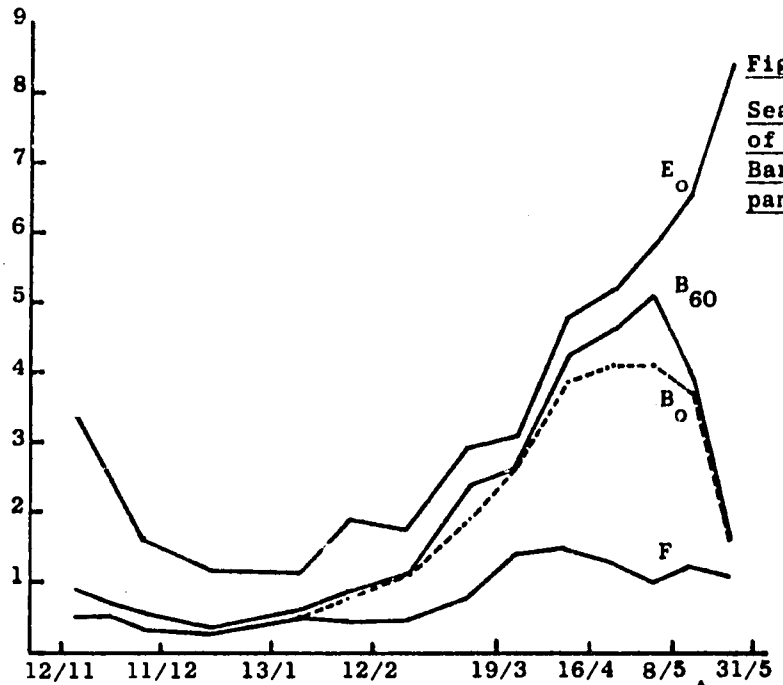


Fig. 3.14a

Seasonal Variation in Rate of Evapotranspiration by Barley, Fallow and Class A pan E_o (mm/day).

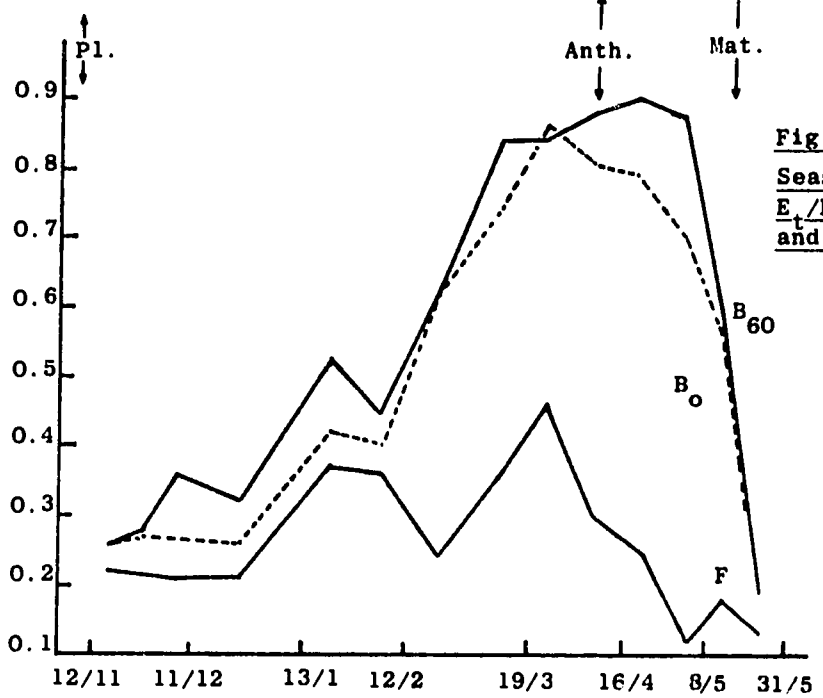


Fig. 3.14b

Seasonal Variation in E_t/E_o ratio of Barley and Fallow.

Table 3.11 Accumulated Water Use by Barley & Fallow
TEL HADYA 1979/80 (mm)

	9/12	23/12	22/1	7/2	20/2	9/3	23/3	9/4	22/4	4/5	13/5	25/5
F	11	17	28	36	53	79	103	140	156	175	185	199
B_o	11	17	28	39	62	95	132	196	239	293	320	331
B_{20}	10	16	28	41	67	100	140	206	262	318	347	360
B_{40}	11	19	31	44	70	106	147	214	266	324	360	370
B_{60}	11	19	32	44	69	104	144	210	264	322	358	368
E_o	32	49	81	105	125	176	217	286	357	441	511	620

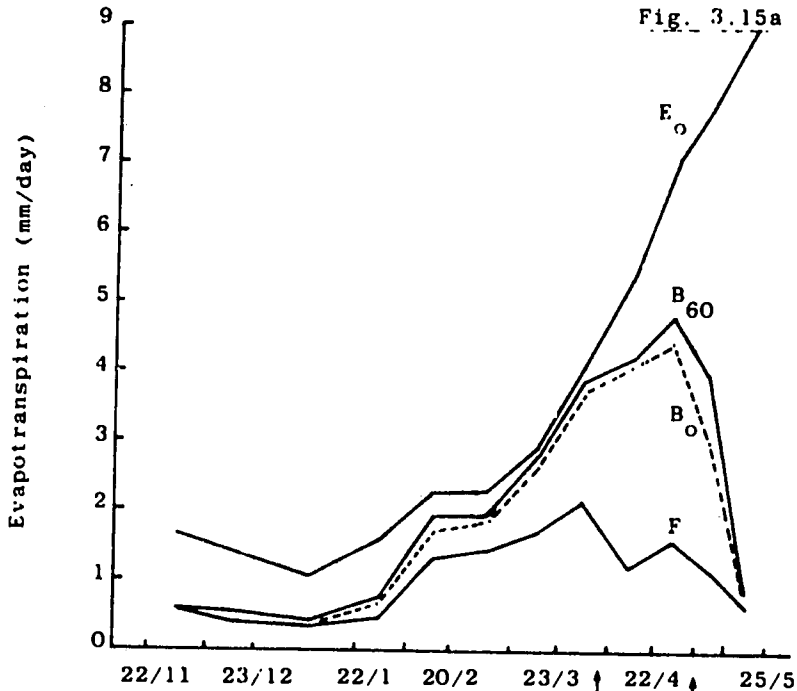


Fig. 3.15a Seasonal Variation in Rate of Evapotranspiration by Barley, Fallow and Class A pan E_o (mm/day).

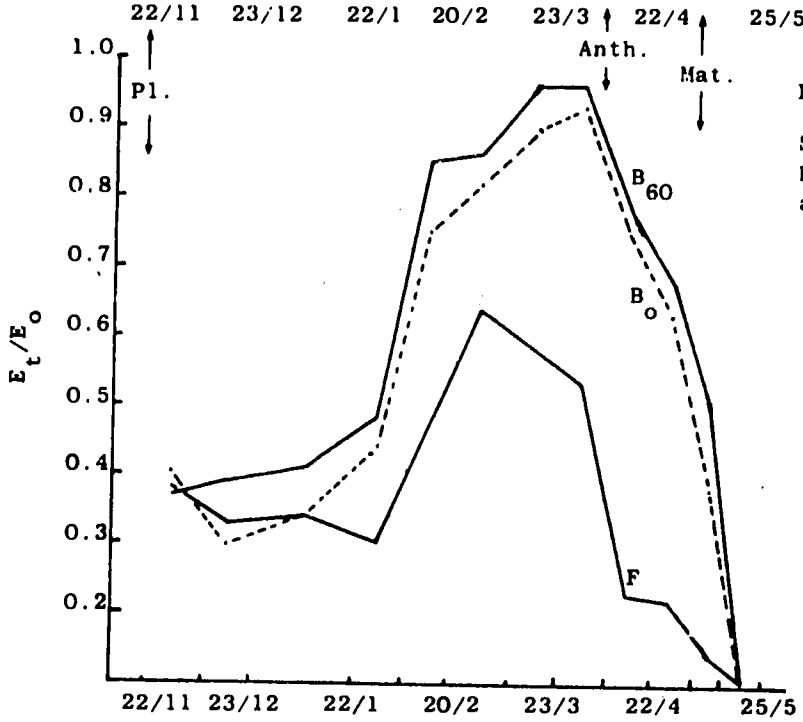


Fig. 3.15b

Seasonal Variation in E_t/E_o ratio of Barley and Fallow.

Table 3.12 Accumulated Moisture Use by Barley & Fallow, BRIDA, 1979/80 (mm)

	25/11	10/12	8/1	11/2	25/2	11/3	26/3	10/4	21/4	1/5	17/5
F	21	29	49	80	100	120	146	178	192	207	225
B_o	20	27	47	84	104	128	159	197	227	251	269
B_{20}	21	30	50	84	105	133	168	204	236	260	278
B_{40}	21	30	50	84	107	136	171	209	247	270	289
B_{60}	21	30	50	84	107	135	173	215	254	279	292
E_o	46	71	102	149	182	217	266	322	376	434	537

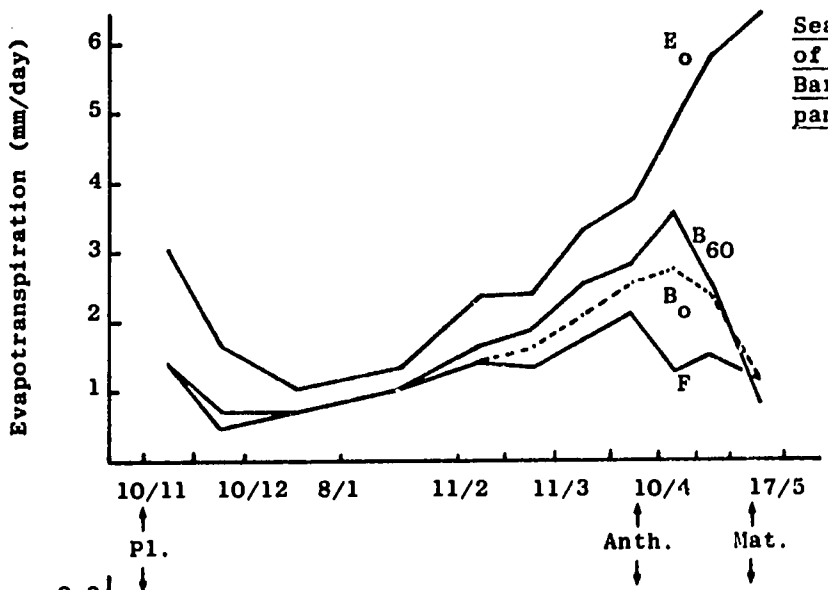


Fig. 3.16a

Seasonal Variation in Rate of Evapotranspiration of Barley, Fallow and Class A pan E_o (mm/day).

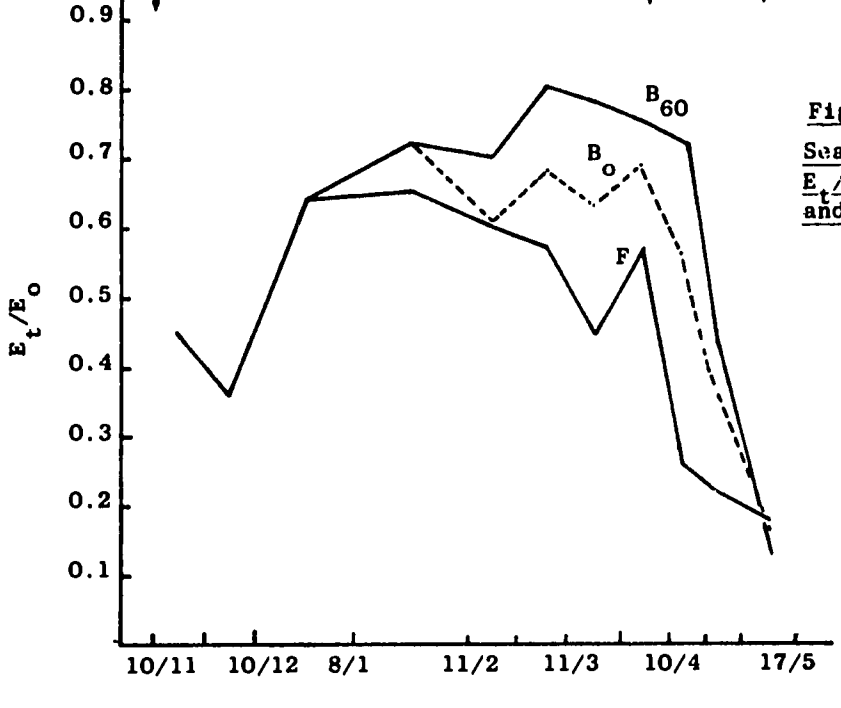


Fig. 3.16b

Seasonal Variation in E_t/E_o ratio of Barley and Fallow.

Table 3.13 Accumulated Water Use by Barley & Fallow KHANASSER 1979/80 (mm)

	3/12	19/12	21/1	5/2	19/2	10/3	24/3	13/4	23/4	5/5	12/5	21/5
F	12	22	35	51	66	94	119	156	177	203	213	216
B_o	10	21	35	51	68	101	129	185	218	240	250	254
B_{20}	10	21	34	52	67	102	130	185	218	243	253	259
B_{40}	10	21	34	52	69	102	134	196	230	252	265	272
B_{60}	10	21	34	52	71	102	136	197	231	256	265	272
E_o	52	75	102	132	166	211	265	357	417	494	551	643

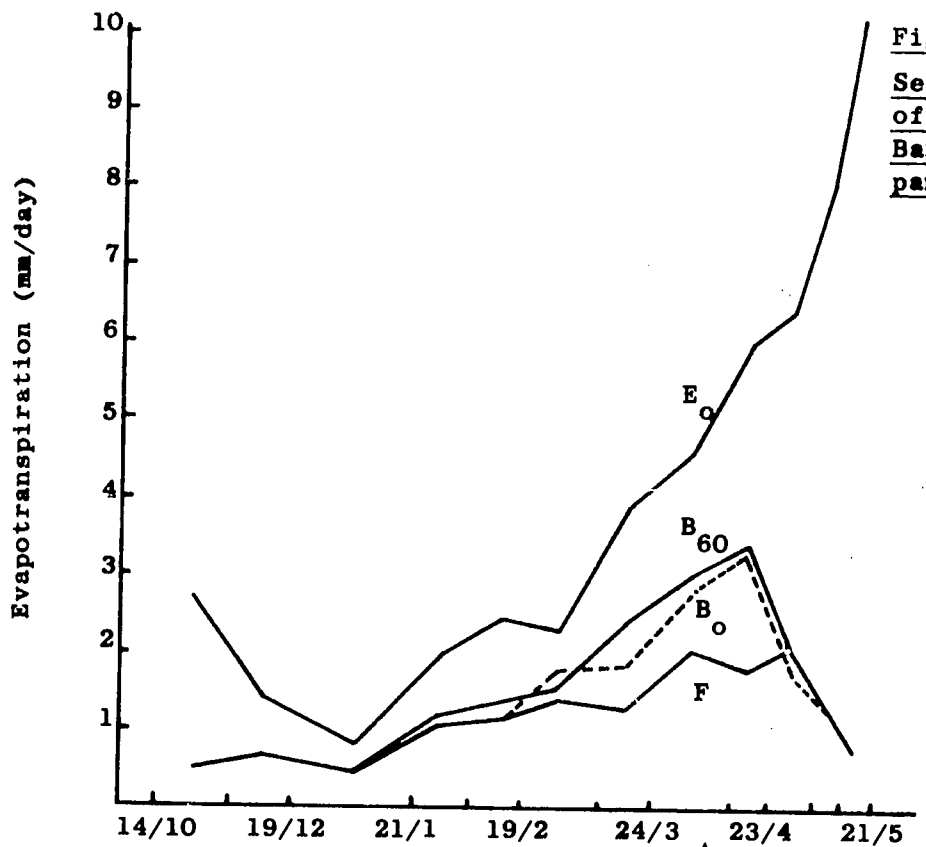


Fig. 3.17a

Seasonal Variation in Rate of Evapotranspiration by Barley, Fallow and Class A pan E_o (mm/day).

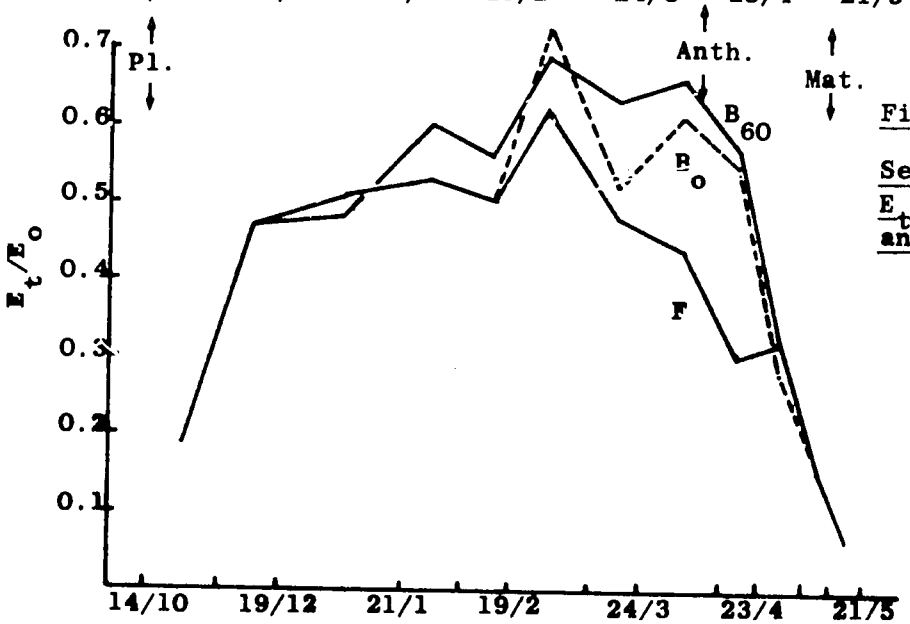


Fig. 3.17b

Seasonal Variation in E_t/E_o ratio of Barley and Fallow.

Table 3.14. Effect of 60 kg N/ha on Maximum Dry Matter of Leaf, Stem and Head at 5 Locations (g/m^2)

Site		Leaf	Stem	Head	Total	% Increase in Total D.M.
Jindiress	B_0	78	256	211	529	82
	B_{60}	129	486	375	961	
Kafr Antoon	B_0	84	291	307	603	82
	B_{60}	146	558	506	1095	
Tel Hadya	B_0	143	527	491	1072	29
	B_{60}	211	612	638	1385	
Brida	B_0	55	173	141	348	84
	B_{60}	95	318	253	642	
Khanasser	B_0	96	335	392	720	7
	B_{60}	100	386	405	768	

Table 3.15. Crop Growth Rate and Thermal Growth Rate during Rapid Stem Elongation and Grain Numbers at Harvest at 5 Locations

Site	Treat.	Mean Crop Growth Rate g/m^2/week	Mean Temperature (°C)	G.D.D./ Week	Thermal Growth Rate (g/m^2/G.D.D.)	Grain No. per / m^2 (x 10^3)
Jindiress	B_0	37.8	11.65	81.6	0.463	5.05
	B_{60}	68.3	11.65	81.6	0.837	8.15
Kafr Antoon	B_0	37.5	9.83	68.8	0.545	6.29
	B_{60}	77.4	9.83	68.8	1.125	10.43
Tel Hadya	B_0	109.7	13.25	92.7	1.183	9.11
	B_{60}	122.3	13.25	92.7	1.319	11.64
Brida	B_0	36.3	12.40	86.8	0.418	4.14
	B_{60}	78.6	12.40	86.8	0.905	7.64
Khanasser	B_0	73.4	11.44	80.1	0.916	7.72
	B_{60}	83.9	11.44	80.1	1.047	8.15

Table 3.16. Yield Component Data from all Treatments at 5 Locations[@]

Treatment		Total Biol. Yield g/m²	Total Grain Yield g/m²	HI	1000 gr Weight (g)	Total Et. mm.	W.U.E. (1)[@@] g/m²/mm	W.U.E. (2)[@@] g/m²/mm
Khanasser	B_0	696	336	0.483	42.8	250	2.78	1.34
	B_{20}	697	344	0.494	44.7	253	2.75	1.36
	B_{40}	752	333	0.443	42.7	265	2.84	1.26
	B_{60}	751	367	0.489	42.7	265	2.83	1.38
		ns	ns	ns	ns			
Brida	B_0	322	146	0.453	40.4	259	1.24	0.56
	B_{20}	478	210	0.439	40.1	268	1.78	0.78
	B_{40}	586	264	0.451	41.0	278	2.11	0.95
	B_{60}	628	275	0.439	40.1	285	2.20	0.96
		f=14.96***	f=17.29***	ns	ns			
Tel Hadya	B_0	869	332	0.382	45.5	311	2.79	1.07
	B_{20}	1021	351	0.343	44.2	337	3.03	1.04
	B_{40}	1067	425	0.398	43.9	348	3.07	1.22
	B_{60}	1069	422	0.395	44.3	346	3.09	1.22
		f= 6.74**	f=10.89***	ns	ns			
K. Antoon	B_0	742	314	0.423	45.5	318	2.33	0.99
	B_{20}	799	329	0.412	44.2	330	2.42	1.00
	B_{40}	863	364	0.422	43.7	337	2.56	1.08
	B_{60}	982	400	0.407	44.1	349	2.81	1.15
		f= 4.89*	f= 7.45**	ns	ns			
Jindiress	B_0	383	174	0.454	42.3	272	1.41	0.64
	B_{20}	563	250	0.444	41.4	303	1.86	0.83
	B_{40}	565	247	0.437	43.6	311	1.82	0.79
	B_{60}	662	293	0.442	43.5	322	2.06	0.91
		f=19.18***	f=17.39***	ns	ns			

@ Yield data are at zero percent moisture.

@@ (1)g (Total Biol. Yield)/m²/mm.

(2)g (Grain yield)/m²/mm.

* $P > 0.10$ ** $P > 0.05$ *** $P > 0.001$

Fig. 3.18a **Dry Matter Accumulation and Partition of Barley at JINDIRESS 1979/80**

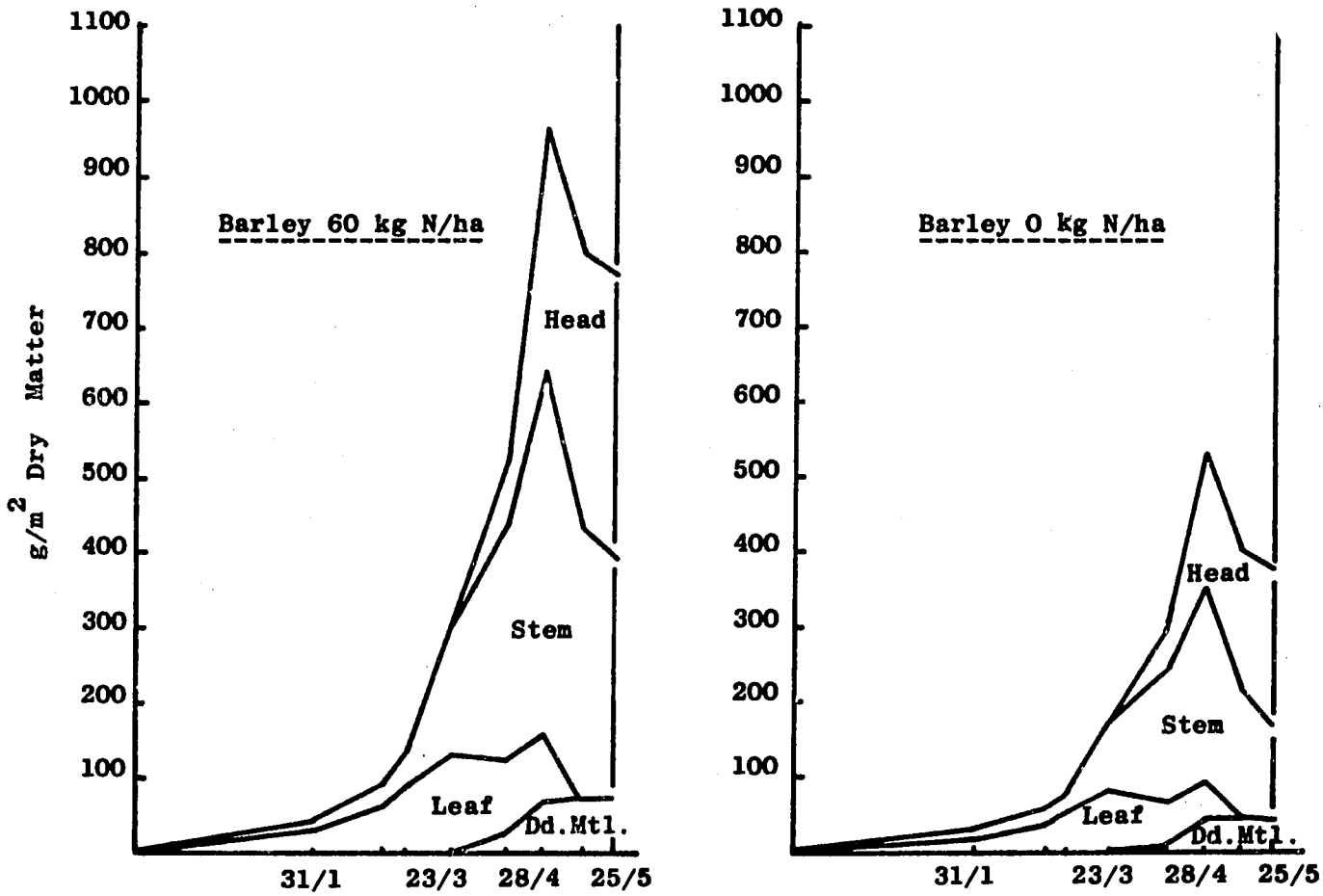


Fig. 3.18b **Seasonal Variation in total number of Stems/m²**

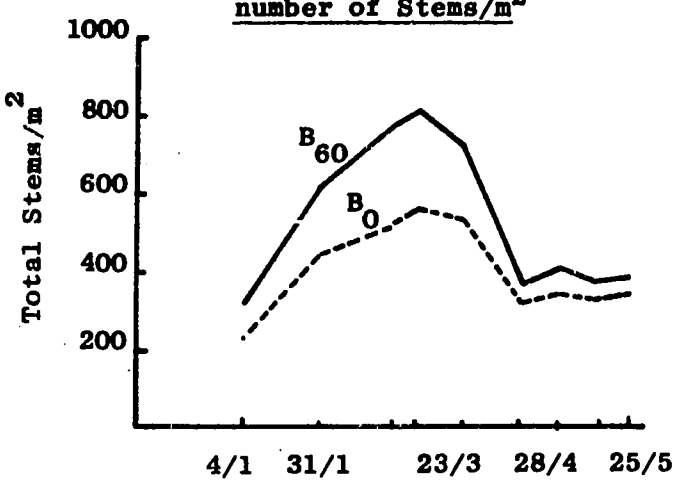


Fig. 3.18c **Increase in 1000 grain wt. (mean of B_0 and B_{60})**

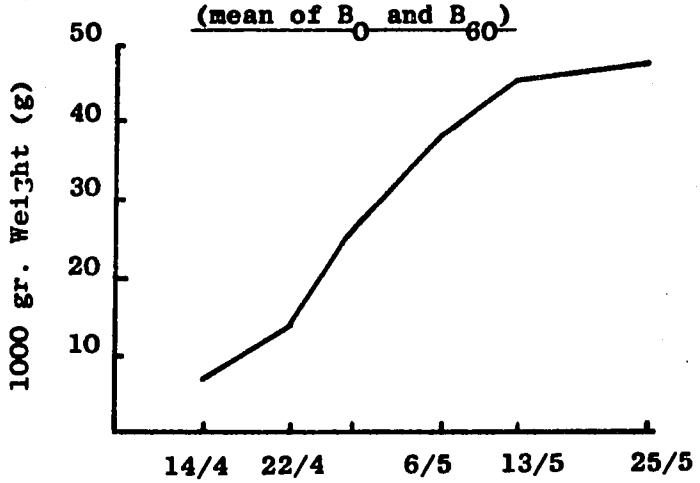


Fig. 3.19a Dry Matter Accumulation and Partition of Barley at KAFR ANTOON 1979/80

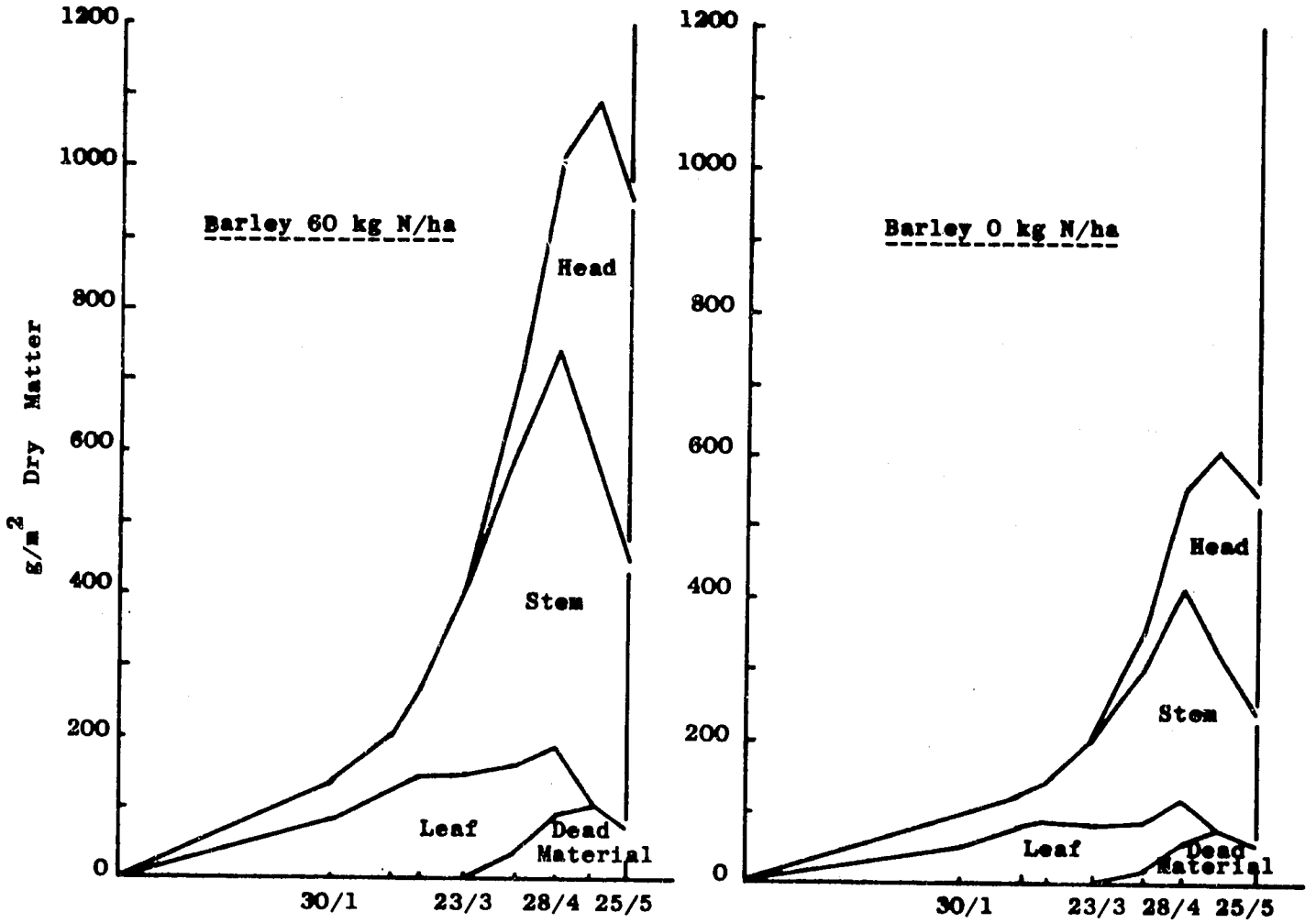


Fig. 3.19b Seasonal Variation in total number of Stems/m²

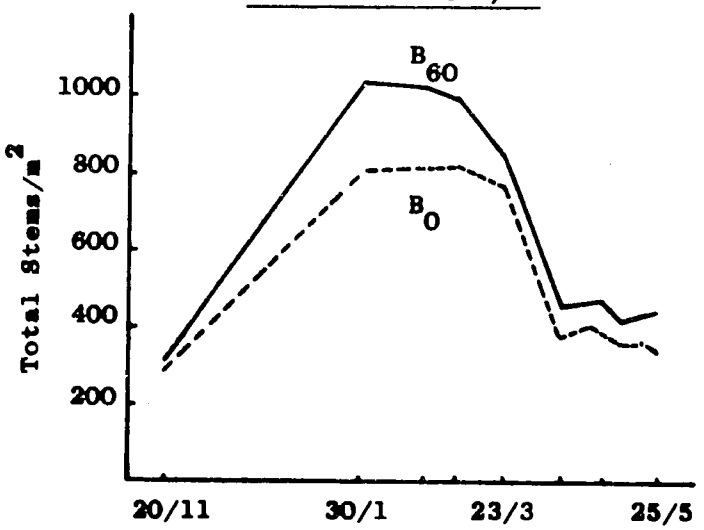


Fig. 3.19c Increase in 1000 grain wt. (mean of B_0 and B_{60})

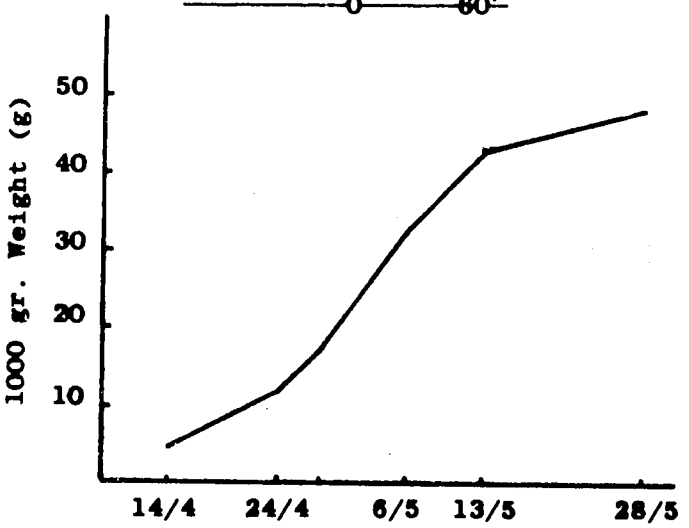


Fig. 3.20a Dry Matter Accumulation and Partition of Barley at TEL HADYA 1979/80

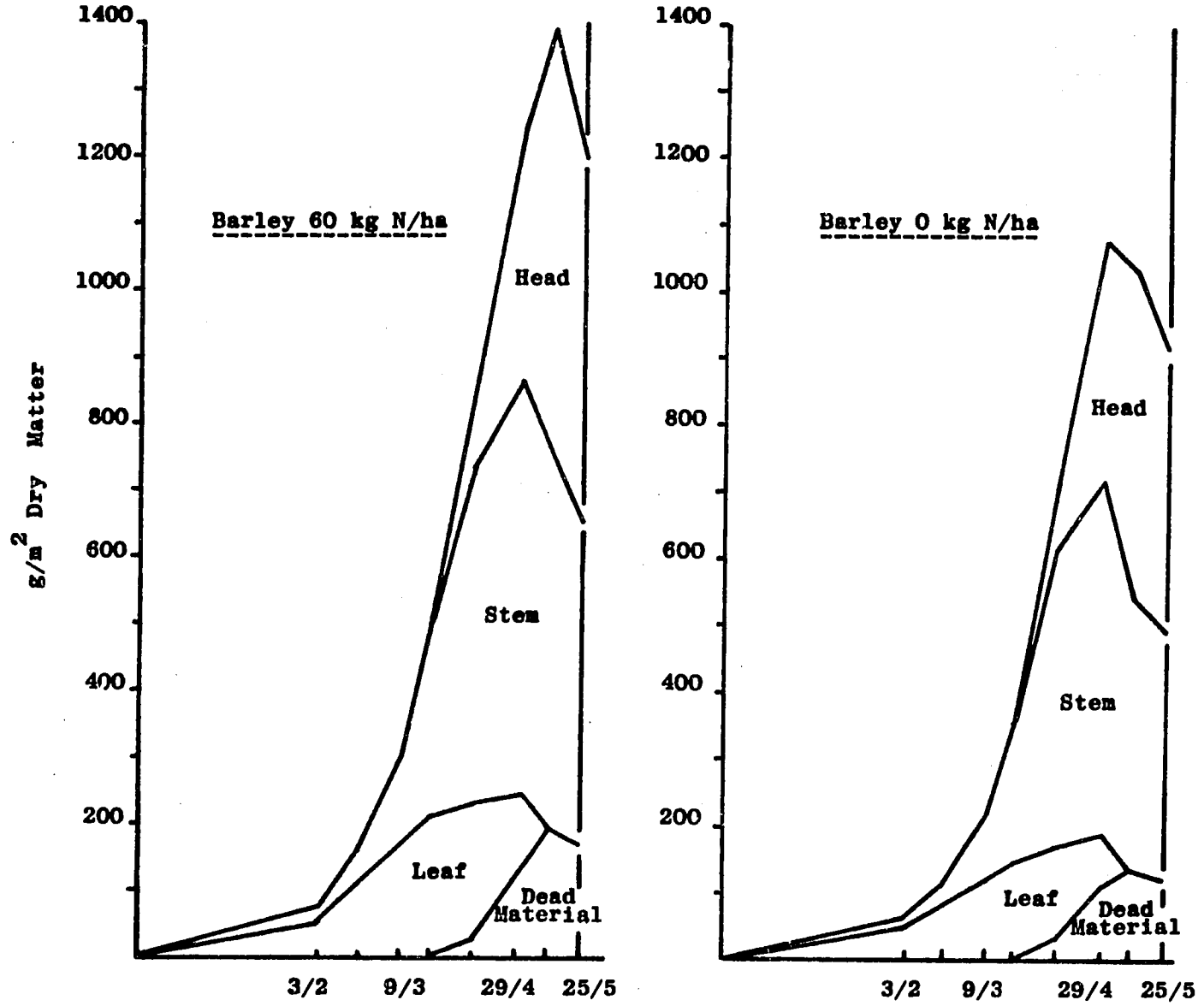


Fig. 3.20b Seasonal Variation in total number of Stems/m2

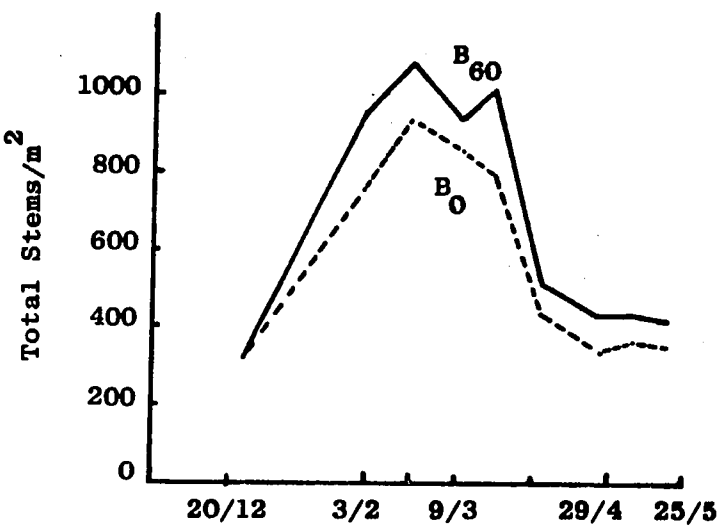


Fig. 3.20c Increase in 1000 grain wt. (mean of B_0 and B_{60})

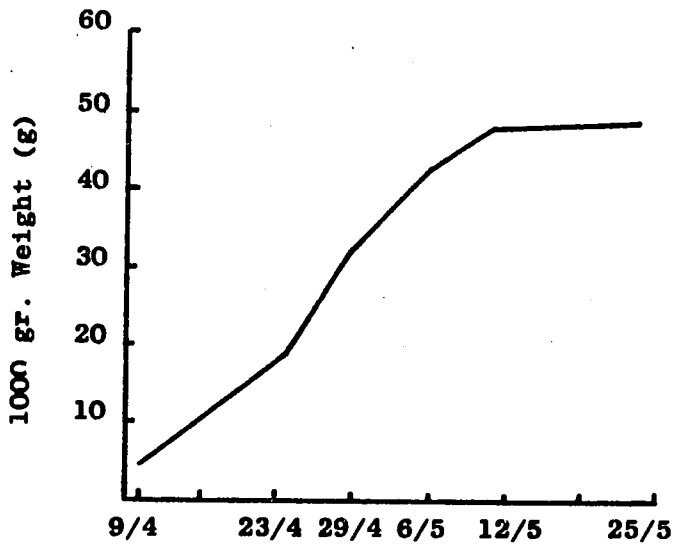
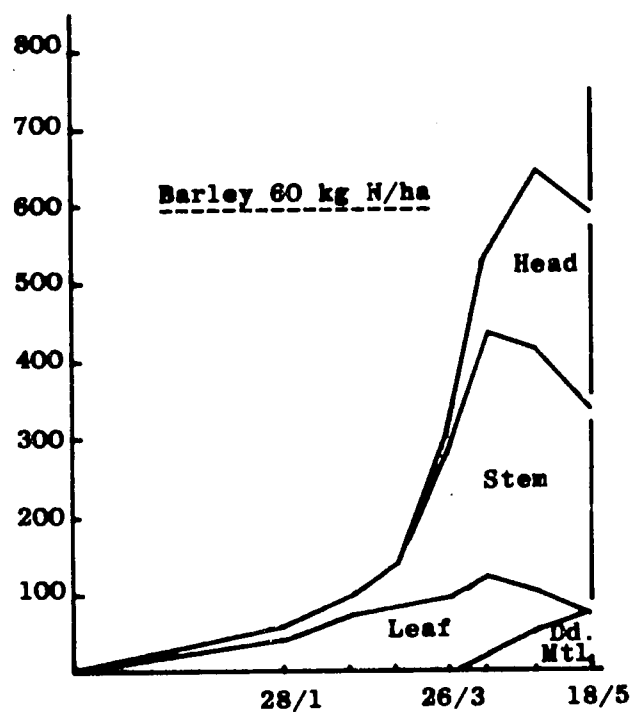


Fig. 3.21a Dry Matter Accumulation and Partition of Barley at BRIDA 1979/80



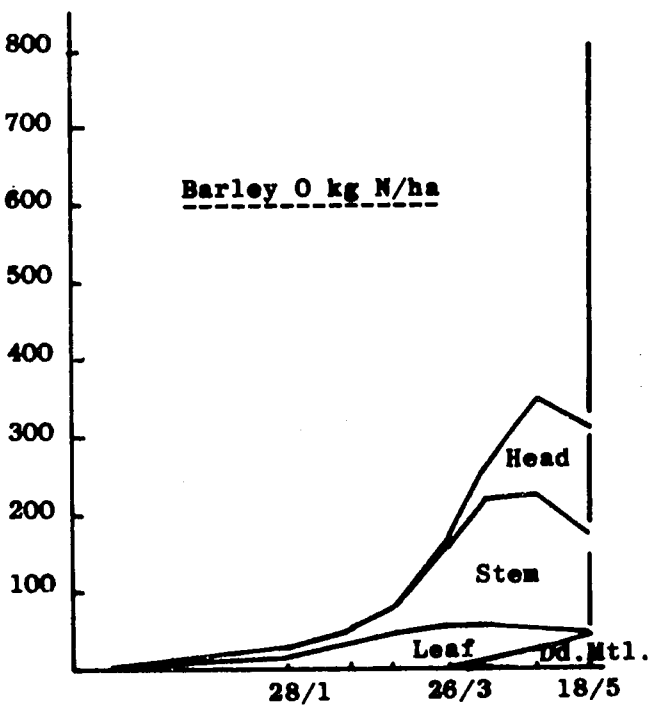


Fig. 3.21b Seasonal Variation in total number of Stems/m²

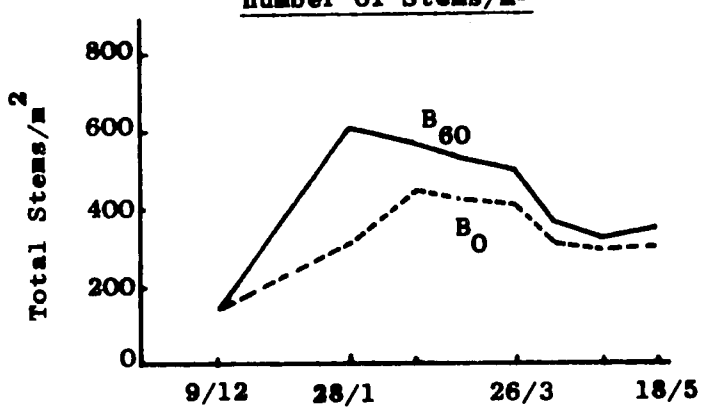


Fig. 3.21c Increase in 1000 grain wt. (mean of B_0 and B_{60})

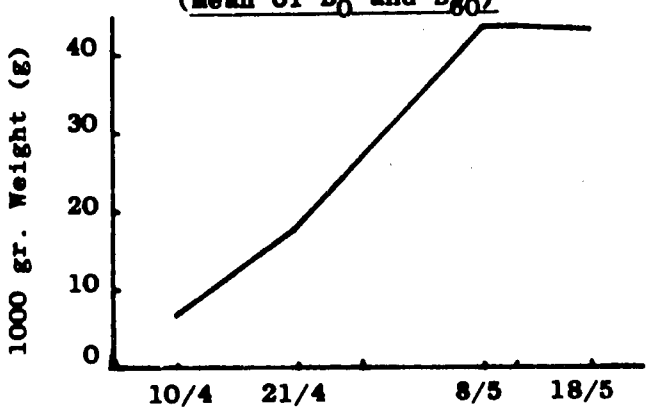
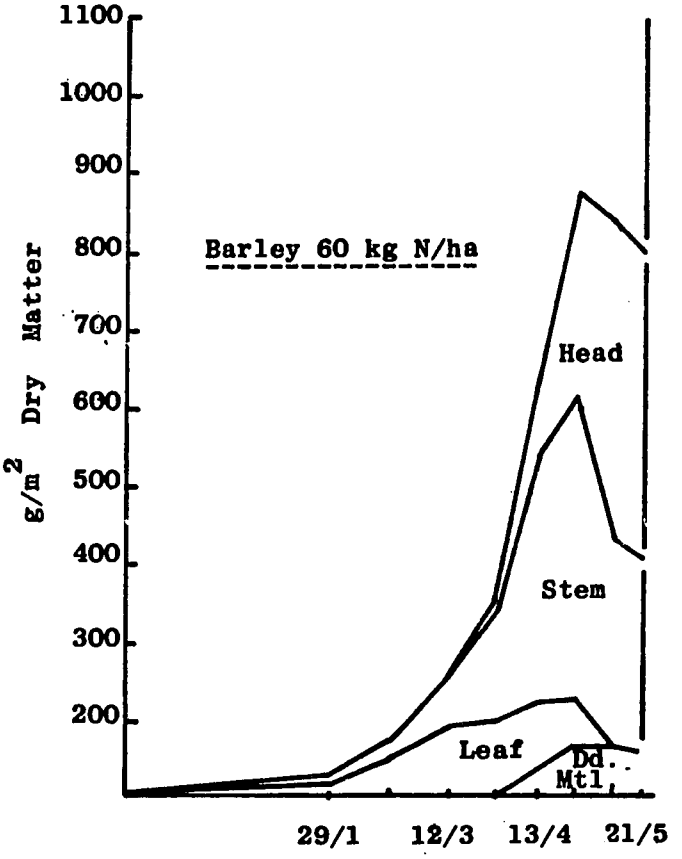


Fig. 3.22a Dry Matter Accumulation and Partition of Barley at KHANASSER 1979/80



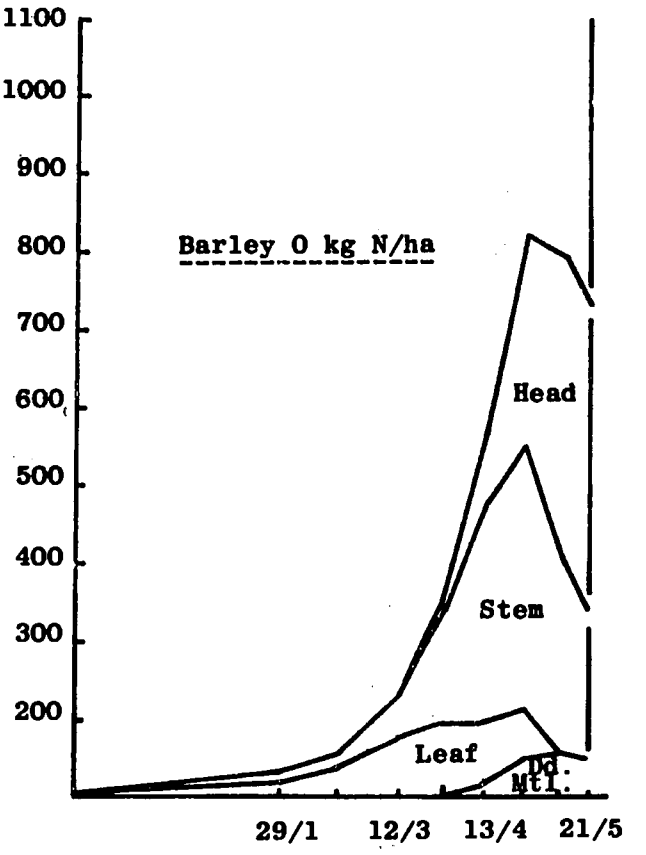


Fig. 3.22b Seasonal Variation in total number of Stems/m^2

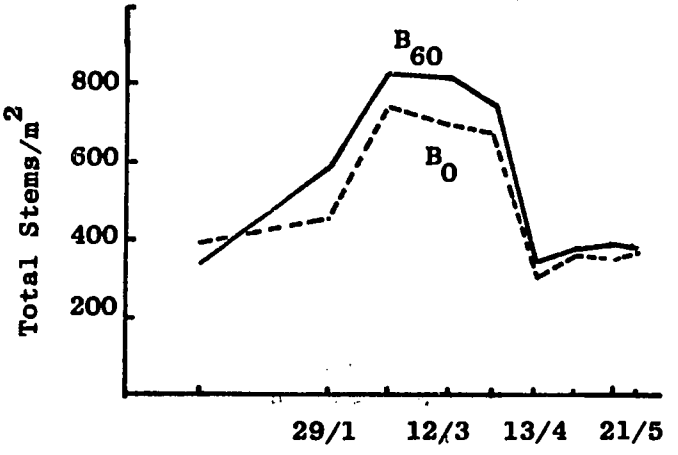


Fig. 3.22c Increase in 1000 grain wt. (mean of B_0 and B_{60})

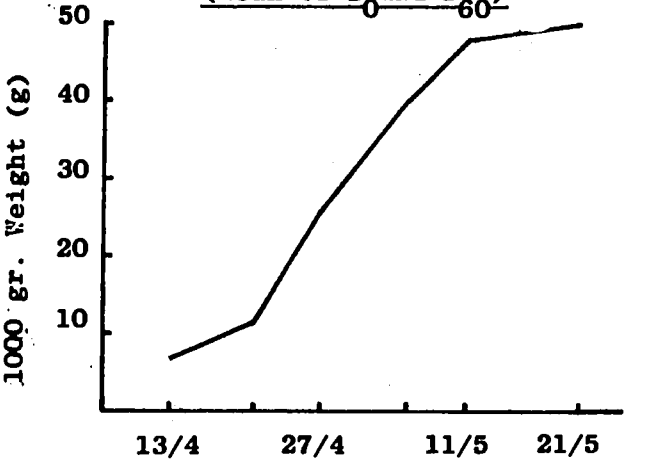


Fig. 3.23 **The Relationships between Crop and Thermal Growth Rates and Final Grain Number**

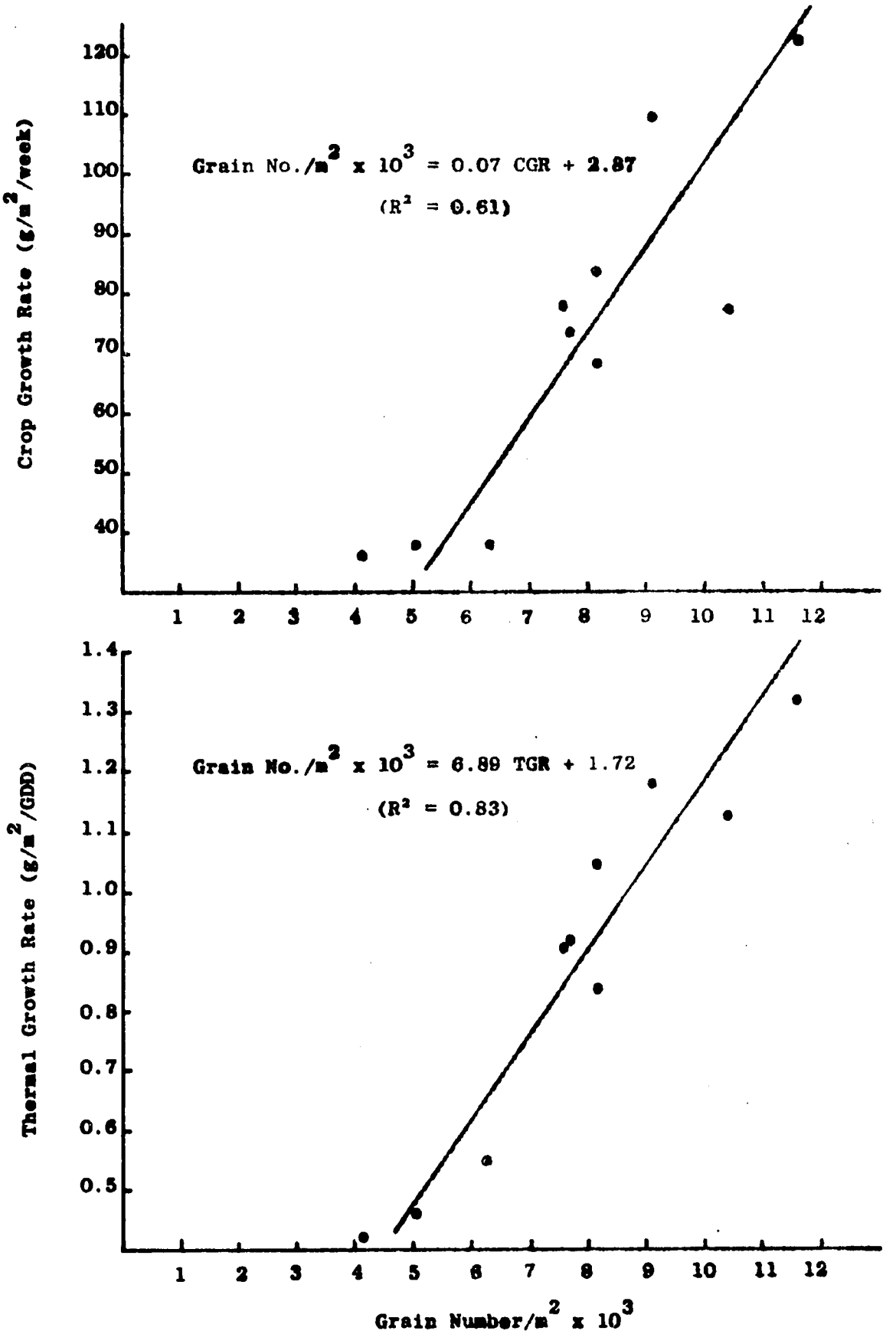


Fig. 3.24a The Relationship between Total Biological Yield (TBY) and Evapotranspiration (Et)

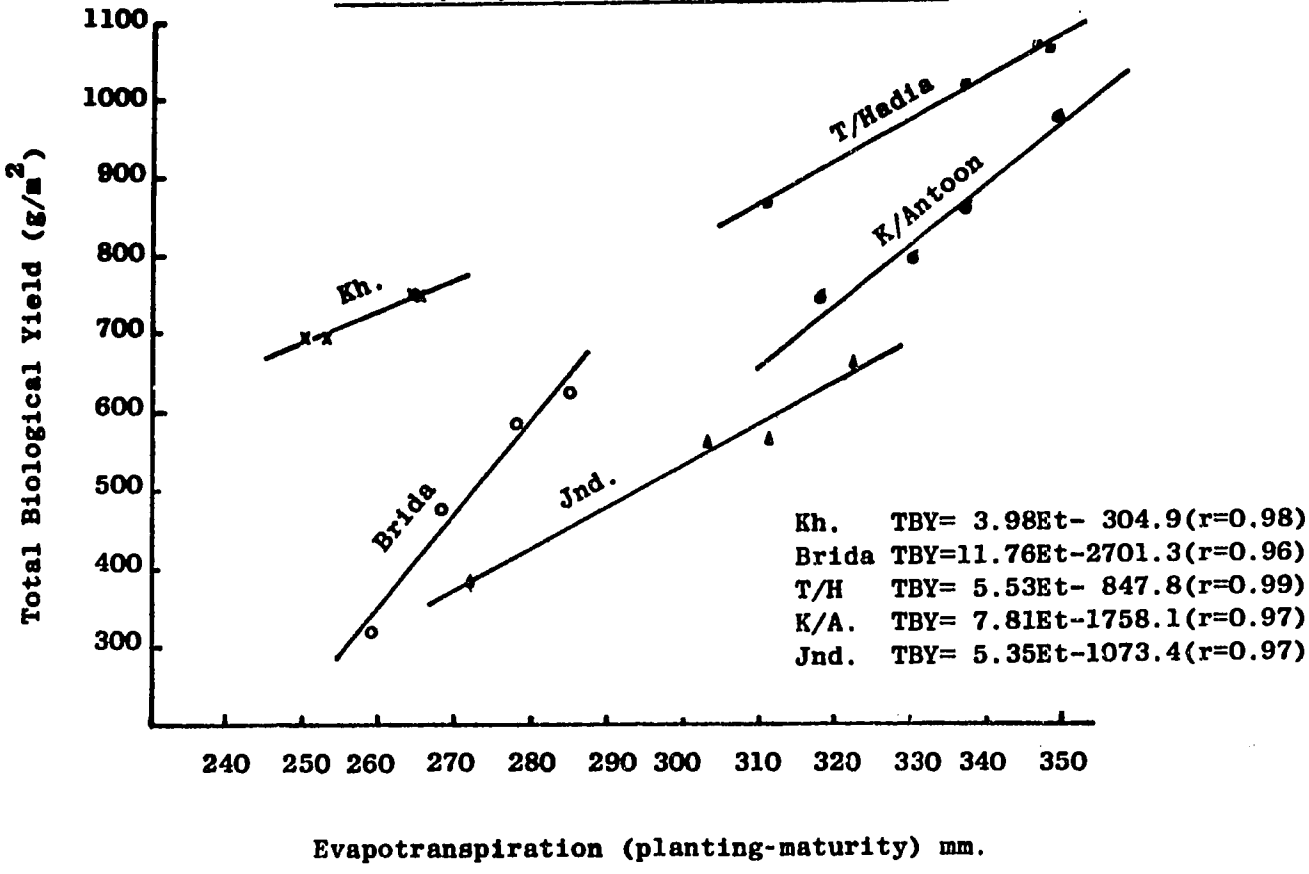
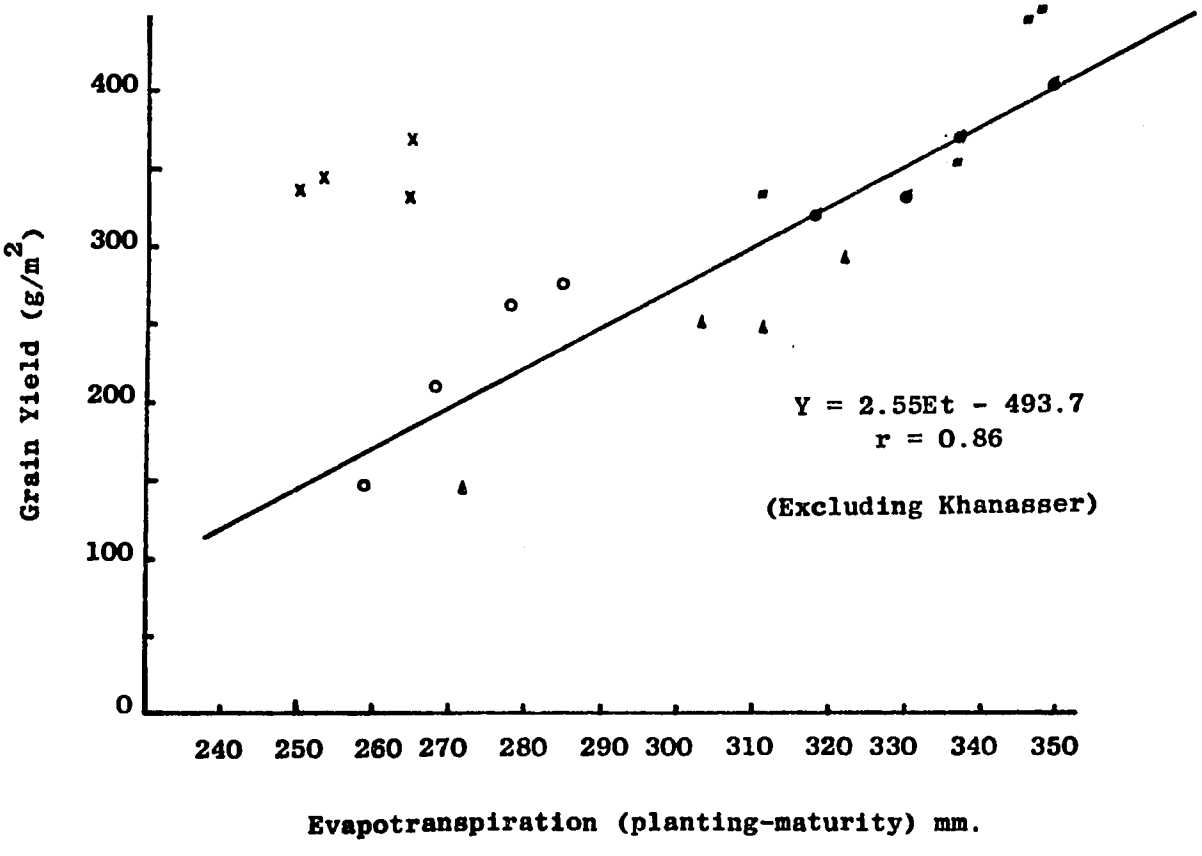


Fig. 3.24b The Relationship between Grain Yield (Y) and Evapotranspiration (Et)



CHAPTER 4

WATER USE OF LENTIL AND FABA BEAN AT TEL HADYA

4.1 Introduction

This study was part of a larger trial conducted in cooperation with the Food Legume Improvement Program. The trial was designed to assess the effect of lentils, chickpeas, faba beans, wheat and fallow (grown under various management practices) on the yield of a uniform wheat crop in the subsequent year.

Various treatments were selected for detailed moisture studies in the first year, and the results of those on lentils, faba beans and fallow are reported in this chapter.

The main objective of this study was to obtain information of the moisture use and moisture extraction patterns of two major grain legume crops of the region. In addition, since crop growth and yield responses to seed inoculation of lentils and faba beans have been reported in the region, a comparison of the moisture use of inoculated and non inoculated lentils and faba beans was made.

4.2 Materials and methods

4.2.1 Treatments

Five treatments were studied and these were.

1. Lentil (Syrian local large) non inoculated seed.
2. Lentil (Syrian local large) inoculated seed plus sitona weevil control.
3. Faba bean (local large) non inoculated seed.
4. Faba bean (local large) inoculated seed.
5. Clean fallow land.

In treatment (2) carbofuran granules (1.5 kg a.i./ha) were placed with the seed at planting to control sitona weevil whose larvae live in the soil and are known to cause extensive damage to rhizobium nodules formed on lentil roots. Treatments 1-4 received 60 kg/ha P_2O_5 at planting. Each treatment was replicated three times in a randomized block design.

4.2.2 Plot management

One access tube per plot was installed (see Section 3.2.3) and the trial was hand planted on 8 November in plots of 8 x 9 m. Lentils were planted at a 17.5 cm between row spacing at a seed rate of 60 kg/ha. Faba beans were planted at a 45.0 cm between row and a 15 cm within row spacing. All plots received 60 kg/ha P_2O_5 at planting.

Lentils emerged on 22 November, flowered on 17 April and reached maturity on 22 May. Faba bean emerged on 23 November, flowered on 20 March and reached maturity on 22 May. Plots were hand weeded on two occasions in March and April. Crops were harvested at the end of May and both grain yield and total biological yield were recorded. Soil moisture studies were conducted as previously described (see Sections 3.2.5 and 3.2.6).

4.3 Results

4.3.1 Moisture recharge under fallow

Total profile recharge and the pattern of recharge under fallow are given in Figs 4.1 ab. There is a marked difference in the profile recharge pattern under fallow in this trial compared with the fallow plots in the barley trial at Tel Hadya reported in Chapter 3 (compare Figs 3.4b with 4.1b).

This contrast is due to the very different moisture status of the two trial areas at the start of the 1979/80 season resulting from the previous 1978/79 cropping season (see Figure 4.2). In this trial, the previous crop was wheat which resulted in a much drier soil profile than in the barley trial where the land had been fallowed the previous season. Thus in fallow following fallow, the whole 180 cm profile had become recharged by 9 April, and drainage below 180 cm was occurring. In contrast, in fallow following wheat, although maximum recharge occurred during the same period, the recharge front did not go below 150 cm and drainage below 180 cm was not recorded.

4.3.2 Moisture discharge under fallow

Following the period of maximum recharge in mid April, profile discharge occurred at all depths down to 120 cm (see Fig. 4.3 ab). Below this depth moisture increased, presumably due to slow drainage from horizons above. Results obtained after 1st June are not presented due to soil cracking around the access tubes as described in Section 3.3.2. Nevertheless it is apparent that due to the different patterns of profile recharge and resultant drainage below 180 cm depth caused by previous cropping history, a greater proportion of the 1979/80 rainfall was stored in the 0-180 cm profile in fallow following wheat than fallow following fallow (15.7 cm in 1st June .v.9.0 cm 25 May).

4.3.3 Moisture recharge under lentil and faba bean

Seed inoculation of lentil and faba bean had no measurable effect on the profile recharge pattern, nor was there any difference between the recharge pattern under the two crop types. Thus the results presented in Figs 4.1 ab are the mean of treatments 1-4.

There was no significant difference between recharge under cropped and fallow land until late February when differences became apparent. Maximum recharge under lentil and faba bean was recorded on 3 Feb. Between 3 Feb. and 14 April rainfall and moisture use were nearly equal and net recharge was zero. Thus, on 14 April the net moisture in the profile under the two crops was nearly the same as on 3 Feb., but due to the heavy rains in late March and early April, the recharge front had reached 120 cm compared to 150 cm under fallow.

4.3.4 Moisture discharge under lentils and faba beans

Rapid profile discharge started under both crops on 14 April and continued until crop maturity. The discharge patterns were similar for both crops (see Figs 4.1a and 4.3a) until 24 April, but thereafter discharge was greater than the lentil crop. Seed inoculation had no significant effect.

4.3.5 Moisture extraction patterns of lentils and faba bean

The three stage analyses described in Chapter 3 were conducted on the moisture data obtained during the period of rapid profile discharge and the results are summarised in Figs 4.3 ab and Table 4.1. The effect of seed inoculation was negligible and the results presented for each crop are the means of the two treatments. All three stages of the

analyses indicate that both lentils and faba bean extracted moisture to a depth of 105 cm. The agreement in depth estimate by the three stages is better than reported in Chapter 3 due to negligible slow drainage from deeper horizons as discussed in Section 4.3.1.

Lentils extracted more moisture than faba beans in all depths to 105 cm, but only significantly so in the 45-60 cm and 60-75 cm depth intervals.

4.3.6 Extractable moisture by lentils and faba beans

Extractable moisture (as described in Section 3.3.7) is given in Table 4.2 for treatments 1-4 for all depth intervals to 105 cm. Seed inoculation has had no apparent effect on extractable moisture, but between 15 and 90 cm depth lentils showed consistently higher extractable moisture than faba bean in all depth intervals.

4.3.7 Crop moisture use

Accumulated crop moisture use was calculated using equation 1 (see Section 3.2.6). Seed inoculation had no significant effect and thus the results are presented as the means of the two treatments for each crop (see Table 4.3).

Up until the end of February there was no difference in moisture use between fallow and cropped land. Beginning in March, crop evapotranspiration became increasingly greater than evaporation from bare soil, but no difference in moisture use between lentils and faba bean was observed until 24 April. From this date to maturity lentils used more moisture than faba bean.

The seasonal variation in rate of evapotranspiration (E_t) and potential evapotranspiration (E_o) is given in Fig. 4.4a. It was shown before with barley (see Fig. 3.12a - 3.16a), that the seasonal variation in E_t is largely determined by that of E_o. Faba beans reached maximum rates of E_t about a month after flowering, and lentils about 2 weeks after flowering after which E_t declined steadily until maturity.

The seasonal pattern of E_t for both crops was also related to leaf-area production and this is shown by the seasonal variation in the E_t/E_o ratio (Fig. 4.4b). Both crops reached maximum or near maximum E_t/E_o ratios at flowering,but in spite of achieving complete crop-

ground-cover by this stage, only an E_t/E_o ratio of 0.78 was reached for both crops. This is very low compared to fertilized barley at Tel Hadya which gave an E_t/E_o ratio of 0.96 at anthesis. Fig. 4.1a indicates that profile recharge was at a maximum under lentils and faba beans at this stage and that rain storms were still occurring. This suggests that the low value was not so much a result of lack of available soil moisture, but possibly due to periodic stomatal closure during parts of the day resulting from atmospheric stress.

4.3.8 Final harvest analyses and water use efficiency

Harvest data, total water use and derived water use efficiency data are given in Table 4.4. Data for fertilized and unfertilized barley grown at Tel Hadya are also indicated for comparison.

Seed inoculation of lentils and faba bean had no significant effect on total biological or grain yield in this trial. Water use efficiencies of total biological yield were very similar for both lentils and faba bean, but both were inferior to the two barley treatments. However, the water use efficiency of grain yield of faba beans was higher than for lentils, and only slightly lower than barley.

4.4 Summary

(1) Previous cropping history has a pronounced effect on profile recharge patterns and thus on drainage losses below rooting depth.

(2) Seed inoculation of lentils and faba beans in this trial had little effect on crop growth, the moisture dynamics of the system or total moisture use.

(3) Both faba bean and lentils extracted moisture to a depth of 105 cm.

(4) Water use by both crops was similar during most of the growing season. Only during the last few weeks of crop growth did lentils show greater moisture use than faba beans. This showed as greater extraction of water within a given depth interval rather than greater rooting depth.

(5) Water use efficiencies of total biological yield were similar for faba bean and lentils, but faba bean gave a considerably higher water use efficiency of grain yield production.

Fig. 4.1a Recharge Discharge Patterns at TEL HADYA under Lentils, Faba beans, Chickpeas and Fallow 1979/80.

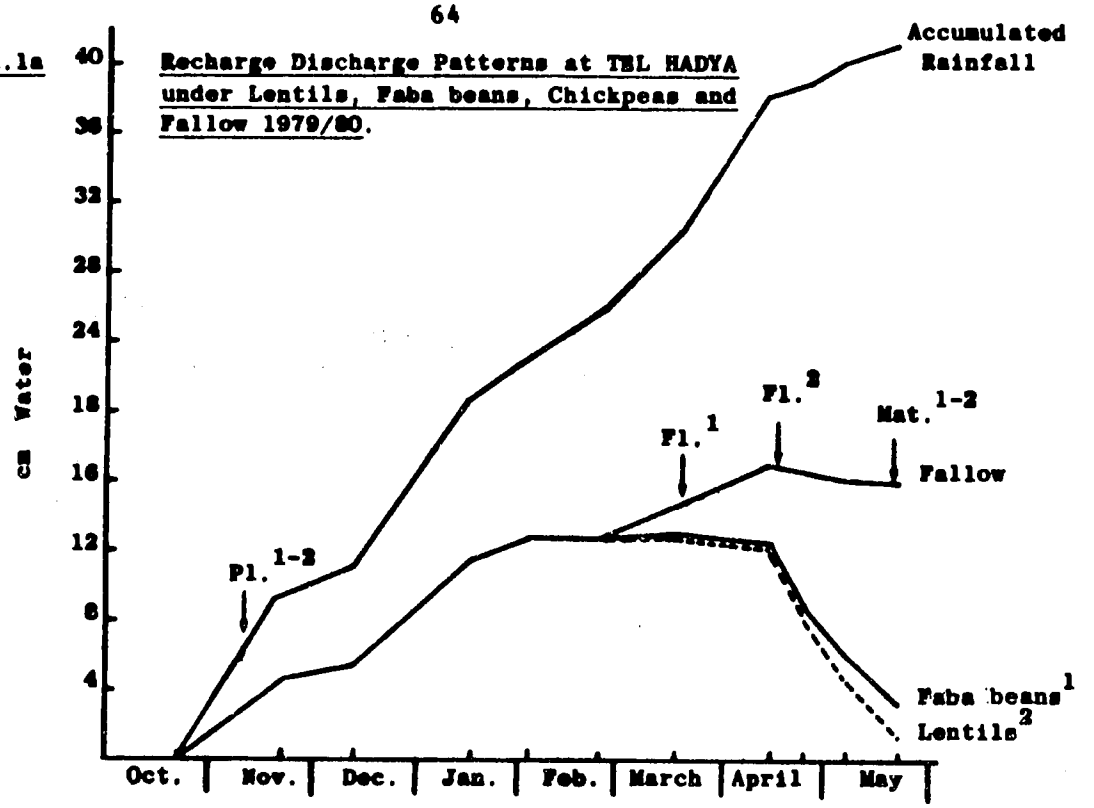


Fig. 4.1b Soil Profile Recharge

(cm Water/Interval)

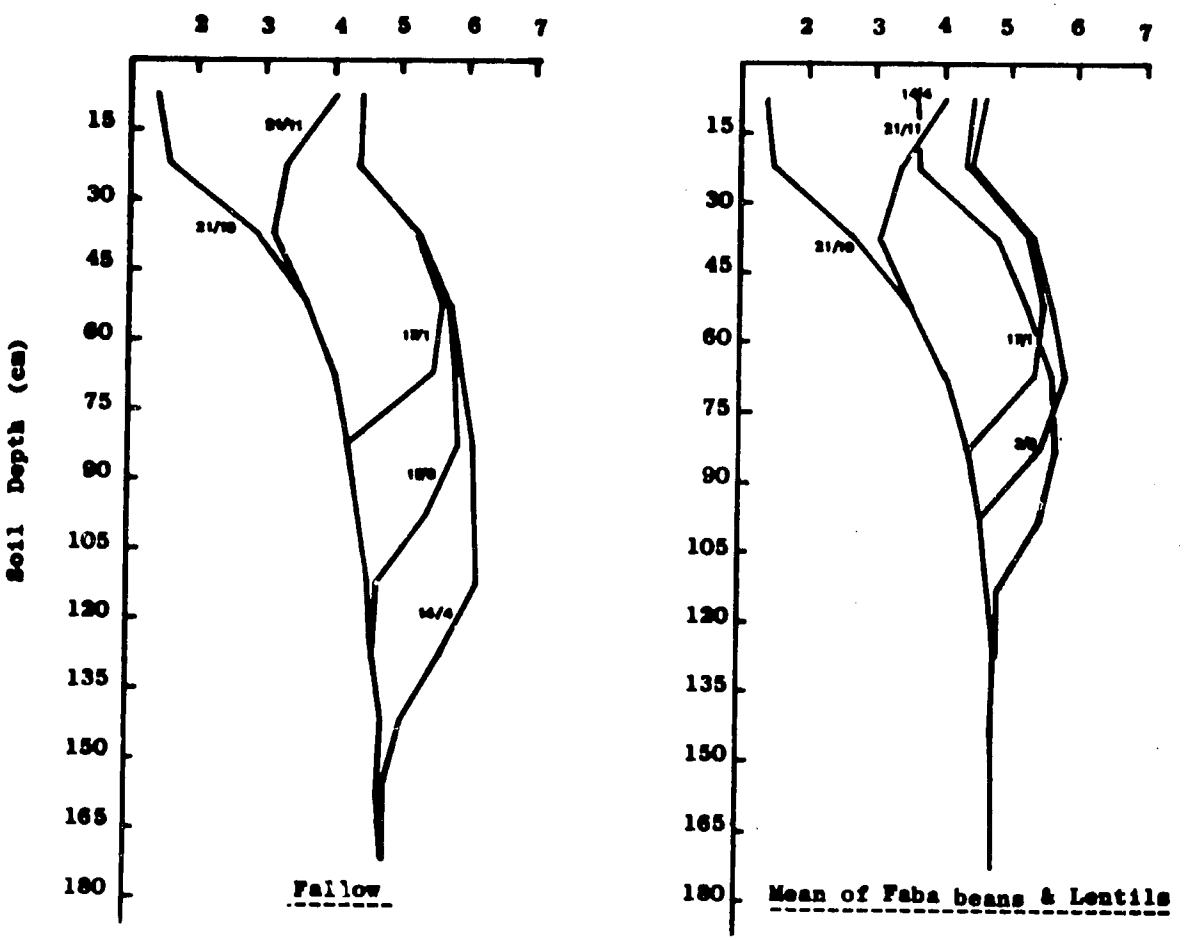
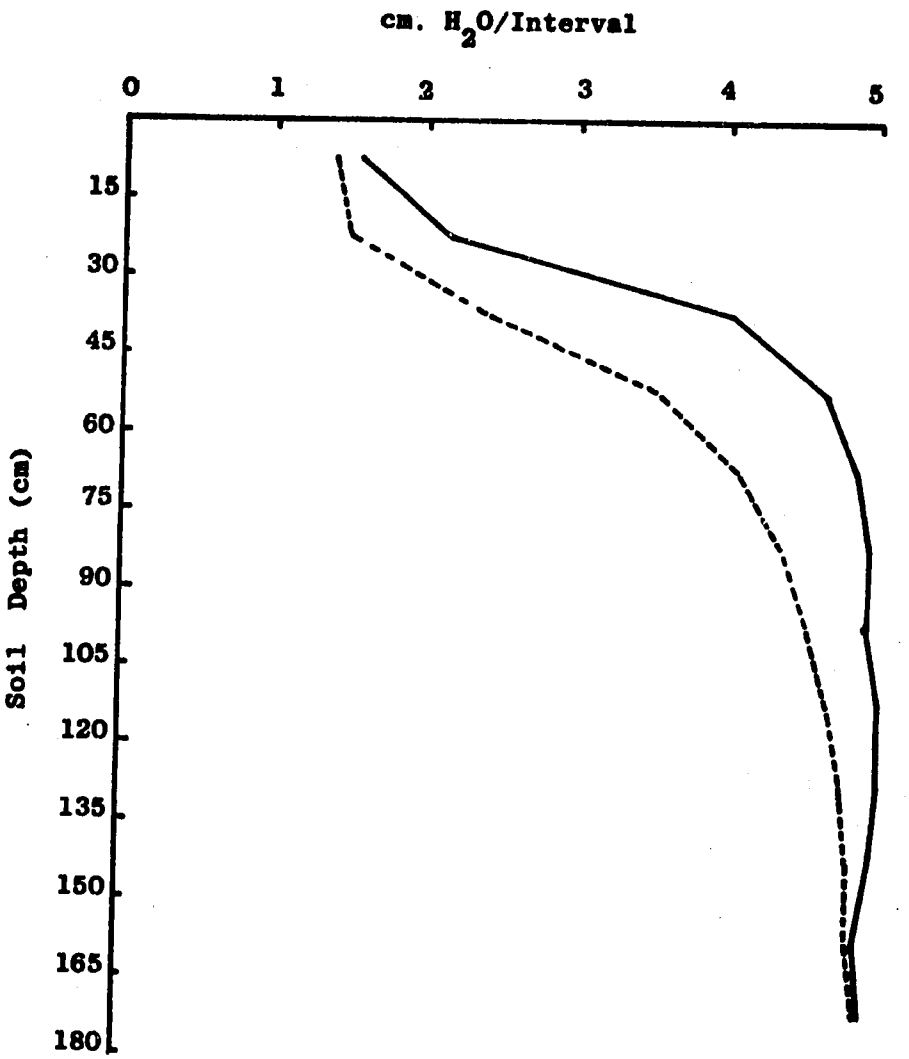


Fig. 4.2 **Moisture Distribution of 2 Tel Hadya Soils on 1/10/79**



—— After fallow (mean 30 tubes) over area of 2500 m^2

----- After wheat (mean 45 tubes) over area of 4500 m^2

Total H_2O after fallow = 51.96 cm

Total H_2O after wheat = 45.75 cm

Fig. 4.3a Pattern of Profile Discharge at TEL HADYA under Fallow, Lentils and Faba beans 1979/80

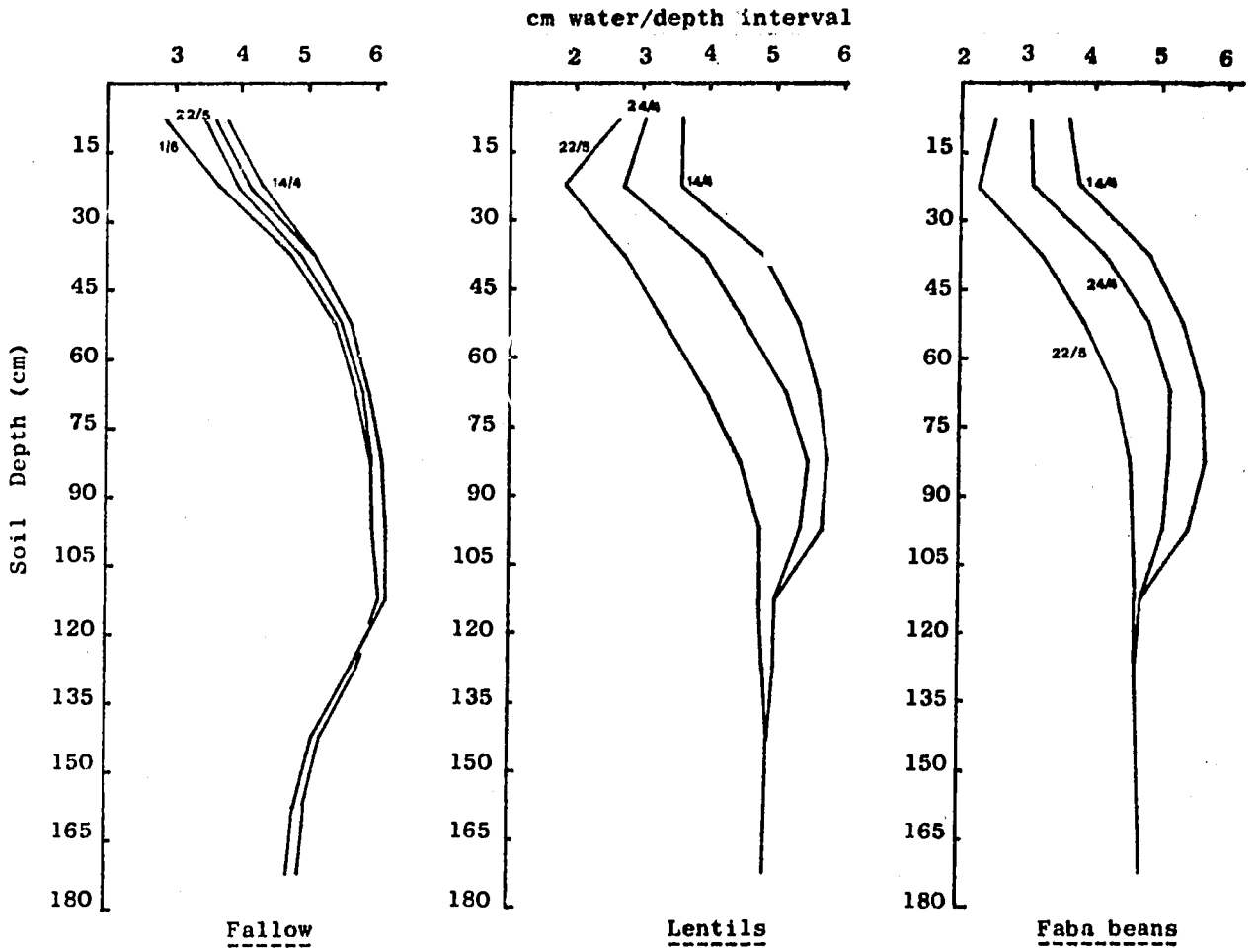


Fig. 4.3b Change in Moisture in Discrete Depth Intervals with Time

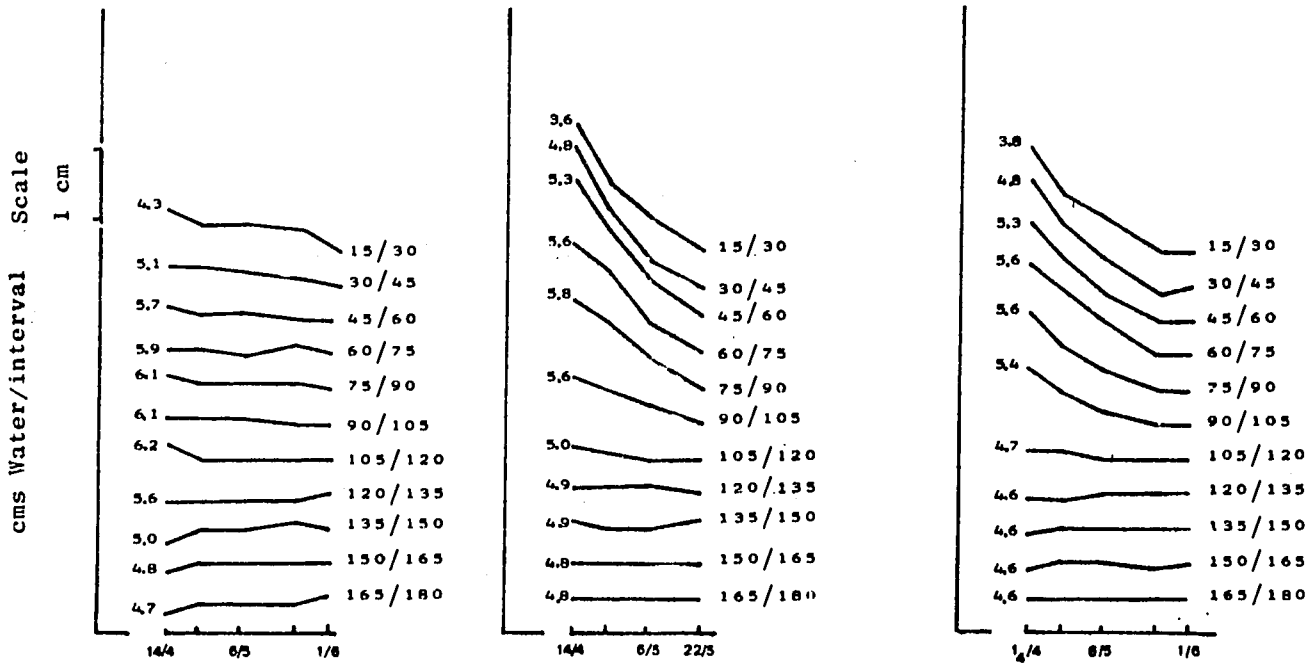


Table 4.1 Moisture Loss from Discrete Depth Intervals under Faba beans, Lentils and Fallow at Tel Hadya during Profile Discharge Period

14/4 - 22/5/1980 (cm)

Depth (cm)	Faba-beans	Fallow	Lentils	T - Test Value@		
				BB.v.F.	L.v.F.	L.v.BB.
15- 30	1.49	0.36	1.94	4.96**	6.51***	ns
30- 45	1.61	0.20	2.03	10.43***	7.14***	ns
45- 60	1.48	0.15	1.93	9.50***	9.34***	2.88*
60- 75	1.28	0.04	1.64	7.96***	11.39***	2.67*
75- 90	1.11	0.12	1.29	9.88***	6.43***	ns
90-105	0.71	0.14	0.88	6.07***	5.89***	ns
105-120	- 0.07	0.15	0.17	ns	ns	ns
120-135	- 0.05	- 0.02	0.13	ns	ns	ns
135-150	- 0.06	- 0.27	- 0.07	ns	ns	ns
150-165	0.02	- 0.21	0.02	ns	ns	ns
165-180	0.02	- 0.09	0.04	ns	ns	ns
TOTAL	7.66	0.57	10.00	10.84***	9.44***	2.28*

Table 4.2. Extractable Moisture (cm/depth interval) under Inoculated and Non-inoculated Lentils & Faba Bean

Depth (cm)	Lentils			Faba Bean		
	Inoc.	Non-Inoc.	Mean	Inoc.	Non-Inoc.	Mean
15-30	2.45	2.50	2.47	2.04	2.35	2.20
30-45	2.50	2.72	2.61	1.98	2.07	2.02
45-60	2.18	2.44	2.31	1.71	1.73	1.72
60-75	1.77	1.78	1.77	1.40	1.38	1.39
75-90	1.40	1.26	1.33	1.07	1.20	1.14
90-105	1.01	0.76	0.89	0.83	0.89	0.86
TOTAL	11.31	11.46	11.38	9.03	9.62	9.33

Table 4.3 Accumulated Water Use by Faba beans, Lentils and Fallow
TEL HADYA 1979-80

	21/11	12/12	17/1	3/2	24/2	17/3	14/4	24/4	6/5	22/5
F	21	36	59	69	93	123	170	177	196	209
B/B	21	36	59	69	96	134	226	264	307	345
L	21	23	59	69	93	134	226	268	321	372 362
E_o	41	91	133	154	199	257	373	429	516	651

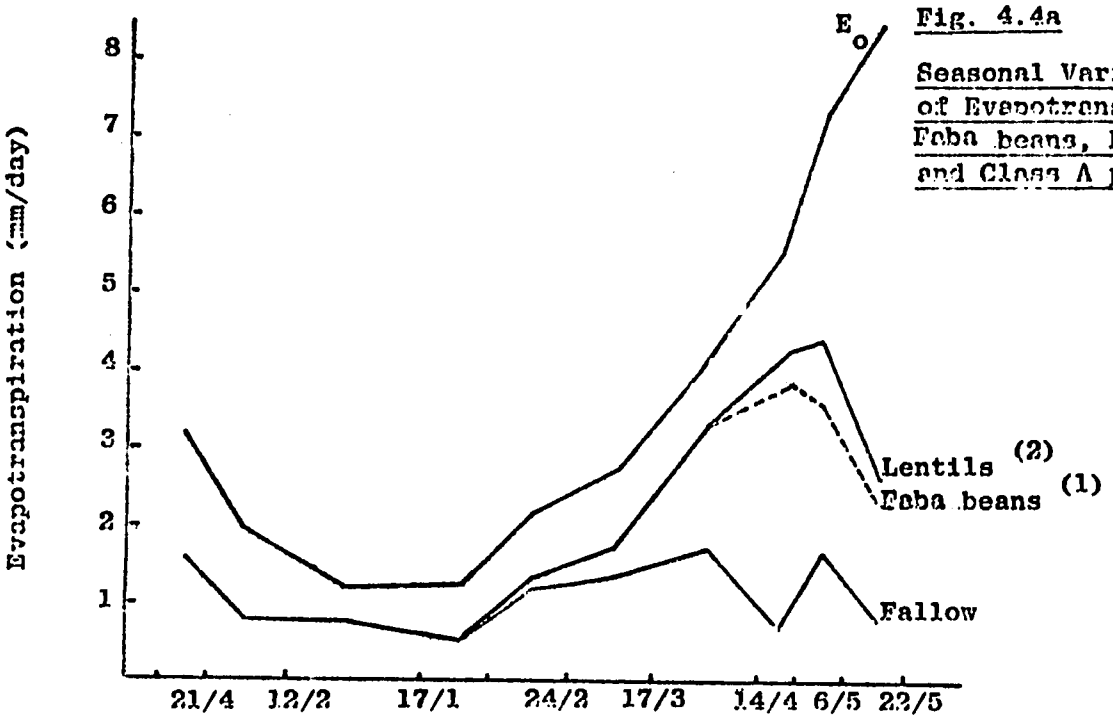


Fig. 4.4a

Seasonal Variation in Rate of Evapotranspiration by Faba beans, Lentils, Fallow and Class A pan E_o (mm/day).

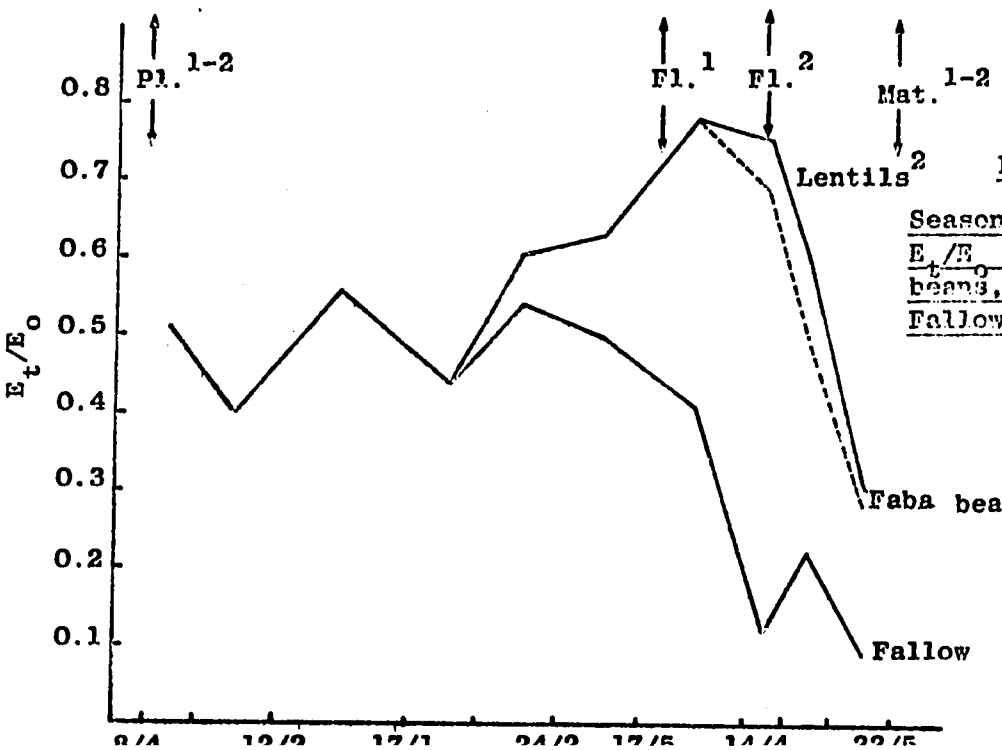


Fig. 4.4b

Seasonal Variation in E_t/E_o ratio of Faba beans, Lentils and Fallow.

Table 4.4 Harvest Data and Water Use Efficiency of Lentils and Faba beans at Tel Hadya

1979/1980@

Treatment	Total Biolog. Yield (g/m^2)	Total Grain Yield(g/m^2)	Moisture Use (mm)	W U E (1)* $g/m^2/mm$	W U E (2)* $g/m^2/mm$
Lentils (uninoculated)	631±26	178± 8	364	1.73	0.49
Lentils (inoculated)	646±36	197±20	360	1.79	0.55
Faba beans (uninoculated)	625±24	302± 9	348	1.79	0.87
Faba beans (inoculated)	676±31	315±10	342	1.98	0.92
Barley (B_0)	869	332	311	2.79	1.07
Barley (B)	1069	422	346	3.09	1.22

@ Yields given at zero % moisture.

* WUE (1) for total biological yield.
WUE (2) for grain yield.

CHAPTER 5

QUANTIFICATION OF SOIL WATER, TEMPERATURE AND NITROGEN LIMITATION TO WHEAT YIELDS

5.1 Introduction

The objective of this experiment is to collect field data necessary to develop and calibrate a spring wheat growth model for the region. Three spring wheat (bread) cultivars of different maturity were used: Sonalika (early), Mexipak (medium) and NS 2568/2 (late).The major part of the first year's study was a trial at Tel Hadya using four water levels (trickle irrigation) and two nitrogen levels (0 and 60 kg/ha) per variety. Seed rates for the individual varieties were adapted for seed weight and seed viability. The seed rates varied from 90 to 130 kg/ha and represented 250 viable seed per m^2.

Phenological development, growth yield components and water use of the crop were measured. Barley (cv. Beecher) was included in this trial and matured a few days earlier than Sonalika. Barley did not respond to the irrigation that was applied in the middle of the grain filling period, and similar data on barley is reported elsewhere in this document (see Chapter 3). The wheat varieties were sown at the four SWAN off-station sites on single plots, mainly for observation of phenological development and final yield estimates. The plots in Khanasser had a poor plant establishment due to bird damage and were disregarded for yield/water-use measurements.

Plant samples were saved at final harvest to determine total nitrogen uptake. Soil samples were taken at Tel Hadya for key treatments and analysed for mineral nitrogen, available phosphorus, pH and electrical conductivity (see Chapter 7). The plant analyses have not yet been completed.

5.2 Results

5.2.1 Plant development

Important phenological events that were observed at Tel Hadya are shown in Table 5.1. Increasing temperatures towards the end of the season caused a decrease in maturity differences between varieties. The difference ranges from 34 days at floral initiation to five days at physiological maturity.

An important stage in development occurs when the shoot apex differentiates, forming floral organs instead of further leaf primordia. This change is caused by a temperature/photoperiod/genotype interaction. A later date of floral initiation will result in more leaves, as is generally the case when going from an early (spring type) to a late (winter type) wheat variety. The rate of leaf appearance was similar for the three wheats and barley and was not affected by nitrogen. More leaves per plant for the longer season varieties, caused a difference in heading dates and thus in maturity.

Table 5.2 shows the number of leaves, leaf area and maximum number of visible tillers per mainstem. These figures indicate a development of a larger source for longer season varieties. Tillering increased with longer season varieties, but the number of tillers that survived was similar for all maturity types. Thus, this is an environmental constraint. Final tiller number is dependent upon plant-to-plant competition and environmental factors (temperature, moisture, nutrients). Mainstem population and availability of moisture and nutrients were similar for the three varieties during the period in which some tillers died. This resulted in similar numbers of spikes per unit area. Nitrogen fertilizer increased the final tiller number slightly. The development of the sink (spikelets/florets) also shows an increase in size with longer season varieties (Table 5.2).

5.2.2 Crop growth and yield components

There were no significant differences in dry matter production between nitrogen treatments at Tel Hadya (Table 5.3). The kernel number per spike and the number of grain contributing tillers were slightly higher on the fertilized treatments. However, a lower kernel weight offset that advantage. The previous year, this area was fallowed and there was, apparently, enough soil nitrogen available for crop growth. Only the fertilized treatment was carried out at the other locations.

Comparing the dry land (W_0) treatments for all four sites, Tel Hadya had the highest yield and Brida the lowest for each variety. Differences in kernel number could partially be compensated for by the weight of the kernels, especially for the early variety Sonalika. The kernel number at harvest was only a fraction of the number of kernel sites (florets) that were initiated after floral initiation, 52 percent, 50 percent and 41 percent for Sonalika, Mexipak and NS 2568/2 respectively (Table 5.2).

Two irrigations were applied late in the season at Tel Hadya. The first one was in the middle of the grain filling period of Sonalika and at anthesis for NS 2568/2. The second irrigation was 14 days later. There was a yield response to watering for the nitrogen treatments. The unfertilized plots showed a negative response to additional water. The water application maintained a high moisture level in the root zone,but it could not prevent a fast senescence of leaves. This had an increasingly negative effect with later maturity types on both grain-filling time (Table 5.1) and post-anthesis production (Table 5.4). An increase in translocation was found with increasing maturity length, thus compensating for the negative factors on grain growth.

Dry matter accumulated prior to anthesis is a measure of potential yield. There was an increase in total dry-weight at anthesis with the longer season varieties. This trend did not continue after anthesis and the higher potential of the late maturity type was not reached. Even with irrigation the longer season varieties could not produce substantially more dry matter after anthesis. The higher grain yields were a result of reallocation of assimilates within the plant. (See Table 5.4). Figure 5.1 shows the partitioning of dry matter to various plant components. The contribution of the tillers to total dry matter production is about 14 percent.

The increase in 1000 grain weight for fertilized dry-land treatments at four sites is shown in Figure 5.2. Maturity (constant 1000 grain weight) of all the three varieties occurred in a short period of time. The potential length of the grain filling period was not reached for the longer season varieties as was discussed above, thus limiting the kernel weight of the later maturity varieties. This early termination of the growing season was probably caused by temperature stress (Tel Hadya), water stress (Brida) or a combination of both. Maturity of a variety occurred within four days under all water levels at both nitrogen levels (Tel Hadya). The unfertilized plots were slightly earlier than the fertilized plots.

Crop growth ceased during the last week of April (Figure 5.1), although there was ample water available in the root zone. The reason may have been the sharp increase of the evaporative demand in that period. In the same period the crop was covered with dust caused by a light rain which could be another reason for the plant stress. The crop recovered (adapted) and the long season varieties attained the same crop growth rate as before.

5.2.3 Crop water use

Measured water-use data are also presented in Table 5.3. The results from the off-station sites are based on measurement of only one neutron access tube. The accumulative evapotranspiration of the three wheats and the accumulative evaporation of a bare soil were similar at Tel Hadya over the first 100 days of the growing season (Fig. 5.3). Crop evapotranspiration was dominated by soil evaporation during this period. Soil evaporation was high due to frequent rains. There were 43 days with rainfall in this 100-day period. Rainfall accumulation started at planting time from a base of 48 mm representing the stored moisture from pre-planting rains.

During the last week of April, the daily evapotranspiration dropped sharply (Fig. 5.4), together with the stagnation of dry matter production mentioned above. The crop adapted and reached again a higher daily evapotranspiration, but the dry-land crop did not attain values above 60 percent of the pan evaporation. The crops could almost satisfy the evaporative demand of the atmosphere during the 50 days prior to this stress. Two irrigations shortly after the stress brought the evapotranspiration again to that level, but the leaf senescence could not be stopped and the crop matured.

After the beginning of March, the bare soil continued to evaporate at a fairly constant rate. Evaporation from a fallowed soil leveled off at the end of the summer. Upward movement of moisture in the profile due to evaporation reached into the 70-90 cm layer at that time. During early April the wetting-front went through the 'bottom' of the measured profile and drainage became another component in the water loss of a fallow. Drainage ceased in October (Fig. 5.3). The water loss under fallow (2nd year fallow) during one year equalled almost the total rainfall, an estimated 15 percent of the water loss being attributed to drainage. At the end of the summer, fallow plots had a net storage of 50 mm compared with plots under dry-land Sonalika and NS 2568/2, and 80 mm in comparison with Mexipak plots.

Measurements showed that Mexipak extracted more moisture per soil layer than the other two varieties. The unfertilized treatments extracted moisture from a 130 cm profile. Nitrogen application caused the plants to root deeper, similar to barley. (See Chapter 2). Sonalika and Mexipak extracted moisture to 150 cm and NS 2568/2 took moisture up from 170 cm, but it took less moisture from each layer. Figure 5.5 shows the recharge and discharge pattern in the soil profile under a fallow and crop of Mexipak.

5.3 Climatic data collation

In anticipation of the application of the spring wheat model to the prediction of potential yields of cultivars of differing maturity types through the ICARDA region, work on the collation of climatic data has been continued.

The long-term mean climatic information which was collated in 1977-78 has been extensively checked, and has been expanded by the inclusion of estimates of daylength (photoperiod) and radiation. A copy of this data set for six countries, Iran, Iraq, Jordan, Lebanon, Syria and Turkey, together with explanatory notes, is being prepared for publication.

Daily records of spring temperature and seasonal rainfall for five locations in Syria have been updated to include data from 1974 to 1979. These records now cover a period of 18 years.

In the light of the recommendation of the ICARDA/UNDP Workshop on Soil Water and Nitrogen that detailed data should be acquired for key locations in the Region, and with the support of the high altitude program, records of rainfall, temperature and radiation for key locations in Turkey have been collected.

All data are currently stored on the University of New England (Armidale, N.S.W.) computer system preparatory to transfer to the ICARDA system as soon as it is installed.

5.4 Plans for 1980/81

The trial with the three wheat varieties under a trickle irrigation system will be repeated this year using the same plots. This will ensure a lower nitrogen/water level at the start of the season compared with a fallow. Thus a stronger nitrogen response on development, growth and water-use of the crop can be expected. This will be studied by using two nitrogen levels. Two water levels will be generated, in addition to the dry-land treatment, using the trickle irrigation system. Three replicates will be used per treatment.

The work of the off-station sites, except Khanasser, will be extended since the trial at Tel Hadya did not generate the range in number of kernels per unit area and biomass production that showed in the other three sites. There will be fertilized (optimal) and unfertilized treatments for the three wheat varieties, each with three replications. Growth, development, yield components and moisture use will be measured at regular intervals during the season. Total nitrogen uptake will be determined at final harvest.

Additional studies will be conducted on a small scale at Tel Hadya to find out whether there is potential longer grain filling period for later maturing varieties and to quantify the constraints on grain filling.

It is essential, for simulation of a cropping system with a fallow, to be able to predict accurately the wetting and drying of the soil profile. Hydraulic characteristics of the soil, necessary to model moisture redistribution in the soil profile, will be measured in situ. For this purpose a profile will be saturated with water and covered. The redistribution of soil water will be measured with a neutron probe and tensiometers.

5.5 Conclusions

Increasing temperatures toward the end of the season caused a decrease in maturing differences between wheat varieties. The difference decreased from 34 days at floral initiation to five days at physiological maturity.

Physiological maturity of the longer season varieties occurred despite the presence of adequate soil water to permit further grain growth. This indicates the importance of temperature and evaporative demand conditions in determining the end of the season.

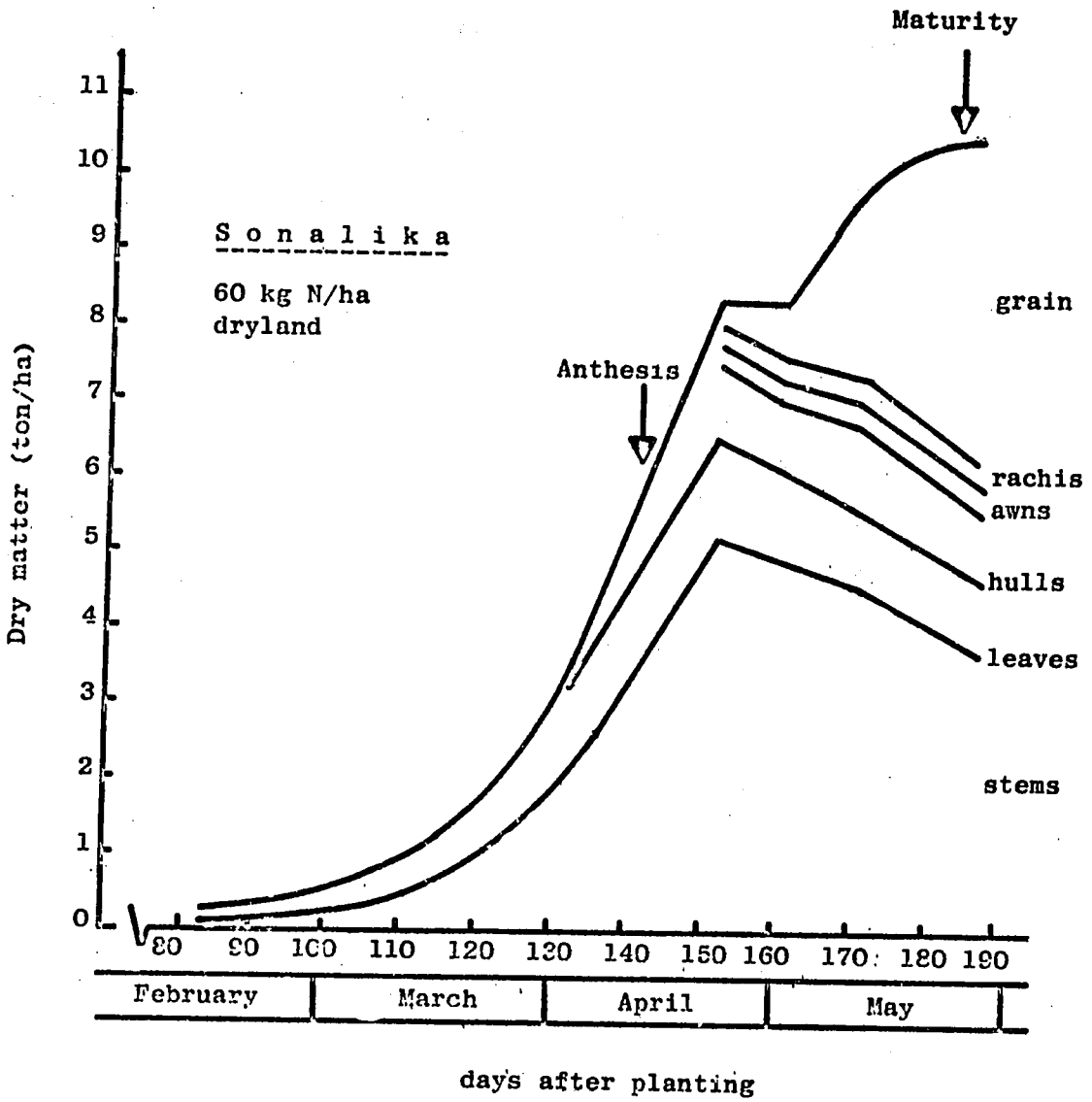
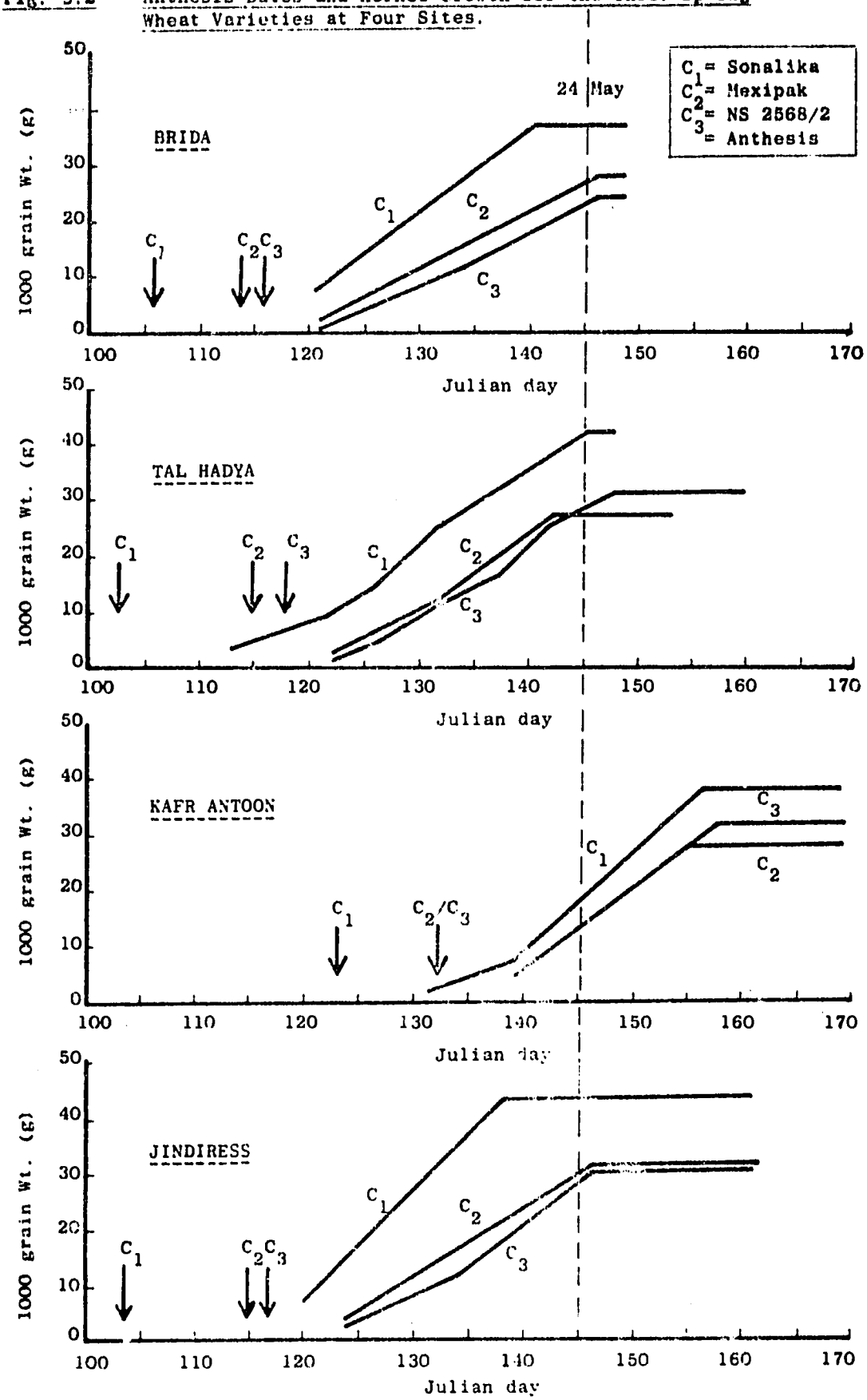


Fig. 5.1 Dry Matter Accumulation and Partitioning of Sonalika During the Season at Tal Hadia.

Fig. 5.2 Anthesis Dates and Kernel Growth for the Three Spring Wheat Varieties at Four Sites.



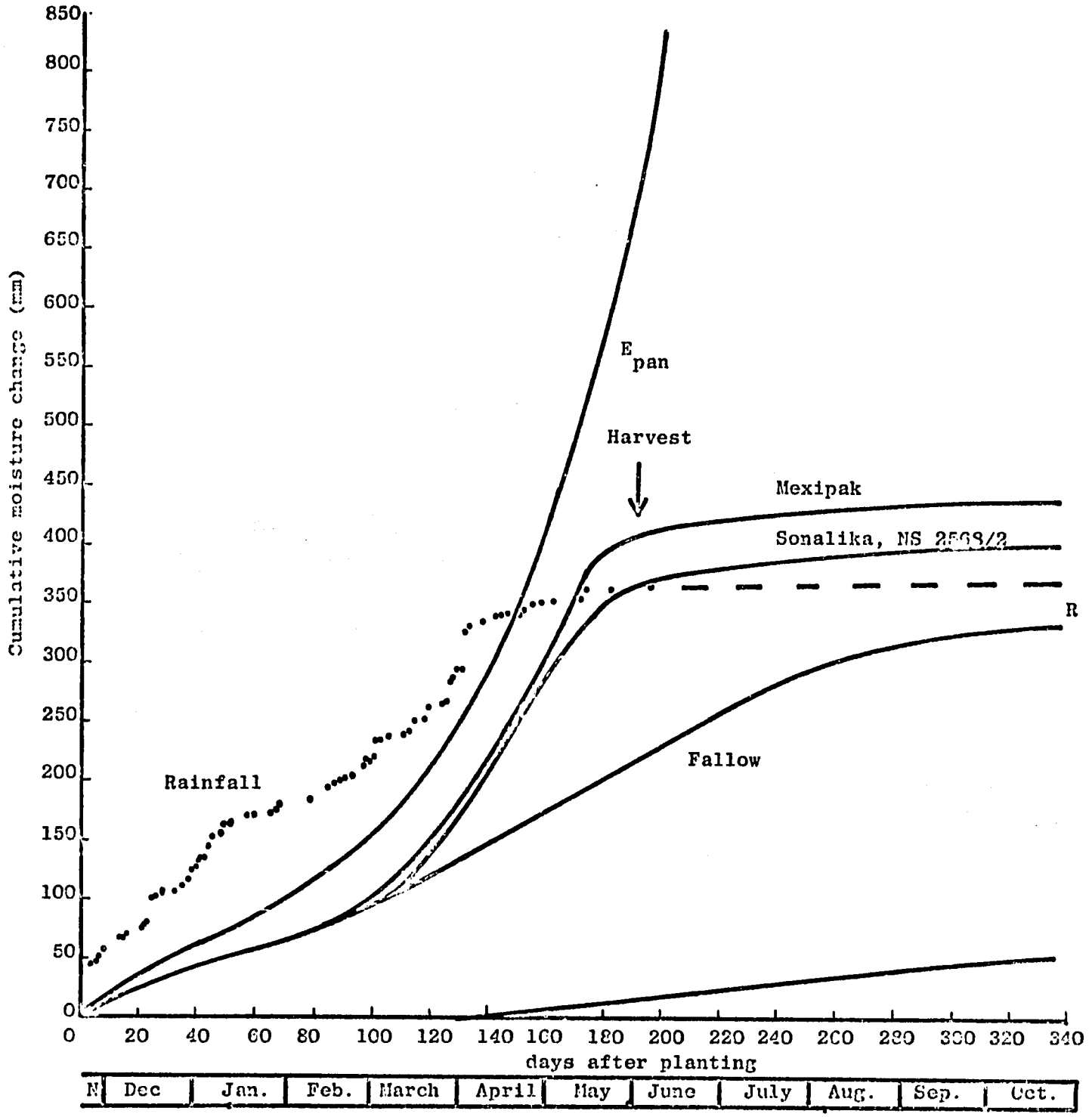


Fig. 5.3 Evapotranspiration of the Three Spring Wheat Varieties Compared with the Evaporation from a Bare Fallow and a Class-A Pan (E_{pan}). D is the Drainage Component of the Moisture Loss under the Fallow and R is Runoff from the Fallow.

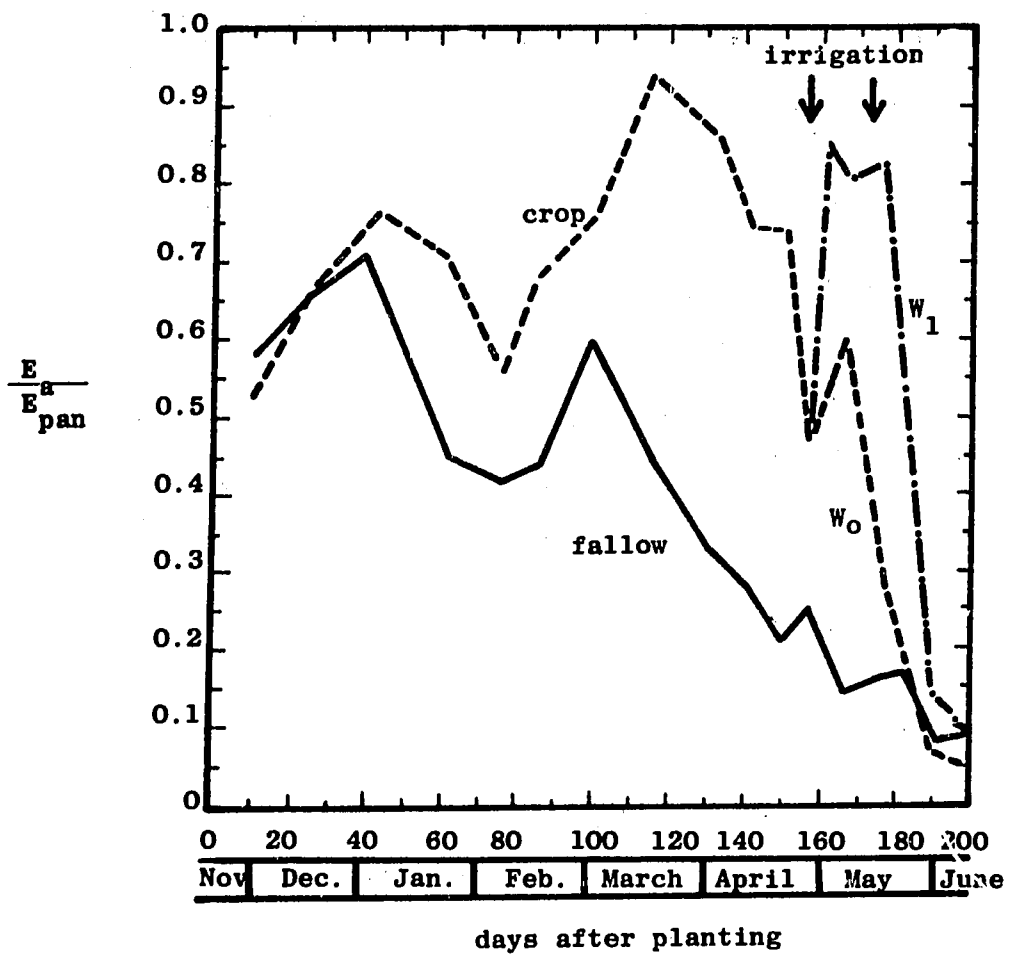


Fig. 5.4 Ratio of Actual Evapotranspiration from Wheat and Fallow (E_a) to Pan Evaporation (E_{pan}) during the Growing Season. W_o is dryland treatment. W_1 is Irrigated Twice.

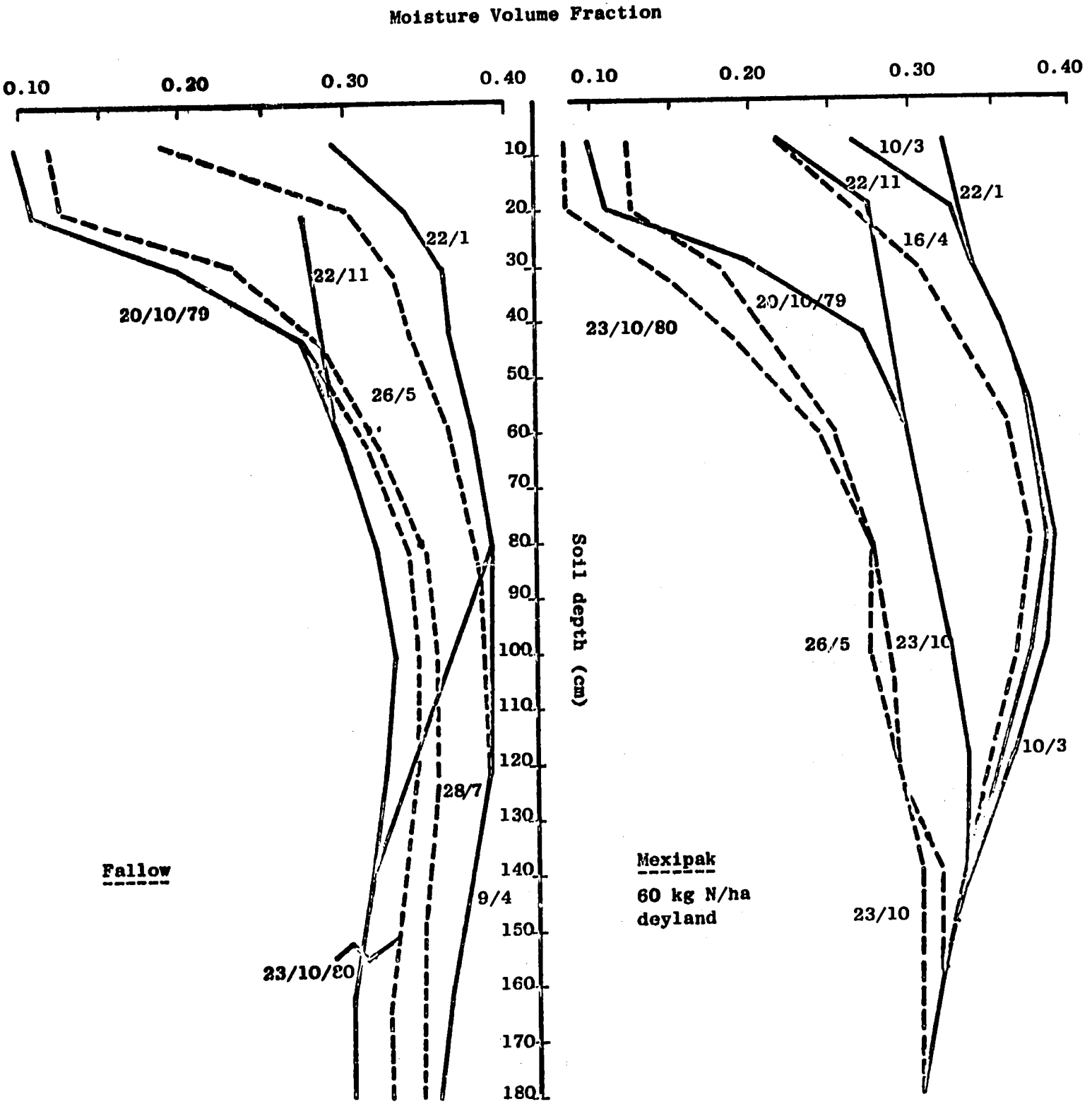


Fig. 5.5 Recharge (———) and Discharge (-----) Pattern in the Soil Profile under a Fallow and Mexipak.

Table 5.1. Timing of Phenological Events of Three Wheat Varieties Sown 22 November 1979 at Tel Hadya. Calendar Days and Growing Degree Days (GDD, Base 0°C) After Planting Are Given

Phenological Event	Timing	Sonalika (Early)	Mexipak (Medium)	NS 2568/2 (Late)
Floral Initiation	Date	21 Jan.	13 Feb.	24 Feb.
	Days after planting	60	83	94
	GDD after planting	472	611	702
Heading	Date	4 Apr.	17 Apr.	23 Apr.
	Days after planting	134	147	153
	GDD after planting	1149	1324	1425
Anthesis	Date	12 Apr.	24 Apr.	27 Apr.
	Days after planting	142	154	157
	GDD after planting	1269	1444	1487
Maturity	Date	22 May	24 May	27 May
	Days after planting	182	184	187
	GDD after planting	1959	1998	2068

Table 5.2 Some Characteristics of Source and Sink Sizes from Three Wheat Varieties Grown on Fertilised Plots at Tel Hadya

Source	SONALIKA	MEXIPAK	NS 2568/2
Number of leaves/mainstem	8.3	9.8	10.2
Leaf area/mainstem (cm^2)	132	222	229
Number of visible tillers/mainstem	0.6	1.9	2.2
Surviving tillers/mainstem	0.35	0.44	0.31
Sink			
Number of spikelets/spike	13.9	19.0	20.1
Number of florets/spike	64.4	92.4	94.9
Number of fertile florets/spike	48.3	64.2	69.0
Number of kernels/spike	31.7	42.9	36.5

Table 5.3 **Plant Growth and Water Use Data at 4 Sites from Unfertilized (N_o) and Fertilized (N_1) Plots with (W_1) or without (W_o) Irrigation**

Location	Nitrogen / Water		Sonalika (Early)		Mexipak (Medium)		NS 2568/2 (Late)	
			N_o	N_1	N_o	N_1	N_o	N_1
T. HADYA	W_o	Tot.Biol. Yld.1/ (g/m²)	1185	1018	1271	1256	1079	1176
		Tot.Grain Yld.2/ (g/m²)	471	400	441	409	359	367
		Harvest index	0.40	0.39	0.35	0.33	0.33	0.31
		1000 gr.wt. (g)	40.8	40.7	29.7	27.3	32.3	31.0
		Kernels/m² (x10³)	11.6	9.8	14.9	15.0	11.1	11.8
		Spikes/m²	355	318	340	359	328	355
		Water use (mm)	378	365	380	408	351	368
	W_1 3/	Tot.Biol. Yld. (g/m²)	934	1212	1127	1305	1105	1217
		Tot.Grain Yld. (g/m²)	376	496	432	488	407	444
		Harvest index	0.40	0.41	0.38	0.37	0.37	0.36
		1000 gr.wt. (g)	46.4	46.5	36.2	34.9	37.0	35.7
		Kernels/m² (x10³)	8.1	10.7	11.9	14.0	11.0	12.4
		Spikes/m²	285	332	294	321	316	331
		Water use (mm)	405	429	449	481	434	465
JINDIRESS	W_o	Tot.Biol. Yld. (g/m²)	-	945	-	630	-	584
		Tot.Grain Yld. (g/m²)	-	320	-	210	-	207
		Harvest index	-	0.34	-	0.33	-	0.35
		1000 gr.wt. (g)	-	44.2	-	32.4	-	31.2
		Kernels/m² (x10³)	-	7.2	-	6.5	-	6.6
		Spikes/m²	-	330	-	257	-	227
		Water use (mm)	-	361	-	399	-	418
K. ANTOON	W_o	Tot.Biol. Yld. (g/m²)	-	850	-	991	-	991
		Tot.Grain Yld. (g/m²)	-	325	-	351	-	356
		Harvest index	-	0.38	-	0.35	-	0.36
		1000 gr.wt. (g)	-	37.3	-	27.3	-	31.5
		Kernels/m² (x10³)	-	8.7	-	12.9	-	11.3
		Spikes/m²	-	348	-	329	-	323
		Water use (mm)	-	na	-	na	-	na
BRIDA	W_o	Tot.Biol. Yld. (g/m²)	-	657	-	572	-	432
		Tot.Grain Yld. (g/m²)	-	229	-	200	-	150
		Harvest index	-	0.35	-	0.35	-	0.35
		1000 gr.wt. (g)	-	37.3	-	28.5	-	24.6
		Kernels/m² (x10³)	-	6.2	-	7.0	-	6.1
		Spikes/m²	-	342	-	251	-	244
		Water use (mm)	-	272	-	287	-	254

1/ Above ground parts.

2/ Zero percent moisture.

3/ Highest irrigation level (118 mm).

Table 5.4 Biomass Production (g/m^2) and Partitioning of Dryland (W_o) and Irrigated (W_1) Fertilized Crops in Relation to Anthesis and Harvest

	SONALIKA		MEXIPAK		NS 2568/2	
	W_o	W_1	W_o	W_1	W_o	W_1
1. Total dry matter at anthesis	570	570	730	730	800	800
2. Total dry matter at harvest	1020	1210	1255	1305	1175	1215
3. Post-anthesis production, (2) - (1)	450	640	525	575	375	415
4. Grain yield	400	495	410	490	365	445
5. Post-anthesis non-grain prod., (3) - (4)	50	145	115	85	10	-30

CHAPTER 6

AGRONOMY TRIALS

6.1 Introduction

The main aims of these trials were to investigate the effects of the most important cultural practices which can be controlled by farmers, and study the interactions between these practices and different environments, initially at the sub-sites around Aleppo. The practices which were studied were selected after discussions with other researchers at ICARDA and after consideration of information from the Village Surveys. The factors studied included time of sowing, seed rates, methods of sowing, rates of nitrogen (N) and phosphatic (P) fertilizers, and time of application of N. All the trials were conducted on barley (c.v. Beecher), as barley is the most important crop throughout the 200-600 mm rainfall transect, and also is the only crop where one cultivar could be recommended from the driest to wettest zones.

6.2 Materials and methods

Four agronomy experiments were designed, all of them factorials so that the magnitude and importance of interactions could be assessed. The experiments were interlinked with various treatments in common, to enable the results to be related meaningfully. Two replicates of each trial were laid down at each site.

6.2.1 Treatments

The four trials, designated A, B, C and D, were:

A. 2 sowing methods with 2 seed rates and 2 fertilizer rates.

B. 2 or 3 dates of planting with 2 seed rates and 2 fertilizer rates.

Both trials were simple 2^3 of 3 x 2 x 2 factorials.

C. 5 seed rates x 5 N rates, using only 13 specific treatment combinations from the full 5 x 5 factorial.

D. 5 N rates at planting x 5 N rates topdressed at stem elongation x 2 rates of P at planting, using only 26 specific treatment combinations from the full 5 x 5 x 2 factorial.

The levels of these various treatments were as follows:

(1) The two sowing methods in trial A were either a) hand-sowing, over ridges set up at 50 cm spacing with a local cultivar, followed by seed-covering effected by dragging a metal bar with chains along the ridges, or b) drilling the seed with the Oyjord plot planter.

(2) The two seed rates in experiments A and B were either 120 or 180 kgs/ha.

(3) The two fertilizer rates/ha in A and B were either no fertilizer or 60 kgs P_2O_5 + 20 kgs N at planting, followed by 40 kgs N topdressed at the start of stem elongation.

(4) Trials A, C and D, and the first date of planting in B were all planted as near the start of the rains as possible at each site. In trial B, the second and third plantings were done approximately three or six weeks after the first - the exact interval depended on climatic conditions and equipment availability, and in fact the third planting could be done at only two sites.

(5) The Seed rates in trial C were 30, 60, 90, 120 and 150 kgs/ha, and the N rates were 0, 20, 40, 60 and 80 kgs/ha. The N was split, with some being applied at planting and the balance topdressed, as detailed in the list of treatment combinations shown in Table 6.1.

(6) In trial D the N rates were 0, 10, 20, 30 and 40 kgs/ha applied either at planting or as topdressing, and the P rate was either 0 or 60 kgs/ha P_2O_5/ha; the treatment combinations are shown in Table 6.2.

6.2.2 Management

The management of the trials was kept as uniform as possible, and corresponded closely with that used in the other SWAN trials. All four trials were laid down at each of the four sub-sites and also at Tel Hadya. All were located on land which had been either fallow or summer crops in the previous season, to correspond with local practice. Plots measured 12.5 m x 6.3 m, and were planted with a 12 m row Oyjord planter, set at 17.5 cm row spacing, using three passes per plant. The phosphate and part of the nitrogen was drilled with the seed. At emergence, one meter row lengths were marked at four representative places in every plot, and these lengths were used for counts of emergence, spike formation and for measuring total dry matter production. At harvest, one meter squares were cut at three representative places in

Hand harvesting near Aleppo.

Hege plot combine harvesting barley at Tel Hadya.

each plot, and were used for estimates of grain yields, and sub-samples for determining 1,000 grain weights. From these measured data, values were calculated for spikes/plant, kernels/spike, kernel no./ha and harvest index.

All the weights were measured on an oven-dry basis, and grain yields were not corrected to 15 percent moisture content. Total dry-weights measured at harvest may be slightly less than the maximum total dry matter actually produced due to the loss of dry leaves and awns before harvest. Thus the harvest index values could be slightly higher than if measured at maximum dry weight.

6.2.3 Growing conditions

Rainfall during the seasons was above average, and it was favourably distributed (see Section 1). Germination was good at all sites except Brida, where it was slightly poorer. Early growth was visibly enhanced by P, and slightly reduced by seed-bed N. A severe frost at Kafr Antoon in mid-January killed the first 3-4 leaves, but the plants recovered well. Voles (*Microtus socialis*) caused damage by grazing in spots at the three wetter sites, in January and February, and a vigorous poison-baiting campaign was required to control them. Weed competition was virtually non-existent at Khanasser and Brida, but caused some problems at the other sites; spraying with Faneron was done quite effectively at Tel Hadya and Kafr Antoon, while hand-weeding was done at Jindiress. Rain and wind caused severe lodging at Tel Hadya on April 3rd, just at heading. Moisture stresses were not noticeably serious, even in the later stages of growth at the drier sites, and kernels filled well and weights were above average.

6.3 Results

The results of trials A and B will be presented together first, followed by those for trials C and D.

6.3.1 Results of trials A and B

The results of trial A are summarised in Tables 6.3, 6.4 and 6.5 and those of trial B in Tables 6.6, 6.7 and 6.8. The tables have been designed to show how the various treatments have influenced the barley crop from emergence through to harvest, and thus show which of the components of yield are most significantly affected by the factors studied.

(1) Table 6.3 summarises the effect of hand sowing on ridges compared with drilling by Oyjord. Overall, drilling increased yield significantly (at the 5 percent level) by 0.24 tons/ha, or 9 percent. The trend was consistent at all sites, though not significant at any individual one. Total dry matter production was similarly affected.

Considering the various yield components, drilling increased the number of plants which emerged, especially at the dry sites, but there was a consistent trend for drilling to decrease the spikes per plant, and this reduced any difference in the spike no./ha caused by sowing methods. There were minor, non-significant variations in kernel no./spike, and these contributed to the kernel no./ha being consistently greater for the drilled plots. Drilling affected kernel weights only at Khanasser, where it caused a significant increase.

(2) Table 6.4 shows that the 120 kg/ha seed rate on average yielded significantly more (at the 5 percent level) than 180 kg/ha, although individual sites again showed no significant differences. These seed rates caused large differences in most parameters, and these effects were consistent over sites. The high seed rate gave a higher plant population at emergence, as expected. However, after emergence, the lower seed rate produced more spikes per plant, more kernels per spike, and heavier kernels, and these components acted together to give slightly higher final yields.

Table 6.7 shows that exactly the same relationship prevailed in trial B which included the same two seed rates.

(3) Table 6.5 summarises the effects of applying fertilizer (60 kg N + 60 kg P_2O_5 per ha) in trial A, and can similarly be considered simultaneously with Table 6.8 from trial B. Fertilizer increased yields significantly overall, but the magnitude and significance of the increases varied from site to site. The higher yields were due mainly to increases in the spikes per plant, and partly to increases in the kernels per spike. Plant emergence and kernel weights were hardly affected.

(4) Table 6.6 indicates that different dates of planting in trial B did not have very large effects on yields in the 1979/80 season; only at Jindiress was the second planting significantly poorer than the first, while at Tel Hadya the second planting was superior. The kernel weights were reduced by later planting, while the kernels per spike were increased.

6.3.2 Some economic implications of the results from trials A & B

1. The average increase of 0.24 tons/ha gained by drilling the seed is worth around 144 SL in Syria at current prices. To attain this increase of about nine percent in yields, farmers would need not only to buy or hire a seed drill, but also to modify their land preparation techniques to produce a flat and more unfirom seedbed. The present system is to make ridges with a tractor-drawn cultivator or an animal-drawn plough, then broadcast the seed and fertilizer over the ridges, and finally cover the seed by splitting the ridges or harrowing with an iron bar (taban).

2. The lower seed rate of 120 kg/ha yielded on average over both trials 0.2 tons/ha more than the 180 kg/ha rate, which would give 120 SL extra income; this would also save 60 kg seed/ha, worth 36 SL, giving a total benefit of 156 SL/ha, for no apparent extra cost.

3. The fertilizer used in these trials cost a total of 220 SL, and yielded an increase of 0.7 tons grain per ha on average, worth 420 SL. The size of increase varied greatly from place to place, ranging from an average of one ton/ha worth 600 SL at Kafr Antoon, down to no significant effect at Tel Hadya.

6.3.3 Results from trial C

The results of trial C are shown in Tables 6.9 to 6.15 and are presented in the form of regression equations with linear, quadratic and linear x linear interaction terms. The adjusted mean yield represents the yield at the centre of the ranges of treatments applied, and may differ slightly from the arithmetic mean yield, due to any quadratic effects. The statistical significances of the regression coefficients are tested by an F-test against the error mean square, and the levels of significance attained are shown. In working out predicted values for particular treatments within the ranges studied, only significant regression coefficients were used.

In trial C, the main effects of the 2 factors will be considered separately; there were, in any case, few significant interactions.

Increasing the seed rate, S, had the following significant effects on the directly measured parameters:-

(1) It increased the number of emerged plants (as expected) and the number of spikes/ha.

(2) It decreased kernel weights at all sites, although the actual magnitude of the decrease was small.

(3) It increased grain yields at Khanasser, but decreased them at Kafr Antoon and Tel Hadya.

(4) It increased total dry matter produced at Khanasser, and reduced it at Kafr Antoon.

With regard to the derived parameters, increasing the seed rate reduced both the number of spikes per plant, and the number of kernels per spike, but its effect on the final number of kernels/ha was variable; at Khanasser kernel numbers were considerably increased, whereas at Tel Hadya, they were much reduced.

The regression coefficients in Tables 6.9 to 6.13 were used (wherever significant) to predict the values for the directly measured parameters, shown in Tables 6.14 and 6.15 and then these predicted values were used to calculate the derived parameters such as spikes/plant etc. for these same two tables. Table 6.14 shows the effects of sowing 30 and 150 kgs seed/ha, and indicates how and when compensation occurred and its relative importance at each site.

Increasing the N application rate had the following significant effects on the directly measured parameters:

(1) It increased the number of emerged plants/ha at Jindiress.

(2) It increased spike nos/ha at Jindiress and Kafr Antoon.

(3) It increased kernel weights at Jindiress, but decreased them at the other four sites (non-significantly at Kafr Antoon).

(4) It increased grain yields and total dry matter at Jindiress, Kafr Antoon and Brida, but reduced them at Khanasser.

With regard to the derived parameters, N increased spikes per plant only at Kafr Antoon. It increased kernels per spike at Brida, but had little effect on this at other locations. N increased kernel numbers considerably at all sites except Khanasser, where it caused a slight reduction.

Table 6.15 shows the values predicted for 0 and 80 kgs N/ha which illustrate the above findings.

6.3.4 Results from trial B

The results of trial D are shown in Tables 6.16 to 6.22, and they are presented in the same way as those of trial C, in the form of regression equations. In this trial, there were virtually no interactions between N and P; also the two times of N application did not affect yields differently. Therefore, the two times of application have been considered together, independently of P, in the subsequent discussion.

Increasing the N application rate had the following significant effects on the directly measured parameters:

(1) It increased number of emerged plants/ha at Jindiress, and decreased it at Khanasser.

(2) It increased spike no./ha at Jindiress and Brida.

(3) It increased kernel weights at Jindiress, but decreased them at other locations, (non-significantly at Kafr Antoon).

(4) It increased grain yields and total dry weights at Jindiress, Kafr Antoon and Brida, but decreased them at Khanasser.

With regard to the derived yield paramaters, N increased spikes/plant at Brida and Khanasser. It increased kernels/spike and kernel no./ha at all locations except Khanasser, where it decreased them.

These results are illustrated in Table 6.21, which shows the predicted yield paramaters for the highest and lowest N rates in trial D. These results correspond closely with the N results obtained in trial C.

Applying 60 kgs P_2O_5/ha in the seed-bed had the following significant effects on the directly measured parameters:

(1) It decreased number of emerged plants/ha at Khanasser only.

(2) It increased spike nos/ha at Kafr Antoon and Tel Hadya.

(3) It decreased kernel weights at Jindiress, but decreased them at Khanasser.

(4) It increased grain yields and total dry matter at all sites except Jindiress.

With regard to the derived yield parameters, phosphatic fertilizer increased spikes per plant at Kafr Antoon, Tel Hadya and Khanasser, and increased kernels per spike at Brida and Khanasser. It increased the total kernel no./ha at all locations, especially at Khanasser, but it increased harvest index only at Khanasser.

Table 6.22 summarises the predicted yield parameters for P responses, and illustrates the above effects quite clearly.

6.3.5 Some implications of the results of trials C and D

1. The finding that seed rates as low as 30 kgs/ha were as good as "normal" rates of 100-180 kgs indicates that they may be a possibility for reducing seed rates considerably, thereby saving grain. However, this needs to be verified for drier seasons, and for other barley varieties - Beecher is a 6-row type, and may have more ability than local 2-row varieties to compensate for low seed rates by increasing tillering, kernels per spike and kernel weights. In addition, the purity and germination capacity of local seed is variable, while the Beecher seed used in the trials was 100 percent pure and had a germination of 95 percent. Nevertheless, a saving of say 50 kg/ha of seed worth about 30 SL merits consideration.

2. There was no difference in yield between applying the N at planting or as a topdressing at the beginning of stem extension. N at planting did not improve early growth and in fact appeared to delay emergence slightly. One of the risks of applying N at the later stage is the increased probability of little or no rainfall. If that is the case then N will probably be ineffective anyway. The advantage of topdressing is that the risk-averse farmer postpones his decision on nitrogen application until he has an opinion of the quality of the season. This gives the farmer a better chance to assess the likelihood of a good fertilizer response, and a better basis for deciding on Nitrogen use. In a dry year he will not add any Nitrogen at all.

3. Examination of the N responses in C and D show that they were quite large and consistent at Jindiress, Kafr Antoon and Brida, but non-existent at Tel Hadya, and negative at Khanasser. The positive responses ranged from 12-18 kgs of grain per kg N. At two SL/kg of Nitrogen and 0.60 SL/kg of grains the response to one kg of N has to exceed 3.3 kg grain to pay for the fertilizer, and preferably should exceed 6.6 kgs to make fertilizer use an attractive investment. Hence Nitrogen appeared very profitable, at three of these sites.

The implications of the negative N response at Khanasser are discussed further in the soil fertility section of this report, where soil analysis data are presented.

4. P responses were all positive and ranged from 4 to 14 kgs of grain for one kg P_2O_5 at the four responsive sites. With P_2O_5 costing 1.66 SL per kg, a yield increase of 2.77 kg grain is needed to pay for an extra kilogram of fertilizer. Thus P use was marginally attractive at three sites, and a better investment at Khanasser.

5.4 Summary and conclusions

These trials indicated that combine drilling led to only a small increase in yield compared with a typical local method of hand-sowing. Low seed rates increased yields slightly at two sites, and decreased them at only one site, hence there appears to be a considerable need for more detailed study of the relationships between seed rates, tillering, spike numbers, kernel setting and filling, and yields, in these environments. Fertilizer responses varied, but large and profitable responses were obtained at most of the sites.

To follow up these results from the first year's work, a series of multifactorial trials have been initiated at the same sites in the second year's programme. Within the two main treatments of hand-sowing versus drilling, combinations of five seed rates, five N rates and five P rates have been laid down. In a parallel trial detailed physiological and water use measurements are being carried out on the treatment combinations 0 N + 0 P, /0 N + 30 P, 60 N + 60 P, 90 N + 90 P, all per ha. In addition, the effects of complete disease control and of foliar nutrition are being investigated on the 90 N + 90 P treatment. These detailed studies are being conducted on plots where the seed is drilled.

Table 6.1. Treatment Combinations for Trial C
Seed Rates x N Rates (kg/ha)

Treatment No.	Seed Rate	N Rate	N Applied	
			At Planting	Topdressed
1	30	0	0	0
2	30	40	20	20
3	30	80	20	60
4	60	20	10	10
5	60	60	20	40
6	90	0	0	0
7	90	40	20	20
8	90	80	20	60
9	120	20	10	10
10	120	60	20	40
11	150	0	0	0
12	150	40	20	20
13	150	80	20	60

These 13 treatments form a modified central composite design, derived from the full 5 x 5 factorial layout, as shown below:-

N Rate kg/ha	Seed Rate kg/ha				
	30	60	90	120	150
0	X	-	X	-	X
20	-	X	-	X	-
40	X	-	X	-	X
60	-	X	-	X	-
80	X	-	X	-	X

Table 6.2. Treatment Combinations for Trial D
Time of N Application x P (kg/ha.)

Treatment No.	N Applied		P_2O_5	Treatment No.	N Applied		P_2O_5
	At Planting	Topdressed			At Planting	Topdressed	
1	0	0	0	14	0	0	60
2	0	20	0	15	0	20	60
3	0	40	0	16	0	40	60
4	10	10	0	17	10	10	60
5	10	30	0	18	10	30	60
6	20	0	0	19	20	0	60
7	20	20	0	20	20	20	60
8	20	40	0	21	20	40	60
9	30	10	0	22	30	10	60
10	30	30	0	23	30	30	60
11	40	0	0	24	40	0	60
12	40	20	0	25	40	20	60
13	40	40	0	26	40	40	60

These 26 treatments (13 N x 2 P) are analogous to those in trial C and the design is similarly a modified central composite version of a 5x5 factorial.

Table 6.3 The Effects of Two Sowing Methods on Yields and Yield Components In Sowing Methods Trials, 1979/80

Site	Treatment - Sowing Method	Emerged Plants Millns. per Ha.	Spikes per Plant	Spikes Millns per Ha.	Kernels per Spike	Kernels No. Millns. per Ha.	Wt per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	Hand	3.31	1.10	4.18	13.1	54.7	43.9	2.40	5.70	0.42
	Drill	4.03	1.05	4.24	13.8	58.6	44.0	2.58	6.25	0.41
KAFR ANTOON	Hand	3.66	1.15	4.21	17.7	74.4	41.1	3.06	7.15	0.43
	Drill	3.33	1.11	3.76^{x}	21.8	32.1	41.9	3.44	7.96	0.42
TEL HADYA	Hand	3.78	1.16	4.40	16.8	74.1	46.4	3.44	8.28	0.42
	Drill	3.97	1.09	4.34	19.3	83.8	45.1	3.78	9.26	0.41
BRIDA	Hand	2.06	1.43	3.04	16.5	50.2	40.8	2.05	4.53	0.45
	Drill	3.07^{x}	1.14^{xx}	3.50	14.5	50.7	39.4	2.07	4.73	0.44
KHANASSER	Hand	2.65	1.14	3.02	19.7	59.5	39.8	2.37	5.01	0.54
	Drill	3.69^{xx}	1.12	4.15^{xx}	14.7	60.9	43.2^{xx}	2.63	5.40	0.49
MEANS	Hand	3.19	1.18	3.77	16.6	62.7	42.4	2.66	6.13	0.43
	Drill	3.63	1.10^{xx}	4.00	17.0	67.9^{x}	42.7	2.90^{x}	6.72^{x}	0.43
Sites x Tmt. Interaction		x	-	xx	-	-	xx	-	-	-

x = Significant at the 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.4

The Effects of Two Seed Rates on Yields and Yield Components in Sowing Methods Trials, 1979/80

Site	Treatment-Seed Rate Kg/Ha	Emerged Plants Millns. per Ha.	Spikes per Plant	Spikes Millns per Ha.	Kernels per Spike	Kernel No. Millns. per Ha.	Wt. per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	120	3.18	1.13	3.58	16.8	60.2	45.2	2.72	6.46	0.42
	180	4.66^{xxx}	1.04	4.84^{xxx}	10.9^{xx}	52.9	42.7^{x}	2.26	5.49^{x}	0.41
KAFR ANTOON	120	2.82	1.21	3.41	23.9	81.3	42.2	3.43	7.80	0.44
	180	4.22^{xxx}	1.08	4.56^{xxx}	16.5^{xx}	75.2	40.8	3.07	7.31	0.42^{x}
TEL HADYA	120	2.88	1.24	3.58	22.3	79.9	46.8	3.74	8.70	0.43
	180	4.87^{xxx}	1.06^{xx}	5.16^{xx}	15.1^{xxx}	77.8	44.7^{x}	3.48	8.84	0.39^{x}
BRIDA	120	2.25	1.35	3.04	16.2	49.2	41.9	2.06	4.55	0.45
	180	2.89	1.21	3.50	15.4	53.8	38.3^{x}	2.06	4.72	0.44
KHANASSER	120	2.61	1.21	3.15	19.7	61.9	41.5	2.57	5.37	0.48
	180	3.73^{xx}	1.08	4.02^{xx}	14.6^{x}	58.6	41.5	2.43	5.04	0.48
MEANS	120	2.75	1.22	3.35	19.9	66.7	43.5	2.90	6.58	0.44
	180	4.07^{xx}	1.08^{xxx}	4.41^{xxx}	14.5^{xxx}	63.9	41.6^{xxx}	2.66^{x}	6.28	0.42^{xxx}
Sites x Tmt. Interaction		x	-	-	-	-	-	-	-	-

x = Significant at the 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.5 The Effects of Fertilizer on Yields and Yield Components in Sowing Methods Trials, 1979/80

Site	Treatment-Fertilizer 60 Kg N + 60 Kg P_2O_5	Emerged Plants Millns. per Ha.	Spikes per Plant	Spikes Millns. per Ha.	Kernels per Spike	Kernel No. Millns. per Ha.	Wt per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	0	4.00	1.07	4.28	10.9	46.6	43.1	2.01	4.60	0.44
	N + P	3.84	1.08	4.14	16.0^{xx}	66.3	44.8	2.97^{xxx}	7.35^{xxx}	0.40^{x}
KAFR ANTOON	0	3.50	1.07	3.76	17.1	64.2	41.6	2.67	5.97	0.45
	N + P	3.54	1.19	4.21^{x}	22.0^{x}	92.5	41.4	3.83^{xx}	9.14^{xx}	0.42^{xx}
TEL HADEA	0	4.03	1.11	4.47	17.0	76.2	47.0	3.58	8.35	0.43
	N + P	3.71	1.15	4.27	19.1	81.4	44.7^{xx}	3.64	9.19	0.40^{x}
BRIDA	0	2.56	1.22	3.12	12.2	38.1	40.7	1.55	3.28	0.47
	N + P	2.57	1.33	3.42	19.0	65.1	39.5	2.57^{x}	5.99^{xx}	0.43^{x}
KHANASSER	0	3.19	1.10	3.51	16.3	57.2	41.4	2.37	4.86	0.49
	N + P	3.16	1.16	3.66	17.3	63.2	41.6	2.63	5.55	0.47
MEANS	0	3.46	1.11	3.83	14.8	56.8	42.8	2.43	5.41	0.45
	N + P	3.37	1.17^{xx}	3.94	18.8^{xxx}	74.0^{x}	42.3	3.13^{x}	7.45^{x}	0.42^{xxx}
Sites x Tmt. Interaction		-	-	-	-	xx	x	xx	x	-

x = Significant at 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.6

The Effects of Time on Planting on Yields, and Yield Components in Date of Planting Trials, 1979/80

Site	Treatment—Date of Planting. Date	Emerged Plants, Millns. per Ha.	Spikes per Plant	Spikes Millns. per Ha.	Kernels per Spike	Kernel No. Millns. per Ha.	Wt per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	Nov 24	3.74	1.06	3.95	13.2	52.0	42.5	2.21	4.99	0.44
	Dec 17	3.53	1.08	3.83	12.2	46.8	40.8xx	1.91xx	4.53	0.42
KAFR ANTOON	Nov 6	3.45	1.26	4.36	15.7	68.2	44.4	3.03	7.30	0.42
	Dec 4	3.64	1.03	3.75	21.0x	78.8	42.9xx	3.38	7.58	0.45
	Dec 25	4.11	1.03	4.25	15.5	65.9	39.0	2.57	5.94	0.43
TEL HADYA	Nov 21	4.26	1.06	4.50	16.2	73.0	47.0	3.43	8.96	0.38
	Dec 13	4.02	1.05	4.21	21.1xx	89.0xx	45.6xxx	4.06x	9.87	0.41
	Jan 3	4.14	0.99	4.11	21.2	87.0	41.6	3.62	8.18	0.44
BRIDA	Nov 10	2.98	1.12	3.34	14.5	48.5	40.2	1.95	4.37	0.45
	Dec 9	3.65	1.05	3.85	14.4	55.4xx	35.4xxx	1.96	4.33	0.45
KHANASSER	Nov 14	3.75	1.07	4.00	15.2	60.9	41.4	2.52	5.57	0.45
	Dec 11	2.42xxx	1.18	2.85xx	17.4	49.6	37.5x	1.86	4.34	0.43
MEANS 5 Sites	Early	3.64	1.11	4.03	15.1	61.0	43.1	2.63	6.24	0.42
	Medium	3.45	1.07	3.70	17.6	64.9	40.5x	2.63	6.13	0.43
Sites x Tmt. Interaction for 5 Sites		xxx	x	xx	-	xx	x	-	-	xx
MEANS KAFR ANTOON + T. HADYA	Early	3.86	1.15	4.43	16.0	70.7	45.7	3.23	8.13	0.40
	Medium	3.83	1.04	3.98	21.0	84.2	44.2	3.72	8.73	0.43
	Late	4.13	1.01	4.18	18.4	76.9	40.3	3.10	7.06	0.44

x = Significant at the 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.7

The Effects of Two Seed Rates on Yields and Yield Components in Date of Planting Trials, 1979/80

(Averaged Over First & Second Dates of Planting at all sites)

Site	Treatment - Seed Rate Kg/Ha	Emerged Plants, Millns. per Ha.	Spikes per Plant	Spikes Millns. per Ha.	Kernels per Spike	Kernel No. Millns. per Ha.	Wt per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	120	2.88	1.14	3.27	14.8	48.4	42.5	2.06	4.72	0.44
	180	4.40^{xxx}	1.03	4.51^{xx}	11.1^{xx}	50.2	40.8^{x}	2.05	4.82	0.43
KAFR ANTOON	120	2.82	1.27	3.59	21.1	75.9	44.0	3.34	7.77	0.43
	180	4.27^{xxx}	1.06	4.52^{xx}	15.7	70.9	43.3	3.07	7.11	0.43
TEL HADYA	120	3.13	1.17	3.65	22.4	81.8	47.2	3.86	9.50	0.41
	180	5.15^{xxx}	0.98^{x}	5.06^{xxx}	15.8^{xxx}	79.9	45.3	3.62	9.34	0.39
BRIDA	120	2.73	1.09	2.98	17.0	50.6	38.9	1.97	4.30	0.46
	180	3.90^{xx}	1.08	4.21^{xx}	12.6^{x}	52.9	36.7	1.94	4.39	0.44^{xxx}
KHANASSER	120	2.50	1.18	2.96	19.4	57.3	40.3	2.31	5.07	0.46
	180	3.67^{xx}	1.06^{x}	3.89^{xx}	13.8^{x}	53.6	38.6	2.07	4.84	0.43^{x}
MEANS	120	2.81	1.17	3.29	19.3	63.6	42.6	2.71	6.27	0.43
	180	4.28^{xxx}	1.04^{x}	4.44^{xxx}	14.0^{xxx}	62.2	41.0	2.55	6.10	0.42
Sites x Tmts Interaction		x	-	-	-	-	-	-	-	-

x = Significant at the 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.8

The Effects of Fertilizer on Yields and Yield Components in Date of Planting Trials, 1979/80

(Averaged Over First & Second Dates of Planting at all Sites)

Site	Treatment-Fertilizer 60 Kg N + 60 Kg P_2O_5	Emerged Plants, Millns. per Ha.	Spikes per Plant	Spikes Millns. Per Ha.	Kernels per Spike	Kernel No. Millns. per Ha.	Wt per Kernel m.g.	Grain Yield, Tonnes per Ha.	Total Dry Wt. Tonnes per Ha.	Harvest Index
JINDIRESS	0	3.86	1.05	4.04	8.9	36.1	40.7	1.47	3.34	0.44
	N + P	3.41	1.10	3.74	16.6^{xxx}	62.0^{xxx}	42.6^{xx}	2.64^{xxx}	6.20^{xxx}	0.43
KAFR ANTOON	0	3.54	1.06	3.76	17.1	64.1	43.2	2.77	6.26	0.44
	N + P	3.55	1.23	4.36^{x}	18.9	82.3	44.2^{x}	3.64^{x}	8.62^{x}	0.42^{x}
TEL HADYA	0	4.18	1.00	4.17	18.9	78.9	46.5	3.67	8.59	0.43
	N + P	4.10	1.11	4.54	18.5	84.1	46.0	3.87	10.24	0.38^{x}
BRIDA	0	3.50	1.07	3.76	9.2	34.6	38.4	1.33	2.88	0.46
	N + P	3.13	1.09	3.42	20.1^{xxx}	68.9^{xxx}	37.3	2.57^{xxx}	5.81^{xxx}	0.44^{xxx}
KHANASSER	0	3.27	1.10	3.59	13.2	47.3	38.9	1.84	4.17	0.44
	N + P	2.90	1.12	3.26	19.5^{xx}	63.5^{x}	40.0	2.54^{x}	5.74^{x}	0.45
MEANS	0	3.67	1.05	3.86	13.9	53.5	41.5	2.22	5.05	0.44
	N + P	3.42	1.13^{x}	3.86	18.8	72.4^{x}	42.0	3.04^{x}	7.32^{xx}	0.42
Sites x Tmt. Interaction		-	-	-	xx	xx	-	x	-	xx

x = Significant at the 5 % level; xx = 1 %; xxx = 0.1 %.

Table 6.9. Effects of Seed Rates & N Fertilizer on Plant No.

(Millns/ha)

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TAL HADYA	BRIDA	KHANASSER
Mean		2.17	2.16	2.35	1.78	2.19
S		.67^{xxx}	.69^{xxx}	.81^{xxx}	.51^{xxx}	.72^{xxx}
N		.42^{xx}	.01	.01	.00	.01
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Trmts.	9	26.61	28.60	37.98	15.43	29.48
S	1	25.39^{xxx}	26.77^{xxx}	37.02^{xxx}	14.56^{xxx}	29.23^{xxx}
N	1	.77^{xx}	0.12	0.23	.00	0.13
Lack of fit	7	0.45	0.71	0.73	0.87	0.12
Error	15	0.94	1.05	3.84	0.70	1.00

$$Y = \text{Mean} + b_s.S + b_n.N$$

Notes:- 1) Mean is the arithmetic mean, as quadratic effects were not incorporated in this analysis only.

2) The mean is the value at 90 kgs seed, and 10 kgs N per ha in this table only.

3) 1 Unit for S is 30 kg seed/ha.
1 Unit for N is 10 kg N /ha, in this table only.

4) The range of treatments, in this table only, is:-

Trmt. Code	-2	-1	0	+1	+2
S (kg/ha)	30	60	90	120	150
N (kg/ha)	-	0	10	20	-

Table 6.10 **Effects of Seed Rates & N Fertilizer on Spike No.**

(Millns/ha)

Regression Coeffts.		Individual Sites				
		MINDIRESS	K. ANTOON	TAL HADYA	BRIDA	KHANASSER
Adj.	Mean	2.68	3.70	3.62	2.54	2.69
	S	.39^{xxx}	.33^{xxx}	.34^{xxx}	.32^{xxx}	.52^{xxx}
	N	.22^{xxx}	.35^{xxx}	- .02	.06	- .07
	SN	.01	.00	.00	- .01	.01
	S^2	.00	.00	.00	.00	.00
	N^2	.00	.00	.00	.00	.00
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	5	2.29^{xxx}	2.65^{xxx}	1.38^{xxx}	1.17^{xxx}	3.16^{xxx}
Lack of fit	7	.09	.20	.11	.10	.09
Error	12	.04	.17	.14	.09	.11

$$Y = \text{Adj. mean} + b_s.S + b_n.N + b_{s_n}.S.N. + b_{s^2}.S^2 + b_{n^2}.N^2$$

Notes:- 1) Adjusted mean is the computed value at the centre of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
S (Kg/ha)	30	60	90	120	150
N (Kg/ha)	0	20	40	60	80

3) 1 Unit S = 30 kg/ha and 1 Unit N = 20 kg/ha.

4) Thus, the adjusted mean is obtained with the combination of 90 kgs seed + 40 kgs N/ha.

5) 60 kgs P_2O_5/ha was applied uniformly on all these trials at planting.

Table 6.11 **Effects of Seed Rates & N Fertilizer on Kernel Wt.**

(m.g.)

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TAL HADYA	BRIDA	KHANASSER
Adj.	Mean	46.13	45.19	47.39	43.06	43.81
	S	- 1.18^{xxx}	- 1.04^{xxx}	- 1.19^{xxx}	- .56^{x}	- .49^{x}
	N	.45^{xx}	- .31	- .54^{x}	- .88^{xxx}	- 1.07^{xxx}
	SN	.18^{x}	- .13	.22	.22	.14
	S^2	.00	.01	.00	.00	- .01
	N^2	.00	.00	.00	.00	.01
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	5	18.83^{xxx}	13.93^{xxx}	19.68^{xx}	13.71^{xx}	16.60^{xx}
Lack of fit	7	1.22	1.08	1.24	.60	2.49
Error	12	0.83	1.32	2.32	2.25	1.87

$$Y = \text{Adj. mean} + b_s.S + b_n.N + b_{s_n}.S.N. + b_{s^2}.S^2 + b_{n^2}.N^2$$

Notes:- 1) Adjusted mean is the computed value at the centre of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
S (Kg/ha)	30	60	90	120	150
N (Kg/ha)	0	20	40	60	80

3) 1 Unit S = 30 kg/ha and 1 Unit N = 20 kg/ha.

4) Thus, the adjusted mean is obtained with the combination of 90 kgs seed + 40 kgs N/ha.

5) 60 kgs P_2O_5/ha was applied uniformly on all these trials at planting.

Table 6.12 **Effects of Seed Rates & N Fertilizer on Grain Yields**

T/ha

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TAL HADYA	BRIDA	KHANASSER
Adj.	Mean	2.63	3.79	4.18	2.69	2.77
	S	- .03	- .20^{x}	- .15^{x}	- .04	.12^{xx}
	N	.35^{xxx}	.40^{xxx}	- .01	.24^{xxx}	- .13^{xx}
	SN	- .01	.00	.01	.07^{xx}	.03
	S^2	.02	.05	.01	.00	.00
	N^2	- .03	- .07	.00	.00	.00
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	5	1.46^{xxx}	2.45^{xxx}	0.24	0.79^{xxx}	3.79^{xx}
Lack of fit	7	0.19^{x}	0.30	0.16	0.06	1.20
Error	12	0.05	0.25	0.16	0.06	0.59

$$Y = \text{Adj. mean} + b_s.S + b_n.N + b_{s_n}.S.N. + b_{s^2}.S^2 + b_{n^2}.N^2$$

Notes:- 1) Adjusted mean is the computed value at the centre of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
S (Kg/ha)	30	60	90	120	150
N (Kg/ha)	0	20	40	60	80

3) 1 Unit S = 30 kg/ha and 1 Unit N = 20 kg/ha.

4) Thus, the adjusted mean is obtained with the combination of 90 kgs seed + 40 kgs N/ha.

5) 60 kgs P_2O_5/ha was applied uniformly on all these trials at planting.

Table 6.13 Effects of Seed Rates & N Fertilizer on Total Dry Wt.

T/ha

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TAL HADYA	BRIDA	KHANASSER
Adj.	Mean	5.87	9.31	10.36	6.26	5.72
	S	- .04	- .34^{x}	.00	.00	.26^{xx}
	N	.85^{xxx}	1.29^{xxx}	.05	.65^{xxx}	- .27^{xx}
	SN	- .02	.03	.03	.15^{xx}	.06
	S^2	.00	.01	.00	.00	.00
	N^2	- .01	- .01	.00	.00	.00
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	5	8.34^{xxx}	20.92^{xxx}	0.11	5.32^{xxx}	1.69^{xx}
Lack of fit	7	.95^{x}	1.54	1.03	.43	.56
Error	12	.28	1.28	1.33	.28	.31

$$Y = \text{Adj. mean} + b_s.S. + b_n.N + b_{s_n}.S.N. + b_{s^2}.S^2 + b_{n^2}.N^2$$

Notes:- 1) Adjusted mean is the computed value at the centre of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
S (Kg/ha)	30	60	90	120	150
N (Kg/ha)	0	20	40	60	80

3) 1 Unit S = 30 kg/ha and 1 Unit N = 20 kg/ha.

4) Thus, the adjusted mean is obtained with the combination of 90 kgs seed + 40 kgs N/ha.

5) 60 kgs P_2O_5/ha was applied uniformly on all these trials at planting.

Table 6.14 **Predicted Yield Parameters for Lowest & Highest Seed Rates in 5 S.N. Trials, 1979/1980**

Site	Treatment Seed Rate Kg/Ha	Emerged Plants Millns per Ha	Spikes per Plant	Spikes Millns per Ha	Kernels per Spike	Kernels No. Millns per Ha	Wt per Kernel m.g.	Grain Yield Tonne per Ha	Total Dry Wt. Tonne per Ha	Harvest Index
JINDIRESS	30	0.83	2.29	1.90	28.5	54.2	48.5	2.63	5.87	0.45
	150	3.51	0.99	3.46	17.4	60.1	43.8	2.63	5.87	0.45
KAFR ANTOON	30	0.78	3.90	3.04	29.1	88.5	47.3	4.19	9.99	0.42
	150	3.54	1.23	4.36	18.0	78.7	43.1	3.39	8.63	0.39
TEL HADYA	30	0.73	4.03	2.94	30.6	90.0	49.8	4.48	10.36	0.43
	150	3.97	1.08	4.30	17.5	75.1	45.0	3.38	10.36	0.33
BRIDA	30	0.76	3.17	1.90	32.1	61.0	44.1	2.69	6.24	0.43
	150	2.80	1.46	3.18	20.2	64.2	41.9	2.69	6.24	0.43
KHANASSER	30	0.75	2.20	1.65	34.2	56.5	44.8	2.53	5.20	0.49
	150	3.63	1.03	3.73	18.8	70.3	42.8	3.01	6.24	0.48

Notes:- 1) These predictions are for the middle rate of N, i.e. 40 kgs N/ha.

2) All trials received 60 kgs P_2O_5/ha at planting.

Table 6.15 Predicted Yield Parameters for Lowest & Highest N Rates in 5 S.N. Trials, 1979/1980

Site	Treatment Nitrogen Rate Kg/Ha	Emerged Plants Millns per Ha	Spikes per Plant	Spikes Millns per Ha	Kernels per Spike	Kernels No. Millns per Ha	Wt per Kernel m.g.	Grain Yield Tonne per Ha	Total Dry Wt. Tonne per Ha	Harvest Index
JINDIRESS	0	1.75	1.28	2.24	13.3	41.1	45.2	1.93	4.17	0.46
	80	2.59	1.20	3.12	21.2	66.2	47.0	3.33	7.57	0.44
KAFR ANTOON	0	2.16	1.39	3.00	22.1	66.2	45.2	2.99	6.73	0.44
	80	2.16	2.04	4.40	23.1	101.5	45.2	4.59	11.39	0.39
TEL HADYA	0	2.35	1.54	3.62	23.8	86.2	48.5	4.18	10.36	0.40
	80	2.35	1.54	3.62	24.9	90.3	46.3	4.18	10.36	0.40
BRIDA	0	1.78	1.43	2.54	19.4	49.3	44.8	2.21	4.96	0.45
	80	1.78	1.43	2.54	30.2	76.8	41.3	3.17	7.56	0.42
KHANASSER	0	2.19	1.23	2.69	24.5	65.9	46.0	3.03	6.26	0.48
	80	2.19	1.23	2.69	22.4	60.2	41.7	2.51	5.18	0.48

Notes:- 1) These predictions are for the middle rate of S, i.e. 90 kgs/ha.

2) For emergence counts only, the highest N rate was 20 kg/ha.

3) All trials received 60 kgs P_2O_5/ha at planting.

Table 6.16 The Effects of N and P_2O_5 at Planting on Plant No.

(Millions/ha)

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TEL HADYA	BRIDA	KHANASSER
Adj.	Mean	3.41	2.80	3.10	2.37	2.92
	N_s	0.09^{xx}	0.02	0.01	- 0.07	$- 0.10^{xx}$
	P	0.02	- 0.01	- 0.03	- 0.01	$- 0.11^{x}$
	N_sP	0.00	- 0.01	- 0.06	- 0.02	0.06
	N_s^2	- 0.04	0.06	- 0.01	0.02	- 0.02
Analyses of Variance - Mean Squares & Significance of F-tests						
Source	d.f.					
Regression	4	0.28	0.18	0.12	0.17	0.58^{xx}
Lack of fit	21	0.13	0.13	0.49	0.11	0.14
Error	25	0.11	0.12	0.26	0.12	0.10

$$Y = \text{Adj. mean} + b_{n_s}N_s + b_pP + b_{n_sp}N_sP + b_{n_s^2}N_s^2$$

Notes:- 1) Adjusted mean is the computed value at the centre of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
N Kgs/ha	0	10	20	30	40
P_2O_5Kgs/ha		0		60	

3) 1 Unit N = 10 kg/ha and 1 Unit P = 30 kg/ha.

4) Thus, the adjusted mean is obtained with 20 kgs N, + (hypothetical) 30 kgs P_2O_5/ha, at planting.

5) The N topdressing (N_t) treatment was not applied until after these plant counts were done, hence N_t is not included in this analysis.

6) The seed rate was 120 kg/ha.

Table 6.17 Effects of 2 Times of N Application, and of P on Spike No.

(Millions/ha)

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TEL HADYA	BRIDA	KHANASSER
Adj. Mean		3.50	3.52	3.65	2.69	3.09
	N_s	.10^{xx}	.06	.00	- .04	- .01
	N_t	- .01	.05	.06	.09^{x}	.01
	P	.03	.18^{x}	.19^{xx}	.07	- .03
	$N_s.N_t$	- .00	.01	- .03	.00	.01
	$P.N_s$	.01	.00	- .00	- .00	.06^{x}
	$P.N_t$	.01	- .01	- .03	.05	.01
	N_s^2	- .05	.05	- .06	.02	- .01
	N_t^2	.04	- .01	- .04	- .03	.02
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	8	0.19	0.34	0.44^{x}	0.23	0.08
Lack of fit	17	0.12	0.22	0.26	0.15	0.09
Error	25	0.12	0.22	0.18	0.15	0.07

$$Y = \text{Adj. mean} + b_{n_s}.N_s + b_{n_t}.N_t + b_p.P + b_{n_s n_t}.N_s N_t + b_{pn_s}.PN_s + b_{pn_t}.PN_t + b_{n_s^2}.N_s^2 + b_{n_t^2}N_t^2$$

Notes:-1) Adjusted mean is the computed value at the centres of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
N_s kg/ha (planting)	0	10	20	30	40
N_t kg/ha(topdressed)	0	10	20	30	40
P_2O_5 kg/ha		0		60	

3) Thus, the adjusted mean is obtained with the combination of 20 kgs N + (hypothetical) 30 kgs P_2O_5 both at planting, + 20 kgs N topdressed.

4) The seed rate was 120 kgs/ha.

Table 6.18 Effects of 2 Times of N Application, & of P on Kernel Wt.

(m.g.)

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TEL HADYA	BRIDA	KHANASSER
Adj.	Mean	45.73	44.66	46.14	41.75	41.34
	N_s	$.23^{x}$	- .22	$- .46^{xx}$	$- .41^{xx}$	$- .54^{x}$
	N_t	$.34^{xx}$	- .16	$- .44^{xx}$	- .01	- .20
	P	$- .63^{xxx}$	.39	.44	.02	2.13^{xxx}
	$N_s.N_t$	- .01	- .03	- .10	- .09	.13
	$P\ N_s$	.07	- .09	.30	- .07	.18
	$P\ N_t$	- .13	- .08	.28	- .16	.21
	N_s^2	.01	.10	- .13	.02	- .17
	N_t^2	- .05	.03	.02	- .03	.02
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	8	5.25^{xx}	2.42	9.98^{xx}	3.02	36.30^{xxx}
Lack of fit	17	1.42	2.10	4.62	2.43	4.74
Error	25	1.12	2.53	2.72	1.57	4.53

$$Y = \text{Adj. mean} + b_{n_s}.N_s + b_{n_t}.N_t + b_p.P + b_{n_s n_t}.N_s N_t + b_{pn_s}.PN_s + b_{pn_t}.PN_t + b_{n_s^2}.N_s^2 + b_{n_t^2}.N_t^2$$

Notes:-1) Adjusted mean is the computed value at the centres of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
N_s kg/ha (planting)	0	10	20	30	40
N_t kg/ha (topdressed)	0	10	20	30	40
P_2O_5 kg/ha		0		60	

3) Thus, the adjusted mean is obtained with the combination of 20 kgs N + (hypothetical) 30 kgs P_2O_5 both at planting + 20 kgs N topdressed.

4) The seed rate was 120 kgs/ha.

Table 6.19 Effects of 2 Times of N Application, & of P on Grain Yield

T/ha

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TEL HADYA	BRIDA	KHANASSER
Adj. Mean		3.26	3.65	3.90	2.20	2.36
	N_s	$.17^{xxx}$	$.15^{xxx}$	- .03	$.11^{xxx}$	$- .13^{xx}$
	N_t	$.19^{xxx}$	$.09^{x}$	.01	$.14^{xxx}$	- .03
	P	.10	$.16^{xx}$	$.12^{x}$	$.16^{xxx}$	$.42^{xxx}$
	$N_s.N_t$	- .03	- .02	$- .05^{x}$	$- .04^{xx}$	-
	$P\ N_s$	.01	.05	.02	.02	- .01
	$P\ N_t$	.05	.07	.01	.02	.06
	N_s^2	- .04	.06	- .07	- .03	- .03
	N_t^2	- .04	- .01	- .02	- .03	.02
Analyses of Variance - Mean of Squares & F-test Significances						
Source	d.f.					
Regression	8	1.09^{xxx}	0.75^{xx}	0.30^{x}	0.72^{xxx}	1.43^{xxx}
Lack of fit	17	.12	0.27	0.22	0.02	0.25
Error	25	.18	0.15	0.14	0.04	0.14

$$Y = \text{Adj. mean} + b_{n_s}.N_s + b_{n_t}.N_t + b_p.P + b_{n_s n_t}.N_s N_t + b_{pn_s}.PN_s + b_{pn_t}.PN_t + b_{n_s^2}.N_s^2 + b_{n_t^2}.N_t^2$$

Notes:- 1) Adjusted mean is the computed value at the centres of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
N_s kg/ha (planting)	0	10	20	30	40
N_t kg/ha (topdressed)	0	10	20	30	40
P_2O_5 kg/ha		0		60	

3) Thus, the adjusted mean is obtained with the combination of 20 kgs N + (hypothetical) 30 kgs P_2O_5 both at planting + 20 kgs N topdressed.

4) The seed rate was 120 kgs/ha.

Table 6.20 Effects of 2 Times of N Application, & of P on Total Dry Matter T/ha

Regression Coeffts.		Individual Sites				
		JINDIRESS	K. ANTOON	TEL HADYA	BRIDA	KHANASSER
Adj. Mean		7.43	8.30	9.68	5.13	4.98
N_s		$.47^{xxx}$	$.42^{xxx}$	- .09	$.34^{xxx}$	$- .19^{x}$
N_t		$.43^{xxx}$	$.24^{xx}$	.04	$.32^{xxx}$	- .02
P		.27	$.48^{xxx}$	$.79^{xxx}$	$.48^{xxx}$	$.74^{xxx}$
$N_s.N_t$		- .07	- .04	$- .16^{x}$	$- .06^{x}$	.02
$P\ N_s$		.05	$.27^{xx}$	- .01	.02	- .06
$P\ N_t$		.13	.11	- .01	.02	.10
N_s^2		- .06	.17	- .26	- .08	- .02
N_t^2		- .08	- .03	- .10	- .07	.01
Analyses of Variance - Mean Squares & F-test Significances						
Source	d.f.					
Regression	8	6.82^{xxx}	6.52^{xxx}	6.83^{xxx}	4.99^{xxx}	4.27^{xxx}
Lack of fit	17	.71	1.51	1.20	0.16	1.11
Error	25	1.04	0.82	1.17	0.21	0.78

$$Y = \text{Adj. mean} + b_{n_s}.N_s + b_{n_t}.N_t + b_p.P + b_{n_s n_t}.N_s N_t + b_{pn_s}.PN_s + b_{pn_t}.PN_t + b_{n_s^2}.N_s^2 + b_{n_t^2}.N_t^2$$

Notes:- 1) Adjusted mean is the computed value at the centres of the ranges of treatments applied.

2)

Treatment Code	-2	-1	0	+1	+2
N_s kg/ha (planting)	0	10	20	30	40
N_t kg/ha (topdressed)	0	10	20	30	40
P_2O_5 kg/ha		0		60	

3) This, the adjusted mean is obtained with the combination of 20 kgs N + (hypothetical) 30 kgs P_2O_5 both at planting + 20 kgs N topdressed.

4) The seed rate was 120 kgs/ha.

Table 6.21 Predicted Yield Parameters for Lowest & Highest N Rates in 5 Time of NxP Trials

1979/1980

Site	Treatment N Rate Kg/Ha	Emerged Plants Millns per Ha	Spikes per Plant	Spikes Millns per Ha	Kernels per Spike	Kernels No. Millns per Ha	Wt per Kernel m.g.	Grain Yield Tonne per Ha	Total Dry Wt. Tonne per Ha	Harvest Index
JINDIRESS	0	3.23	1.02	3.30	17.3	57.0	44.6	2.54	5.63	0.45
	80	3.59	1.03	3.70	22.9	84.9	46.9	3.98	9.23	0.43
KAFR ANTOON	0	2.80	1.26	3.52	20.1	70.9	44.7	3.17	6.98	0.45
	80	2.80	1.26	3.52	26.2	92.4	44.7	4.13	9.62	0.43
TEL HADYA	0	3.10	1.18	3.65	25.1	91.5	42.6	3.90	9.68	0.40
	80	3.10	1.18	3.65	26.1	95.4	40.9	3.90	9.68	0.40
BRIDA	0	2.37	1.06	2.51	15.9	39.9	42.6	1.70	3.31	0.45
	80	2.37	1.21	2.87	23.0	66.0	40.9	2.70	6.45	0.42
KHANASSER	0	3.13	0.99	3.09	20.3	62.7	42.4	2.66	5.36	0.50
	80	2.73	1.13	3.09	16.9	52.1	40.3	2.10	4.60	0.46

Notes: 1) These predictions are for the average, "middle" rate of P_2O_5 , (hypothetical) 30 kg P_2O_5/ha.

2) For emergence numbers, the highest N rate was 40 kg N/ha.

3) The seed rate was 120 kg/ha.

Table 6.22 Predicted Yield Parameters in Absence & Presence of 60 Kgs/Ha of P_2O_5 in 5 Time of NxP Trials, 1979/1980

Site	Treatment P_2O_5 Rate Kg/Ha	Emerged Plants Millns per Ha	Spikes per Plant	Spikes Millns per Ha	Kernels per Spike	Kernels No. Millns per Ha	Wt per Kernel m.g.	Grain Yield Tonne per Ha	Total Dry Wt. Tonne per Ha	Harvest Index
JINDIRESS	0	3.41	1.03	3.50	20.1	70.3	46.4	3.26	7.43	0.44
	60	3.41	1.03	3.50	20.7	72.3	45.1	3.26	7.43	0.44
KAFR ANTOON	0	2.80	1.19	3.34	23.4	78.1	44.7	3.49	7.82	0.45
	60	2.80	1.32	3.70	23.0	85.2	44.7	3.81	8.78	0.43
TEL HADYA	0	3.10	1.12	3.46	23.7	82.0	46.1	3.78	8.89	0.43
	60	3.10	1.24	3.84	22.7	87.2	46.1	4.02	10.47	0.38
BRIDA	0	2.37	1.14	2.69	18.1	48.8	41.8	2.04	4.65	0.44
	60	2.37	1.14	2.69	21.0	56.5	41.8	2.36	5.61	0.42
KHANASSER	0	3.15	0.98	3.09	16.0	49.5	39.2	1.94	4.24	0.46
	60	2.71	1.14	3.09	20.7	63.9	43.5	2.78	5.72	0.49

Notes: 1) These predictions are for the middle rates of N, i.e. 20 kg at planting + 20 kg topdressed.

2) The seed rate was 120 kg/ha.

CHAPTER 7

SOIL FERTILITY RESEARCH

7.1 Introduction

At harvest time, 1980, soil and plant samples were taken from a number of plots at Tel Hadya and the off-station sites to assess the fertility status of the soils and to establish relationships between crop response to fertilizer application and nutrient status of the soils at harvest.

Most of the soil samples were analysed in the ICARDA laboratory during the period December 1980 to February 1981. Analyses of plant samples are not yet performed. The results of the soil analyses are presented in this chapter and, although they only represent the nutrient status of the soils at harvest, some tentative conclusions of a more general nature can be drawn on the basis of these data.

7.2 Treatments selected for sampling

At harvest 1980, a number of soils at Khanasser, Brida, Tel Hadya, Kafr Antoon and Jindiress were sampled for soil fertility assessment. At Khanasser and Brida the soils were sampled at five depth intevals: 0 - 20 - 40 - 60 - 90 - 120 cm, and at the other sites a sample at 150 cm,depth was also added.

The samples were transported in cool-boxes to Tel Hadya and stored in freezers to prevent the conversion from ammonium to nitrate (nitrification), until the laboratory became operational by the end of the year. Prior to analysis, the soil samples were dried, ground to pass a 2 mm sieve, and subsamples were taken by a riffle-type sample splitter. Soil samples of replicate treatments were mixed pior to analysis, and results presented are mean values of at least two replicate analyses.

There were five experiments where this soil sampling was undertaken first, the treatments selected for soil samples at all sites were:-

- fallow
- cereal, N_p= 20, N_t= 40, P = 60
- cereal, N_p= 20, N_t= 40, P = 0
- cereal, N_p= 0, N_t= 0, P = 60
- cereal, N_p= 0, N_t= 0, P = 0

where N_p is nitrogen applied as Ammonium Nitrate (33 percent of N) at planting (kg of N/ha) mixed with the seed, N_t is nitrogen topdressed at the start of stem elongation and P is phosphorus applied as Triple Super Phosphate (46 percent of P_2O_5) at planting (kg of P_2O_5/ha) mixed with seed. Soil samples from cropped plots were taken in the row, the spacing between the rows was approximately 17.5 cm.

The main objective of the sampling of these treatments was to assess the N and P status of soils under fallow, fertilized and unfertilized cereal crops, and to compare the results with crop responses to fertilizers.

Secondly, in the uniform barley block at Brida, a number of spots were observed which showed a significantly better growth of barley than the surrounding area. It turned out that these spots were associated with the presence of ants. A number of these "ant-spots" were sampled, as well as number of reference locations next to these spots. The objective of this sampling was to investigate whether the enhanced barley growth on the ant-spots could be ascribed to a nutrient effect, in particular higher levels of available N and P.

At Tel Hadya, two more experiments were sampled. One was an experiment in which the performance of three different wheat varieties, a short-season (Sonalika), a medium-season (Mexipak), and a long-season variety (Novi Sad). These were grown under different moisture regimes, ranging from no irrigation to a total of 118 mm, and at different levels of nitrogen fertilization. Water was applied using a trickle irrigation system, and nitrogen was applied as Ammonium Nitrate at planting. The objective of sampling these treatments was to investigate the effect of trickle irrigation and wheat variety on the dynamics and uptake of nitrogen, and to compare the efficiency of nitrogen applied only at planting versus a split application.

Finally, a number of treatments involving food legume crops were sampled. The legume crops involved were lentils, faba beans and chickpeas, and the treatments included the effect of inoculation on nitrogen fixation, winter versus spring planting (chickpeas), the effect of row-

spacing, addition of Carbofuran for Sitona control (lentils), and harvesting for hay. Fallow, fertilized and unfertilized wheat were included for reference. The objective of analysing soils from these experimental plots was to investigate the effect of biological nitrogen fixation on the amount of mineral nitrogen in soils under legumes, as compared to wheat and fallow.

7.3 Methods for soil analysis

Criteria for the selection of methods for soil analysis were that they should:

(1) apply to the soils in the region, i.e. in particular to calcareous soils,

(2) be in common use in the world, in particular in the ICARDA region, or compare well with methods adopted by regional laboratories, and

(3) be simple, i.e. require no sophisticated equipment, which would hamper their distribution in the region.

In the selection of the methods, use has been made of "A Report on Survey of Some Laboratories in Eight Arab Countries", by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD, Damascus, 1979), and of "Physical and Chemical Methods of Soil and Water Analysis", by J. Dewis and F. Freitas (Soils Bulletin 10, FAO, Rome, 1970). Furthermore, use has been made of existing textbooks, such as "A Textbook of Soil Chemical Analysis", by P.R. Hesse (Murray, London, 1971), and "Methods of Soil Analysis", by C.A. Black, Editor-in-Chief (ASA, Madison, Wisconsin, 1965). In addition, a number of manuals used by laboratories in the region have been consulted.

7.3.1 pH

The pH of soil is generally measured in aqueous suspensions of different soil-water ratios. The assessment of alkalinity of soils is generally based on the measurement of pH in a saturated soil paste (pH_{sat}). While this method is generally preferred, a saturated soil paste is not always easy to prepare, and results may vary.

The method selected for use at the ICARDA laboratory was the measurement of pH in a 1:1 (w/v) suspension of soil and 1 N KCl (pH-KCl). This method determines the potential acidity of the soil and the pH-KCl is less subject to seasonal fluctuations as the pH determined in aqueous suspensions.

To provide a basis for comparison, the pH-KCl was compared with pH measured in saturated soil paste, and 1:1 and 1:5 (w/v) aqueous soil suspensions.

7.3.2 Electrical conductivity

The electrical conductivity (EC) is preferably measured in saturation extracts of soil (EC_{sat}). The EC_{sat} is also used to assess the salinity of soils. The preparation and filtration of saturated soil pastes is not easy, and the results can be variable. Therefore, the EC is sometimes measured in 1:1 (EC_1) or 1:5 (EC_5) w/v soil extracts.

The EC_1 is generally closely correlated with the EC_{sat}, but is easier to prepare, requires less soil material, and generally gives more consistent results.

This method, therefore, was selected for use at the ICARDA laboratory. To provide a basis for comparison, the EC_1 was compared regularly with EC_5 and EC_{sat} measurements.

7.3.3 Available phosphorus (P-Olsen)

Available phosphorus is determined in a soil extract using 0.5 M $NaHCO_3$ at pH 8,5 as the extractant solution in a 1:20 (w/v) soil to solution ratio. This method was first described by Olsen, Cole, Watanabe and Dean (Circular 929, USDA, Washington, 1954) and has since been widely applied to calcareous soils. Phosphorus in solution is determined colorimetrically at a wavelength of 660 mm, using ammonium molybdate and stannous chloride in sulphuric acid.

7.3.4 Mineral nitrogen (according to Bremner)

Mineral nitrogen is determined using 2 M KCl solution as the extractant solution in a 1:3 (w/v) soil to solution ratio. This method has been described by Bremner and Keeney (Soil Sci. Soc. Am. Proc.). 30(1966): 577-582), and is most commonly used for the determination of mineral nitrogen in soils.

The method determines adsorbed as well as dissolved forms of ammonium, nitrite and nitrate, the sum of which is referred to as mineral nitrogen. Ammonium is determined in the potassium chloride extract by a simple stem distillation method, using magnesium oxide to raise the pH of the sample, and saturated boric acid to collect the distillate. Nitrite plus nitrate are determined in the same sample, using Devarda's Alloy to reduce nitrite and nitrate to ammonium. The boric solutions are back-titrated to pH5 with a standardised sulphuric acid solution.

7.3.5 Kjeldahl nitrogen

Total nitrogen in soil is determined by a semi-micro Kjeldahl procedure using concentrated sulphuric acid and a K_2SO_4-$CuSO_4.2H_2O$-Se catalyst mixture in a 100:10:1 (by weight) ratio for the digestion of the samples. Digestion is performed in a block digestion unit placed in a fume hood. Ammonium is determined in the digest by a stem distillation method, using 10 N NaOH to raise the pH of the sample and saturated boric acid to collect the distillate. The boric acid solutions are back-titrated to pH5 with standardised dilute sulphuric acid.

7.3.6 Oxidizable organic carbon (Walkley-Black)

Oxidizable organic carbon is determined by adding concentrated sulphuric acid to a mixture of soil and potassium dichromate solution. The residual potassium dichromate is titrated against ferrous ammonium sulphate, after addition of phosphoric acid and diphenylamine indicator solution.

The Walkley-Black method determines a variable fraction of the soil organic carbon, referred to as active carbon. To calculate total organic carbon, results obtained by the Walkley-Black method are sometimes multiplied by a factor of 1.33. To calculate the organic matter content of the soil, the figure for organic-C can then be multiplied by 1,724 ("Van Bemmelen factor").

However, both factors appear to vary between soils and the depth the sample was taken. Therefore, it is more appropriate to report the results of the organic-carbon determinations according to Walkley-Black without modification.

7.4 Results

The results of soil analyses are presented in Tables 7.1-7.12 in an Appendix. In the following sections, these results will be briefly discussed and some tentative conclusions will be drawn.

7.4.1 pH-KCl

Many soil chemical processes depend on the pH of the soil solution. The availability of micronutrients and phosphorus, and the volatilisation of ammonia are examples.

The extraction of the soils with potassium chloride removes most of the H+ from the adsorption complex, and therefore the pH-KCl is lower than the pH measured in aqueous suspensions. For example, for the soils at Brida, the pH of the saturated soil paste is about 1,0 pH-unit higher than the pH-KCl.

In figure 7.1 the mean pH-KCl for all treatments is plotted for five sites. There were no significant differences in pH-KCl among the treatments on each site, but there are significant differences among the sites, in particular between the three wetter sites (Jindiress, Kafr Antoon and Tel Hadya) and the two drier sites (Brida and Khanasser).

The pH-KCl tends to increase with decreasing annual rainfall, even though all soils are calcareous. This may be due to a more intensive leaching of active calcium carbonate at the wetter sites.

At a pH-KCl of about 7 (pH_{sat} about 8) the availability of micronutrients such as iron, zinc and copper would be low, whereas applied phosphorus would be transformed in the presence of lime into compounds with a very low solubility, such as apatite. A high pH would favour the volatilisation of ammonia.

7.4.2 Electrical conductivity

The electrical conductivity of an aqueous soil extract is a measure for the amount of soluble salts in the soil.

There were no significant differences among treatments on each site, but there are significant differences among sites, again between the three wetter sites which are quite similar, and the two drier sites.

Figures 7.2 and 7.3 show that the amounts of soluble salts tend to increase with decreasing annual rainfall.

Saline soils may be defined as soils with an EC_{sat} higher than 4 mS/cm. In saline soils, crop production may be adversely affected by the presence of soluble salts in solution, both through the higher osmotic potential of the soil solution, and through the (competitive) effect of salts on the crop. For most of the soils studied, the saturation percentage is between 30 and 70 percent (v/v), with an average of about 50 percent. In the case of soluble salts one would therefore expect the EC_{sat} to be about two times higher than EC_1, disregarding the effect of ionic strength and of ion-exchange on the electrical conductivity of the aqueous soil extract.

It follows from Figures 7.2 and 7.3 that the electrical conductivity of the wetter sites is quite low, whereas Brida soils would be saline below 90 cm depth and Khanasser soils below 40 cm depth. For Barley, which is rather more salt-tolerant, the salinity of the sub-soils at Brida and Khanasser would probably not have much of an adverse effect on yield, also because the rooting depth will be mainly determined by the depth of infiltration of rainwater in these soils.

The salinity of the subsoils at Brida and Khanasser may be due to the presence of gypsum. Figure 7.4 shows the relationships between EC_1 and EC_5 for Khanasser. If the salts have a limited solubility, the relationship between EC_1 and EC_5 would be close to the 1:1 line in Figure 4 (i.e. $EC_5=EC_1$), whereas highly soluble salts would follow the 1:5 line (i.e. $EC_5= 0.2\ EC_1$). In the top 60 cm of the soil the relationship between EC_5 and EC_1 is given by : $EC_5= 0.30\ EC_1 + 0.09$ ($r^2= 0.94$), indicating the presence of soluble salts, such as chlorides. Below 60 cm the relationship becomes: $EC = 0.25\ EC + 1.41$ ($r^2= 0.99$), also indicating the presence of soluble salts, similar to those on the top soil, plus a constant amount of salt in solution in equilibrium with a solid phase. The solid phase is probably gypsum, which fits in with the expected contribution to the electrical conductivity.

An example of highly soluble salts is given in Figure 7.5, for saline soils at Hagla (south of Sfireh, near the Salt Lake of Jabul), where some salt tolerance work is being done by the cereals program. Here the relationship between EC_{sat} (saturation percentage: 50-54) and EC_5 is given by $EC_5 = 0.11\ EC_{sat} + 0.16$ ($r^2= 0.99$). Highly soluble salts are present plus a small amount of salts with a limited solubility, such as carbonates. Figure 7.6 shows the salinity of the 1.5 hectare experimental site at Hagla. The EC_{sat}-values can be estimated from the EC_5-values using the relationship:

$$EC_{sat} = 9.23\ EC_5 - 1.48\ (r^2= 0.99)$$

As can be seen in Figure 7.6, this site is highly saline, with EC_{sat}-values up to 100 mS/cm.

7.4.3 Available phosphorus

The Olsen-method would provide on estimate for plant-available phosphorus, and has been widely applied to calcareous soils. Available-phosphorus contents in the range of 0-6 ppm are considered to be low, 6-12 ppm medium, and > 12 ppm high.

Figure 7.7 shows that unfertilized soils of all sites are medium in available phosphorus in the top 20 cm, and low below that depth. There seems to be a tendency of available phosphorus to increase with decreasing annual rainfall. This needs to be investigated further, since it could also be a residual effect of previous P-fertilizer applications on these sites. An application of 10 kg of P_2O_5/ha(i.e. 4.4 kg of P/ha) would raise the level of available phosphorus in a 20-cm soil layer (bulk density: 1.1 g/cm^3) by 2.0 ppm, if it were all in available form.

Figure 7.8 shows that soils which received P-fertilizer are significantly higher in available phosphorus in the top 20 cm than the P_0-treatments. Figure 7.8 shows that soils which received 60 kg of P_2O_5 but no nitrogen, tend to be higher in available phosphorus than soils which received both nutrients. This suggests that plant uptake of phosphorus is more efficient in the presence of nitrogen. The difference between the N_0P_{60} - and the P_0-treatments is about 60 kg of P_2O_5/ha in the top 20 cm (at a bulk density of 1.0 g/cm^3). Recall, however, that phosphorus was drilled with the seed, and that soil samples were taken in the rows where concentrations would be higher. Therefore, the actual available-phosphorus content on a per hectare basis, may be lower, in view of the limited mobility of phosphorus in soils.

Available-phosphorus contents below 20 cm depth are not significantly different between treatments. They are all in the range of 2-3 ppm of P. This also points to the limited mobility of phosphorus in these soils. The fact that all soils are deficient in available-phosphorus below the surface horizon may cause phosphorus deficiencies, even in fertilized treatments, later in the season when the plants are forced to take up moisture and consequently nutrients from deeper layers.

Figure 7.9 shows that up to a depth of 40 cm the ant-spots are higher on available - phosphorus than either the reference locations or the mean of all treatments. This may help to explain the enhanced barley growth on these ant-spots, in particular because the reference soils would be deficient throughout the profile, whereas the ant-spots are high to medium in available phosphorus in the top 40 cm of the soil. The higher levels of available phosphorus in the ant-spots are not necessarily due to higher total phosphorus contents in these spots, that may also be due to mobilisation of native phosphorus by organic acids or similar compounds excreted by the ants or released in the decompostion of organic matter.

7.4.4 Kjeldahl nitrogen

Mean Kjeldahl-nitrogen contents of soils at all sites are shown in Figure 7.10. There were no significant differences between treatments on each site, but there are differences between sites, both in total amount and in distribution with depth. All Kjeldahl-nitrogen contents are low, below 0,1 percent of N, and decrease with depth. Khanasser is highest in Kjeldahl-nitrogen in the top 20 cm, whereas Kafr Antoon and Tel Hadya are lowest. Figure 7.11 shows that the Kjeldahl-nitrogen contents at the drier sites, Khanasser and Brida, decrease more rapidly with depth than at the wetter sites, where the distribution is more uniform. This may be due to the more intensive leaching of organic compounds at the higher-rainfall sites, or to differences in soil type between the sites.

Figure 7.12 shows that the ant-spots at Brida are higher in Kjeldahl-nitrogen than the mean of all treatments, which may be due to organic materials collected by the ants and accumulated in these spots.

7.4.5 Mineral nitrogen

7.4.5.1 Comparison between treatments at all sites

Figure 7.13 shows mean mineral-nitrogen content for N_0P_0 and $N_0P_{60}(N_0)$-treatments on all sites. The distribution of mineral nitrogen on the wetter sites , Jindiress, Kafr Antoon, and Tel Hadya, is quite uniform with depth, in the range of 3-4 ppm of N. Mineral-nitrogen contents at Khanasser are very high (see Figure 7.19).

An application of 10 kg of N/ha (i.e. about 30 kg of Ammonium Nitrate/ha) would raise the mineral-nitrogen contents of 20-cm soil layer, with a bulk density of 1.1 g/cm^3, by about 4.55 ppm.

Figure 7.14 shows mean mineral-nitrogen contents of all cropped plots for all sites. There seem to be no significant differences between fertilized and unfertilized treatments. This indicates that a split application of nitrogen fertilizer, 20 kg at planting and 40 kg topdressed, is quite efficient.

Figure 7.15 shows mineral-nitrogen content of fallow plots on all sites. There are differences between sites, but the significance of this is difficult to assess without detailed knowledge about the cropping history of these sites (see Fig. 7.31). In general, the fallow plots are higher in mineral-nitrogen than the cropped plots (see Fig. 7.17).

Figure 7.16 shows the mean mineral-nitrogen contents of N_0-and N_{60}-treatments on all sites, except Khanasser. There is very little difference between these treatments, although the N_{60}-treatments tend to be a little higher in the top 20 cm (1-2 kg of N/ha). Although there is no information available on losses of nitrogen by volatilisation or leaching, Figure 7.16 strongly suggests that a split application is a very efficient way of applying nitrogen fertilizer.

Figure 7.17 shows that the fallows are significantly higher in mineral-nitrogen than the cropped plots. The amount of mineral-nitrogen stored in the soils, in fallow plots relative to the cropped soils, was highest at Tel Hadya and lowest at Jindiress, with an average of 40-50 kg of N/ha in the 0-120 cm layer (average bulk density:1.2 g/cm^3). Hence part of the beneficial effect of the fallow on the following crop may well be due to the higher levels of plant-available nitrogen in these soils.

Figure 7.18 shows that the fallow are higher in ammonium between 40 and 90 cm depth than the cropped plots, but that the main difference between the two treatments is the amount of nitrate (plus nitrite), which is significantly higher in the fallow throughout the profile than in the cropped plots.

Most of the ammonium will be present in adsorbed form in the soil, whereas most of the nitrate will be present in the solution, or in the form of easily soluble salts. One may expect that the nitrates will leach down at the start of the rainy season. Therefore part of the nitrate may leach down to below the rooting zone, in particular on the higher rainfall areas. The question how much of the mineral-nitrogen stored in the fallow is really available (accessible) to the following crop, needs to be investigated.

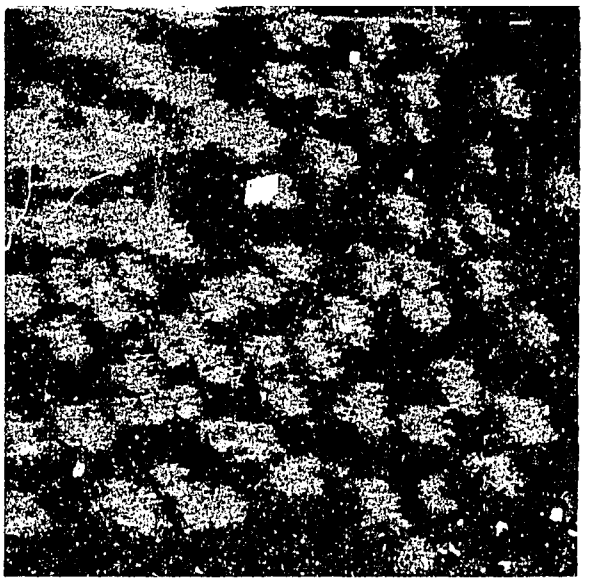
The soils at Khanasser are very high in mineral nitrogen, most of which is present in the form of nitrates. Figure 7.19 shows the mineral-nitrogen contents for different treatments at Khanasser. Evidently, the differences between the treatments are not caused by differences in plant uptake or mineralisation of nitrogen during one growing season, but rather reflect the heterogeneity of the test site at Khanasser. There is no clear correlation between Kjeldahl-nitrogen and mineral-nitrogen among the treatments (see Table 7.9, Appendix III), but there is highly significant correlation between electrical conductivity (EC_1) and mineral-nitrogen (correlation coefficient = 0.79 for n = 25). The differences in electrical conductivity may reflect differences in micro-relief at the test site. The high mineral-nitrogen contents may be due to mineralisation of nitrogen, nitrification, and subsequent accumulations of nitrates in the soil profile. The depth of infiltration of rainwater will generally not be below 60-90 cm depth, whereas plant uptake of nitrogen will generally be limited to the top 60 cm, also because of the presence of gypsum below that depth. Whether the salinity at Khanasser may be associated with groundwater at a shallow depth, would have to be investigated. In general, however, groundwater is not high in nitrate. Therefore, the high mineral-nitrogen contents are thought to be due to mineralisation of organic nitrogen followed by accumulation of nitrates, and possibly some lateral movement of nitrates in the soil.

Figure 7.20 shows the mineral-nitrogen content of ant-spots as compared to reference locations and fallow at Brida. Most of the nitrogen in the ant-spots is present in the form of nitrates. The high mineral-nitrogen contents of these spots may explain part of the enhanced growth of barley on these spots. Other factors could be a higher water-use efficiency by the crop, less evaporation from the soil due to a more complete coverage of the soil, some lateral water movement into the spots, a better structure of the soil, and possibly higher levels of available micronutrients resulting from the release of organic acids or chelating compounds.

7.4.5.2 Wheat variety/soil moisture/nitrogen experiment

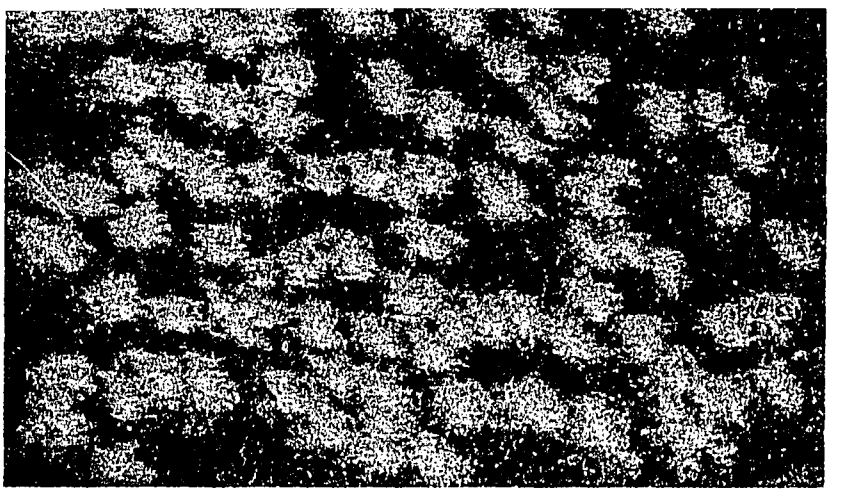
The objective of this experiment was to study the performance of three wheat varieties, a long-season (Novi Sad), a medium-season (mexipak), and a short-season variety (Sonalika), as affected by soil-moisture regime and fertilizer application.

Figure 7.21 shows that there was little difference in nitrogen uptake between wheat varieties, although the long-season variety may be slightly more efficient in taking up nitrogen from the 20-40 cm soil layer.



Greatly enhanced growth of Beecher barley at Brida resulting from high native soil N-P levels within ants nests.

The yield response and advanced maturity resulting from phosphate application at Brida. Both plots received 60 kg/ha of N, but the plots on the left also received 90 kg/ha P_2O_5.



Residual effects showing in a uniform block of wheat at Tel Hadya (1979/80). In 1978/79 the poor growth areas were wheat plots and the luxuriant growth areas were bare soil (i.e. fallow) alleyways. The poor growth was due to N-deficiency illustrating the importance of N-accumulation under fallow.

Figure 7.22 shows that there was little difference between irrigated (trickle irrigation in spring) and non-irrigated treatments. Irrigated treatments are slightly higher in mineral nitrogen at 60-90 cm depth, and slightly lower in the top 20 cm. Apparently there was little downward movement of soil moisture as a result of trickle irrigation, and irrigation mainly served to keep the soil moist, which may have resulted in slightly higher uptake of nitrogen from the top soil.

Figure 7.23 shows that there was a significant difference in mineral-nitrogen levels between fertilized and unfertilized treatments. The fertilized treatment was about 30-40 kg of N/ha higher than the unfertilized treatment, suggesting that application of all nitrogen at planting is less efficient than a split application (see also Figure 7.24). Figure 7.25 shows that the ammonium contents of N_0- and N_{60}-treatments are very similar and that almost all of the nitrogen stored in the fertilized treatment is in the form of nitrates, between 40 and 90 cm depth.

7.4.5.3 Food legume rotational experiment

Figure 7.26 shows the mineral-nitrogen content of soils under different food legumes, as compared to wheat and fallow. It can be seen that wheat and lentil take up about the same amount of mineral nitrogen from the soil, suggesting that lentils are not very efficient in biological nitrogen fixation. Faba beans and chickpeas behave similarly, and the mineral-nitrogen in soils in these plots is in between that found in wheat plots and fallow plots. Figure 7.27 shows that mineral-nitrogen in soils under fertilized-nitrogen has disappeared from the soil, either by plant uptake, by volatilisation or leaching. Figure 7.28 shows that inoculated lentils tend to be more efficient in biological nitrogen fixation than non-inoculated lentils, but they are less efficient than inoculated winter chickpeas or faba beans (see Figure 7.29).

More research on the efficiency of biological nitrogen fixation by legume crops in association with rhizobia is needed. The beneficial effect on the following crop (wheat) will be both through the lesser use of available soil nitrogen during one season, and through the decomposition of organic materials and the mineralisation of organic nitrogen the following season.

7.4.5.4 Fallow plots at Tel Hadya

Figure 7.30 shows mineral-nitrogen content in fallow plots at three different locations at Tel Hadya, with different cropping histories. The highest levels of mineral nitrogen were observed in the fallows in the wheat variety/soil moisture/nitrogen trials, where fallow followed fallow. Quite high levels of mineral nitrogen were observed in the fallows in the moisture use efficiency trials, where fallow followed summer crop. The lowest levels of mineral nitrogen were observed in the soils in fallow plots, in the food legume rotational trials, where fallow followed wheat. These examples show that the amount of mineral nitrogen in fallow plots depends on the cropping history of the plots. Therefore, fallowing has to be studied within the context of rotational systems to properly assess the significance of the fallow with respect to making mineral nitrogen available to the following crop.

7.4.6 Oxidisable organic carbon

Figure 7.31 shows the distribution of oxidisable organic carbon with depth in soils on all sites. There were no significant differences between treatments, but there are differences between sites. The ant-spots in Brida are higher in oxidisable organic carbon than the mean for all treatments at Brida.

The distribution of oxidisable organic carbon and Kjeldahl nitrogen, varies between 5 and 7.5, with a mean value of 6.7 (± 0.5) for the top 60 cm of all soils. The C/N ratio, expressed as the ratio of total organic carbon to Kjeldahl nitrogen, would then be in the range of 7 to 10, with a mean value of 8.9 (± 0.7).

Organic-matter contents of the top-soils of all sites would be in the range of 1.4 (Khanasser) to 0.8 percent (Tel Hadya).

7.5 Summary

At harvest time, 1981, soil samples were taken from a number of plots at Khanasser, Brida, Tel Hadya, Kafr Antoon and Jindiress. All soils studied were deficient in available phosphorus below 20 cm depth. Soils which received phosphorus fertilizer were medium to high in available phosphorus in the top 20 cm. All other soils were medium to low in the top 20 cm. Mineral-nitrogen levels in most soils were rather

low, except in Khanasser, where high levels were observed. Fallow plots were significantly higher in mineral nitrogen at all sites, indicating that soils under fallow may store mineral nitrogen which would be available to a subsequent crop. A split application of nitrogen fertilizer, 20 kg of N/ha at planting and 40 kg of N/ha top-dressed at stem elongation, appeared to be an efficient way of fertilizer application, since virtually all nitrogen applied was presumably taken up by the crop.

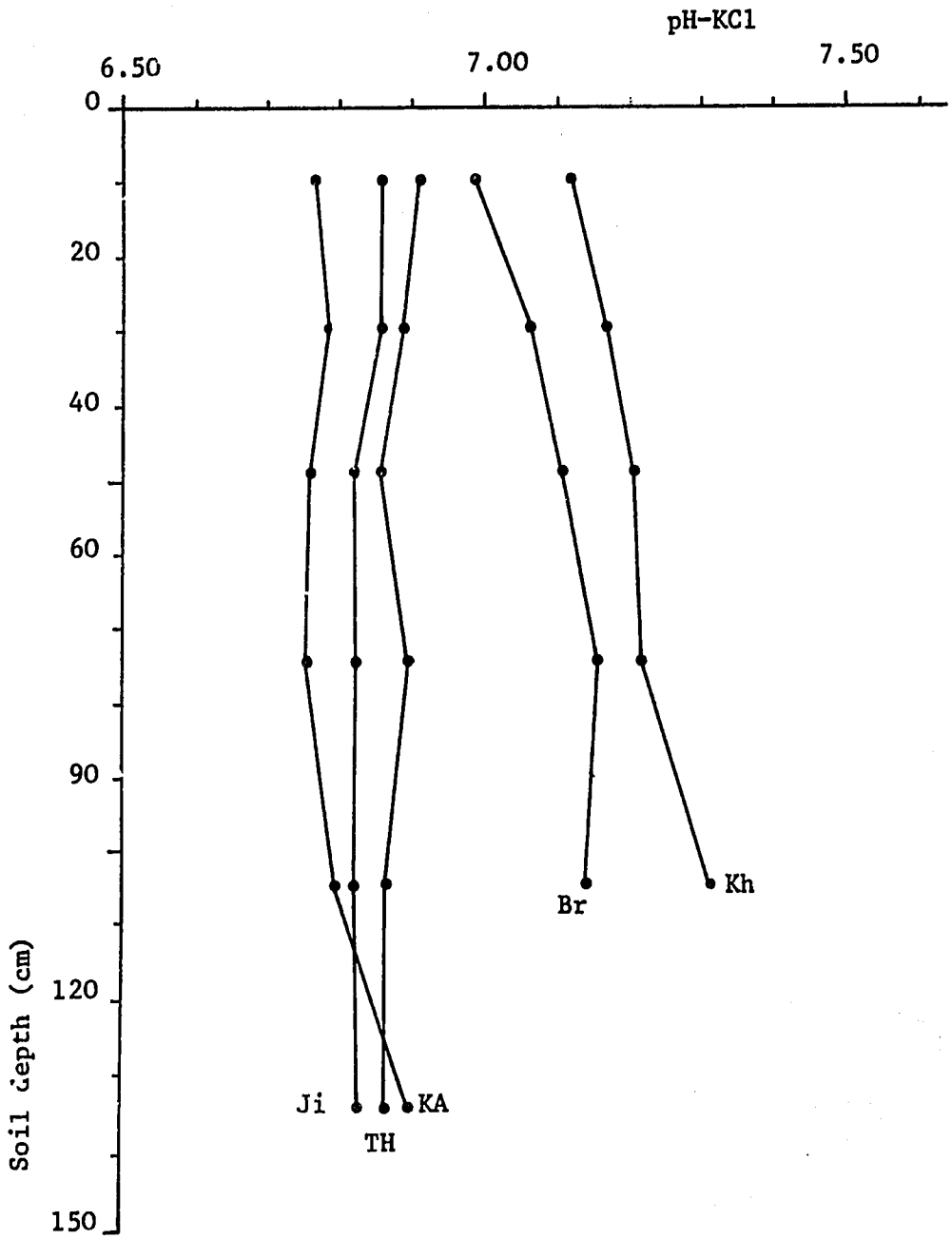


Figure 7.1. Mean values of pH-KCl (1N, 1:1 w/v) for five experimental sites: Jindiress (Ji), Kafr Antoon (KA), Tel Hadya (TH), Brida (Br) and Khanasser (Kh).

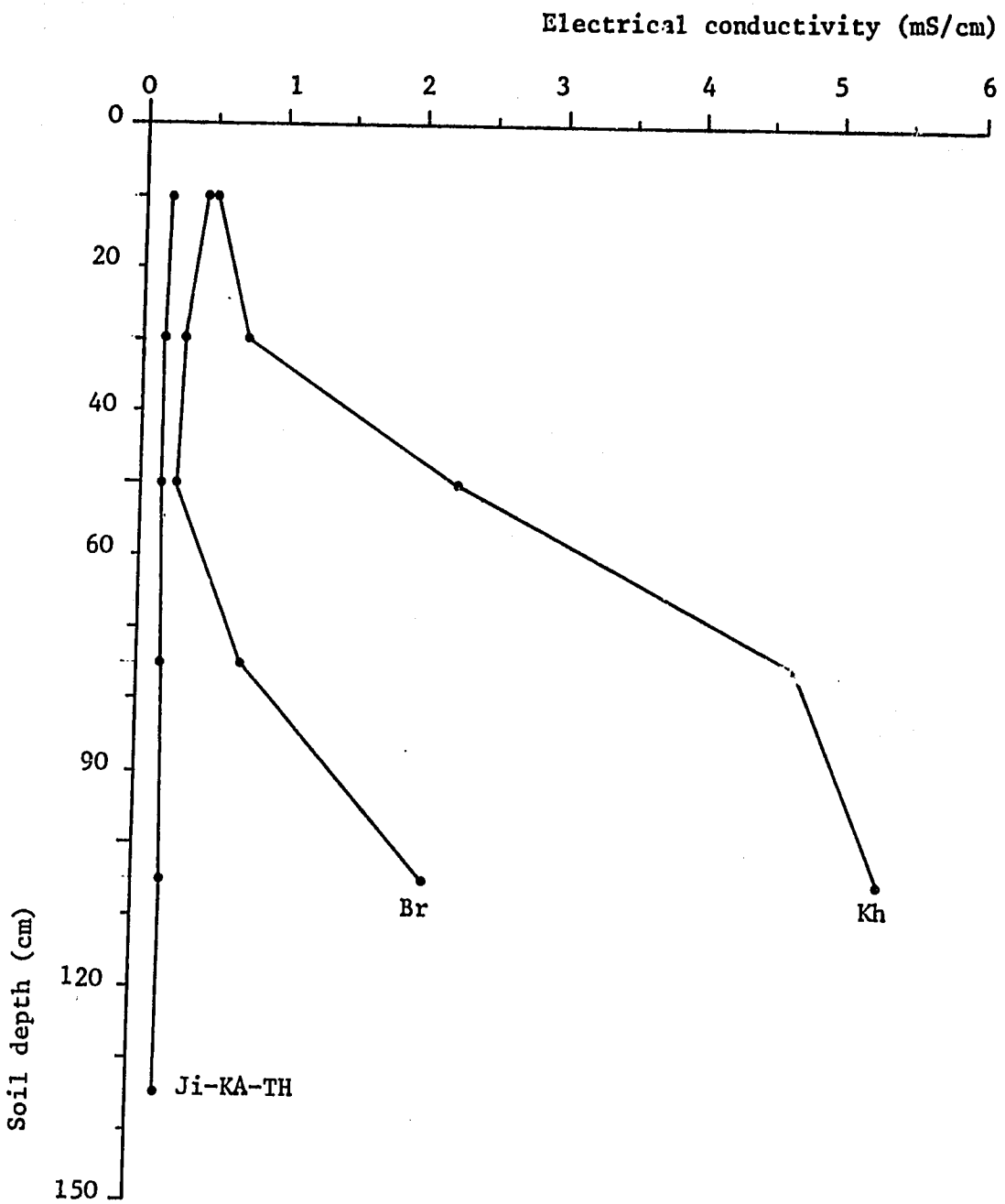


Figure 7.2. Mean values of electrical conductivities of 1:1 (w/v) aqueous soil extracts for Khanasser (Kh), Brida (Br), and the mean of Jindiress, Kafr Antoon and Tel Hadya (Ji-KA-TH).

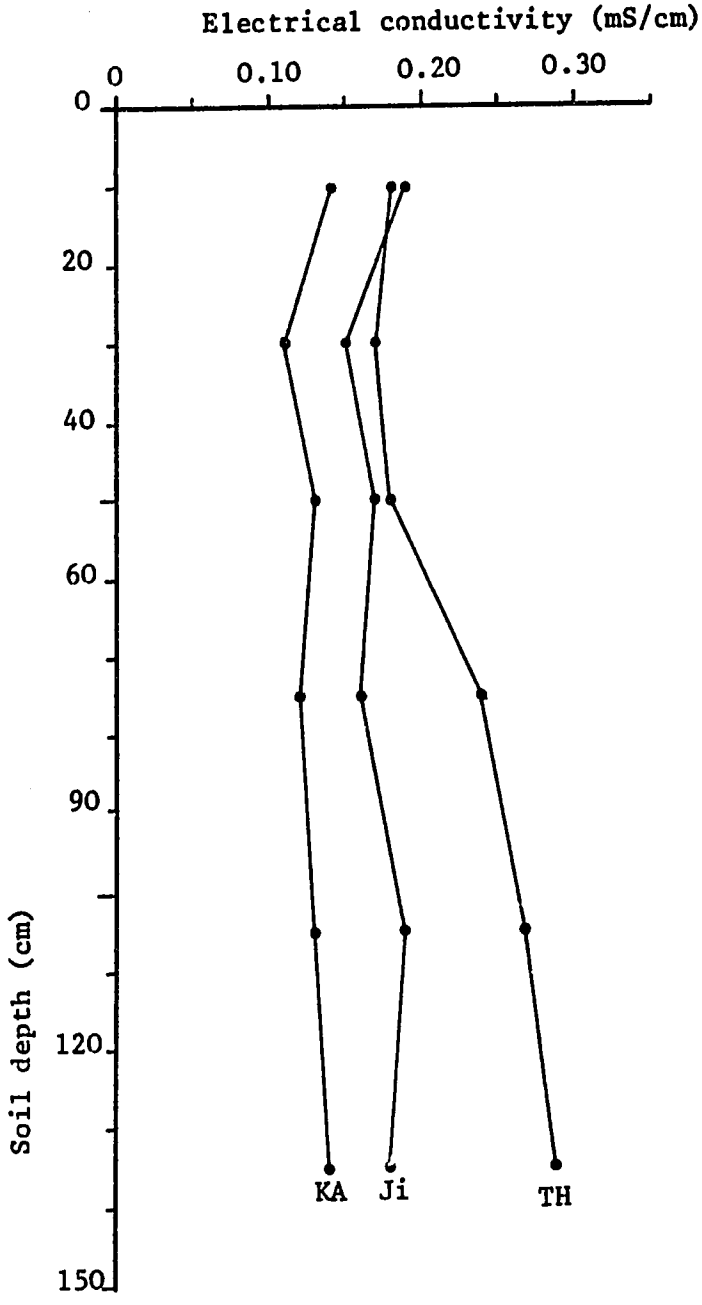


Figure 7.3. Mean values of electrical conductivities of 1:1 (w/v) aqueous soil extracts for Jindiress (Ji), Kafr Antoon (KA) and Tel Hadya (TH).

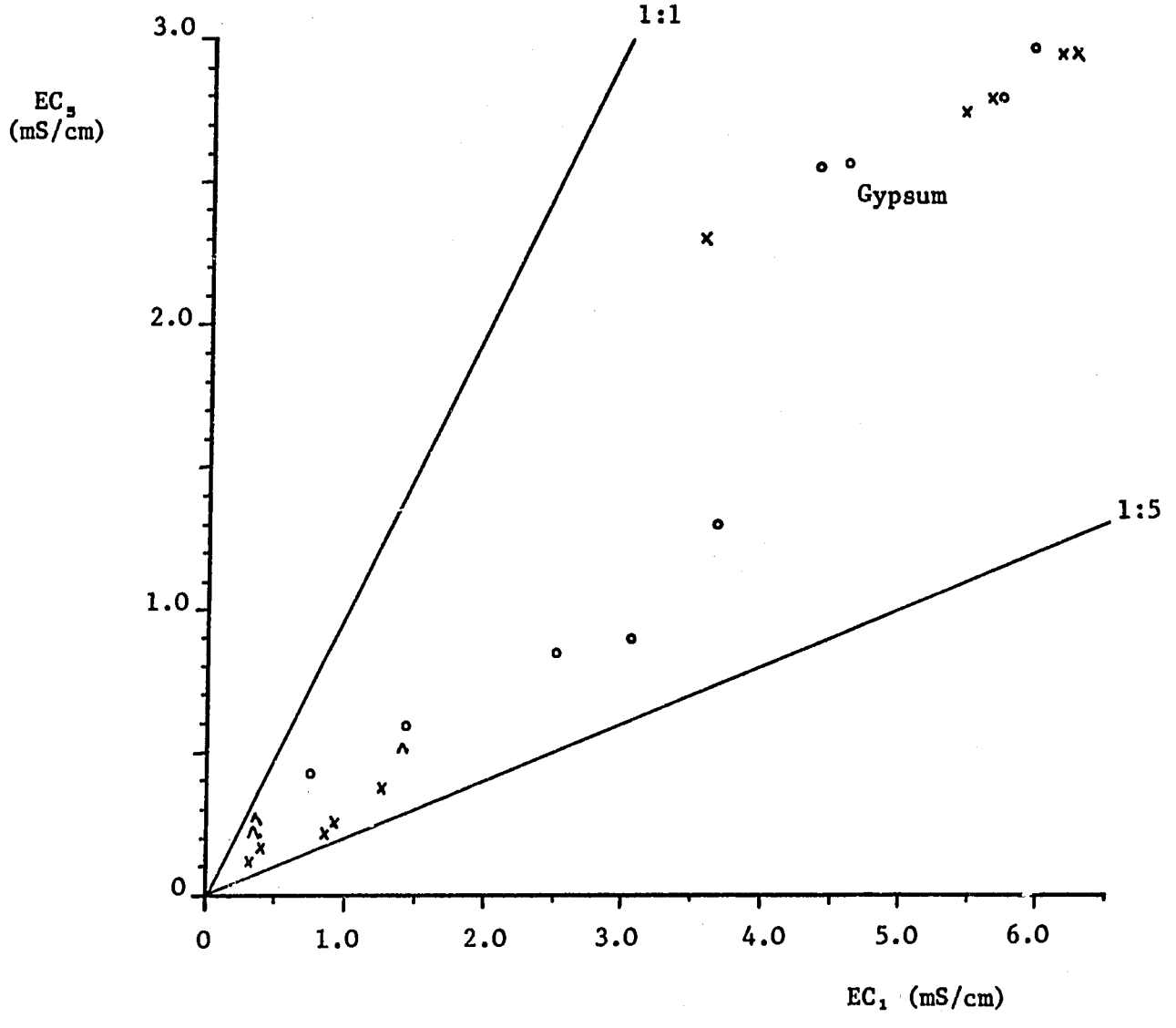


Figure 7.4. Relationship between electrical conductivities of 1:1 (EC) and 1:5 (EC_1) w/v aqueous extracts of soils at Khanasser sampled at different depths: 0-20 (Δ), 20-40 (+), 40-60 (o), 60-90 (o) and 90-120 cm depth (x).

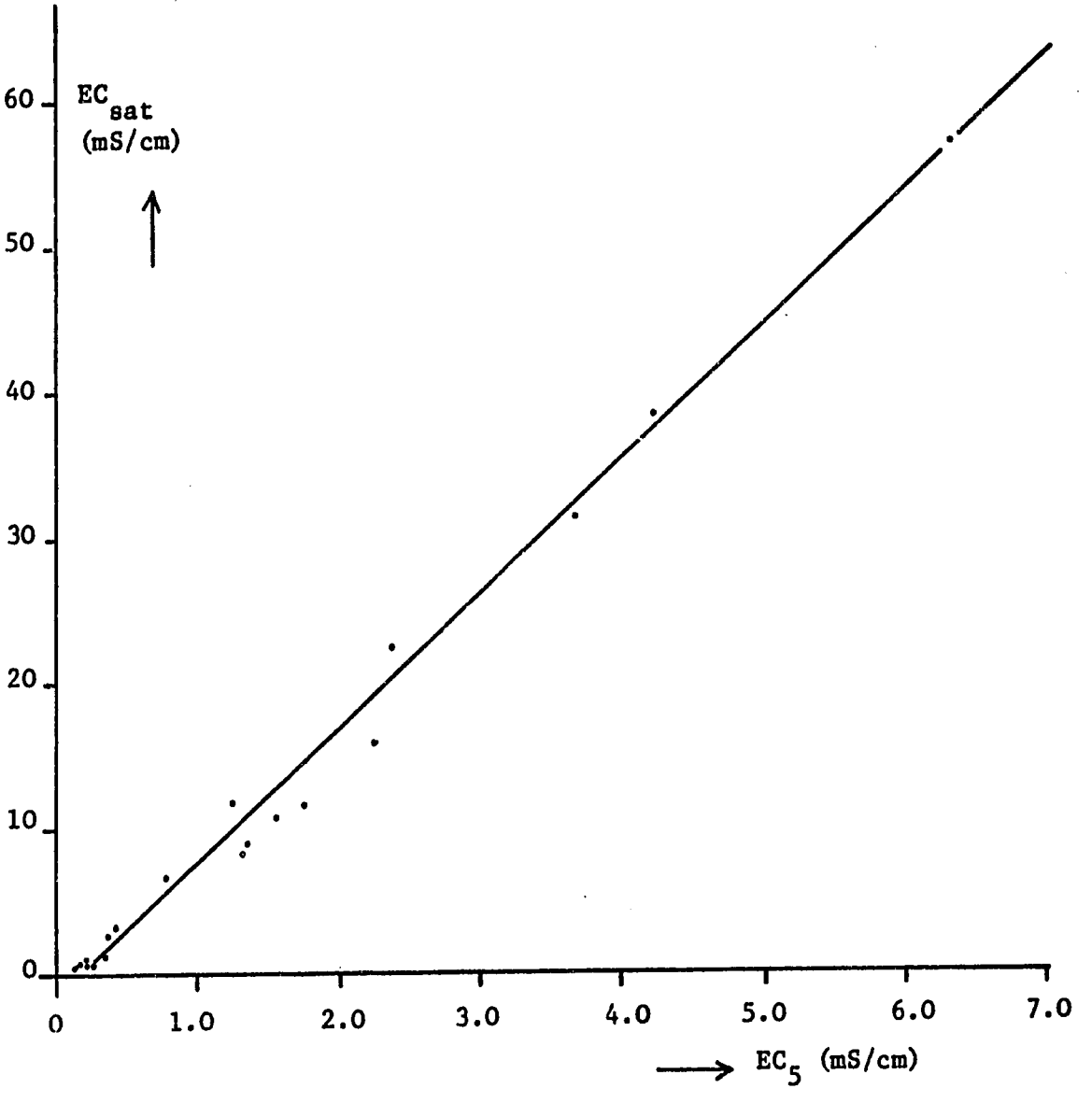


Figure 7.5. Relationship between electrical conductivities of 1:5 (EC_5) and saturation extracts (EC_{sat}) of soils at Hagla (saline site).

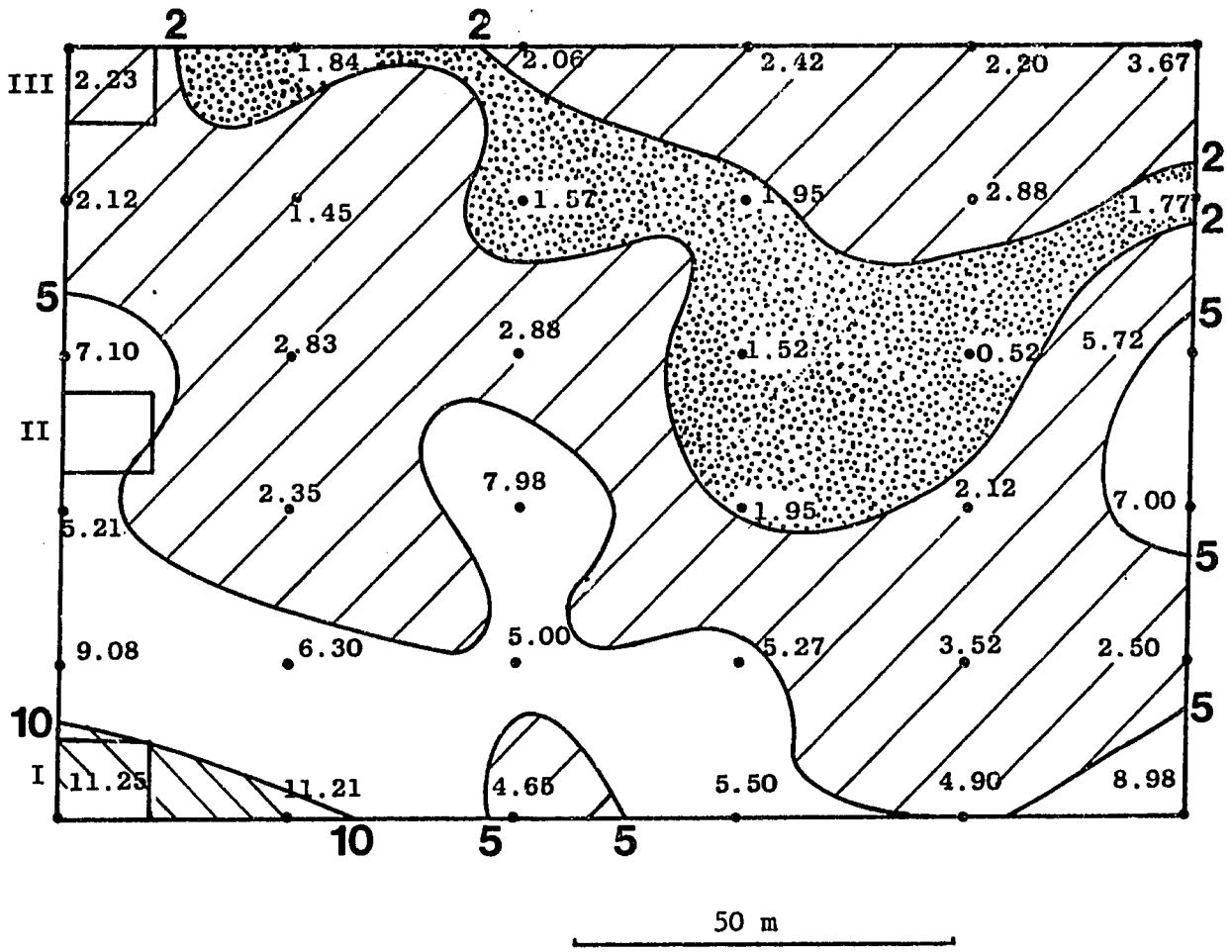


Figure 7.6. Electrical conductivity of 1:5 (w/v) aqueous extracts of surface soils (0-20 cm) at the experimental site of Hagla.

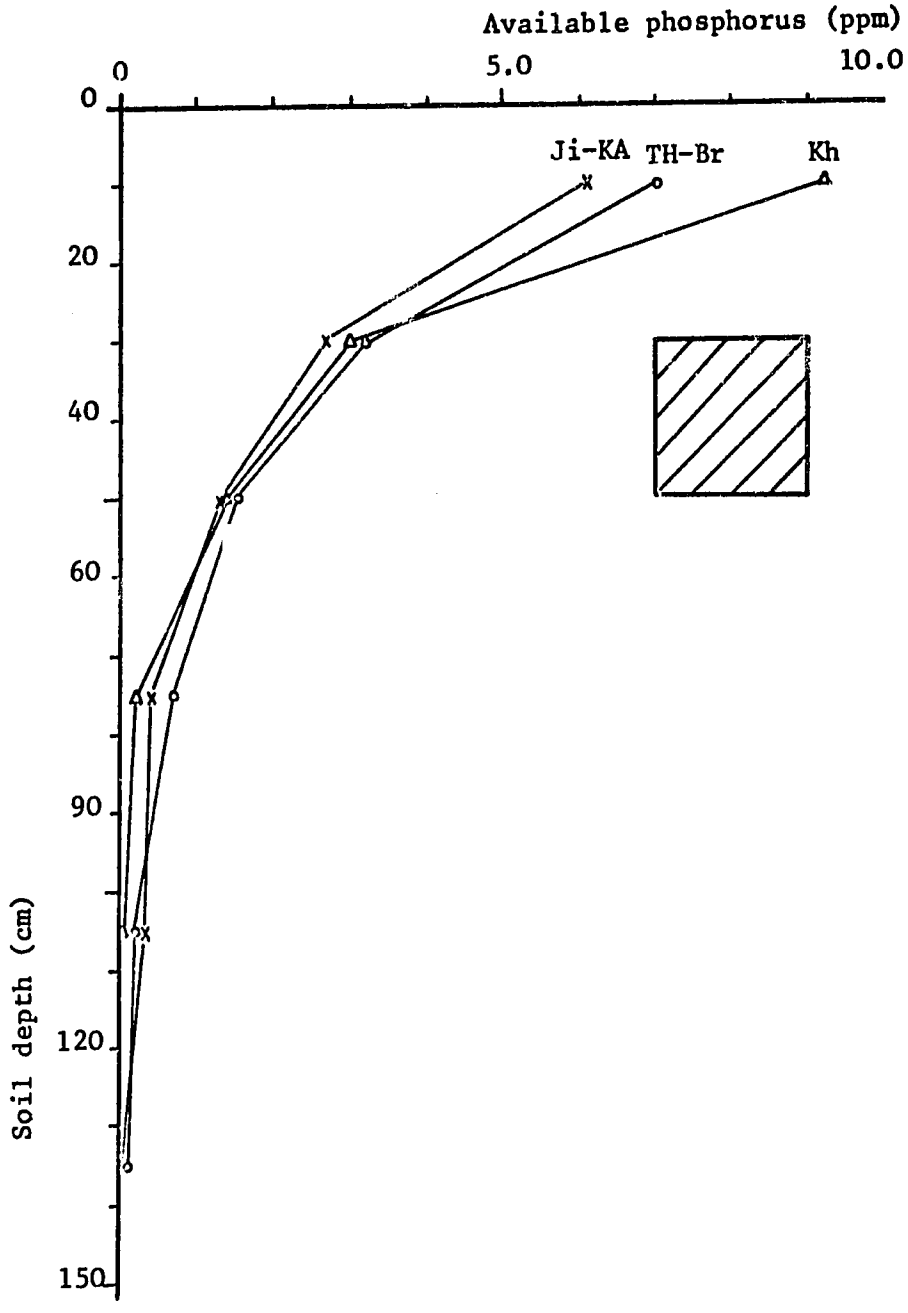


Figure 7.7. Mean available-phosphorus contents of N_0P_0- and $N_{60}P_0$-treatments at Jindiress and Kafr Antoon (Ji-KA), Tel Hadya and Brida (TH-Br), and Khanasser (Kh). The shaded area represents 10 kg of P_2O_5/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

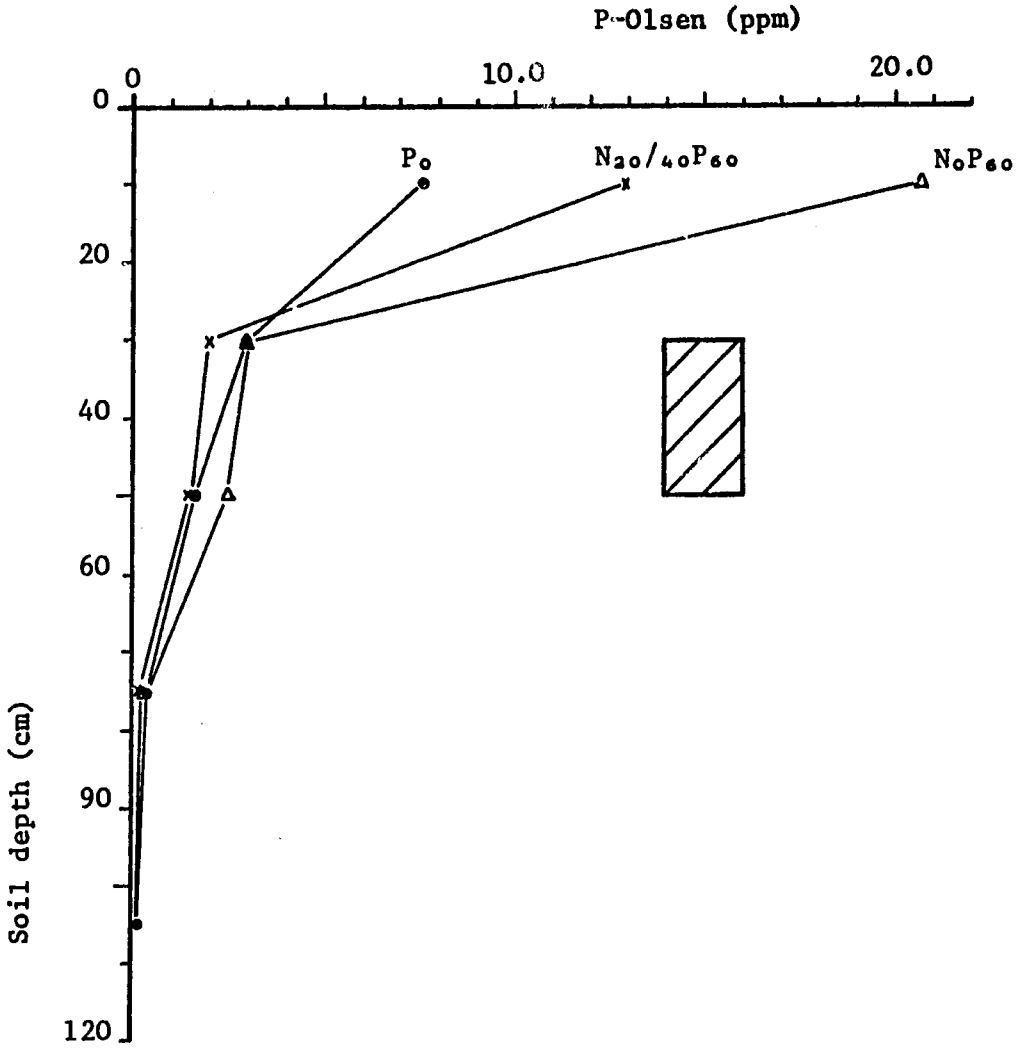


Figure 7.8. Mean available-phosphorus contents of fallow, $N_{60}P_0$ and N_0P_0 (P_0)-, $N_{60}P_{60}$-, and N_0P_{60}-treatments. The graphs represent mean values for five sites: Jindiress, Kafr Antoon, Tel Hadya, Brida and Khanasser.
The shaded area represents 10 kg of P_2O_5/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

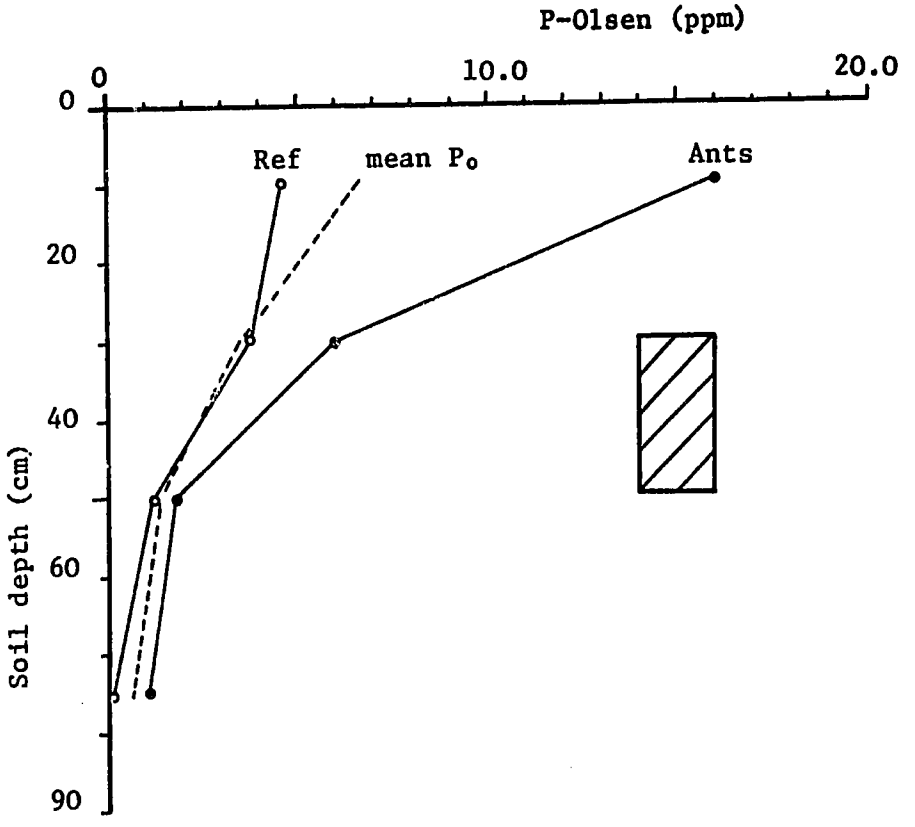


Figure 7.9. Available-phosphorus contents of ant spots and reference soils next to the spots at Brida. The dotted line represents the mean of fallow, N_0P_0- and $N_{60}P_0$-treatments at Brida. The shaded area represents 10 kg of P_2O_5/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

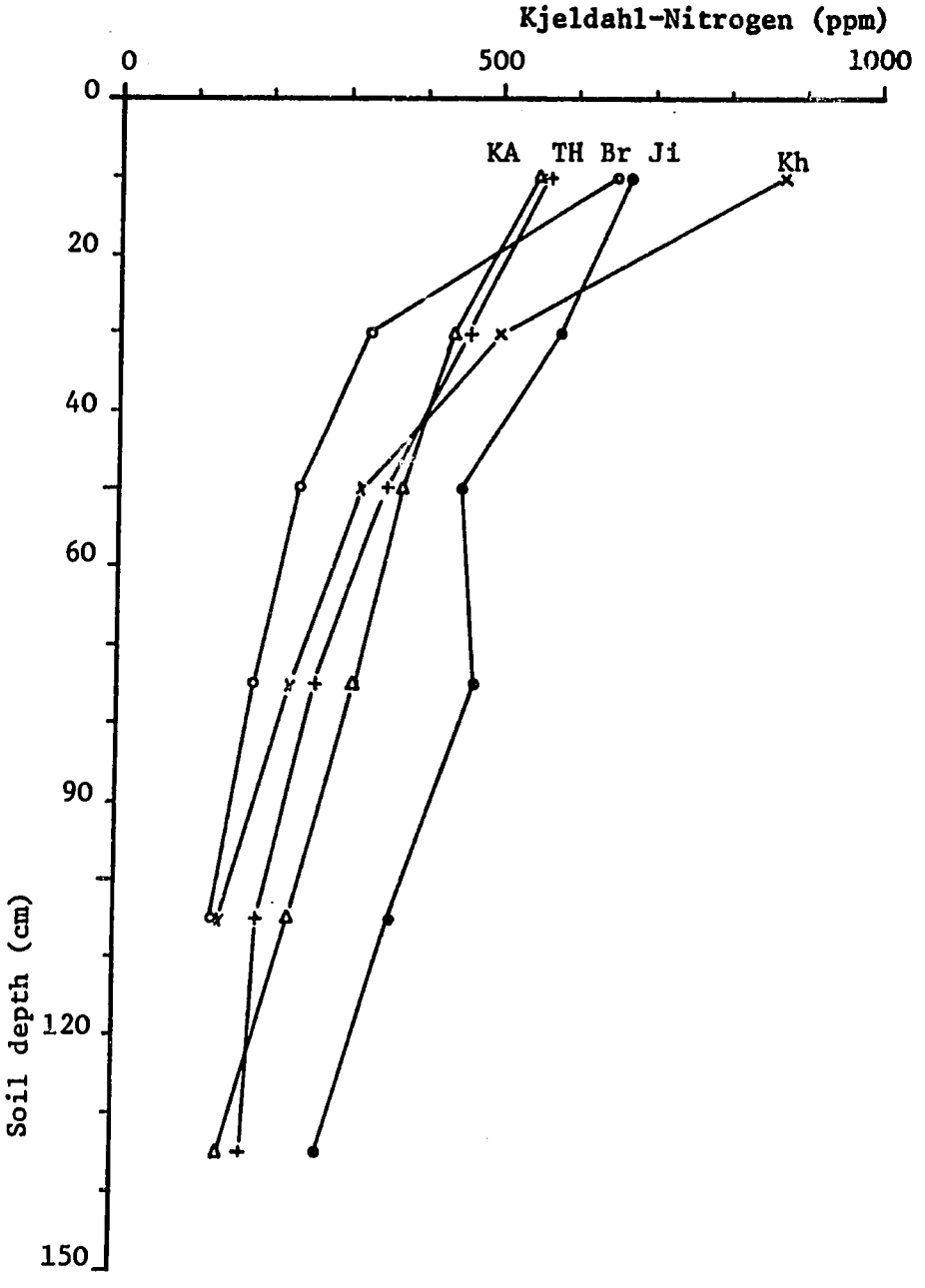


Figure 7.10. Mean Kjeldahl-nitrogen contents of soils at Khanasser (Kh), Brida (Br), Tel Hadya (TH), Kafr Antoon (KA) and Jindiress (Ji).

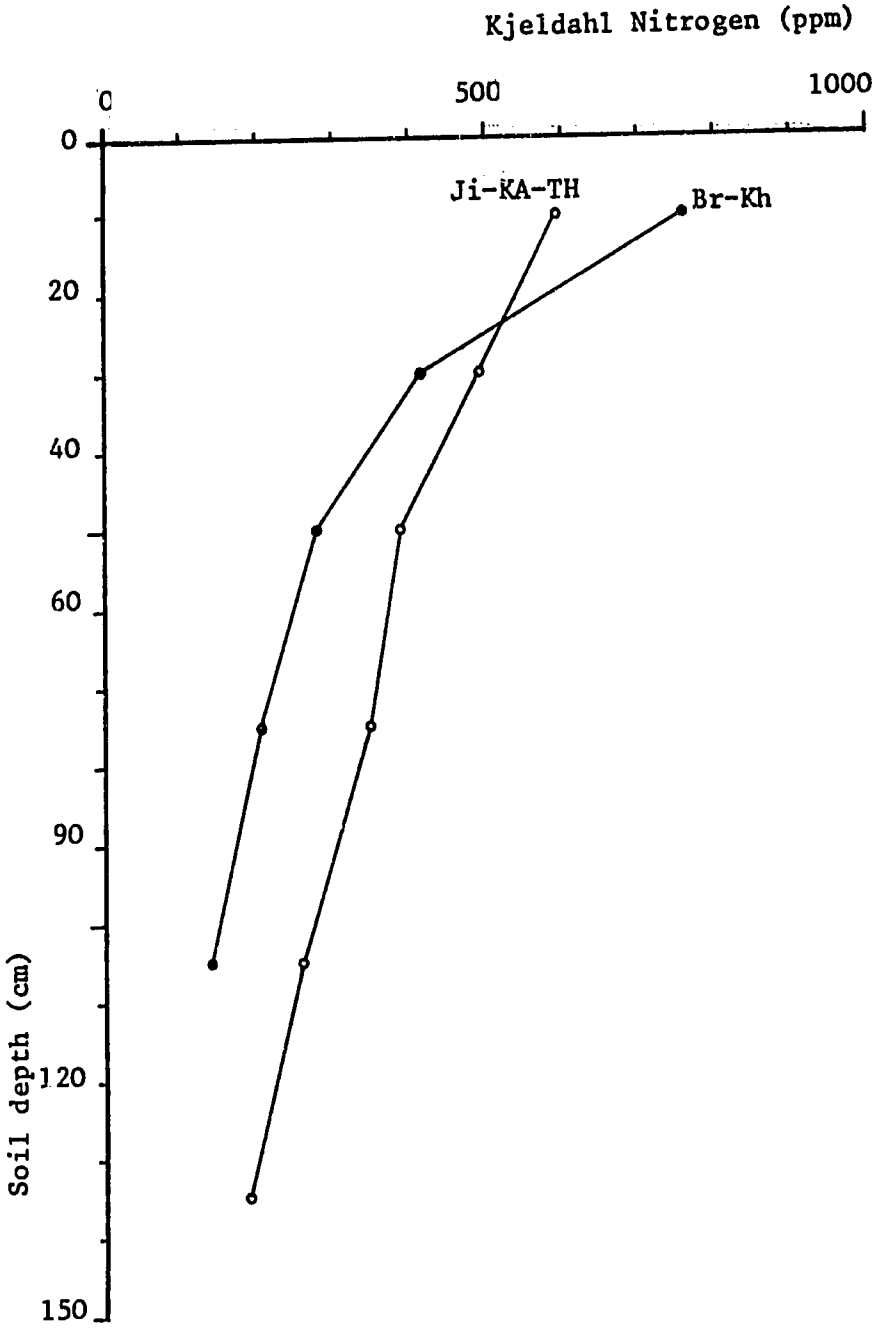


Figure 7.11. Mean Kjeldahl-nitrogen contents of soils at Khanasser and Brida (Br-kH), and Tel Hadya, Kafr Antoon and Jindiress (Ji-KA-TH).

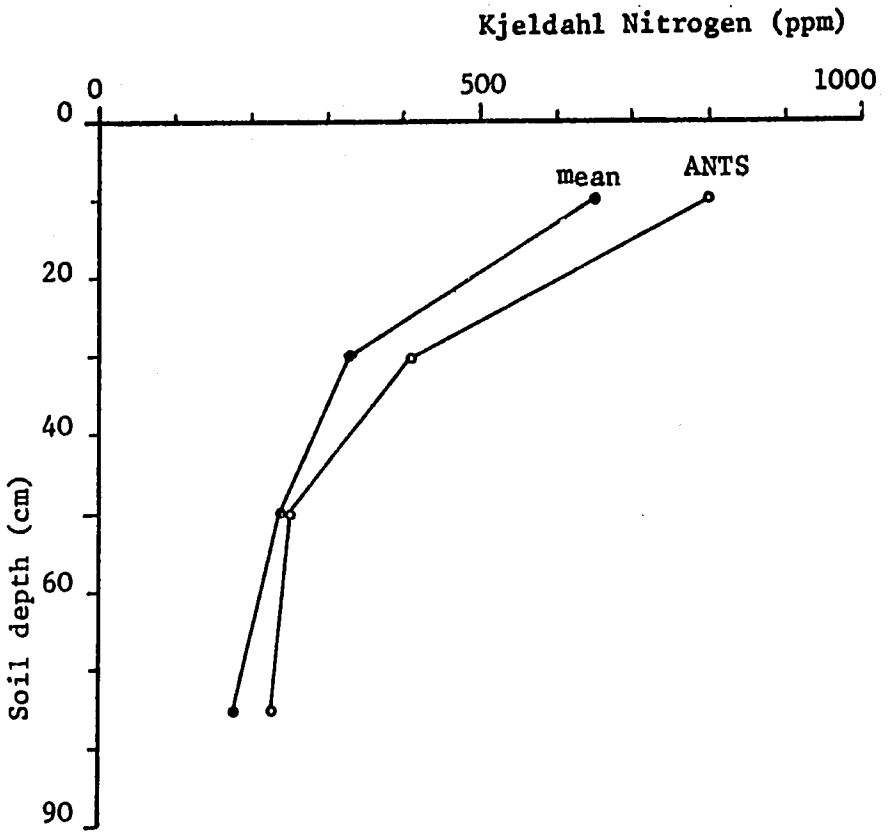


Figure 7.12. Kjeldahl-nitrogen content of ant spots at Brida (ANTS), and the mean content of all treatments at Brida, except for ant spots.

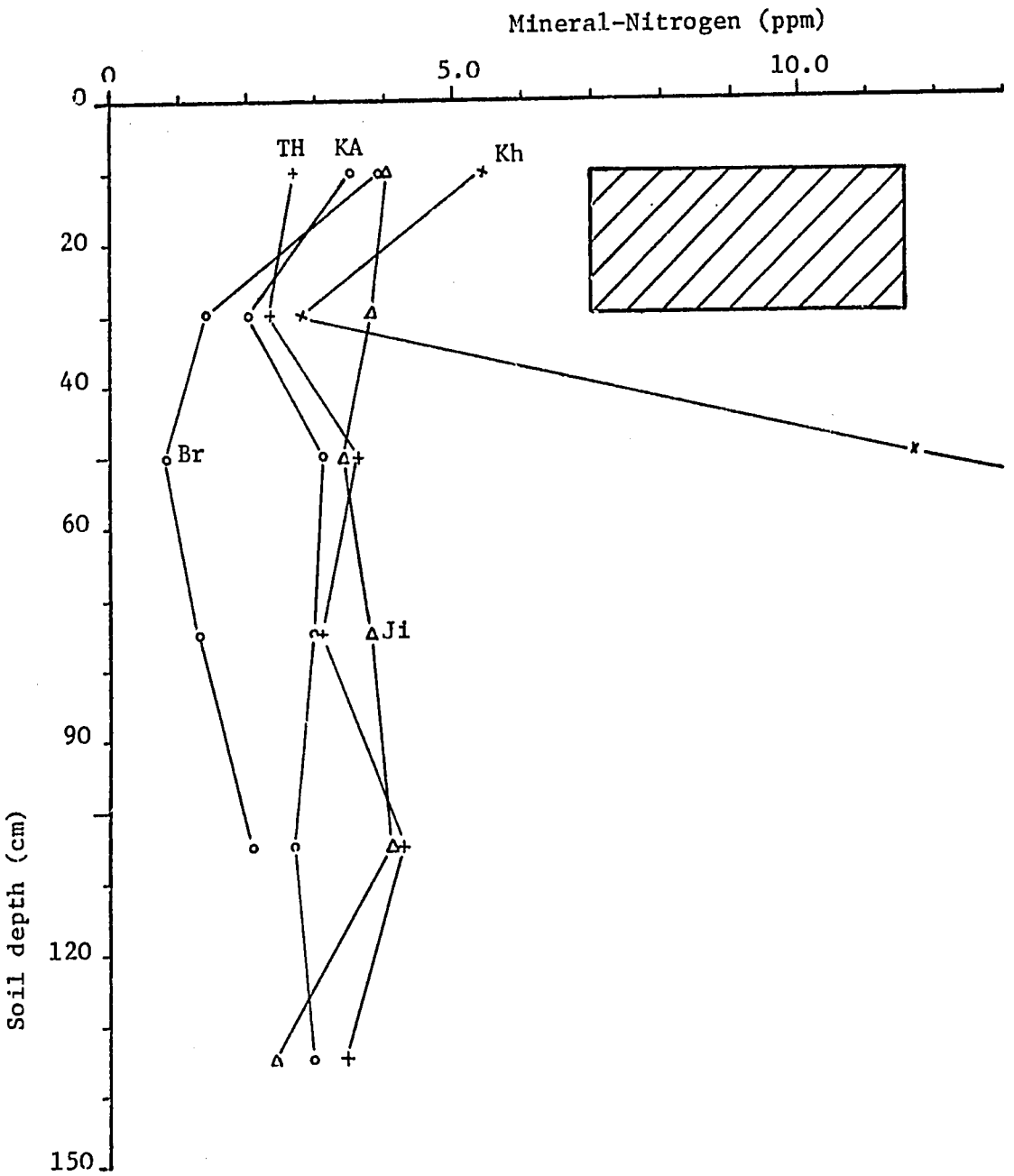


Figure 7.13. Mean mineral-nitrogen contents of N_0P_0 and N_0P_{60} (N_0)-treatments at Khanasser (Kh), Brida (Br), Tel Hadya (TH), Kafr Antoon (KA) and Jindiress (Ji).
The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

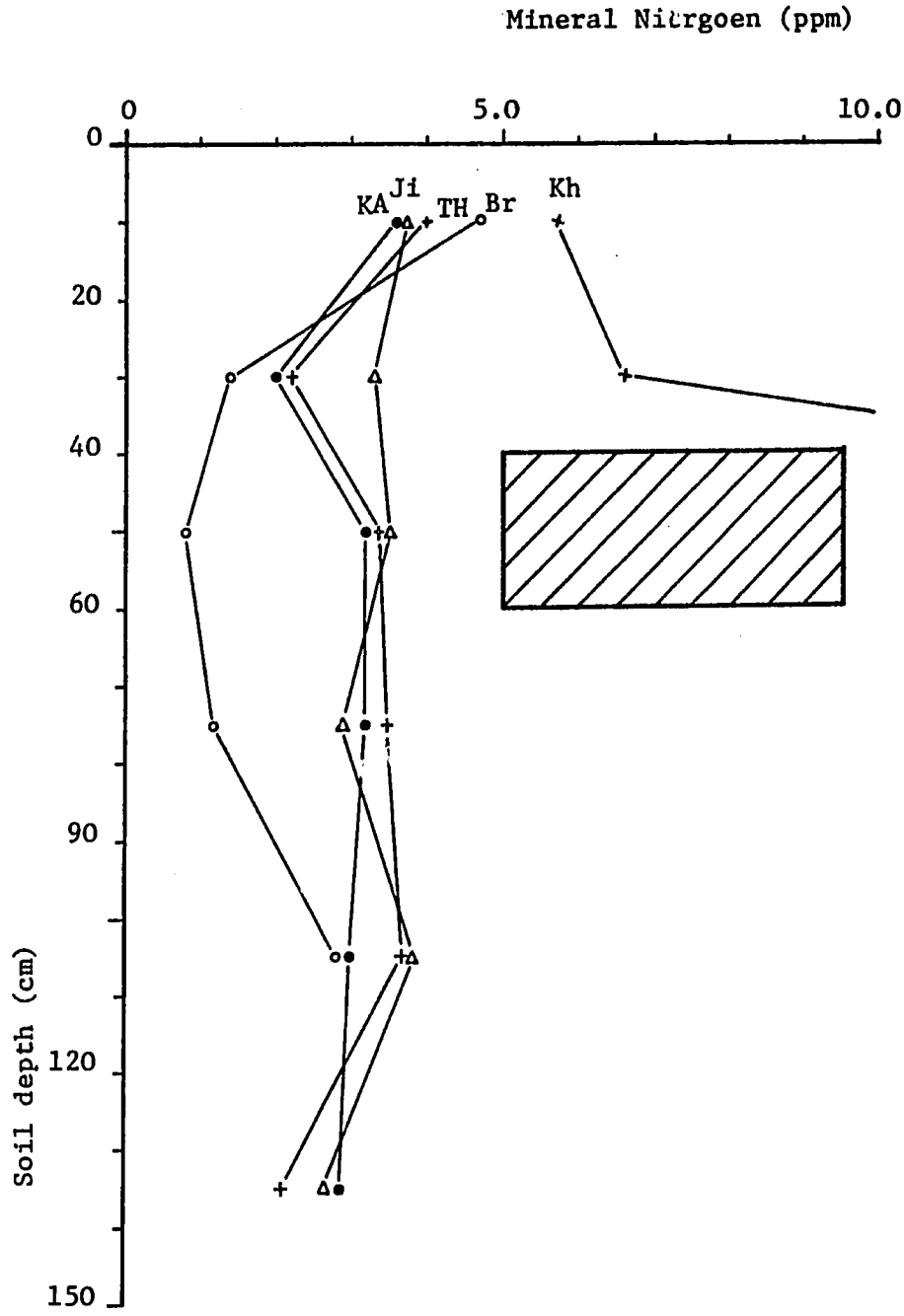


Figure 7.14. Mean mineral-nitrogen contents of cropped (N_0+N_{60})-treatments at Khanasser (Kh), Brida (Br), Tel Hadya (TH), Kafr Antoon (KA) and Jindiress (Ji).
The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

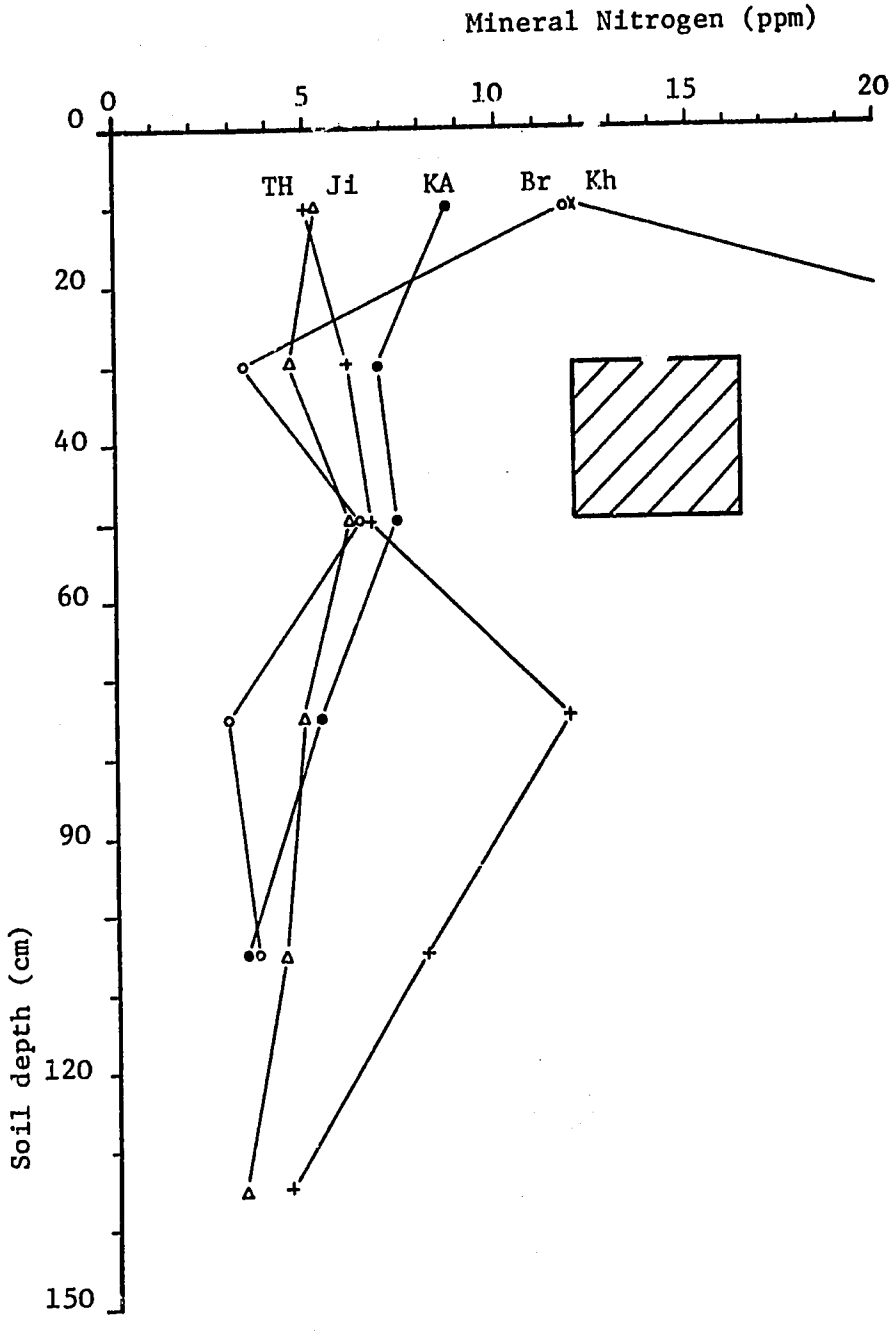


Figure 7.15. Mean mineral-nitrogen contents of fallow-treatments at Khanasser (Kh), Brida (Br), Tel Hadya (TH), Kafr Antoon (KA) and Jindiress (Ji).
The shaded area represents 10 kg of N/ha in a 20-cm layer with a bulk density of 1.1 g/cm^3.

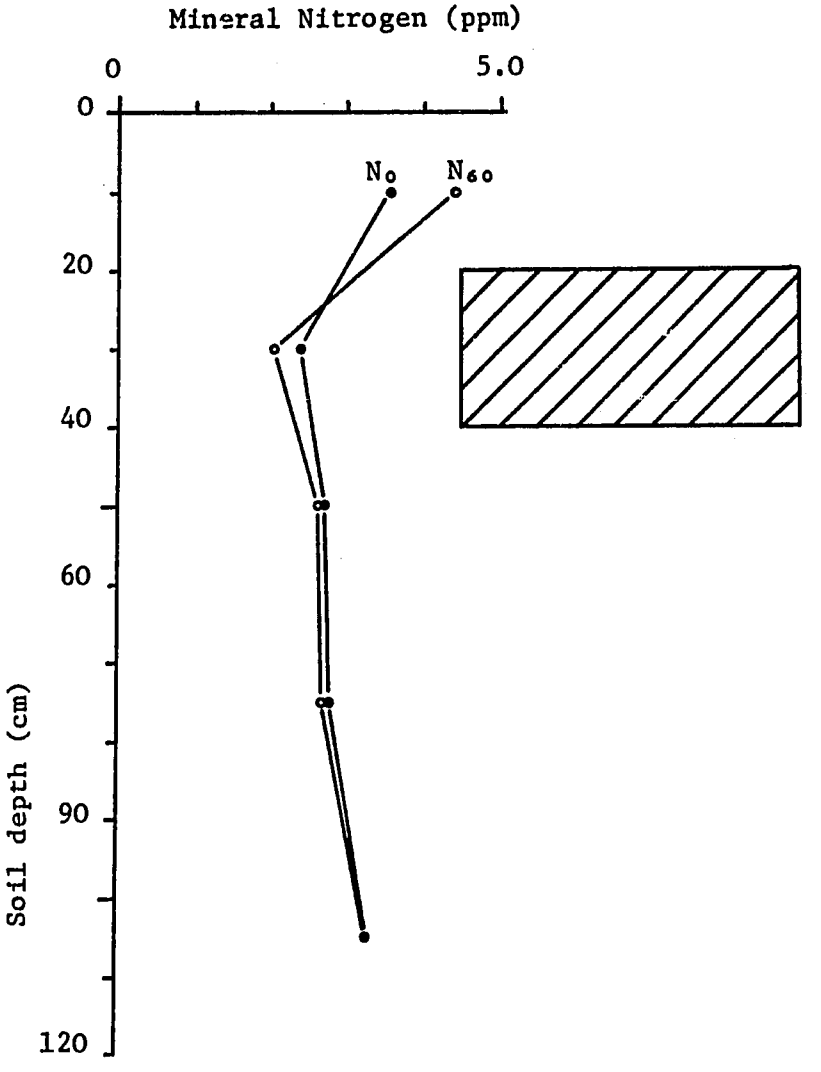


Figure 7.16. Mean mineral-nitrogen contents of N_0P_0 and N_0P_{60} (N_0)-, and $N_{60}P_0$ and $N_{60}P_{60}$ (N_{60})- treatments at all sites except Khanasser. The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

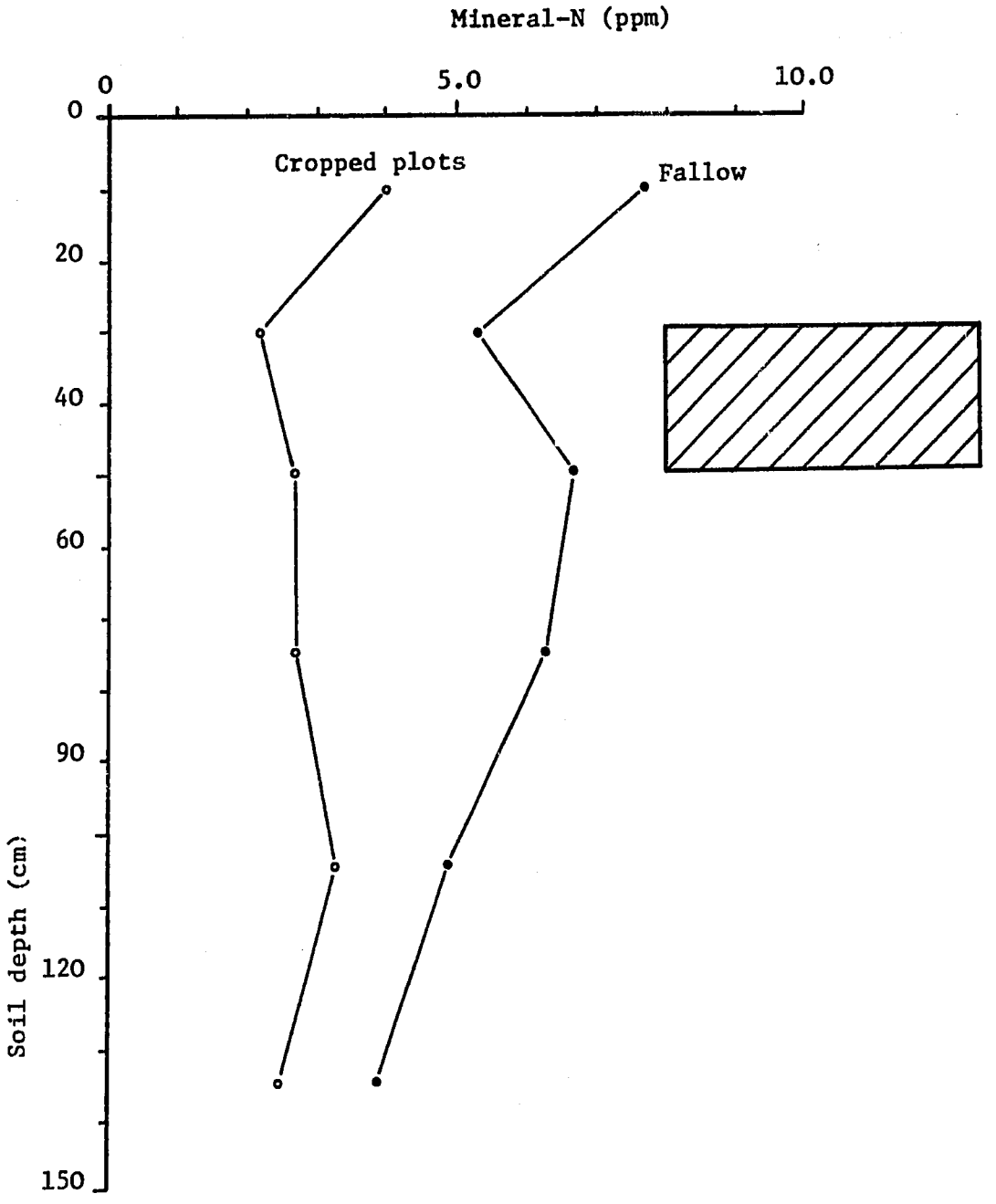


Figure 7.17. Mean mineral-nitrogen contents of cropped soils and fallows at all sites except Khanasser. The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1:1 g/cm^3.

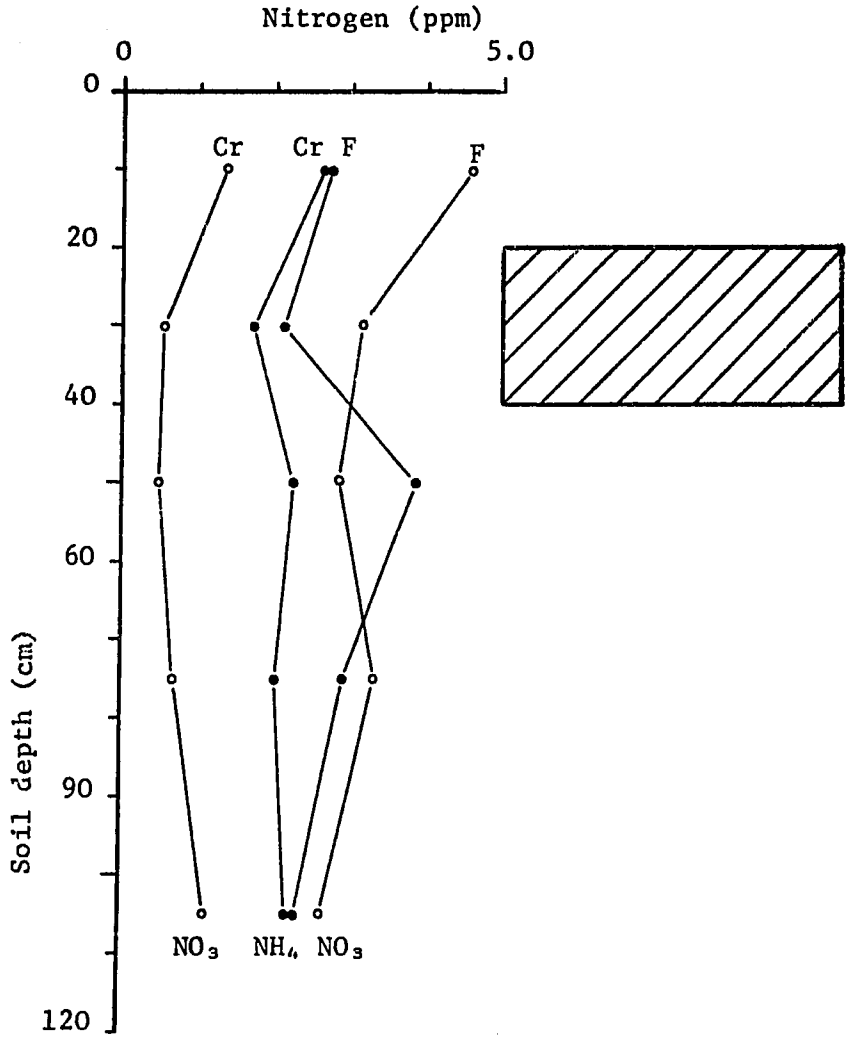


Figure 7.18. Mean ammonium (NH_4)- and nitrate plus nitrite (NO_3)-contents of cropped (Cr) soils and fallows (F) at all sites except Khanasser. The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

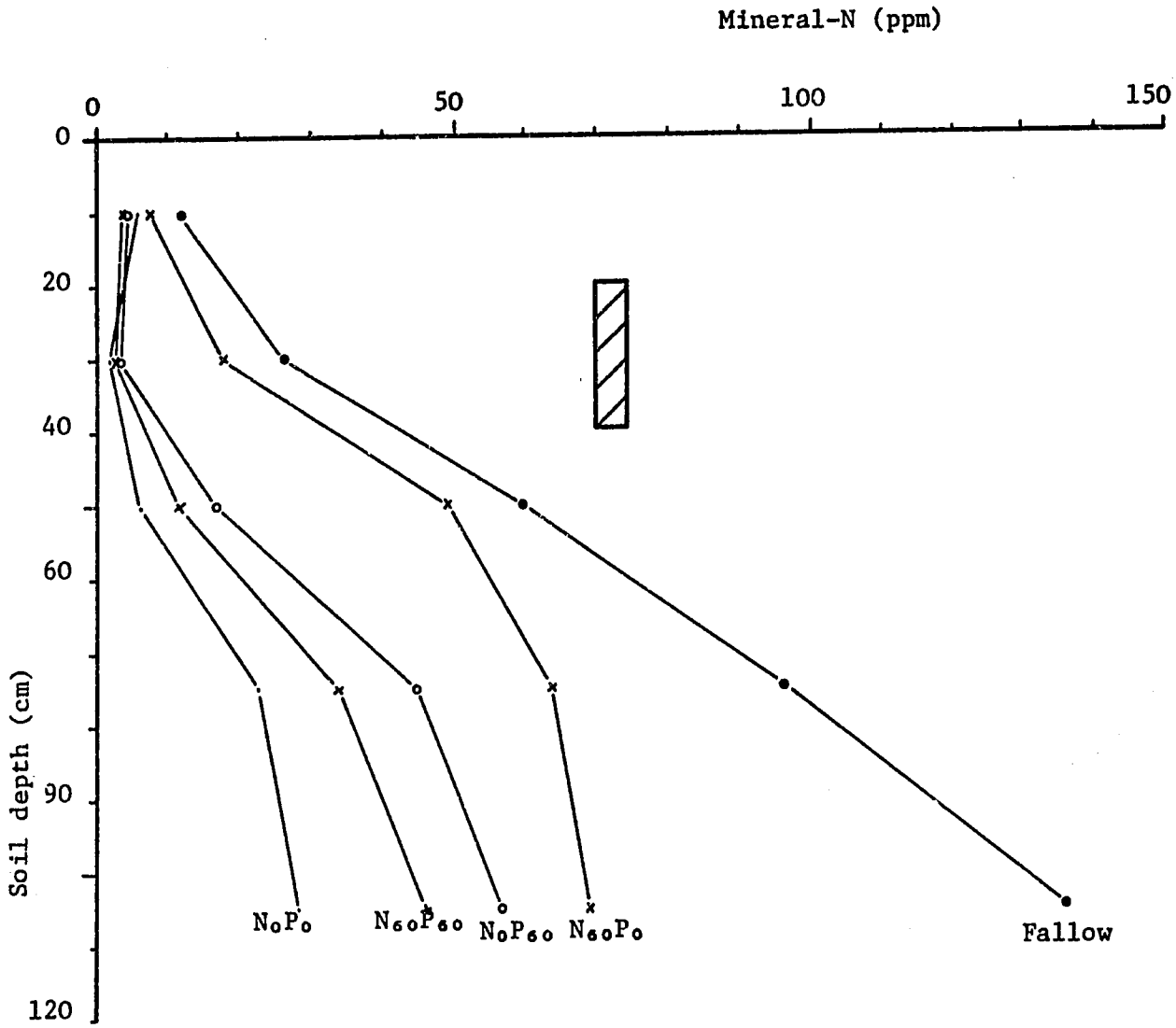


Figure 7.19. Mineral-nitrogen contents of fallow, N_0P_0-, N_0P_{60}-, $N_{60}P_0$- and $N_{60}P_{60}$- treatments at Khanasser. The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

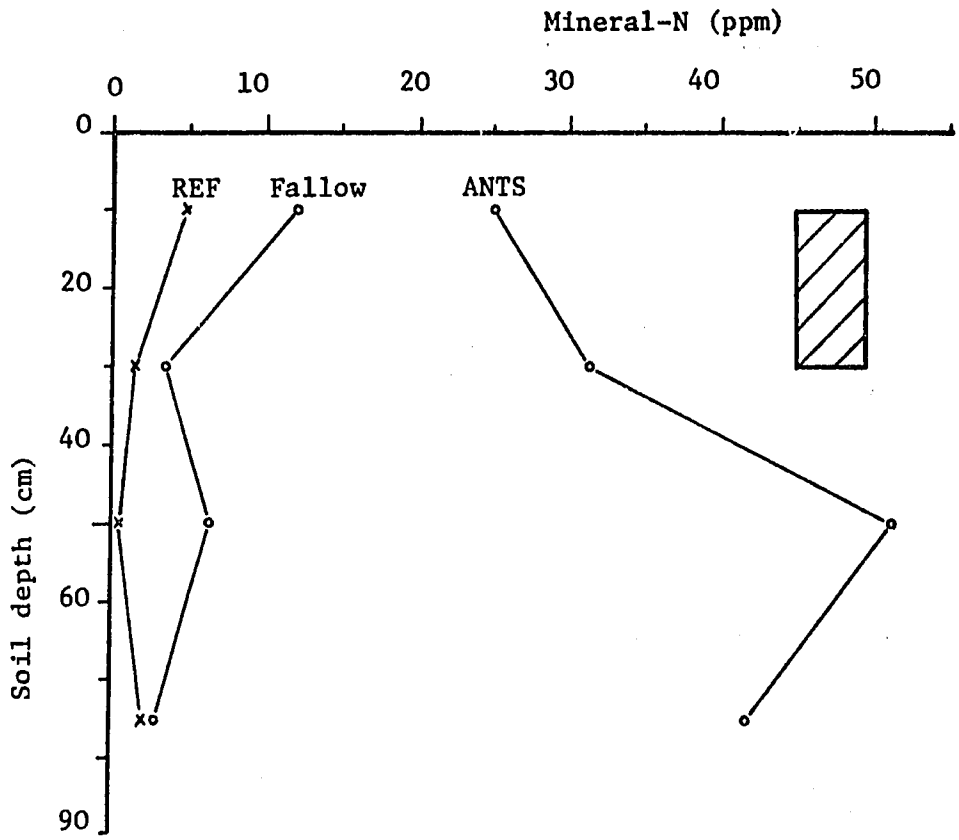


Figure 7.20. Mineral-nitrogen contents of ant spots (ANTS), reference soils next to the spots (RFP), and fallow treatments at Brida.
The shaded area represents 10 kg of N/ha in a 20-cm soil layer with a bulk density of 1.1 g/cm^3.

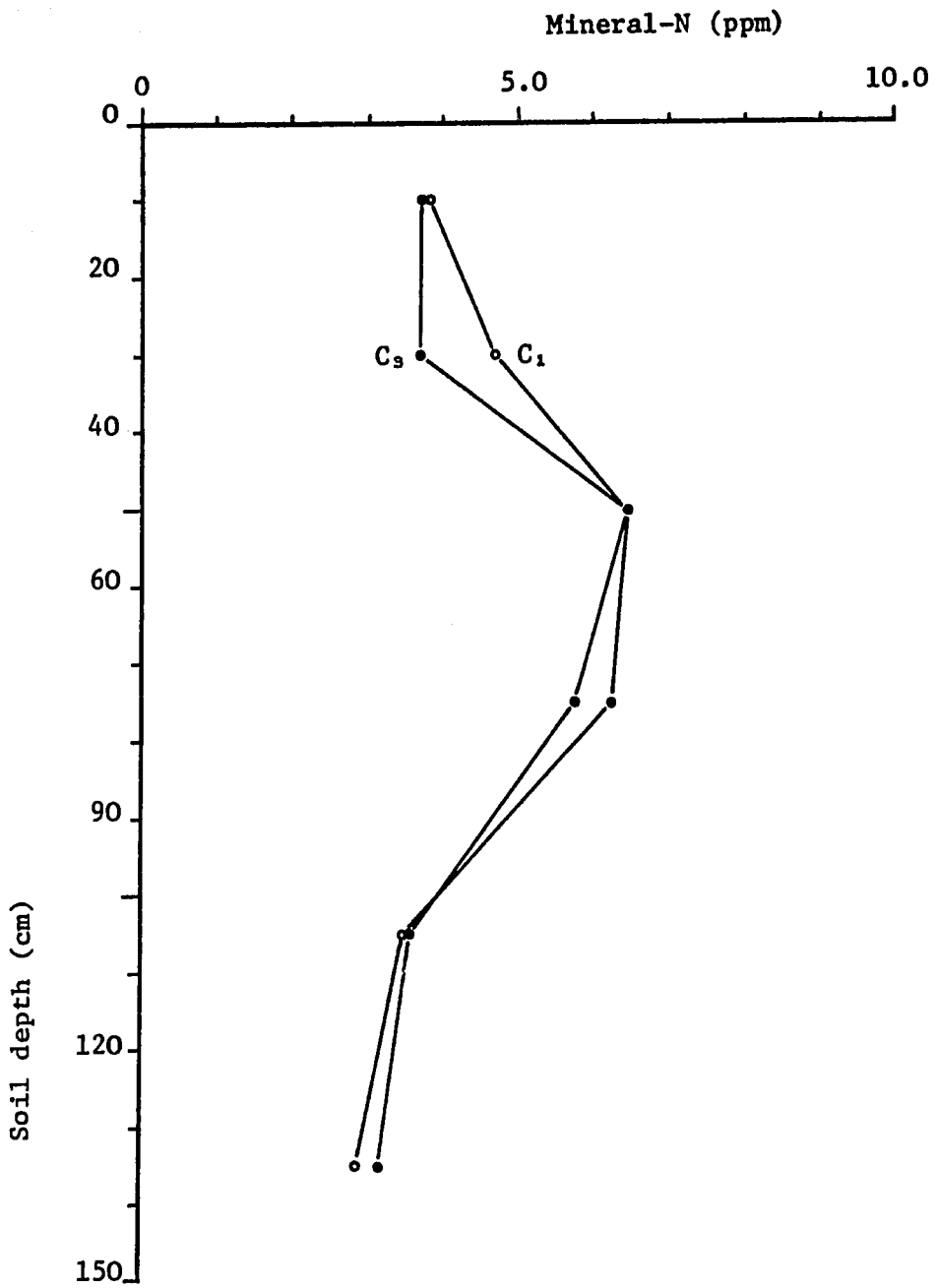


Figure 7.21. Mean mineral-nitrogen contents of long season (C_3) and short season (C_1) wheat-variety treatments in wheat variety/soil moisture/nitrogen experiment at Tel Hadya.

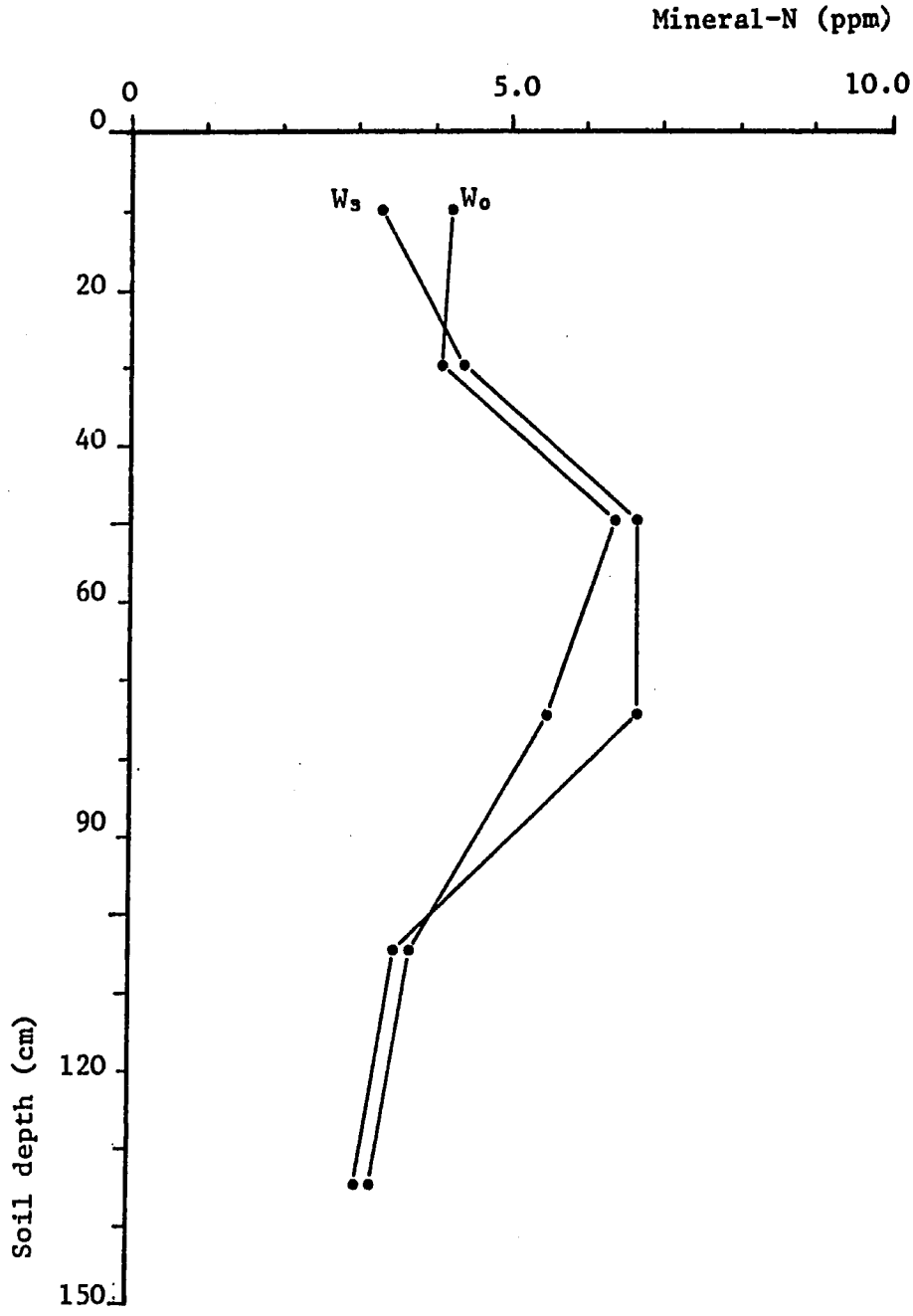


Figure 7.22. Mean mineral-nitrogen contents of rainfed (W_3) and irrigated (W_0) treatments in wheat variety/soil moisture/nitrogen experiment at Tel Hadya.

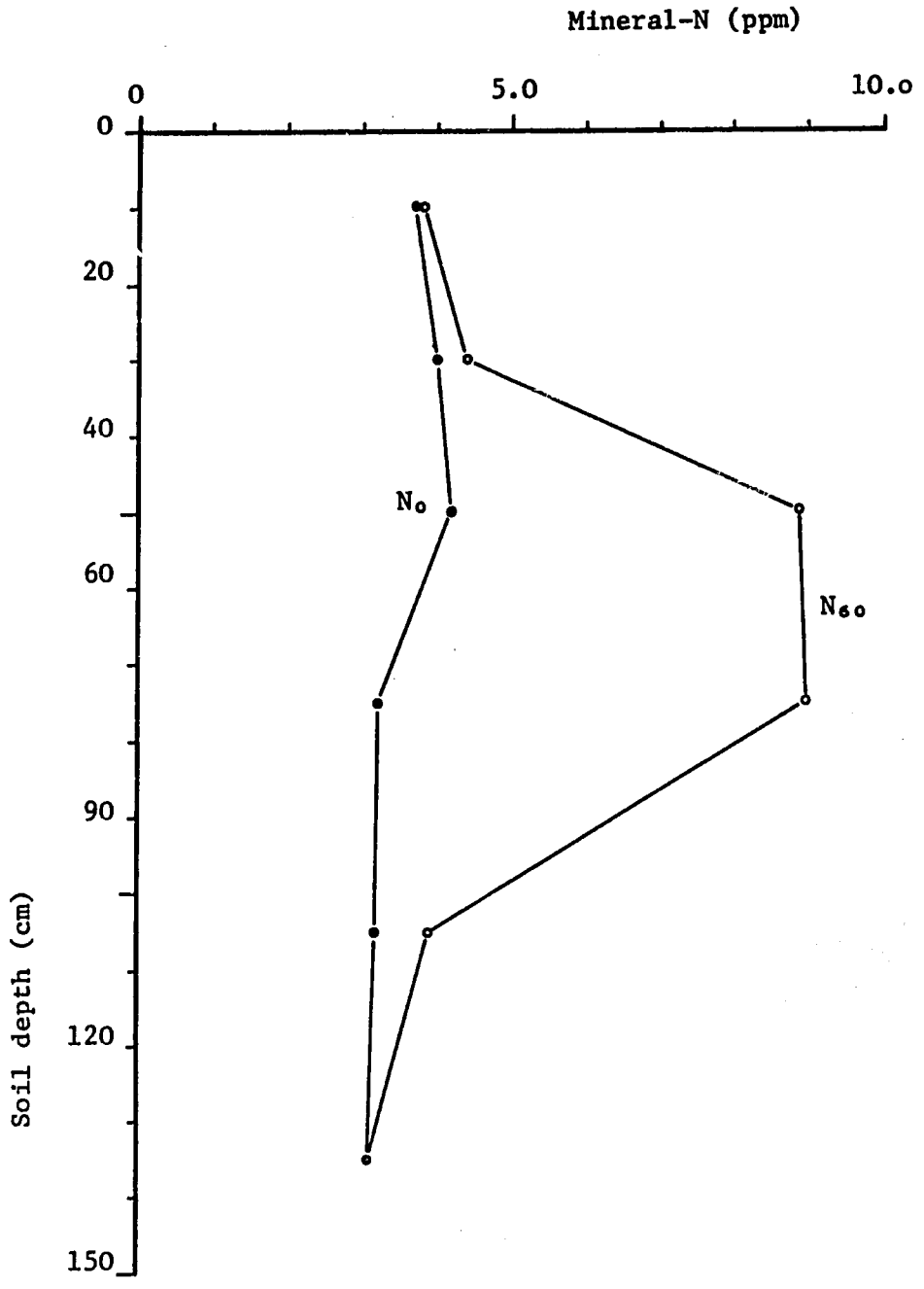


Figure 7.23. Mean mineral-nitrogen contents of unfertilized (N_0)- and fertilized (N_{60})- treatments in wheat variety/soil moisture/nitrogen experiment at Tel Hadya.

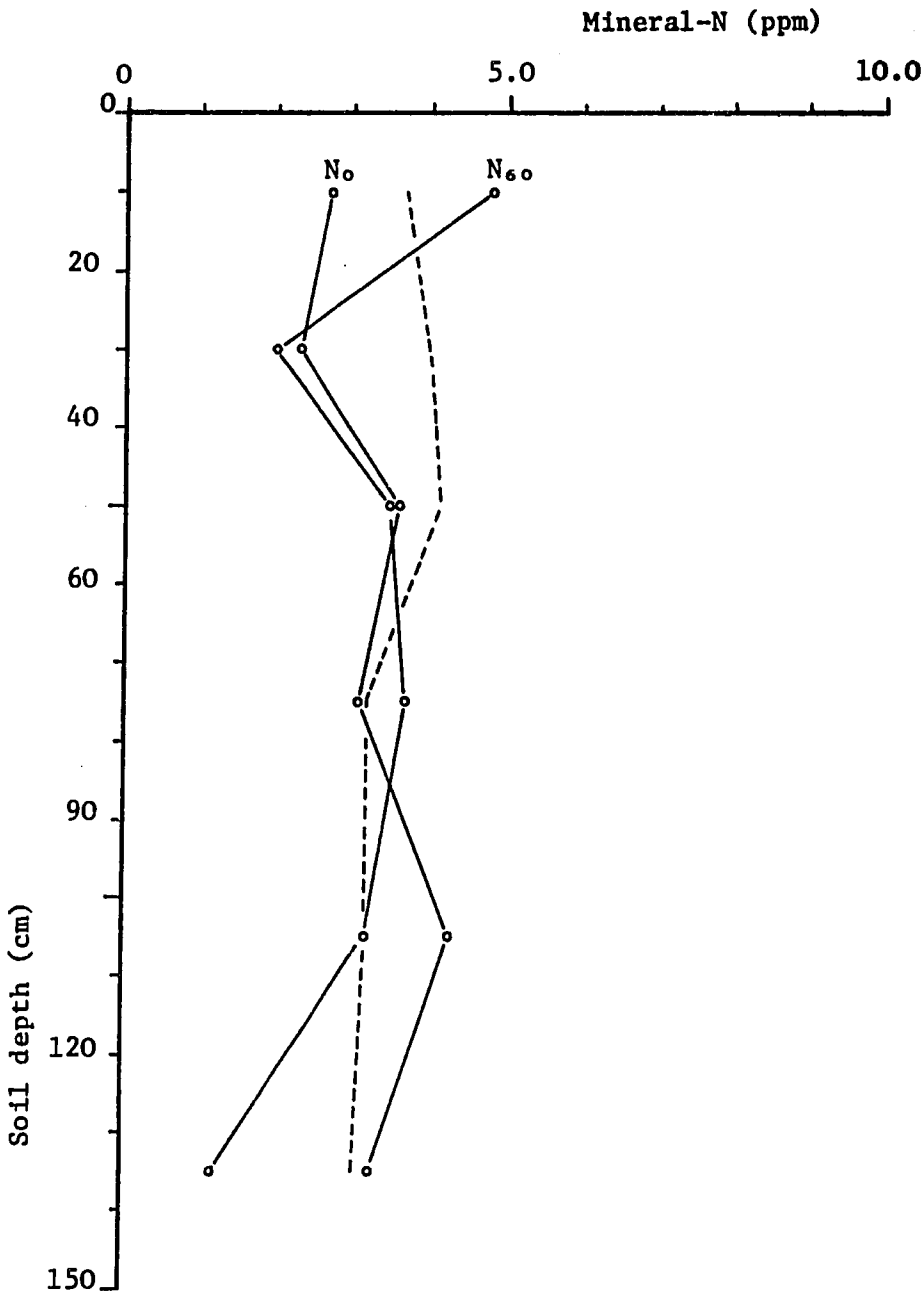


Figure 7.24. Mean mineral-nitrogen contents of N_0P_0 and N_0P_{60} (N_0)- and $N_{60}P_0$ and $N_{60}P_{60}$ (N_{60}) treatments in N and P experiment at Tel Hadya.
The dotted line represents the mean mineral-nitrogen content of unfertilized (N_0) treatments in wheat variety/soil moisture/nitrogen experiment at Tel Hadya.

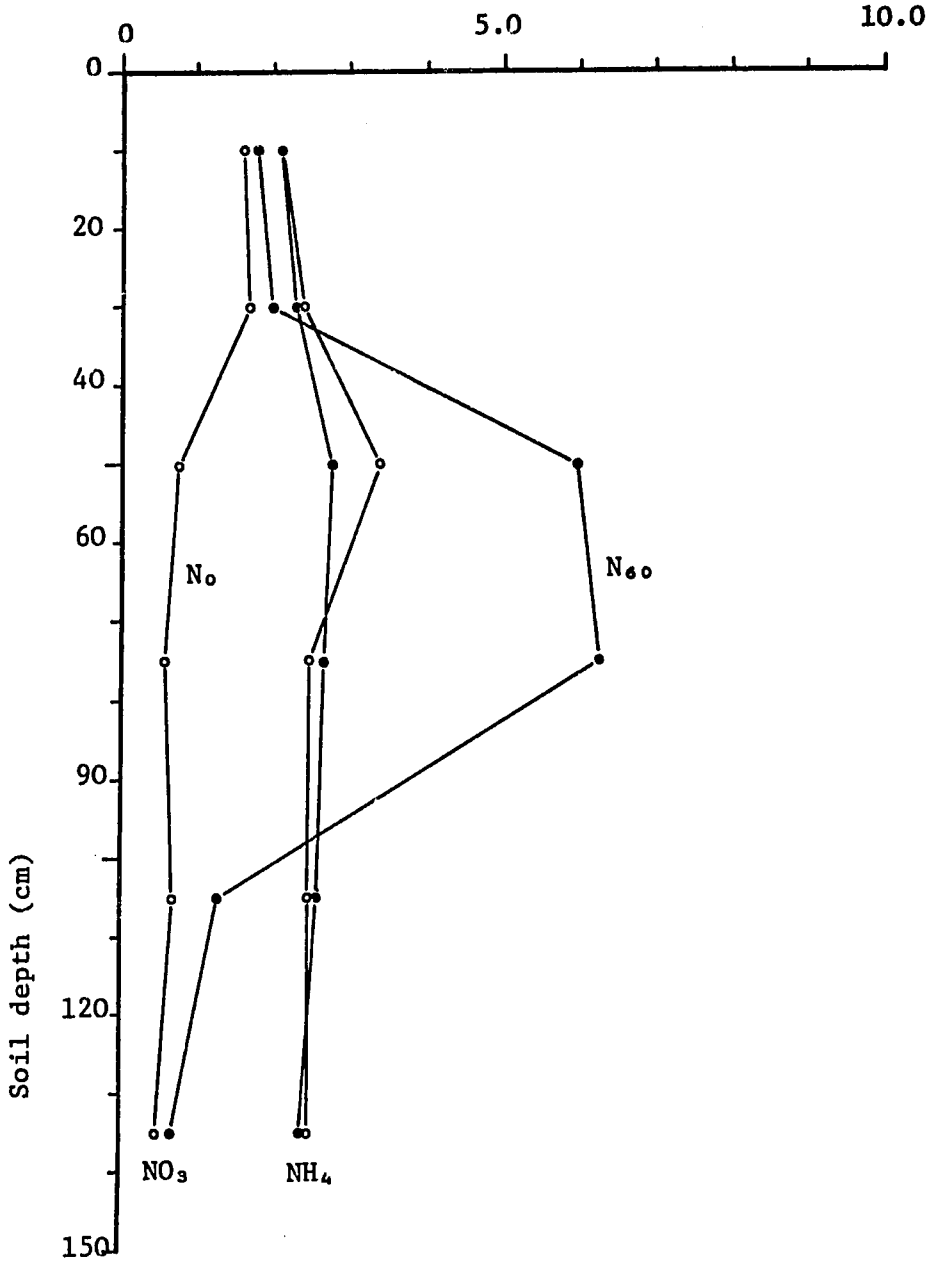


Figure 7.25. Mean ammonium and nitrite plus nitrate contents in fertilized (N_{60})- and unfertilized (N_0)- treatments in wheat variety/soil moisture/nitrogen experiment at Tel Hadya.

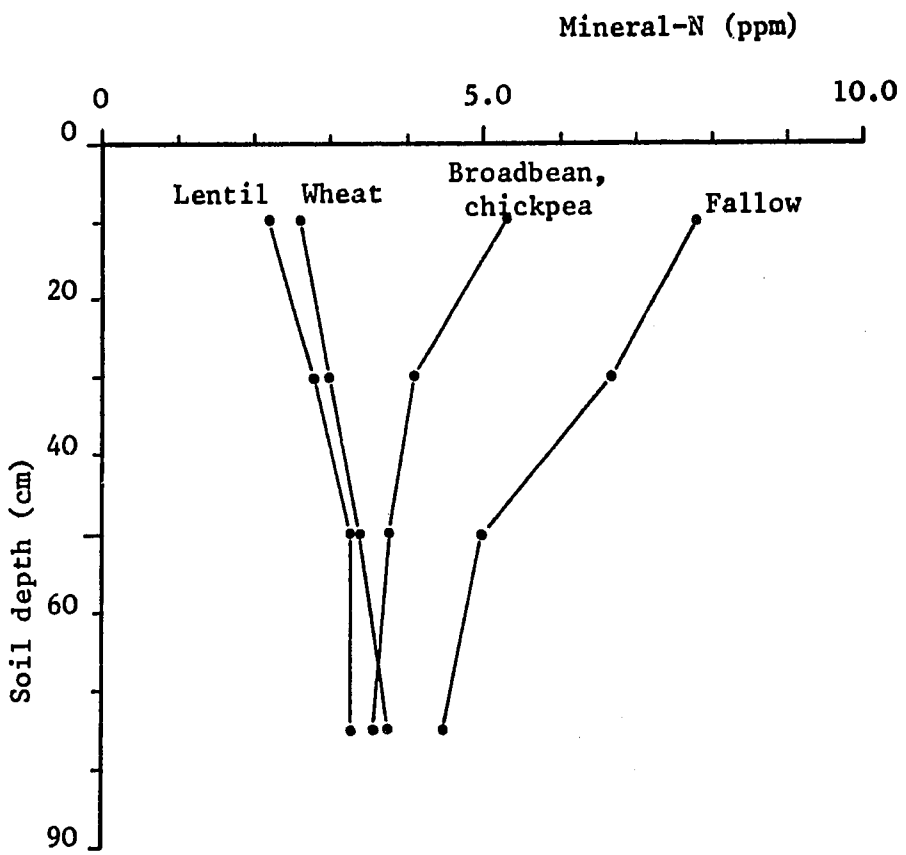


Figure 7.26. Mineral nitrogen contents in soils under lentils, wheat, broadbean, chickpea, and fallow in legume rotational experiment at Tel Hadya.

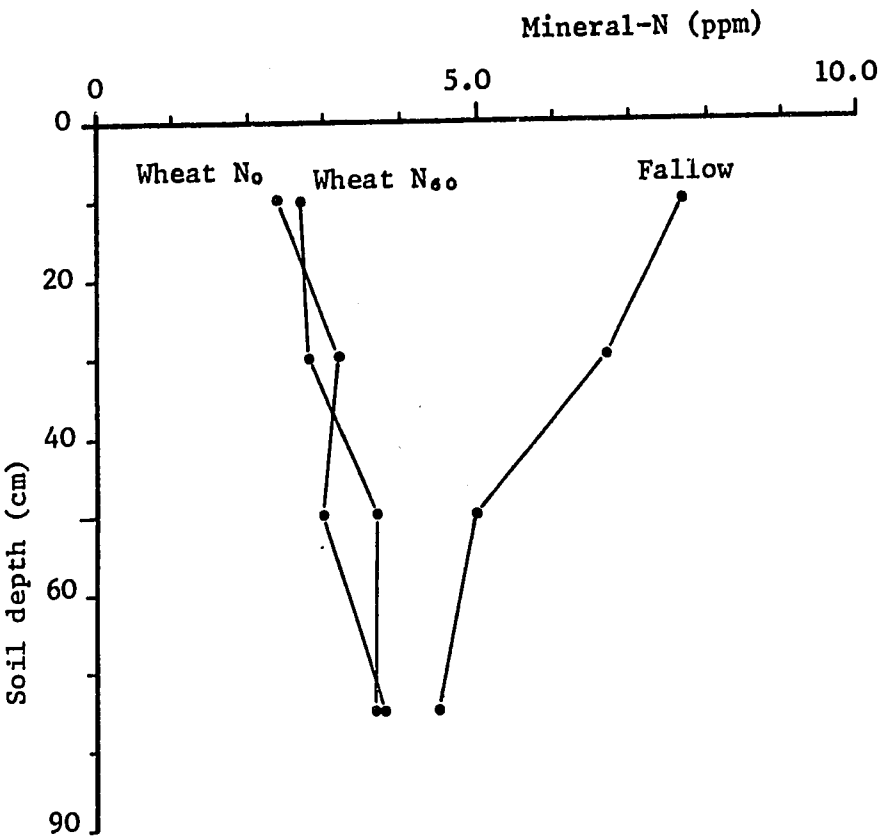


Figure 7.27. Mineral nitrogen contents in soils under fertilized (N_{60}) and unfertlized (N_0) wheat, and fallow in food legume rotational experiment at Tel Hadya.

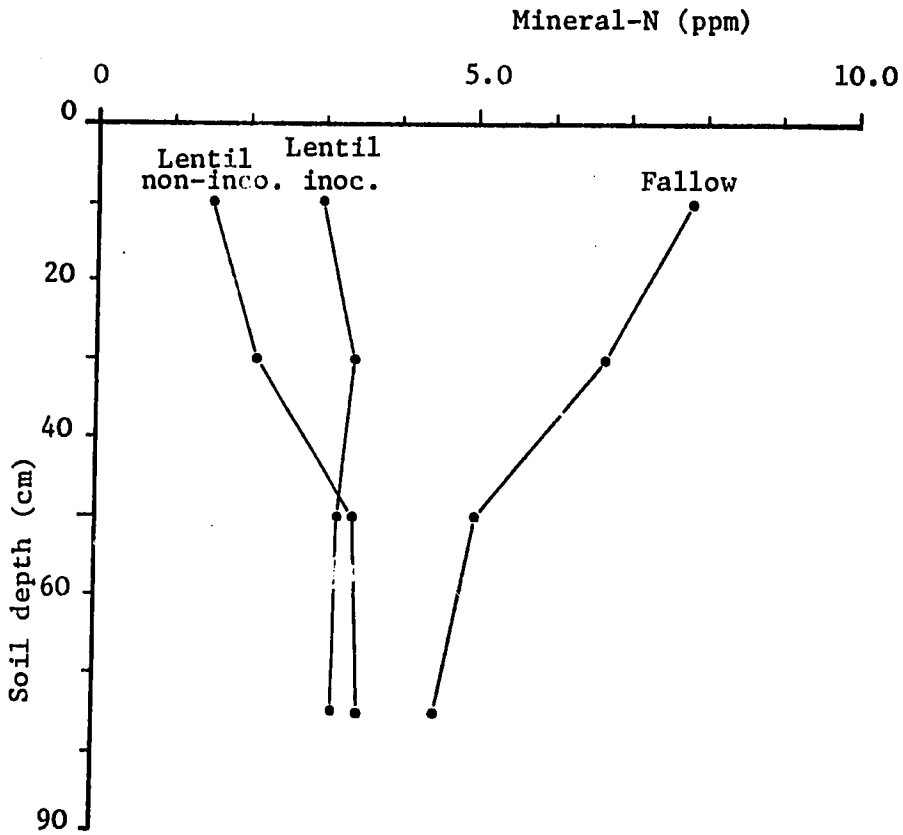


Figure 7.28. Mineral nitrogen contents in soils under inoculated (inoc.) and non-inoculated (non-inoc.) lentils, and fallow in food legume rotational experiment at Tel Hadya.

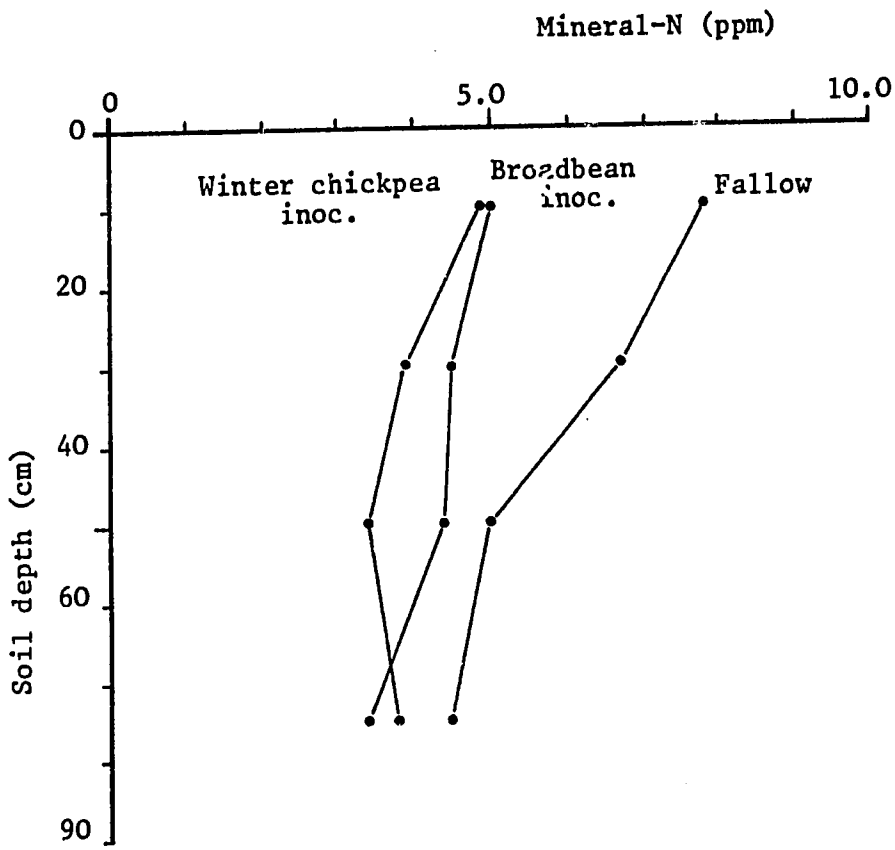


Figure 7.29. Mineral nitrogen contents in soils under inoculated broadbeans and winter chickpeas, and fallow in food legume rotational experiment at Tel Hadya.

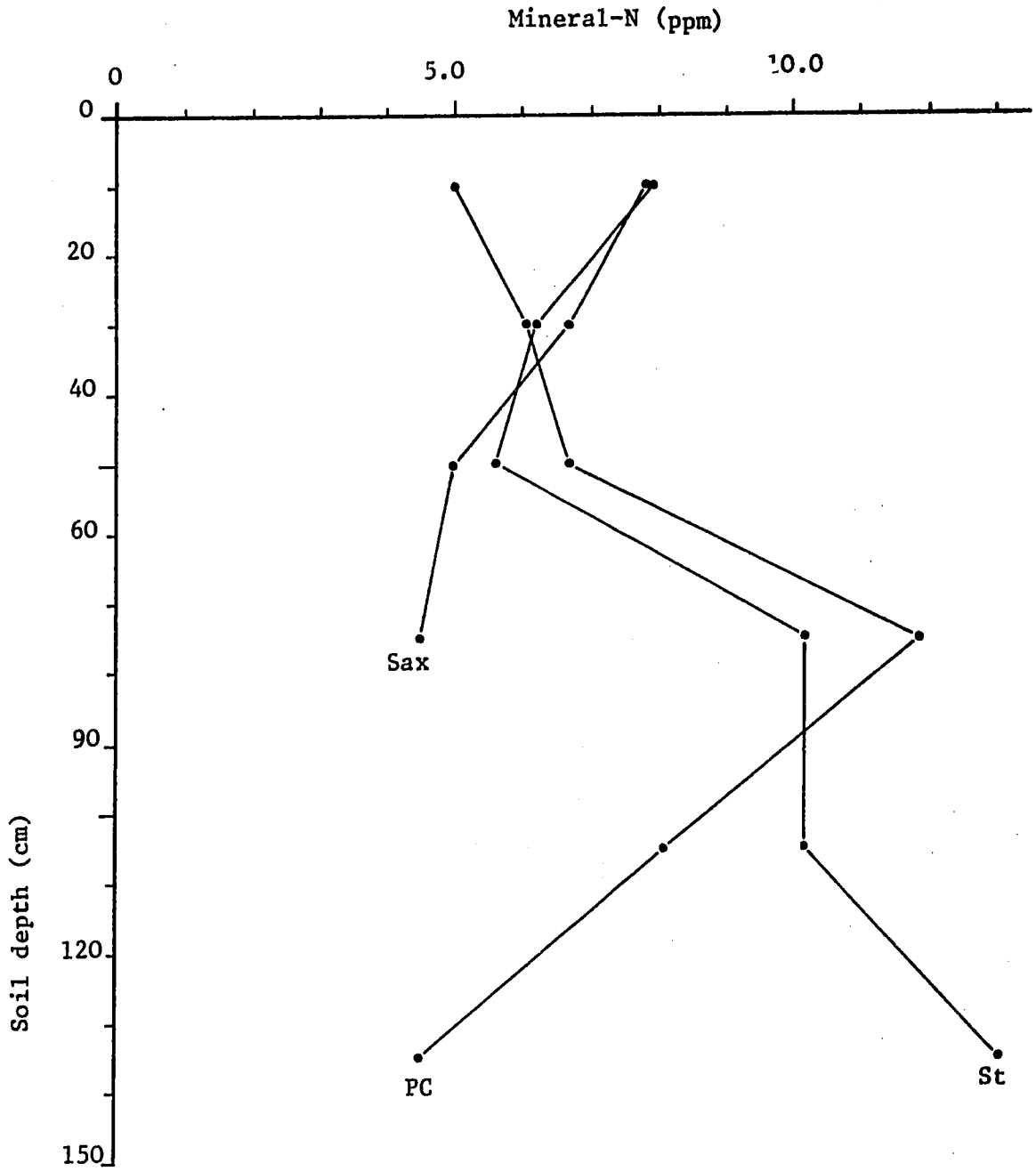


Figure 7.30. Mineral nitrogen contents in soils under fallow in moisture use efficiency trials (PC), food legume rotational trials (Sax), and wheat variety/soil moisture/nitrogen trials (St) at Tel Hadya.

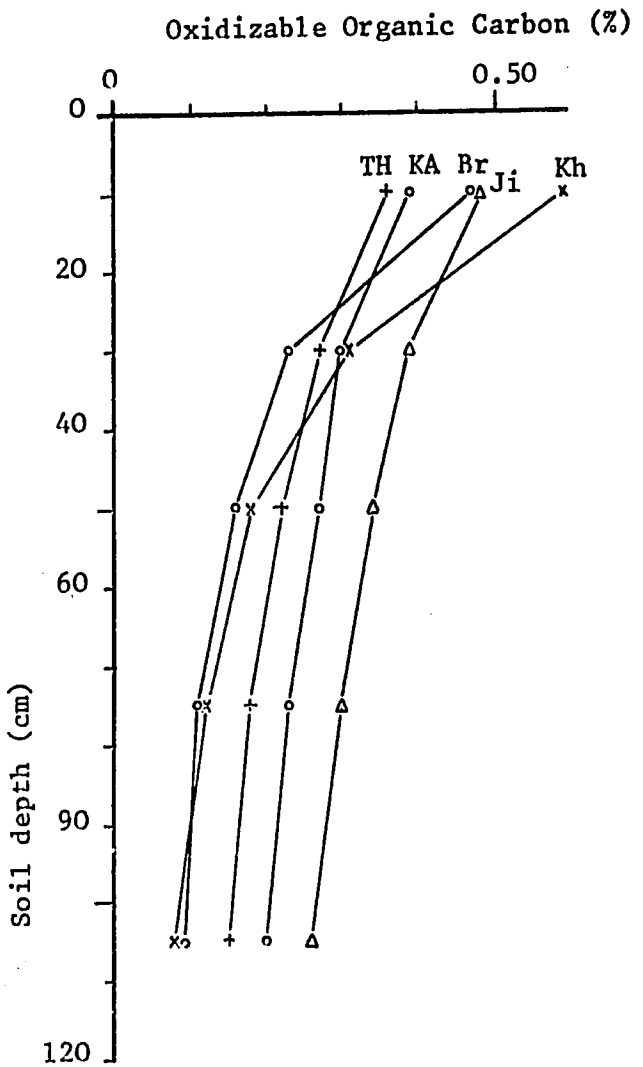


Figure 7.31. Mean oxidizable organic-carbon contents of soils at Khanasser (Kh), Brida (Br), Tel Hadya (TH), Kafr Antoon (KA) and Jindiress (Ji).

CHAPTER 8

BIOLOGICAL DINITROGEN FIXATION STUDIES

8.1 Introduction

The agriculture in the dry areas of West Asia and North Africa is characterised by a very low input of nitrogen fertilizer. The production of food and feed in the region depends very heavily on the nitrogen fixed biologically in the soil in association with the grain and forage legume components of the cropping system. Since the productivity of the farming systems in the region is often limited by shortage of available nitrogen to the crops, one of the major objectives of the soil microbiology research at ICARDA is to enhance the biological dinitrogen fixation associated with ICARDA's mandated crops of food and forage legumes. It is believed that this will contribute to increased productivity of the legume crops and improve and stabilise the productivity of non-leguminous crops of the cropping system as well as preventing the depletion of soil nitrogen.

In order to achieve these above objectives several projects have been developed. One of them involves surveying of the status of nodulation of food and forage legume crops in different parts of the region in order to predict the responses to seed inoculation. Since the region is the place of origin of most of the ICARDA-mandated food and forage legumes, it is likely that considerable variability for the efficacy of dinitrogen fixation also occurs in the strains of rhizobia associated with these legumes. Therefore, collection, isolation, evaluation and maintenance of effective strains of rhizobia is an important aspect of the study. Examination of the *Rhizobium* strain and host genotype interactions is a vital part of this study.

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* This chapter was written by Dr. Mohan Saxena, Acting Leader of the Food Legume Program and Dr. Rafik Islam, a microbiologist in the Research Support Group. Although they are not working in the SWAN Project their work is very relevant to the objectives of the UNDP grant. They are actively collaborating with the Farming Systems Program in several projects at the present time.

The crops in ICARDA region are often exposed, at various stages of growth, to different kinds of stresses, which doubtless affect both the host plant and Rhizobium, and therefore biological dinitrogen fixation as well. The common stresses that crops experience in the region include soil drought, low as well as high temperature and various levels of soil salinity. Use of herbicides and other pesticides also put stress on the Rhizobium, thus adversely affecting the association. Screening a large number of rhizobial strains to identify the ones more tolerant to stress stituations is, therefore, another important research objective.

Simple and reliable methods of Rhizobium inoculant production and use are necessary for improving symbiotic nitrogen fixation. This is necessary in cases where the naturalised Rhizobium is already present but is not efficient enough to permit full realisation of the potential dinitrogen fixation. It is also essential in areas which are newly brought under the cultivation of a specific legume and are, therefore, devoid of the right strains of rhizobia.

Nodules can be prematurely damaged by insect pests resulting in early cessation of symbiosis. Scope for improving the crop performance by preventing such damage to nodules is being studied.

Obtaining quantitative estimates on the magnitude of fixation, examining whether the symbiosis is capable of providing adequate nitrogen to meet the needs of the crop for a good yield, and determining if the fixation is being limited by shortages or excesses of any other soil nutrient are other important aspects of biological dinitrogen fixation. The residual effect of a legume crop on a subsequent crop of cereals has been studied to evaluate the contribution to the overall nitrogen economy of the cropping system.

Results of these studies, which were started in early 1978, are briefly presented in the subsequent sections. Data are mainly from the 1979-1980 cropping season.

8.2 Nodulation survey, and collection, isolation and evaluation of rhizobial strains

8.2.1 Surveys

Nodulation survey for lentils (*lens culinaris*), chickpeas (*Cicer arietinum*) and faba beans (*Vicia faba*) was carried out on farmer's fields as well as on experimental stations of the national programs in Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Spain, Sudan and Tunisia. In most of the locations, faba beans and lentils were found to be well nodulated by the native *Rhizobium* (see Table 8.1). However, there was considerable variation in the proportion of effective nodules to total nodules present on the sampled plants. Lentils were very poorly nodulated on farmer's fields in Egypt and Morocco. Chcikpeas were found to be very irregularly nodulated by the native *Rhizobium* presumably because of sporadic distribution of *Cicer Rhizobium*, which are very specific and are known not to readily nodulate other legumes. Considerable variation in nodulation has been observed in chickpeas within short distances (less than 50 cm) in the same field, particularly in parts of Syria, Egypt, Sudan and Morocco. The nodulation status of the crop on research stations was generally better than on the farmer's fields.

Surveys of nodulation also revealed that the nodules of lentils, peas (*Pisum sativum*) and faba beans at several locations were very extensively damaged by insects. In the case of lentils it was mainly due to the *Sitona* weevil, whose larva finds a comfortable niche in root nodules. Of the 120 lentil locations surveyed in northern Syria at early flowering stage during 1979-80 season, at 72 locations more than 70 percent of the nodules were damaged. Nodule damage of this magnitude at such a critical stage must have serious effect on the nitrogen nutrition of the crop and eventually on yield. The significance of controlling this damage through the use of insecticides is discussed in Section 8.4.

Collection of fresh nodules was undertaken, during the survey, in small glass vials containing anhydrous $CaCl_2$. Rhizobial strains were isolated in the laboratory from these nodules. The number of strains isolated and purified for different food and forage legumes stands at 150. These have been authenticated by plant infection tests with specific hosts. Some of the most promising strains for each crop have been evaluated under field conditions and the best ones have been advanced to multilocation strain evaluation trials.

8.2.2 Evaluation

Evaluation of the field performance of these isolates with different host genotypes has revealed that some of these are superior to the native strains at ICARDA's Tel Hadya site and that there is a conspicuous rhizobial strain x host genotype interaction.

The population of faba bean and lentil rhizobia in Tel Hadya soils is around 3.2×10^3 and 1.7×10^4 cells per gram of dry soil. In spite of this population, positive response to inoculation with newly isolated strains of rhizobia has been obtained in these crops, suggesting that some of the newly isolated strains are more efficient than the ones already existing in the field. Only data for 1979-80 season trials are presented in Tables 8.2 and 8.3 although they represent the trends obtained in the past. Interaction between host genotype x rhizobial strain is quite conspicuous in both the cases.

The population of chickpea *Rhizobium* in Tel Hadya soil is very low and highly variable, as is reflected by uneven and erratic nodulation in uninoculated crops. The response of two chickpea cultivars to inoculation with eight strains of *Cicer Rhizobium*, three (IC-26, 45 and 74) from ICRISAT and five from ICARDA, is shown in Table 8.4. Inoculation with suitable strains resulted in significantly heavier grain yield compared with those without inoculation. The local cultivar (ILC-1929) produced highest yields with CP-32b and the improved genotype ILC-195 with IC-45 was also excellent, again establishing the existence of strong genotype x strain interaction.

Amongst the forage legumes, five isolates of *Rhizobium* for annual medics, five for *Vicia species* (*V. ervilla*, *V. sativa* and *V. narbonensis*) and two for *Lathyrus* species were evaluated for nodulation and green forage yield using several genotypes of each of the forage legume species. Isolates Am 2a and Am 9a resulted in significantly higher nodulation and heavier forage yields with different annual medic species in comparison to uninoculated control. In general, *M. truncatula* responded more to artificial inoculation than did the other medic species. In the case of *Vicia* species, isolate Vs-4a consistently gave significantly better nodulation and higher forage yield than uninoculated control. Unlike the above two forage crops, *Lathyrus* species showed little advantage from inoculation with the two isolates used, although they responded very well to fertilizer nitrogen application. This proves the ineffectiveness of these isolates and points again to a certain degree of specificity between host genotypes and *Rhizobium* strain.

Further screening of more strains of Rhizobium for different genotypes of Lathyrus species is needed to make full use of potential symbiosis in this crop.

8.3 Strains for specific situations

As already mentioned in Section 8.1.3, the food legume crops in ICARDA's region are often grown under conditions where the Rhizobium, as well as the host plant is exposed to a varying degree of stress. The overall performance of the association under such conditions can improve if strains of Rhizobium more tolerant of such situations and compatible with the well adapted host genotypes are identified.

8.3.1 Irrigated faba beans

Faba beans in the region are generally grown either under irrigation or in areas where the seasonal precipitation is more than 500 mm. Rainfed crops in areas with lower rainfall are often exposed to soil moisture stress. An attempt to identify strains of Rhizobium tolerant to this situation was undertaken and several isolates were evaluated at Tel Hadya under rainfed conditions (with a seasonal precipitation of 424 mm) with a local large seeded land race of faba bean (ILB-1814). Results (Table 8.5) showed that one of the isolated (BB-39a) performed particularly well under this situation. More strains have been evaluated in the 1980-81 cropping season which had less precipitation.

8.3.2 Saline soils

Irrigated faba beans in parts of Syria, Iraq, Egypt, Sudan and Libya are subjected to varying degrees of salinity and the impaired nodulation under these conditions often can be attributed to lack of tolerance of the Rhizobium to salinity. A laboratory study was carried out to identify strains of Rhizobium tolerant of salinity by growing faba bean plants in Jensen's Agar medium salinised at the rate 0 (S_o), 0.16 (S_1) and 0.32 percent (S_1) NaCl and inoculated with 10 different strains of faba bean Rhizobium. The results (Table 8.6) showed that strains BB-48a, BB 54b and BB 85b resulted in good nodulation and highest dry matter yield under S_o, S_1 and S_2 levels of salinity respectively. The results reveal the differential susceptibility of Rhizobium strains to salinity and give indications that more tolerant strains can be identified. Further studies are planned for field evaluation of these strains under saline conditions.

8.3.3 Weed problems

Weeds pose a serious problem and limit both nitrogen fixation and yield of faba beans and lentils, which are grown during the wet winter season. Chickpeas planted in the winter, which promise much higher yield than the conventional spring planting, are also exposed to severe weed competition. In view of the rising cost of hand weeding and uncertain weather conditions, it is necessary that weeds in these crops are controlled by some suitable herbicides. The herbicides, however, can put stress on Rhizobium and thus adversely affect the symbiosis. Identification of strains of Rhizobium that would tolerate the herbicide should, therefore, be of great value.

Field experiments were conducted at Tel Hadya during the 1979-80 season to evaluate the performance of four promising strains of Rhizobium each for faba beans, lentils and chickpeas under various weed control treatments, including a control with the most effective herbicide for each crop. The results, presented in part in Table 8.7, showed that strains of Rhizobium differed in terms of their compatibility with the herbicide and strains could be identified which permit effective symbiosis in the presence of herbicides. Table 8.7 includes data only for those strains which proved most effective in case of each crop. For chickpeas, there is a need to evaluate more strains as the best strain (3889) gave only partial improvement in the performance of the symbiotic association in the presence of the herbicide.

8.4 Protection of nodules from insect damage by insecticide use

As already mentioned in Section 8.2, the nodules of lentils, peas and faba beans are often damaged by certain insect larvae at a very critical stage which may affect the symbiotic nitrogen fixation. Studies on the larvae revealed that they were generally Sitona species. Effective control of larvae of this weevil in soil was achieved in the case of lentils by pre-planting soil incorporation of 1.5 kg a.i. of carbofuran insecticide per hectare. The insecticide application at Tel Hadya resulted in more luxuriant shoot growth, protected the nodules from insect damage and increased the yield of lentils (Table 8.8) and forage peas (Table 8.9) significantly during 1979-80 season. The lentil results confirm the observations made during 1978-79 season at Tel Hadya and at nine 'On-farm' sites and the four SWAN sites during 1979-80.

8.5 Methods of inoculant production and use

Mixing the broth culture of Rhizobium with irradiated peat in small polyethylene bags has been a very effective method of producing inoculant for use. Such a system gives adequate shelf-life for the use of inoculant at short intervals. However, for long storage and distant shipping this may not be adequate. Evaluation of single vs. multiple strains in the inoculant is being carried out with a view to develop inoculant which may perform better under varied environmental conditions and with different host genotypes. As a substitute for peat, which may not be easily available everywhere, alternate carriers have been evaluated. Ground meal of the respective seeds showed good promise for the laboratory level production of inoculant.

For field use, the conventional method of inoculating the seeds with the peat slurry of the inoculant made with methylated cellulose seems to be the best. However, for inoculating large numbers of small samples of seeds for the crop improvement program the inoculum could be very effectively applied by making an aqueous suspension of the peat culture and pouring it in the seed furrows. This method proved particularly effective for spring planted crops and small seeded species such as lentils and medics.

8.6 Effect of agronomic factors on the magnitude of symbiotic dinitrogen fixation

A quantification of the amount of symbiotic dinitrogen fixation is important in evaluating the role of a nodulated legume in the cropping system of a region. It is also important in evaluating various agronomic practices and comparing different genotypes in relation to symbiotic dinitrogen fixation.

A quantitative measurement of the amount of soil nutrient in the units of fertilizer standard labelled with suitable isotope has long been done by using the 'A' value concept (Fried and Dean, 1952). Fried and Broeshart (1975) have shown that the amount of nitrogen fixed by a nodulated legume can also be measured in terms of fertilizer standard by substracting the 'A' value obtained with a non-nodulating crop from the 'A' value obtained with a nodulating crop. By using the fertilizer use efficiency which is experimentally determined by isotopic measurements, the 'A' value in the fertilizer units can be converted to the actual amounts of nitrogen fixed by the crop. The symbiotic dinitrogen

fixation in lentils, faba beans and chickpeas has been evaluated by the user of this technique in a set of trials conducted at Tel Hadya during 1977-78 and 1978-79 cropping seasons. Wheat was used as a non-nodulating crop. Fertilizer was tagged with ^{15}N. Results of these trials are briefly described below.

Effect of phosphate fertilization on the symbiotic dinitrogen fixation of local small seeded land race of lentil (ILL 4401) was studied during the 1977-78 season on a soil with an available phosphorus content of 6.9 ppm P. The seasonal precipitation was 360 mm and the crop was planted on December 1st. The results are shown in Table 8.10. About 50 percent of the nitrogen in lentil was contributed by symbiosis. Phosphate application at the rate of 50 kg P_2O_5/ha increased the contribution of symbiotic nitrogen fixation to total nitrogen yield. The latter was only slightly increased in comparison to that without phosphate fertilization. It emphasises the fact that limited supply of phosphate may limit the symbiotic fixation in lentil and thus encourage the depletion of soil nitrogen as occurs in soil where cereals are produced.

Studies were also carried out on the effect of phosphate fertilization on the symbiotic dinitrogen fixation in two land races of faba beans planted at the optimum time in the same season but on different fields where the available soil phosphorus in the top 15 cm was 8 ppm. The results are presented in Table 8.11. The contribution of symbiosis to total nitrogen yield in faba beans was much higher (about 90 percent of the total plant N) than that in lentils and there were conspicuous genotypic differences in-so-far as the effect of phosphate application was concerned. Genotype ILB-1814 showed improvement in the symbiotic N fixation with phosphate application whereas ILB-1813 showed little improvement, although the latter gave higher response to phosphate fertilization than the former in terms of yield of grain and straw. This emphasises the importance of host-genotype x rhizobial strain interaction in affecting symbiotic nitrogen fixation in relation to supply of phosphate to the growth medium.

As a part of a 'coordinated research program on isotopic techniques in studies of biological dinitrogen fixation, for the dual purpose of increasing the crop production and decreasing fertilizer use to conserve the environment', a study was carried out during 1978-79 cropping season. The objective was to evaluate the symbiotic dinitrogen fixation by inoculated chickpeas alone and in intercropping with Sudan grass as well as uninoculated chickpea alone compared to inoculated lentils and inoculated faba beans at two rates of nitrogen fertilizer application.

The trial was planted rather late (in January 1979) and the seasonal precipitation was only 246 mm. Hence the yield levels were low (Table 8.12), particularly in case of lentils and faba beans. However, interesting results were obtained on the contribution of symbiotic dinitrogen fixation to total nitrogen yield. Inoculation, as expected, increased and higher rates of nitrogen application decreased the symbiotic dinitrogen fixation in chickpeas. Contribution of symbiosis to total N in the crop at 20 kg N/ha was about 47 percent in inoculated faba beans and 9 percent in inoculated lentils. Both values are far lower than the values obtained during 1977-78 season, which perhaps was due to the effect of delayed planting and exposure of the crop to drier conditions during 1978-79.

The highest contribution of symbiosis to total plant N was obtained under the treatment 'Intercropped chickpea + Sudan grass'. However, in this treatment, establishment of Sudan grass failed because of low temperatures. This resulted in an inoculated chickpea plot with half the population (i.e. 16.6 plants/m^2) compared to that obtained in the pure chickpea plots (33.3 plants/m^2). Thus the effect is essentially that of lower plant population. It is appropriate to emphasise that the total seasonal rainfall was rather low and the availability of moisture per plant would have been much greater in the plot with the lower plant population. This might account for the higher contribution of symbiosis to total nitrogen yield.

It can be concluded from the data in Table 8.12 that although inoculation of chickpeas with Rhizobium in this case did not result in a significant increase in grain or total shoot yield or total nitrogen yield it might still, had the crop been better managed, be beneficial in the cropping system by increasing the contribution of symbiosis to total nitrogen yield in the crop and thus resulting in lower depletion of soil nitrogen.

8.7 Summary and conclusion

8.7.1 Summary

The following results have been generated by microbiological research at ICARDA during the past two years.

(1) Lentils and faba beans in the region are generally well nodulated although there exists considerable variability in the proportion of effective nodules. Chickpeas show slightly variable nodulation.

(2) More than 150 isolates of Rhizobium spp. from different parts of the region for different food and forage legumes have been made, purified and authenticated by infection tests on host plants. Some of the promising strains have been evaluated for different host-genotypes and environmental conditions. It has been possible to identify strains tolerant of soil moisture stress, moderate levels of salinity and different promising herbicides for some of the legumes.

(3) Strong host genotype x Rhizobium strain interactions have been established for most of the test legumes.

(4) Inoculation with effective strains of Rhizobium has resulted in improved nodulation and heavier yields than with control under the presence of native Rhizobium population in the soil. Studies have been carried out on the production and use of inoculants.

(5) Protection of nodules of lentils and peas from damage by larvae of Sitona weevil, which is fairly widespread in the region, through the use of insecticide carbofuran has resulted in significant improvements in yield.

(6) More than 40 percent of plant nitrogen in lentil and about 90 percent in faba beans was contributed by symbiosis, and phosphate fertilizer application increased this contribution under low available phosphorus conditions. Delaying the date of planting to late winter resulted in a reduction in dinitrogen fixation. Higher rates of nitrogen application had a similar effect. Under low rainfall conditions (246 mm seasonal precipitation) smaller plant populations (16.6 plants/m^2) of chickpeas gave higher symbiotic dinitrogen fixation than higher populations (33.3 plants/m^2).

8.7.2 Conclusion

The results indicate that there is considerable scope for the improvement of symbiotic dinitrogen fixation by the manipulation of the two partners of the symbiosis and by appropriate crop management practices. Obviously, all these approaches are necessary for an overall improvement in the symbiotic dinitrogen fixation which is vital for sustained productivity and stability in the farming systems of the dry areas in West Asia and North Africa. Notwithstanding the

importance of symbiosis, it is to be accepted that this is only one aspect of the whole system of biological dinitrogen fixation. Other aspects will have to be given greater attention in the future.

References

Fried, M. and L.A. Dean (1952). A concept concerning the measurement of available soil nutrient. Soil Sci. 73: 263-271.

Fried, M. and H. Broeshast (1975). An independant measurement of the amount of nitrogen fixed by a legume crop. Plant and Soil 43: 707-711.

Table 8.1 Countries, Number of Locations and Nodulation Status of Faba Beans in the West Asia and North Africa Region.

Countries	Number of Locations	Nodulation Status		
		Good*	Moderate**	Poor***
Syria	43	13	13	17
Egypt	36	10	14	12
Sudan	15	0	10	5
Morocco	12	5	4	3
Tunisia	9	0	2	7
Algeria	8	0	1	7
Libya	6	0	0	6
Jordan	6	0	3	3
Spain	4	0	0	4
Lebanon	4	0	3	1

* More than 50 large and pink nodules/plant.

** 25 and 50 large and medium sized pink nodules/plant.

*** Less than 25 smaller and some white coloured nodules per plant.

Table 8.2 Effect of Inoculation with Several Strains of *Rhizobium* and Nitrogen Fertilization on Nodule Production and Grain Yield in Three Faba Bean Cultivars During Winter 1979-80.

Treatment	Syrian Local Large			Syrian Local Small			Green Windsor		
	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)
Uninoc	98.3	104.9	2456.1	73.3	82.0	2333.5	136.3	196.7	1667.9
BB 10c	65.5	101.2	2614.2	93.3	107.1	2472.7	115.7	266.7	1980.7
BB 32b	80.7	150.3	2843.8	117.9	130.0	2795.6	94.5	255.3	1986.6
BB 39a	103.4	203.5	2657.8	96.6	153.2	2824.1	115.5	418.7	2329.8
BB 48a	117.8	201.6	2493.3	114.8	88.5	2396.4	142.0	478.8	1965.9
BB 54b	60.8	179.4	2516.1	121.3	115.0	2031.5	93.8	159.4	2019.2
BB 64a	72.1	106.2	2203.6	65.7	80.9	2125.0	107.9	251.8	2135.0
120 kg N/ha	35.4	87.4	2432.2	46.4	33.6	2711.8	77.9	155.2	2170.5
L.S.D. 5%	15.5	32.0	319.5	26.0	23.1	267.6	30.7	52.6	266.6

Table 8.3 Effect of Inoculation with Several Srains of *Rhizobium* and Nitrogen Fertilization on Nodule Production and Grain Yield in Three Lentil Cultivars During Winter 1979-80.

Treatment	Syrian Local Large			Syrian Local Small			ILL - 435		
	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Dry Wt. (mg/plant)	Grain Yield (kg/ha)
Uninoc	37.8	14.4	1745.6	27.3	6.7	1465.0	9.6	6.7	1207.7
L-25b	40.5	14.3	1902.5	31.2	6.9	1619.9	13.2	7.1	1517.9
L-28a	44.8	15.1	1953.8	31.7	7.0	NIL*	15.2	6.3	1510.3
NZP 5400	46.6	12.9	1926.7	30.5	7.0	2110.0	11.9	6.7	NIL
L-34a	46.2	16.1	1719.7	27.2	7.5	1241.3	12.4	6.2	1282.8
L-35a	41.6	16.3	1738.5	28.1	7.3	1393.3	17.7	8.7	NIL
120 kg N/ha	36.5	6.4	1780.7	25.8	3.1	NIL	9.9	3.9	1214.5
L.S.D. 5%	9.2	1.3	277.[illegible]	6.7	0.8	311.5	4.0	0.9	245.8

* Yield data could not be obtained because of damage by *Fusarium Oxysporum*.

Table 8.4 Effect of Inoculation with Several Strains of *Rhizobium* on Nodule Production and Grain Yield in Two Chickpeas Cultivars During Sprind 1980.

Treatment	Syrian Local			ILC - 195		
	Nodule No./ Plant	Nodule Dry Wt. (mg/Plant)	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Dry Wt. (mg/Plant)	Grain Yield (kg/ha)
Uninoc	2.2	57.2	1624.2	1.5	41.4	875.4
IL-26	29.0	138.2	1472.0	8.8	56.9	1032.4
CP-5b	3.1	91.7	1649.3	2.9	53.3	1246.6
IC-45	6.2	72.4	1832.8	5.4	93.0	1329.6
IC-74	3.6	109.8	1517.6	1.9	84.4	731.2
CP-26a	3.2	75.1	1749.2	1.4	43.4	986.5
CP-32b	12.6	111.7	2209.6	11.5	67.8	671.1
CP-35a	5.3	71.2	1454.7	6.8	89.4	1169.6
CP-37a	11.0	66.1	1657.9	11.8	100.9	995.9
120 kg N/ha	2.9	38.9	1889.0	1.0	4.9	1032.2
L.S.D. 5%	3.1	17.2	187.0	1.5	13.6	126.7

Table 8.5 Production of Nodules, Nodule Dry Matter and Grain by Faba Bean as Affected by Several Strains of *Rhizobium* under 424 mm Rainfall in Tel Hadya.

Treatment	Nod. No./ Plant	Nod. Dry Wt. (mg/Plant)	Yield kg/ha
Uninoc	77.0	240.9	2223
BB-10C	125.0	293.8	2352
BB-21b	82.0	259.6	2071
BB-22b	144.0	284.8	2211
BB-64a	71.7	225.3	2316
BB-39a	154.6	299.6	2578
BB-48a	138.6	386.1	2429
BB-54b	147.2	290.0	2458
IC-9253	199.7	193.6	2490
120 kg N/ha	52.1	110.7	2367
L.S.D. 5%	20.5	41.3	243

Table 8.6 Production of Nodules, Nodule Mass and Total Dry Matter by Faba Bean Plants with Faba Bean *Rhizobium* in Different Salt Concentrations

Rhizobium Strains	S0			S1			S2		
	Nodule No./ Plant	Nodule Dry Wt. (mg/Plant)	Total Dry Wt. (g/Plant)	Nodule No./ Plant	Nodule No./ (mg/Plant)	Total Dry Wt. (g/Plant)	Nodule No./ Plant	Nodule Dry Wt. (mg/Plant)	Total Dry Wt. (g/Plant)
BB - 10C	33.8	17.2	0.54	9.5	4.1	0.50	0.0	0.0	0.39
BB - 32b	9.3	5.9	0.45	8.5	4.1	0.45	4.0	3.7	0.38
BB - 39a	11.3	8.4	0.42	14.5	6.3	0.47	14.5	5.7	0.46
BB - 54b	28.0	7.9	0.63	22.3	5.3	0.56	5.0	7.5	0.50
BB - 48a	16.0	12.1	0.65	10.5	5.4	0.38	13.5	8.1	0.41
BB - 22b	15.3	3.7	0.40	34.0	16.5	0.50	24.3	7.4	0.46
BB - 85b	7.0	5.3	0.62	33.3	15.7	0.43	17.8	10.7	0.51
BB - 80b	7.3	3.8	0.47	19.5	8.9	0.38	16.5	6.2	0.40
BB - 66a	16.0	10.2	0.63	18.3	14.3	0.55	0.3	0.1	0.40
BB - 40b	27.3	12.4	0.48	27.3	13.3	0.46	5.5	2.3	0.35
Uninoc	0.0	0.0	0.36	0.0	0.0	0.34	0.0	0.0	0.35

L.S.D. 5%	Nod. No.	Nod. Dry Wt.	Total Dry Wt.
Salt Concentration	4.6	2.5	0.06
Rhizobium Strain	9.4	4.2	0.11
Salt Conc. X Rhizobium Strain	16.0	7.2	0.18

Table 8.7 Effects of Rhizobium Inoculation and Weed Control Treatments on Nodulation and Grain Yield of Faba Bean, Lentil and Chickpeas, and the Development of Weed Biomass During Winter 1979-80.

Crop	Treatment	Nodule No./ Plant	Nodule Dry Wt. (mg/Plant)	Weed Biomass (kg/ha)	Grain Yield (kg/ha)
Faba Bean	Uninoc + Unweeded	46.7	132.5	3255.6	1664.1
	Uninoc + Hand weeded	56.4	162.2	NIL	2725.4
	BB 48a + Hand weeded	88.9	293.4	NIL	2891.0
	Uninoc + Tirbunil	90.4	196.1	59.4	2564.1
	BB 48a + Tribunil	102.9	298.6	69.2	3050.8
	L.S.D. 5%	10.5	27.5	174.6	293.6
Lentil	Uninoc + Unweeded	27.8	11.1	5526.9	527.2
	Uninoc + Hand weeded	24.6	8.7	NIL	1668.2
	L-28a + Hand weeded	25.2	8.6	NIL	1819.1
	Uninoc + Gesagard	24.8	7.8	1779.4	1028.8
	L-28 + Gesagard	19.4	7.4	825.4	1727.8
	L.S.D. 5%	4.1	0.6	534.3	209.6
Chickpea	Uninoc + Unweeded	5.2	121.1	5987.1	1123.4
	Uninoc + Hand weeded	4.7	190.8	NIL	1947.4
	3889 + Hand weeded	24.7	214.4	NIL	1738.8
	Uninoc + Tribunil	5.8	215.4	592.6	1332.7
	3889 + Tribunil	17.2	241.7	497.2	1408.3
	L.S.D. 5%	2.6	19.4	273.4	242.3

Table 8.8

Effect of Application of Carbofuran on Nodulation Nodule Damage and Grain Yields of Two Lentils Cultivars.

Treatment	Syrian Local Large				ILC - 280			
	Nodule No./ Plant	Nodule Wt. (mg/Plant)	Percent. Nodule Damage	Grain Yield (kg/ha)	Nodule No./ Plant	Nodule Wt. (mg/Plant)	Percent. Nodule Damage	Grain Yield (kg/ha)
Untreated	28.8	1.1	81.0	1921.4	22.4	2.4	80.5	1389.7
Carbofuran	50.0	17.7	5.3	2351.8	33.1	9.9	10.4	1775.2
Carbofuran	49.1	16.8	11.5	2105.1	31.5	11.3	9.1	1690.7
Carbo. + 120 kg N/ha	37.9	9.7	6.3	2046.8	24.7	5.8	4.7	1552.1
L.S.D. 5%	7.1	1.1	7.6	185.4	6.9	0.8	9.7	234.3

R_1 = 1.5 kg a.i./ha at the time of planting.

R_2 = 1.5 kg a.i./ha at the time of planting + 0.75 kg a.i./ha applied 28 days after germination.

Table 8.9 Effect of Carbofuran Application and *Rhizobium* Inoculation on Nodule Production and Forage Yield in Two Cultivars of *Pisum* spp.

Cultivar	Treatment	Nodule No./Plant		Nodule Dry Wt. (mg/Plant)		Dried Forage Yield (kg/ha)	
		-CARBO	+CARBO	-CARBO	+CARBO	-CARBO	+CARBO
IFPI-25	UNINOC	35.2	31.4	7.2	10.6	386	2278
	INOC	24.7	30.2	6.2	12.0	706	2102
	60 kg N/ha	15.3	21.7	2.3	8.3	668	2387
IFPI-35	UNINOC	23.2	20.7	6.3	16.4	597	2546
	INOC	25.6	22.4	8.0	14.6	524	3005
	60 kg N/ha	10.5	17.4	2.6	6.2	482	2775

Table 8.10 Contribution of Symbiotic N_2-Fixation to N Harvested in Lentil 1977-78

Treatments (kg/ha) N - P_2O_5	Yield (kg/ha) Grain	Yield (kg/ha) Straw	Total N Yield (kg/ha)	% N Derived from Symb.	% N Derived from Fert.	% N Derived from Soil
Lentil						
0 - 0	778	1768	47.84	-	-	-
20 - 0	852	1678	52.88	49.3	7.7	42.9
20 - 50	961	1857	55.08	57.8	6.4	35.7
Wheat						
60 - 60	1331	2633	46.38	-	35.3	64.9

Table 8.11 Contribution of Symbiotic N_2-Fixation to N Harvested in Faba Beans 1977-78

Faba Bean Genotype	Treatments (kg/ha) N - P_2O_5	Yield (kg/ha) Grain	Yield (kg/ha) Straw	Total N Yield (kg/ha)	% N Derived from Symb.	% N Derived from Fert.	% N Derived from Soil
ILB-1814							
	0 - 0	1622	1105	67.4	-	-	-
	20 - 0	1812	1338	75.7	93.9	0.88	5.13
	20 - 50	1915	1277	79.2	96.8	0.46	2.73
ILB-1813							
	0 - 0	1342	675	51.0	-	-	-
	20 - 0	1667	752	62.0	95.7	1.95	2.35
	20 - 50	1812	952	70.6	84.8	2.20	12.90
Wheat							
	60 - 60	2155	3410	65.3	-	34.0	65.9

Table 8.12 Total Dry Matter Yield, Nitrogen Uptake and Percentage Contributions of Symbiosis, Fertilizer and Soil to Total Plant Nutrition in Different Crops at Two Rates of Nitrogen Application.

Crop	Rate of Fertilizer Nitrogen per ha.				Rate of Fertilizer Nitrogen per ha.					
	20 kg N		100 kg N		20 kg N			100 kg N		
	Dry Matter Yield (kg/ha)	Nitrogen Uptake (kg/ha)	Dry Matter Yield (kg/ha)	Nitrogen Uptake (kg/ha)	% Contribution			% Contribution		
					Symb.	Fert.	Soil	Symb.	Fert.	Soil
Wheat	2783 ± 188	43.98	2705 ± 365	43.00	0	5.23	94.77	0	21.41	78.59
Uninoculated Chp.	2331 ± 155	48.50	2638 ± 33	57.30	19.40	4.22	76.38	10.55	19.15	70.30
Inoculated Chp.	2343 ± 178	50.14	2370 ± 130	53.32	25.13	3.92	70.95	16.11	17.96	65.93
Inoculated Chp. + Sudan Grass	2128 ± 155	47.45	2364 ± 88	53.66	46.14	2.82	51.04	48.57	11.01	40.42
Inoculated Lentils	1826 ± 180	44.55	1829 ± 206	42.22	9.09	4.76	86.15	0.00	21.82	78.18
Inoculated Faba Bean	1536 ± 93	43.16	1739 ± 73	48.00	46.71	2.79	50.50	30.76	14.82	54.42

CHAPTER 9

CROP PHYSIOLOGICAL STUDIES

9.1 Introduction

The results of the 1979-80 research activities presented in the previous chapters of this report clearly demonstrate that the effects of interacting environmental variables on crop growth form a highly complex system. In order to efficiently elucidate the mechanisms of this system, it is necessary to adopt the type of multidisclinary approach which is evident in the SWAN Project. However, in 1979-80 the crop physiological aspect of the project had been inadequately developed due to the lack of an appropriately trained staff member. This vacancy has now been filled and in the 1980-81 and subsequent cropping years this aspect of the research will receive more emphasis. This will help to balance the quality of the information flow from the project and thus will result in a more efficient and beneficial use of resources. An enhanced understanding of the mechanisms of the crop growth system is a fundamental prerequesite for the establishment of functional and realistic predictive powers from the project's research findings. Such prediction is an essential mechanism by which locally derived research conclusions may be made to have much greater applicability to the region covered by the ICARDA mandate.

9.2 Methodology

The major scientific problem in the area of crop physiology is the extreme difficulty in the establishment of realistic "controlled" experiments on a field scale where variables such as radiant energy interception, drought tolerance and soil temperature/phosphate availability interactions have to be considered. It would appear that the only feasible method by which it is possible to quantify the significance of individual environmental variables on crop growth behaviour is by detailed observation under naturally varying conditions. The power of the conclusions from this observation is considerably enhanced when experiments can be replicated over a range of climatic and soil conditions. The five research sites used in the 1979-80 SWAN research program provide a convenient and efficient manner in which the extent of the effects of the environmental variations on crop growth found

in the dryland farming regions of the Middle East can be assessed, as they cover a precipitation gradient ranging from 600-200 mm per year. Observations made across this range of climatic and fertility conditions should result in a predictive ability of effective and wide scope.

The methods by which these necessary growth observations are now being obtained (1980-81) may be considered to be of three mutually compatible forms all of which are closely integrated with moisture use and nutrient availability studies.

1. Crop growth behaviour is being analysed in considerable detail in the manner pioneered in 1972 by Professor J.L. Monteith at the University of Nottingham, England. This approach places major emphasis on the ability of a crop to collect and use solar energy for growth. This involves a detailed examination of crop canopy development and their ability to intercept incoming radiant energy. This intercepted energy is converted by the crop via the photosynthetic process into assimilate useable for growth. The second step in this analysis considers the efficiency by which this assimilate is converted into real growth (dry matter) and finally the third step assesses the proportion of the dry matter gained which is finally converted into economic yield. All other variables such as nutrient supply, moisture availability, temperature, etc. are viewed with respect to the ways in which they may alter the fundamental relationships between radiant energy interception/use and productivity. Laboratory facilities in which this type of analysis can be performed are being developed in the 1980-81 season.

2. Observation of stem apical development by dissection and microscopic analysis is a basic technique which is being used to monitor the timing, extent and rate of reproductive activity in all crops. This enables the earliest possible assessment of the development of grains, in which final yield level is very often determined by environmental factors, well before heads or pods are visible in the field. This technique will thus help to highlight the environmental variables whose timing and duration of operation may be highly significant in yield determination. Furthermore, the detailed timetable of phenological development which this technique provides is an effective guide for the recommendation of the most efficient time to initiate agronomic treatments such as topdressing of fertilizer, time of first grazing, etc.

3. In the final stages of the growth season it is normal for moisture supply to become limiting. Th effects of this limitation on the diurnal growth pattern of a crop will be examined in terms of responses to increasing diffusive resistances and decreasing plant water potentials. By monitoring these variables quantitative information on changes in cell turgor and stomatal opening engendered by environmental factors can be assessed. This will assist in defining significant environmental variables, the levels at which they can initially reduce growth and the levels to which they reduce growth to the extent that senescence is promoted.

As these three modes of plant growth observation are equally suitable for all crops currently considered under the ICARDA mandate they provide a basic tool with which it is possible to positively assist the SWAN Project in the attainment of its current research goals. In particular they are vital to the study of the relationship between crop growth patterns and agronomic variables, environmental factors and moisture use.

In the 1980-81 field season, analysis of the growth behaviour of crops which are able to symbiotically fix nitrogen will be emphasised in the physiology section of this project. It is envisaged that this emphasis will be further developed in subsequent seasons. Such studies are currently in progress in close cooperation with other programs within ICARDA and it is expected that these links will be further developed and strengthened in the 1981-82 growth season.

9.3 Research outline 1980-81

(1) The effects of environmental factors on the growth and development of contrasting erect (ILC 72) and spreading (ILC 482) chickpea genotypes are being examined at Jindiress, Tel Hadya and Brida. The erect cultivar was winter seeded at recommended and high seeding densities whereas the spreading cultivar was both winter and spring seeded, but only at the recommended density. All three forms of growth observation (discussed in 9.2) are being utilised in this experiment. Particular emphasis is being placed on assessing the relationship between canopy development, moisture use efficiency and crop productivity.

(2) At Tel Hadya and Brida a detailed growth analysis of wheat (cv. Mexipak) and barley (cv. Beecher) respectively is being made in association with nutrient translocation and soil moisture supply studies. In addition, diurnal profiles of plant water status, diffusive resistance, canopy temperature and radiation interception are being obtained in order to examine the interactive roles of evaporative demand and soil moisture supply on crop development.

(3) Analysis of the competitive development of barley/vetch forage mixtures is being conducted by comparing treatments of added phosphate fertilizer (60 kg/ha) and Rhizobial inoculation with Rhizobial inoculation alone. These trials are being carried out at the two low rainfall sites, Brida and Khanasser. The study is being performed in association with moisture use efficiency and soil chemical studies. Emphasis is being placed on the changes in competitive productivity of the two crops in response to environmental factors.

CHAPTER 10

OVERVIEW OF RESEARCH FINDINGS

10.1 Introduction

The scope of work described in this research report is wide ranging. Crops studied include barley, wheat, lentils and faba beans and the research was conducted at five locations with contrasting long term average rainfalls (550-200 mm) and soil types. These crops were studied under various management practices including such factors as date and method of sowing, seed and fertilizer rate (both N and P) for barley, supplementary irrigation (at four levels) and different nitrogen levels for three varieties of wheat and seed inoculation with rhizobia for lentils and faba bean. It is thus difficult to provide a summary of the first season's research and caution must be used in suggesting firm conclusions or making recommendations based on one year's results.

There are other reasons for exercising caution in interpreting these results. The 1979/1980 season was above average with regard to total rainfall and its distribution especially at the drier sites. Due to the timing of staff arrivals, crop physiological studies could be conducted on only a few selected treatments and soil chemical analyses were limited to samples taken at harvest. Studies on the behaviour of soil moisture and crop moisture use were also restricted to selected treatments.

Thus, although the results reported here are as complete as the objectives and design of our trials will allow, there remain large gaps in our knowledge of the dynamics of crop growth and development, moisture fluxes, and moisture and nutrient availability. The presence of a crop physiologist/agroclimatologist and a soil chemist, and more experience in recognizing and selecting important areas of research, will, in large measure, allow us to fill these gaps in our knowledge in the future. In addition, the recruitment of a soil microbiologist will enable us to reinforce and extend the work reported in Chapter 8 and will enhance the interdisciplinary approach of the project.

Nevertheless, there are already some practical conclusions which indicate how farmers in the region may influence and improve crop performance and thus make more efficient use of their limited resources. These are discussed below.

10.2 Highlights of research and implications

10.2.1 Soil fertility and fertilizer response of Beecher barley

Significant fertilizer responses were obtained in most trials at nearly all sites. The response to 1 kg N ranged from increases of 17 and 20 kg grain at the two wettest sites to a decrease of 6.5 kg at the driest site. The response to 1 kg P_2O_5 ranged from zero up to 14 kg grain, the largest increase being at the driest site. P advanced crop maturity by up to 10 days (depending on the N level), and thus appears not only to enhance yield, but also to confer some drought avoidance benefits by shortening the growing season. Further investigations into the correct P nutrition of barley in the dry zones, on soils with high pH, high calcium levels and hence low P availability should be of considerable practical value to farmers there.

The soil analyses at harvest indicated medium to low levels of available P at all sites, and of mineral N except at the driest site, but there were no clear correlations between the fertilizer responses and soil analytical data at harvest. However, correlations would not necessarily be expected, as the availability of nutrients is essentially dynamic. Thus a study of their availabilities at planting and their subsequent variation during the growing season would be more useful for assessing crop responses to fertilizers.

With regard to N fertilization, the negative response at the driest site, Khanasser, is of particular interest. High levels of mineral N, ranging from about 30 ppm at 30 cm, to nearly 100 ppm at 75 cm, were measured there. More analyses of soils at other dry location are needed to assess the extent of these high levels of mineral N.

Soil moisture and crop moisture use studies indicated that where there was a response to nitrogen application, increased water use also occurred. However, the increase in water use was not in proportion to the increased yield, and thus nitrogen application (in the presence of adequate phosphorus) resulted in much improved water use efficiency in

terms of kilograms of grain produced per millimeter of moisture used, e.g., 5.6, 7.8, 9.5, 9.6 kg/ha/mm resulting from 0/60, 20/60, 40/60 and 60/60 kg N and P_2O_5/ha at Brida.

It was also apparent that nitrogen fertilizer increased the crop's ability to extract soil moisture, both in terms of root proliferation within discrete horizons and in rooting depth.

It must be borne in mind that these results were obtained in a wetter than average year with very favourable rains at the start of the grain filling period. Further studies are required to assess nitrogen responses in drier years with unfavourable distribution of rainfall, since enhanced moisture stress during vegetative growth may, in such years, result in greater moisture stress during grain filling and very different N-response patterns.

Both agronomic yields and soil analyses suggest that a split dressing (a small "starter dose", plus top dressing at the start of stem elongation) is the most efficient way of applying nitrogen fertilizer. This also offers the farmer the chance to assess the current season's rainfall before having to make the final decision whether or not to apply a top dressing of nitrogen fertilizer in the spring and thereby reduces his risk.

10.2.2 Method of sowing and seeding rate of Beecher barley

In view of the current low level of mechanization of farmers in Northern Syria, it was interesting to note in this year's results that across the different seed rates and fertilizer rates, the local method of hand broadcasting seed and fertilizer gave over 90 percent of the yield achieved by combine drilling. The lack of interaction between method of sowing and fertilizer response suggests that broadcasting phosphate with the seed across ridges is as efficient as placement with the seed by combine drill. Calcareous soils, such as are common in the ICARDA region, have a high "fixing capacity" of phosphate fertilizer, and thus for most efficient use, some form of fertilizer placement is desirable. If broadcasting of phosphate on ridges with the seed had been found an inefficient method of placement, new recommendations to farmers on method of seeding and phosphate fertilizer placement would have been necessary, but this was not the case. However, the hand methods used by local farmers to sow barley vary from region to region, and further studies are required to ascertain if different methods of sowing interact with fertilizer (particularly phosphate) response.

Seed rates as low as 30 kg/ha gave a high or higher yields than "normal" rates of 100-180 kg/ha. However, the seed used in these trials was 100 percent pure and gave 95 percent germination. More information is needed on the viability and purity of farmers seed before definite recommendations of seeding rate can be made. There is most likely to be a seed rate x variety x year interaction which should be quantified. Nervertheless, the results suggest that there is a broad plateau of yield response to seed rate which may offer the chance of saving a substantial amount of grain for other purposes.

10.2.3 Soil water, temperature and nitrogen limitations to wheat yields

One of the objectives of this experiment is to collect data necessary to develop and calibrate a spring wheat growth model for the region. Intensive crop physiology and soil moisture studies were carried out in 1979/80, and similar studies will be conducted this year.

It is intended that the results of these studies should be used in conjunction with a detailed analyses of existing weather data collected from 300 locations within the region to produce a wheat growth simulation model. Such a model will predict the potential and actual length of growing season and yield for different regions and thus will provide a much more exact description of the climatic environment of the ICARDA region. This could be used as a guide for the introduction of new environment-specific crops. In addition, by the use of risk analyses, this model would assist in examining the potential stability of newly introduced crops and rotational combinations.

It is not possible to evaluate the full impact of this work after one season, but two major points of interest are apparent.First, the results show that in spite of adequate soil moisture in the soil profile, senescence and physiological maturity occurred in the "long season" wheat varieties before their full yield potential (with regard to grain growth) could be realised. This observation demonstrates the importance of high temperatures and evaporative demand as factors which influence the timing of the growing season. Secondly, soil analysis results indicate that when nitrogen fertilizer is applied in a single dressing at planting, subsequent rainfall can result in much of the nitrate being leached to deep horizons where it cannot be effectively reached by the plant roots. Both these observations require further study. Future experiments must also take notice of the production factor found to be significant in other parts of the study such as P-application and placement and seeding rates.

10.2.4 Nutrient and moisture dynamics under fallow

Due to the problems caused by soil cracking around neutron probe accession tubes in the summer, the redistribution of moisture stored under fallow during the winter months was not followed throughout the summer months. Nevertheless, it is clear that in the wetter regions (350 mm and above), where the profile is recharged to depths of 1.50 meters or more, current farming practices of winter fallow management are quite efficient since farmers are able to grow summer crops such as melons, sesame, and cotton on stored soil moisture.

However, in the drier regions (e.g. Brida and Khanasser) which are typified by a two course barley/fallow rotation, it is not yet clear how much of the beneficial effect of a fallow on subsequent crops can be attributed to stored soil moisture. In the drier areas, our results show that the soil profile will not be recharged to depths much below 75 cm during the winter months. Although improved fallow management may well enable some moisture to be stored at depth, a careful economic study would be required to assess the cost/benefit ratio of the tillage operations required. In addition, the practice of "weedy fallowing" is quite common, and the value of grazing for sheep at critical times of the year must be weighed against the obvious disadvantages of such a practice with regard to moisture storage. Some soil analyses at harvest time indicated that the fallow plots at all locations were considerably higher in mineral nitrogen than cropped land. Such nitrogen is available for the subsequent crop, this may well be one important beneficial aspect of fallowing which requires further investigation. If storage of available nitrogen is found to be the major benefit of fallowing in dry areas, then there might be scope for replacing the fallow with a leguminous grain or forage crop, or even growing continuous barley with the addition of some nitrogenous and phosphatic fertilizer. Such alternatives will be evaluated in coming seasons by the establishment of rotation trials at the two driest sites.

10.2.5 Biological dinitrogen fixation

Nodulation surveys in various parts of the region showed that lentils and faba beans are generally well nodulated, but nodulation on chickpeas was highly variable. Some promising Rhizobia strains appear tolerant of soil moisture stress, of moderate soil salinity and of certain herbicides which seem useful for legumes.

There were large interactions between host genotypes and Rhizobia strains, and inoculation with effective strains gave better nodulation and yields than local strains. Studies of inoculum production showed that the flour obtained by grinding legume seeds was a promising carrier for Rhizobia for that legume species.

Damage to nodules caused by Sitona weevil larvae could be effectively controlled in peas and lentils by incorporating carbofuran insecticide into the soil before planting, resulting in significant improvement in nodulation and crop yield.

Studies of symbiotic dinitrogen fixation showed that symbiosis could contribute 40 percent of plant N in lentils and about 90 percent in fababeans. P fertilizer increased this on soils low in P. A delay in planting until late winter reduced it.

These initial studies showed that symbiotic dinitrogen fixation can be improved by various techniques which influence the host, the Rhizobium, and the crop management practices.

10.3 Conclusion

In conclusion, it can be seen that a start has been made with investigations into several of the most important lines of research which fall within the scope of this project, and the first year's trials have already provided a large amount of detailed information. These results form a good foundation for further studies, and not only have suggested the main directions for future research, but also have already indicated some practical guidelines for improving yields.

The recruitment of the soil chemist and of the crop physiologist/agroclimatologist before the second season's field work allowed an even wider range of studies to be undertaken; the forthcoming addition of the soil microbiologist to the team will enable biological dinitrogen fixation studies to be carried out in much more detail, within the interdisciplinary framework of the project, and this should rectify some of the remaining defficiencies in the research program.

APPENDIX I

A Short Description of Soil Profiles at Brida, Khanasser, Tel Hadya, Kafr Antoon and Jindiress.

Profile Number: (BRIDA)

Classification:
Typic Calciorthid
(USDA Soil Taxonomy, 1975).

Diagnostic horizons:
Ochric epipedon, calcic horizon, cambic horizon.
The cambic horizon has (i) a structure, (ii) a more intensive colour, (iii) redistribution of lime (calcic horizon).

Soil mapping unit:
Calcic-Xerosol, XK-3a
(FAO-Unesco, Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 19, 1980.

Location:
Profile pit located next to meteorological station on ICARDA F/S-SWAN- site near Brida, Aleppo Province, Syria.

Latitude : 35°55' North
Longitude : 37°10' East.

Land-form:
Flat area with hills at distance of 2-3 km.

Land use:
Cultivated land, fallow-barley rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mixed with colluvial or other transported materials.

Drainage:
Probably good, no water table.

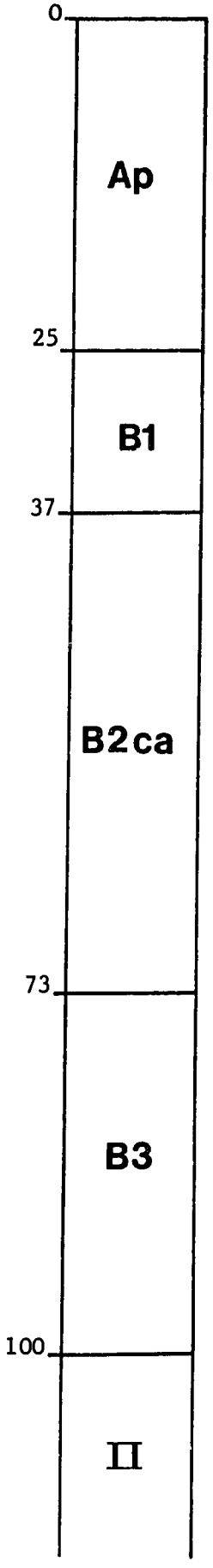
193

Remarks:

1. Throughout the profile some rounded-off stones occur, sizes up to 10 cm, less than 5 percent of the soil volume.

2. The calcic horizon represents the mean depth of infiltration of water.

   All colours are for moist soil; colour names according to Standard Soil Colour Charts (1967).



Ap : 0-25 cm. Dull reddish brown (5YR 4/4) clay loam*.
Moderate angular blocky structure,
aggregates occur in all sizes due to plowing.
Consistency of dry soil is hard.
Many very fine pores, many fine roots.
Clear boundary.

B1 : 25-37 cm. Dull reddish brown (5YR 4/4) clay loam.
Weak to moderate, fine to medium, prismatic structure.
Consistency of dry soil is hard.
Many very fine pores,many fine roots.
Some (5 %) distinct soft lime spots (< 5 mm).
Gradual boundary.

B2ca : 37-73 cm. Dull reddish brown (5YR 4/4) clay loam.
Weak to moderate, fine to medium, prismatic structure.
Consistency of dry soil is hard.
Many very fine pores, few fine roots.
Many (15 %) prominent soft lime spots (5-15 mm).
Some pressure skins occur on aggregate, and possibly
some clay skins. Gradual boundary.

B3 : 73-100 cm. Reddish brown (5YR 4/6) clay loam.
Weak to moderate, fine to medium, prismatic structure.
Dry consistency is hard.
Many very fine pores.
Some (7 %) distinct soft lime spots (5-15 mm).
Abrupt boundary.

II : 100 + cm. Bright reddish brown (5YR 5/6) sandy clay,
a mixture of mineral materials with various colors.

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* Texture classifications are tentative; lab analyses are to follow.

195

Profile Number: 1 (KHANASSER)

Classification:
Typic Calciorthid
(USDA Soil Taxonomy, 1975).

Diagnostic horizons:
Ochric epipedon, calcic horizon, cambic horizon.
The cambic horizon has (i) a structure, (ii) redistribution of lime (calcic horizon).

Soil mapping unit:
Calcic Xerosol, XK-3a
(FAO-Unesco Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 19, 1980.

Location:
Profile pit located next to meteorological station on ICARDA F/S-SWAN- site near Khanasser, Aleppo Province, Syria.

Latitude : 35°45' North
Longitude : 37°32' East.

Elevation:
350 m.

Land-form:
Flat land, level to gently sloping land nearby, surrounded by two ranges of hills. At the lower end of a "bajada".

Land-use:
Cultivated land, fallow-barley rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mixed with colluvial materials.

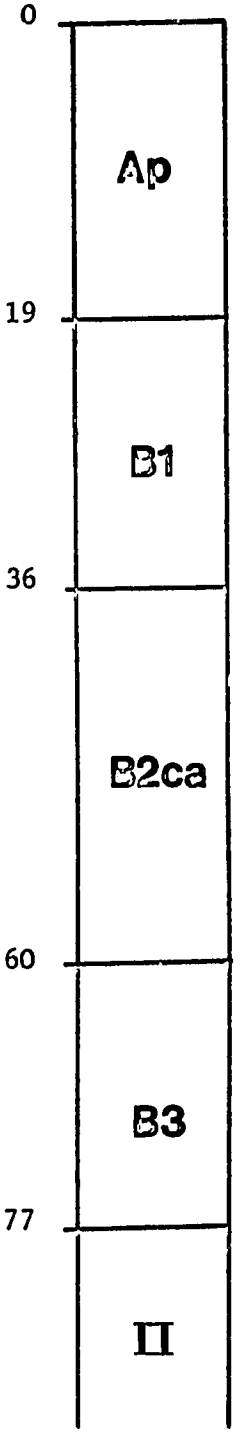
Drainage:
Probably good, no water table.

196

Remark:

The present soil is drier (Bca is shallower) than the profile at Brida.

All colours are for moist soil; colour names according to Standard Soil Colour Charts (1967).



Ap : 0-19 cm. Reddish brown (5 YR 4/6) silty clay.
Weak, fine to medium, angular blocky structure.
Dry consistency is soft.
Many very fine (0.2-1 mm) pores, many fine roots.
Clear boundary.

B1 : 19-36 cm. Reddish brown (5 YR 4/6) silty clay.
Moderate, medium angular blocky structure.
Dry consistency is slightly hard.
Many very fine pores, few fine roots.
Some (2 %) faint fine (< 5 mm) soft lime spots.
Gradual boundary.

B2ca : 36-60 cm. Reddish brown (5 YR 4/6) silty clay.
Moderate, medium angular blocky structure.
Consistency of dry soil is medium hard.
Many very fine pores, few fine roots.
Many (10 %) distinct medium (5-15 mm) soft lime spots.
Gradual boundary.

B3 : 60-77 cm. Reddish brown (5 YR 4/6) silty clay.
Moderate, medium angular blocky structure.
Consistency of dry soil is slightly hard.
Many very fine pores, few fine roots.
Few (2 %) faint fine (< 5 mm) soft lime spots.
Abrupt boundary.

II : 77 + cm. Bright reddish brown (5 YR 5/6) sandy loam, some grains up to 1-2 mm.
Many glazy white crystals (gypsum).
Weak, fine to medium, angular blocky structure.
Consistency of dry soil is hard.
Some very fine pores.

Profile Number: 3-South (TEL HADYA)

Classification:
Chromoxerertic-Rhodoxeralf
(USDA Soil Taxonomy, 1975).

Diagnostic characteristics:
Ochric epipedon, argillic horizon, calcic horizon, slickensides.

Soil mapping unit:
Vertic (calcic) Luvisol LV-3a.
(FAO-Unesco Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 20, 1980.

Location:
Profile pit located in block B-4 next to the road on ICARDA's experiment station near Tel Hadya, Aleppo Province, Syria.

Latitude : 36° 2' North
Longitude : 36°56' East.

Elevation:
287 m.

Land-form:
Nearly flat (1-2 percent). On the south-side of the hill.

Land-use:
Cultivated land, 3-course rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mixed with colluvial materials.

Drainage:
Probably good, no water table.

191

Remarks:

1. Although roots penetrate up to 1 m depth or deeper, the actual volume available for rooting is limited, since most of the roots are on ped surfaces.

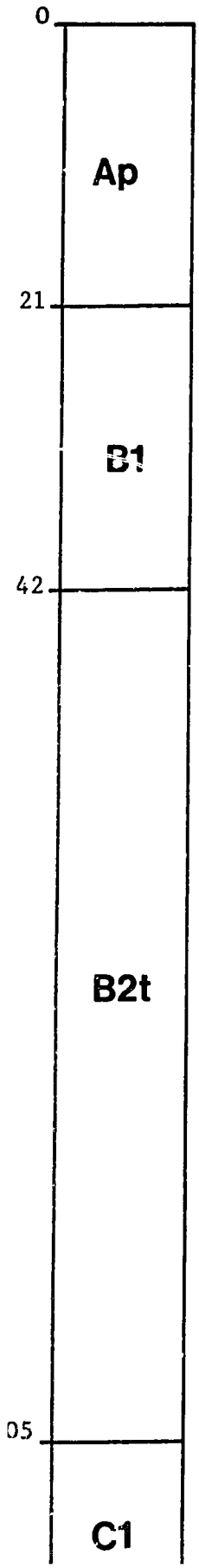
2. Rain will infiltrate the soil through cracks, and infiltration into structural aggregates will be slow, due to surface coatings. Hence, the soils may be drought-sensitive early in the season, after the initial rains, since only a small fraction of the rain is retained in the top-soil, and also because the plant roots do not penetrate the aggregates.

3. The profile was somewhat moist below 30 cm depth, at the date of description of the soil.

4. The soil is classified as (a somewhat pale) chromoxerertic rhodoxeralf. The soil has characteristics of a vertisol, viz cracks in the surface, and slickensides. However, the cracks are not 1 cm wide at 50 cm depth, and therefore the soil is not a vertisol, but an alfisol in transition to a vertisol. If the cracks would have been wide enough, the soil would have been classified as a rhodoxeralfic chromoxerert.

5. The soil has a calcic horizon, but this characteristic does not appear in the name of the soil, since in the case of transitions between great groups (rhodoxeralfs and chromoxererts), no sub-group qualifications (calcic) enter in the name of the soil.

All colours are for moist soil; colour names according to Standard Soil Colour Charts (1967).



Ap : 0-21 cm. Reddish brown (2.5YR 4/6) silty clay.
Strong, coarse angular blocky structure.
Consistency of dry soil is very hard.
Few very fine pores.
Some (2 %) small (1-5 mm), hard lime concretions ("kankar"), few larger hard lime concretions.
Gradual boundary.

B1 : 21-42 cm. Dark reddish brown (2.5YR 3/4) silty clay.
Strong, medium angular blocky structure.
Consistency of dry soil is very hard. Few fine pores.
Some (3 %) small (1-5 mm) hard lime concretions, few larger concretions. Some (3 %) distinct soft lime spots in vertical direction, about 5 mm wide and 1-3 cm long.
Many small pressure coatings on aggregate surfaces and plains of fracture (glancing).
Gradual boundary.

B2t : 42-105 cm. Dark reddish brown (2.5YR 3/6) silty clay.
Strong, medium prismatic structure.
Consistency of dry soil is very hard.
Many glancing (pressure) coatings on structural aggregates and plains of fracture. These coatings probably are transformed clay coatings.
Many clear slickensides, and wedge-shaped structural aggregates with their long axis tilted (about 45°) from the horizontal.
Few fine pores, many fine roots on ped surfaces.
About 5 % hard lime concretions (1-5 mm), and 10 % soft lime spots, some round, others about 1 cm wide and 3 cm long.
Clear boundary.

C1 : 105 + cm. Weathering limestone of medium hard consistency.

201

Profile Number: 3-North (TEL HADYA)

Classification:
Calcic Rhodoxeralf
(USDA Soil Taxonomy, 1975).

Diagnostic characterisitcs:
Ochric epipedon, argillic horizon, calcic horizon, slickensides.

Soil mapping unit:
Chromic (calcic) Luvisol LC-3a
(FAO-Unesco Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 20, 1980.

Location:
Profile pit located in block C-17 along the road on ICARDA's experiment station near Tel Hadya, Aleppo Province, Syria.

Latitude : 36° 2' North
Longitude : 36°56' East.

Elevation:
298 m.

Land-form:
Level to gently sloping (3-5 percent), on the north-side of a hill, halfway down the "bajada".

Land-use:
Cultivated land, 2-course rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mainly colluvial materials.

Drainage:
Probably good, no water table.

Remarks:

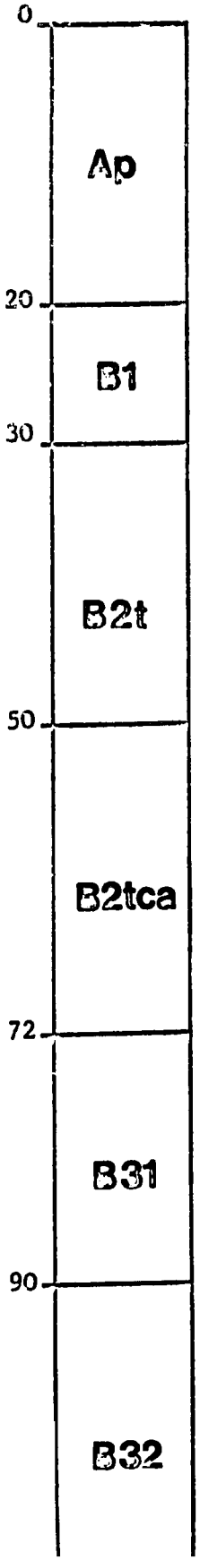
1. Kankar often occurs in pockets, possibly because the particles fall into cracks.

2. Below 30 cm depth the soil is somewhat moist.

3. Profile 3-north has no slickensides in the B2-horizon, like profile 3-south.
   Slickensides do occur in the deeper subsoil on surfaces and plains of fracture that are titled from the horizental. Pressure coatings and possibly clay coatings occur on the horizental and vertical ped surfaces. Profile 3-north might be called: Calcic Rhodoxeralf with slickensides in the subsoil.

4. In the sewage lagoon at the bottom of the bajada on the north side of the hill, medium to large dark-coloured, rounded-off stones occur at the boundary between the reddish brown clay and the limestone. The stones are probably transported by water and indicate that the reddish brown clay is not formed in situ, but probably colluvial material from the surrounding hills. Near the sewage lagoon, the soil is deeply cracking (Vertisol).

   All colours are for moist soil; colour names according to Standard Soil Colour Charts, (1967).



Ap : 0-20 cm. Reddish brown (2.5YR 4/6) silty clay.
Moderate, coarse angular blocky structure.
Consistency of the dry soil is hard.
Few very fine pores, few roots.
Few (< 1 %) fine soft lime spots.
Some (5 %) small (1-5 mm) hard lime concretions. ("kankar"); few larger concretions.
Gradual boundary.

B1 : 20-30 cm. Dark reddish brown (2.5YR 3/4) silty clay.
Moderate, coarse angular blocky structure, locally some platy structures.
Consistency of the dry soil is hard.
Few very fine pores, few roots.
Some (5 %) small (1-5 mm) hard lime concretions, few larger concretions. Few (1 %) fine soft lime spots.
Gradual boundary.

B2t : 30-50 cm. Dark reddish brown (2.5YR 3/4) clay.
Moderate, coarse prismatic structure, with clay cutans on all aggregate surfaces (root imprints on clay cutans).
Many small pressure coatings on plains of fracture within aggregates.
Consistency of dry soil is hard.
Few very fine pores, fine roots on ped surfaces.
Some distinct (2 %) soft lime spots, and about 3 % kankar.
Gradual boundary.

B2tca : 50-72 cm. Description as B2t, but prominent and more (5 %) soft lime spots.
Gradual boundary.

B31 : 72-90 cm. Dark reddish brown (2.5YR 3/6) clay.
Moderate, coarse prismatic structure with less clay cutans; transition to slickensides.
Dry consistency is hard.
No pores, few fine roots on ped surfaces.
About 5 % soft limes spots and 3 % kankar.
Gradual boundary.

B32 : 90 + cm. Dark reddish brown (2.5YR 3/6) clay.
Moderate, coarse prismatic structure, with clear slickensides on wedge-shaped structural aggregates, with their long axis tilted from the horizental.
Dry consistency is hard.
No pores, few fine roots on ped surfaces.
About 3 % soft lime spots and 2 % kankar.

204

Profile Number: 4 (KAFR ANTOON)

Classification:
Palexerollic Chromoxerert
(USDA Soil Taxonomy, 1975).

Diagnostic characteristics:
Ochric epipedon, deep cracks, slickensides, prismatic structure.

Soil mapping unit:
Chromic Vertisol VC-3a
(FAO-Unesco Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 21, 1980.

Location:
Profile pit located next to meteorological station on ICARDA F/S-SWAN- site near Kafr Antoon, Aleppo Province, Syria.

Latitude : 36°28' North
Longitude : 37° 3' East.

Land-form:
Nearly flat area (1-2 percent), plain, surrounded by hills.

Land-use:
Cultivated land, 3-course rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mixed with colluvial or other transported materials.

Drainage:
Probably good, no water table.

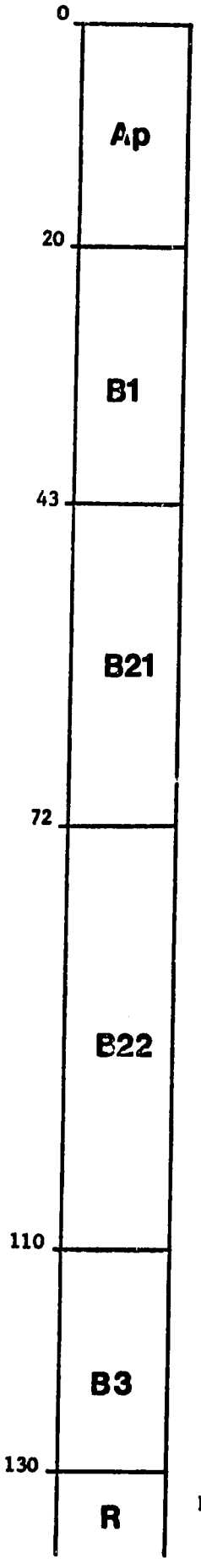
Remarks:

1. Climate in Kafr Antoon is more moist than in Tel Hadya therefore the churning of the soil is more intensive, and as a result only a few soft lime spots are left in the profile as compared to Tel Hadya.

2. The soil could have been classified as Entic Chromoxerert, because of the low organic matter content (dry climate). The soil is classified as Palexerollic, however, because the pronounced prismatic structure within 1 m is considered more important for the classification of the soil.

3. Below 40 cm the soil is somewhat moist.

All colours are for most soil; colour names according to Standard Soil Colour Charts (1967).



Ap : 0-20 cm. Reddish brown (5YR 4/6) clay. 15
Strong, coarse subangular blocky structure.
Deep cracks from polygonal pattern on the surface. Cracks are 1 cm wide at a depth of 50 cm.
Consistency of dry soil is hard.
Few very fine pores, many fine roots.
About 1 % kankar, few larger concretions (1-3 cm).
Gradual boundary.

B1 : 20-43 cm. Description as for Ap, but color is reddish brown (5YR 4/4), and structure is locally more platy.
Gradual boundary.

B21 : 43-72 cm. Dark reddish brown (5YR 3/4) clay.
Strong, very coarse prismatic structure.
Prisms are somewhat platy. Very clear slickensides on plains of fracture with their long axis tilted from the horizental.
Consistency of the dry soil is hard.
Few very fine pores, few roots on ped surfaces.
About 1 % kankar.
Gradual boundary.

B22 : 72-110 cm. Dark reddish brown (5YR 3/3) clay.
Strong, very coarse prismatic structure.
Wedge-sharped structural aggregates with their long axis tilted from the horizental. Very clear slickensides on all surfaces. Slickensides curve into the subsoil.
Few very fine pores, few roots on ped surfaces.
Few distinct fine soft lime spots. About 1 % kankar.
Irregular boundary.

B3 : 110-130 cm. Transitional layer. Mixture of dark reddish brown (5YR 3/3) clay and limestone.
About 5 % distinct soft lime spots. About 1 % kankar.
Irregular boundary.

R : 130 + cm. Mixture of white, powdery limestone, light olive-brown hard limestone, and greenisl coarse sandy material.
Below 150 cm all sandy material is cemented, and all limestone is hard (unweathered).

Profile Number: 5 (JINDIRESS)

Classification:
Palexerollic Chromoxerert
(USDA Soil Taxonomy, 1975).

Diagnostic characteristics:
Ochric epipedon, deep cracks, slickensides, prismatic structure.

Soil mapping unit:
Chromic Vertisol VC-3a
(FAO-Unesco Soil Map of the World, Vol. I, 1974).

Described by:
P. Buringh and K. Harmsen, Oct. 21, 1980.

Location:
Profile pit located next to meteorological station on ICARDA F/S-SWAN- site near Jindiress, Aleppo Province, Syria.

Latitude : 36°23' North
Longitude : 36°41' East.

Elevation:
200 m.

Land-form:
Nearly flat area (1-2 percent), on one side hills at a distance, on the other side the river Afrin.

Land-use:
Cultivated land, 3-course rotation.

Climate:
Aridic, thermic.

Parent material:
Residuum from limestone, probably mixed with colluvial materials.

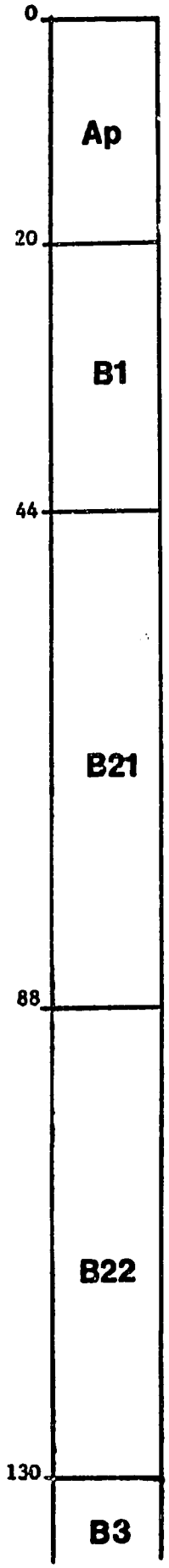
Drainage:
Probably good, no water table.

Remarks:

1. Below 40 cm the soil is somewhat moist.

2. Some (1 percent) flintstones and limestones (1-2 cm) occur throughout the profile.

All colours are for moist soil; colour names according to Standard Soil Colour Charts (1967).



Ap : 0-20 cm. Reddish brown (5YR 4/6) silty clay.
Strong, coarse subangular blocky structure.
Many deep cracks form polygonal patterns on the surface.
Cracks are generally 1 cm wide at 50 cm depth.
Consistency of dry soil is hard.
Few very fine pores, many fine roots.
About 1 % small (1-5 cm) hard lime concretions (kankar).
Few limestones and flintstones (1-2 cm).
Gradual boundary.

B1 : 20-44 cm. Dull reddish brown (5YR 4/4) clay.
Strong, coarse subangular blocky structure, transition to platy structure.
Consistency of dry soil is hard.
Few very fine pores, many fine roots.
About 1 % kankar, few larger stones.
Gradual boundary.

B21 : 44-88 cm. Dark reddish brown (5YR 3/4) clay.
Strong, coarse prismatic structure. Slickensides present on surfaces with their long axis tilted from the horizontal.
Consistency of dry soil is hard.
Few very fine pores, few roots on ped surfaces.
About 1 % kankar, locally some (1-3 %) distinct soft lime spots (oblong and oval).
Gradual boundary.

B22 : 88-130 cm. Dull reddish brown (5YR 4/4) clay.
Strong, coarse prismatic structure.
Wedge-shaped structural aggregates. Very pronounced slickensides on virtually all surfaces.
Consistency of dry soil is hard.
Very few fine pores, virtually all roots on ped surfaces.
About 1 % kankar, locally some (1-2 %) soft lime spots.
Irregular boundary.

B3 : 130-140 cm. Transitional layer, mixture of dull to dark reddish brown clay, soft white lime, greenish glauconitic material, and rounded-off white to greyish hard limestone.

R : 140 + cm. White to greyish limestone, and light olive-green to brown sandy material, which is heavily cemented below 150-160 cm depth.