FARM RESOURCE MANAGEMENT PROGRAM

Annual Report for 1993

ICARDA

About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is governed by an independent Board of Trustees. Based at Aleppo, Syria, it is one of 18 centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is an international group of representatives of donor agencies, eminent agricultural scientists, and institutional administrators from developed and developing countries who guide and support its work.

The CGIAR seeks to enhance and sustain food production and, at the same time, improve socioeconomic conditions of people, through strengthening national research systems in developing countries.

ICARDA's mission is to meet the challenge posed by a harsh, stressful and variable environment in which the productivity of winter rainfed agricultural systems must be increased to higher sustainable levels; in which soil degradation must be arrested and possibly reversed, and in which the quality of the environment needs to be assured. ICARDA meets this challenge through research, training and dissemination of information in a mature partnership with the national agricultural research and development systems.

The Center has a world responsibility for the improvement of barley, lentil, and faba bean, and a regional responsibility in West Asia and North Africa for the improvement of wheat, chickpea, forage and pasture—with emphasis on rangeland improvement and small ruminant management and nutrition—and of the farming systems associated with these crops.

Much of ICARDA's research is carried out on a 948-hectare farm at its headquarters at Tel Hadya, about 35 km southwest of Aleppo. ICARDA also manages other sites where it tests material under a variety of agroecological conditions in Syria and Lebanon. However, the full scope of ICARDA's activities can be appreciated only when account is taken of the cooperative research carried out with many countries in West Asia and North Africa.

The results of research are transferred through ICARDA's cooperation with national and regional research institutions, with universities and ministries of agriculture, and through the technical assistance and training that the Center provides. A range of training programs is offered extending from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and specialized information services.

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

This report was written and compiled by program scientists and represents a working document of ICARDA. Its primary objective is to communicate the season's research results quickly to fellow scientists, particularly those within West Asia and North Africa, with whom ICARDA has close collaboration. Owing to the tight production deadlines, editing of the report was kept to a minimum.

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1. INTRODUCTION

1.1 Content of this Report

The research agenda of the Farm Resource Management Program encompasses the whole rainfed agricultural environment of WANA: the climate, the natural resources, soil, water and natural vegetation; the farming systems that utilize those resources; the social, economic and policy contexts in which those systems function; and the interactions between these, particularly as they affect productivity and the conservation of the resource base. Research is interdisciplinary, both within the Program and through linkages with other Programs and national scientists. It seeks to promote the effective and sustainable utilization of soil, water and vegetation; to identify constraints to productivity and ways to relieve them, technical, socio-economic or through policy measures; and to gauge the effectiveness of new inputs and technologies through studies of adoption and impact. The information generated is fed back into research planning centerwide.

These various research activities continue to be grouped and administered within three broad national projects:

- Agroecological characterization for resource management;
- Management of soil, water and nutrients;
- Adoption and impact of technology;

and each project is covered by a separate chapter in this report.

However, as was noted last year (FRMP 1993), the interdisciplinary approach encourages many cross-linkages between activities, and in reality project boundaries tend to be diffuse. This has been particularly the case with research on water in 1993. Studies of the resource (groundwater) have been carried out jointly with studies of the irrigators' perceptions of that resource; effects of groundwater quality on soil and crop yield have been demonstrated, as have the users' awareness of these effects; and from technical data, an economic assessment has been made of supplemental irrigation, with indications towards the policy measures required to optimize the utilization of a finite resource. For these reasons, and no less for the reason that water is rapidly becoming one the hottest issues in agriculture and agricultural research in the WANA region, a special focus chapter: 'Groundwater and Supplemental Irrigation' has been placed first in this report.

1.2 Staff News

With its smaller numbers of support staff, FRMP was perhaps less severely hit by the budgetary constraints of 1993 than one or two other Programs. Even so, during the latter part of the year we regretfully said goodbye to Ralla el-Naeb, Dolly Mousally, Shahba Morali, Subih el Dehni, Samir Barbar, Abdul Basset el Khatib, Mohamed Karram, Mohamed Zeki, Elianor Nasseh, Nabil Musatat, and

Mahmoud Oglah. We thank each of them for his/her contribution over many years and wish them well in their new occupations. Thanks are also due to those who have remained and, with the help of daily-paid staff, have labored to keep the work of the Program going smoothly.

Another departure at the end of the year was that of Ben Timmerman, after three years working in a post-doctoral position to establish studies of wind erosion. At the time of writing, we still hold out some hope that resources will be found to bring him back to continue this important activity. One of the few gains during the year was the arrival in January of Dr Aden Aw-Hassan, a citizen of Somalia, the latest in a distinguished sequence of FRMP postdoctoral fellows funded by the Rockefeller Foundation. Based in Cairo, he is studying the adoption of improved crop production technology within the Nile Valley Regional Project in Egypt and Sudan and will increasingly spearhead FRMP's renewed involvement in the NVRP as Egypt's new resource management research component gains momentum during 1994.

Temporarily lost from FRMP for the second half of 1993 was Mustafa Pala, enjoying a well-deserved sabbatical and an Anatolian-type winter at Washington State University. We look forward to his return in the middle of 1994, refreshed and ready for many new challenges. Regrettably, it seems that we shall have to wait rather longer to welcome scientists to the vacant posts of agricultural economist and soil conservation/land management specialist, which have remained deep frozen since 1992. However, there are signs of a thaw for the position of agroclimatologist, previously held by Graham Waker. Advertised in 1993, we look forward to position being filled in 1994.

1.3 The Weather in WANA during the 1992/93 Season

The main features of the weather in WANA during the season of 1992/93 were remarkably similar to those of the season before:

- The drought in Morocco continued unabated for a second year;
- The winter in the Middle East, from Turkey through Syria, Lebanon and Jordan down into Egypt, was again much colder than usual. But while during the previous winter abundant rain and snow accompanied the low temperatures in this region, this time precipitation was less plentiful, but sufficient to ensure a generally good harvest in Turkey, Syria and Egypt because it fell well distributed throughout the growing season. In Lebanon and Jordan, however, the harvest was average at best, in part due to excessive rainfall at harvest time in May.

During this season, the largest area receiving above-average precipitation was located further to the east. Up to February, the southern half of Afghanistan, central, eastern and southern Iran, the northeast of Saudi Arabia and the Emirates received unusually heavy precipitation, causing flooding in several Iranian provinces. From March to May, the wet weather shifted further west to western Iran, Iraq and the areas bordering the northwestern end of the Arabian Gulf. Growing conditions were quite favourable in Iraq, parts of Afghanistan and especially in Iran where cereal production was distinctly above average. Conditions were less favourable in northern Afghanistan and northwestern Pakistan where precipitation was inadequate and the winter unusually warm.

North Africa provided a varied picture. Going eastwards from drought-stricken Morocco, precipitation increased across Algeria, the northeast as well as northern Tunisia being very wet throughout the season. Further east, rainfall decreased again, the western half of Libya being affected by a drought as exceptional as the one ravaging Morocco. Eastern Libya, on the contrary, enjoyed above-average rainfall from January to March as did Northern Egypt. With temperatures generally cold, but not exceptionally so, crop yields mirrored the distribution of the available moisture. While cereal production in Morocco was less than half of the average, it was still below average in western Algeria but clearly above average in the eastern half of the country and in Tunisia for the third year in a row.

The small rains in Ethiopia started erratically, but were exceptionally heavy in April and May, the harvest being somewhat below average. Judging from the weather records, the main rains were generally adequate, although the regional distribution was uneven, heavy rains in the center of the country, surrounded by areas with below-average rainfall, especially in the south and west. The overall result was a marked decrease in the production of cereals and other crops compared to the previous year. In nearly all parts of Sudan where rainfed cropping is practised, precipitation and crop yields were below average. In Yemen, on the contrary, yields were sharply up compared to 1992 following a good rainy season.

The Weather in Northern Syria during the 1992/93 Season

Seasonal rainfall totals were about 10 % below average in the wetter part of North Syria, 10 % above average in the usually drier areas. Crop yields were, however, uniformly above average, due to the favourable intra-seasonal rainfall distribution and its interaction with temperature.

The rains started mid-November, giving crops a good start before temperatures dropped in the second half of December. They remained quite low until February, but there were no damaging late frosts. The cool weather helped to conserve some of the rain received during this period and slowed down the plant development.

Crops were beginning to suffer from moisture stress during a long dry spell lasting from mid-March to early May, when late rains brought relief just in time to save the harvest. Had winter and spring been warmer, the May rains would have come too late. As it was, both wheat, which had just reached the flowering stage, and barley, which had reached grain filling, were still able to benefit.

An unusual event was the thunderstorm which brought 13mm of rainfall (or 14 times the long-term average) to Tel Hadya in late August.

Table 1.1 Monthly precipitation (mm) for the 1992/93 season

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Jindiress													
1992/93 season	1.0	0.2	74.8	49.7	57.5	53.8	71.6	23.2	69.8	15.2	0.0	20.2	437.0
Long term average (33s.)	1.5	30.1	55.4	92.2	81.6	73.9	64.9	41.8	21.1	3.8	0.3	1.4	468.0
% of long term average	67	1	135	54	70	73	110	56	330	400	0	1442	93
Tel Hadya													
1992/93 season	0.3	0.0	49.0	50.1	57.8	40.3	41.7	0.6	36.9	0.6	0.0	12.8	290.1
Long term average (15s.)	0.5	26.1	46.9	54.9	60.9	51.2	41.8	24.7	16.3	2.8	0.0	0.9	327.0
% of long term average	60	0	104	91	95	79	100	2	226	21	-	1442	89
Breda													
1992/93 season	11.2	1.0	69.4	32.6	42.7	50.0	36.9	8.0	30.0	1.2	0.0	0.0	283.0
Long term average (35s.)	1.5	16.4	31.8	52.2	48.6	39.7	34.0	29.8	16.9	1.5	0.1	0.0	272.5
% of long term average	747	6	218	62	88	126	109	27	178	80	0	-	104
Boueidar													
1992/93 season	0.6	0.0	53.4	28.6	58.0	33.2	27.0	8.6	11.8	2.4	0.0	0.6	224.2
Long term average (20s.)	0.1	14.4	24.3	35.3	39.1	35.9	28.5	16.2	10.0	1.0	0.1	0.0	204.9
% of long term average	600	0	220	81	148	92	95	53	118	240	0	-	109
Ghrerife													
1992/93 season	3.4	0.0	55.0	28.3	59.0	44.8	37.5	1.2	48.8	4.8	0.0	0.0	282.8
Long term average (8s.)	0.4	31.2	27.4	39.2	46.7	41.0	35.0	10.1	18.6	3.0	0.0	0.0	252.6
% of long term average	850	0	201	72	126	109	107	12	262	160	-	-	112
Terbol													
1992/93 season	0.0	0.0	142.2	168.0	131.2	51.6	125.2	14.2	31.6	0.0	0.0	0.0	664.0
Long term average (12s.)	0.0	22.2	70.9	100.6	97.6	104.9	104.5	24.0	17.5	2.5	0.3	0.0	545.0
% of long term average	-	0	200	167	134	49	120	59	181	0	0	-	122

Table 1.2 Monthly air temperature (°C) for the 1992/93 season

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Jindiress												
Mean max.	32.7	30.1	17.9	9.2	10.8	11.5	15.8	21.4	24.4	32.8	33.8	35.0
Mean min.	16.5	13.3	6.3	1.6	0.3	0.8	2.5	7.1	11.1	16.1	19.6	21.9
Average	24.6	21.7	12.1	5.4	5.5	6.1	9.2	14.2	17.8	24.5	26.7	28.4
Abs. max.	40.8	35.5	32.4	15.0	17.2	18.5	26.0	30.0	34.8	41.2	38.2	42.8
Abs. min.	7.0	9.0	-4.0	-6.3	-5.8	-8.0	-1.7	1.8	6.0	11.7	16.0	19.0
Tel Hadya												
Mean max.	33.6	30.7	17.8	9.0	11.5	11.8	16.8	24.0	27.0	34.4	37.2	37.7
Mean min.	16.1	11.5	5.6	2.2	0.3	0.1	2.4	7.3	11.4	15.3	20.1	21.3
Average	24.9	21.1	11.7	5.6	5.6	5.9	9.6	15.6	19.2	24.8	28.7	29.5
Abs. max.	41.0	35.2	29.0	15.6	16.5	18.2	27.2	33.2	36.6	41.0	41.3	42.6
Abs. min.	5.7	7.8	-4.5	-7.2	-8.7	-7.5	-2.4	0.4	4.8	10.6	13.1	16.0
Breda												
Mean max.	32.9	30.2	17.5	8.3	11.0	11.3	16.4	23.3	25.9	33.7	36.4	36.7
Mean min.	15.2	12.1	4.8	1.9	0.6	1.3	2.3	6.7	11.5	15.1	18.4	19.4
Average	24.0	21.1	11.1	5.1	5.8	6.3	9.3	15.0	18.7	24.4	27.4	28.1
Abs. max.	40.5	35.1	29.1	14.0	15.9	18.0	26.1	33.0	34.8	40.4	42.0	43.0
Abs. min.	6.5	8.8	-3.2	-5.5	-5.9	-6.5	-2.3	0.6	6.1	11.3	15.2	16.2
Boueidar												
Mean max.	33.2	30.2	17.2	7.5	11.4	11.4	17.1	23.5	26.7	34.5	37.8	37.5
Mean min.	12.1	8.4	2.4	0.8	-0.3	0.5	1.1	4.1	9.1	12.2	15.8	16.9
Average	22.6	19.3	9.8	4.1	5.6	6.0	9.1	13.8	17.9	23.4	26.8	27.2
Abs. max.	41.3	36.0	29.6	14.0	17.1	18.0	25.9	34.0	36.0	41.5	41.6	44.5
Abs. min.	2.0	4.8	-4.8	-6.2	-5.9	-5.7	-3.1	-2.1	3.3	8.7	12.1	11.6
Ghrerife												
Mean max.	34.1	30.1	17.1	8.1	11.5	12.3	16.8	23.1	25.9	33.5	36.6	36.8
Mean min.	18.1	13.6	4.8	1.8	1.3	2.5	3.6	8.0	12.2	16.7	19.3	21.2
Average	26.3	21.9	11.0	5.6	6.4	7.4	10.2	15.5	19.1	25.1	27.9	29.0
Abs. max.	41.0	35.8	29.0	13.9	17.0	18.9	27.1	33.1	35.1	39.9	42.0	41.2
Abs. min.	8.0	10.1	-3.0	-5.0	-5	-3.0	-0.1	2.6	7.3	13.3	16.9	19.0
Terbol												
Mean max.	30.7	29.4	18.3	9.5	10.8	11.1	16.1	24.6	25.8	33.2	35.5	35.8
Mean min.	9.7	6.0	3.1	-0.4	-2.3	-1.3	1.0	4.5	7.1	10.2	11.1	12.0
Average	20.2	17.7	10.7	4.6	4.2	4.9	8.6	14.5	16.5	21.7	23.3	23.9
Abs. max.	39.5	33.6	27.7	17.4	16.2	22.2	27.0	34.0	33.5	40.6	37.8	40.7
Abs. min.	3.4	3.6	-3.6	-8.0	-7.8	-4.9	-5.0	-2.7	2.2	7.0	7.5	8.4

Table 1.3 Frost events during the 1992/93 season

	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Jindiress								
No. of frost days	6	13	17	12	5	-	-	53
Abs. min. (°C)	-4.0	-6.3	-5.8	-8.0	-1.7	-	-	-8.0
Tel Hadya								
No. of frost days	4	9	15	15	7	-	-	50
Abs. min. (°C)	-4.5	-7.2	-8.7	-7.5	-2.4	-	-	-8.7
Breda								
No. of frost days	5	8	13	8	4	-	-	38
Abs. min. (°C)	-3.2	-5.5	-5.9	-6.5	-2.3	-	-	-6.5
Boueidar								
No. of frost days	7	13	18	12	14	4	-	68
Abs. min. (°C)	-4.8	-6.2	-5.9	-5.7	-3.1	-2.1	-	-6.2
Ghrerife								
No. of frost days	5	11	11	6	2	-	-	35
Abs. min. (°C)	-3.0	-5.0	-5.0	-3.0	-0.1	-	-	-5.0
Terbol								
No. of frost days	9	20	24	22	15	2	-	92
Abs. min. (°C)	-3.6	-8.0	-7.8	-4.9	-5.0	-2.7	-	-8.0

Table 1.4 Frost events at 5 cm above the ground during the 1992/93 season

Abs. min (°C)	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Tel Hadya								
Frost days	7	9	17	16	13	2	-	64
Abs. min (°C)	-6.5	-8.6	-9.2	-8.9	-4.4	-1.5	-	-9.2

2. SPECIAL FOCUS: GROUNDWATER AND SUPPLEMENTAL IRRIGATION

Introduction

Water has become an increasingly urgent issue in all parts of the West Asia-North Africa region. At the international level, the allocation of river flows is the subject of much bitter dispute and negotiation; and, nationally and more locally, there is widespread government concern over the perceived overutilization of underground water and the declining levels of aquifers. Already, agriculture is regionally by far the largest user of water, while rapidly growing populations exert an immense pressure on agriculture to expand, to provide both more food and more employment. In fact, there is little room for areal expansion. Rainfed farming has already been pushed in most areas to its driest limits, and opportunities for major expansions of irrigation are few. Indeed, part of the battle is to retain in production even the existing agricultural area, against major threats from erosion, salinization and urbanization. The essential prescription, therefore, is an intensification of agriculture in currently productive areas jointly with all necessary measures to ensure the preservation of that productivity. The key everywhere is water and, outstandingly, its more efficient agricultural utilization.

With its dryland mandate, ICARDA initially gave little research attention to water, except in so far as different rainfall amounts defined particular farming systems and imposed limitations on the distributions of its various mandate crops. However, in the mid-1980s, the potential of supplemental irrigation to increase and, especially, stabilize the yields of basically rainfed winter crops like wheat was recognized; and work on supplemental irrigation has formed part of FRMP's research portfolio since that time.

Supplemental irrigation requires a water source. In Syria, around 70% of all supplemental irrigation (ie 260,000 ha) depends on pumped groundwater (see 2.3, below). Reliable information on the quantity and quality of this resource is scarce. What is clear is that many farmers extract more of it than their crops really need, even where declining aquifers require them to deepen their wells, or drill new ones, at fairly frequent intervals. Underground water is, in effect, an open access resource to all those who live above it, and little incentive exists for any individual to conserve it. Thus, even at village level, the question of water and water-use efficiency is complex, embracing not only agronomic issues but also, on the one hand, hydrogeology, and on the other, human, economic and social issues. Research interest in FRMP in recent years has broadened to take in this complexity, and this 'special focus' chapter brings together reports of several strands of our work.

The first of these (2.1) was directed at communal and individual awareness of the issues of common property management, taking village-level groundwater utilization as a case study. The longer-term objective of such studies is to identify approaches by which communal responsibility for the management of endangered resources might be encouraged by education and by appropriate government support and regulation. The present work included both technical and social studies: regular monitoring of the depths to water level in selected wells in the study area built up, over time, a rapport with the farmers which allowed their ideas about groundwater and its management to be explored through informal interviews. The interesting finding was that farmers do not share researchers' and officials' perceptions of the nature of groundwater and the mechanisms governing its behavior. It is clear, farmers' beliefs will have to be better understood and accommodated, if communities and individuals are to be persuaded to act together to conserve the resource upon which their agricultural production heavily depends.

At the same time, improved technical knowledge of the resource is urgently required. One aim had been to utilize the well-monitoring data to build a model of the study-area aquifer, and this may still be possible in the longer term. However, a hydrogeological consultancy (summarized in 2.2) revealed the complexity of the underlying geology and serious deficiencies in currently available hydrogeological information. For instance, wells in the present study area appear to draw much of their water from what had earlier been reported to be an impermeable layer. Lack of a sufficiently long time series of data of depth to water level is also a serious handicap. Nevertheless, a number of significant points emerged: three aquifers apparently underlie the study area at different depths; a relatively small part of their catchment area for recharge is permeable, justifying fears about their capacity to support continued pumping at current rates; the shallowest aquifer appears close to failure; and, because of the poor water quality of the deepest aquifer and the danger of draining the two shallower aquifers downwards into it, drilling to this depth should probably be restricted.

Quality of groundwater and its effects on soil conditions and crop yield under supplemental irrigation is the subject of the third section of this chapter (2.3). It is a fact that the water used by some farmers for supplemental irrigation is slightly or even moderately saline. Results from a group of farms in north-eastern Syria demonstrate that salt accumulates in the soil even from the first year of use of saline water, and an average decline in wheat yield of 50% over five years was recorded as the consequence of using irrigation water with an electrical conductivity of 3-4 mmhos/cm.

This is a problem that can only get worse -- as more and more farmers drill wells to augment and stabilize their yields and drill ever deeper to tap poorer quality water as shallower aquifers fail -- unless remedial action is taken. Farmers are not unaware of the problem. They notice salt accumulating in their topsoils and modify their rotations accordingly, avoiding salt-sensitive legumes and eliminating high-consumption summer crops. It is noted that none of the areas supplementally irrigated with saline water is provided with a drainage network, although to ensure through drainage and removal of salt via such a network it would be necessary to irrigate at higher rates than those currently recommended assuming good quality water. All else equal, the economics of supplemental irrigation deteriorates with any decline in the quality of the water used.

The final section of this chapter (2.4) looks specifically at the economics of producing wheat under supplemental irrigation. The two major factors are the cost of water and the price of wheat. It is substantial increases in the price of wheat, while water costs have remained low, that has driven the rapid expansion of supplemental irrigation in Syria in recent years. In the present report, data from a number of supplemental irrigation trials over several years are used to effect an optimization analysis of supplementally irrigated wheat production under different rainfall and cost/price scenarios. Where pricing and marketing conditions are determined, as in Syria, by the government, such analyses can be used to help: farmers to attain optimal production for the prices offered and/or policy makers to take decisions to achieve government goals. In the latter case, the goal of a reduction in the pumping of groundwater would be achieved by increasing water costs (through taxation or decreased subsidies) or reducing wheat prices. The analysis presented provides simple quantitative models, from which the necessary changes in costs and/or prices might be calculated.

Undoubtedly, water for agriculture poses to the whole region a large and multifaceted complex of problems, political, economic, social and technical in nature. Fueled by demographic and economic pressures, "solutions" to those problems will -- at worst -- impose themselves, and such imposed solutions will likely be short-term expedients. To avoid, for instance, the rapid draining of aquifers and the widespread salinization of arable land, governments and resource users must be provided with information upon which they can act, wisely. This should comprise not just appraisals of the current situation, but also the trends in that situation, possible future scenarios, <u>and</u> the measures required to realize those scenarios. Such information will not be obtained without a massive research thrust. The work presented in this chapter shows the way. The information it provides is, of course, negligible in relation to what is needed; but the approach -- not just multidisciplinary but broad in its thinking across interrelated natural, technical, social and economic factors -- is the approach we believe is needed if research is to provide the sound and sustainable solutions to the many urgent water problems of the region.

2.1 Resource Users' Perceptions and Natural Resource Management: A Groundwater Case Study

2.1.1 Introduction

The reasons for conducting this study were: (i) that groundwater appears to be a resource under threat (groundwater levels in NW Syria have fallen about 1 meter per year since the last major survey, in the 1960s (see 2.2), and similar falls appear to have occurred elsewhere in the region); and (ii) that farmers' perceptions of the nature and behavior of groundwater are increasingly seen as important in determining the effectiveness of conservative policies and measures.

The latter viewpoint has developed relatively recently. Groundwater is a common property resource (CPR), ie it is not divided up into blocks or zones which are each the property of some individual or corporation (indeed, unlike the case of some other common property resources, such as open rangeland, this is probably technically impossible -- if I pump hard enough from deep enough, "your" water will end up in my well). Common property resources have always been something of a conundrum for mainstream economics; the image of human nature that underpins the model of the competitive market implies that such resources should always be subject to destructive competition, in which each rushes to grab his share, with no regard for the long-term good of all. This is the "tragedy of the commons" thesis, described in a famous paper by Hardin (1968). In this situation, individualistic competition powers the much-praised hidden hand of the market as it delivers a sharp blow to the body politic, instead of discharging its (allegedly) normal role of lubricating the transactions that bind society together. This has tended to make CPRs a salient issue for mainstream economics; its response has typically been to recommend that CPR situations should be modified in such a way that individual property rights could be established over them, making them amenable to the standard tools of the profession. This response effectively defines the resource users' perceptions as irrelevant.

In the foregoing, "individual property rights" is intended to refer to other sorts of legal persons (eg corporations), as well as natural persons; however, a major difficulty lurks here, since what is needed is a corporation or association with real unity of intent and purpose. In reality, wherever government or other development agencies have felt the need to influence CPR management by institutional measures, bodies have been set up which may have legal existence, but which often lack this crucial unity. There is an extensive literature on failure of bodies -- particularly cooperatives -- created in this way (Smith 1990a). Vesting ownership of a CPR in such a group will not help; this may affect the usefulness of the approach suggested by Bromley and Cernea (1989), which emphasizes the distinction between open-access resources (ie those exposed to the full force of destructive competition, because of the lack of any regulatory framework, formal or informal) and CPRs proper, in which property rights exist, but are exercised by a group. This still does not tell us how to square the institutional circle: setting up a viable and effective group.

Over the last decade or so, an alternative view of the CPR problem has emerged. It relies on the proposition that human nature is characterized by both competitive and collaborative behaviors. This has re-ignited interest in examining how people see situations, as a route to understanding how they manage resources, react to policy changes, etc. It originates in two independent lines of thought.

Perceptions and game theory: The first is game-theoretic modelling of situations in which the actors have, individually, temptations to defect from a course of action that is socially optimal. Much of this is based on the properties of the Prisoner's Dilemma game, which provides a convenient test-bed of behavior in circumstances in which short-run individual advantage conflicts with the long-run good of the particular "community". In this game, the players take the parts of two felons who have jointly committed a crime, and are now held in isolation from each other. The practice of the "justice system" is such that individuals who confess and inform on their confederates get off very lightly, while those who keep silent but are betrayed by a confederate are given heavy punishments. Those who protect each other tend to escape with only moderate sentences. In any one case, there is thus created a temptation to be the first one to defect and inform, although as a long-run policy this is unwise for both.

Axelrod (1984) showed that, given certain conditions, "public-spirited" behavior would arise spontaneously and could invade a community of non-altruistic, individualistic and competitive individuals. The main conditions favoring the emergence of responsible behavior are: that the same actors should have to continue to play together in some form of extended tournament; that there should be some form of sanction, recognisable as such, which can be exercised against defectors; and that it is exercised in a tit-for-tat fashion, ie one defection earns one -- and only one -- reaction (otherwise the system gets taken over by the reverberations of mutual reprisals). In an extended series of tournaments, this assertive but non-aggressive strategy outperformed those modelled on one-shot "rationality". At least some CPR situations seem to have the required characteristics; and there seems to be scope for applying these ideas in CPR management.

The results of such modelling suggest that the actors' perceptions affect outcomes in two ways. Firstly, a predisposition to assume everyone else is an individualistic competitor, prone to one-shot, short-term "rationality" (homo economicus, in fact) biases the outcome towards mutual defection and losses for all, so that, for example, a modified tit-for-tat strategy which assumes that the other side <u>will</u> defect in the first game is grossly inferior to one that embodies the alternative optimistic assumption. Secondly, the sanction has to be perceived correctly (not, for example, as a piece of random aggression, unrelated to the main game).

The "tough-but-fair" flavour of the tit-for-tat strategy has made Axelrod's work widely popular as a model of conflict management. Later work by Forrest (1985), using a sophisticated coding of this game within a genetic-algorithms technique, suggested that other premium strategies can be found. These permit marginal exploitation of the situation by an exceptionally skilled operator -- but they actually depend on probing the "perceptions" (ie inbuilt assumptions) of opponents' strategies. (And they do not undermine the robustness of basically collaborative strategies.)

Axelrod's work has been buttressed by a reappraisal of the sources of the (Western?) conviction that people are "essentially" individualistic and competitive. Although traceable to antiquity, this seems to have its immediate roots in the work of Hobbes, the 17th century English philosopher (Hampson 1978:28ff). In attempting to explain the existence of an ordered society, he postulated a state of nature in which each person fought for the necessities of life with all others, in a life "nasty, brutish, and short", from which they rescued themselves by establishing a contract with an absolute ruler, by which they gained protection in exchange for privelege. Criticisms (eg Elster 1983) centre on the points that Hobbes: ignores the considerable social support that exists between individuals within other species, which are presumably in a "state of nature"; inevitably ignores evolution, in the sense that these proto-people -- fully formed, and shaken out of a box onto the earth, with no previous development of any social mechanisms -- never existed; and relies on the observed behavior of outcasts from society, as a model of behavior before society. This may seem a digression, but the Hobbesian model, as an illusion of an empirical fact about human nature, has been incorprated into much later thinking, including the image of human nature that supports much current thinking on economic management -- although it is odd that his conclusion on the need for strong central control of the forces that might disrupt society has been rejected. (Hardin's tragedy-of-the-commons notion relies on this truncated Hobbesian model.)

We are still limited by Hobbes' errors and simplifications, some three centuries after; his ideas have become part of our folk-theories, which we believe to reflect all of reality. Other instances of the inertia of ideas -- over decades, rather than centuries -- figure in the discussion below.

Perceptions and models of behavior change: The second main line of thought emphasizing the importance of landusers' perceptions arose in the field of behavior change. Until fairly recently, the theories that received most public attention were mechanistic ones, such as behaviorist ideas particularly associated with Skinner (1982), and "infection" theories that seem to underlie much of the older extension work (and still appear to be very influential in practice).

During the last two decades, a radically different set of theories has come to the fore. Most of them can be described as "cognitive": they postulate that people behave as they do because of the goals they have and the way they view the world, and that, if you want to change their behavior, you need to deal with their cognitions. Most cognitive theories abandon naive realism and accept the possibility that different "reasonable" interpretations of even the physical world can coexist. By suggesting that cognitions control behavior, and that cognition may be negotiable, they appear to open up another potential line of attack on CPR problems. However, in implying that -- in at least some arenas of practical interest -- there is no unique objectively "best" view of the world, they open up the possibility that the would-be change agent may become the changee, a possibility that causes some consternation among traditional extensionists and developers.

To some extent, this reversal of intended roles happened in the present study. Its original object was to explore peoples' perceptions of various options for collaboration and restraint in relation to the over-use of groundwater, with a view to seeing how some of the modern ideas on CPR management outlined above could be mobilized.

Methodological problems in studies of farmers' perceptions: There were two main options. The first was to adopt a closed instrument (eg, a questionnaire), in which the questions to be asked are fixed in advance by the investigator's theoretical framework; in these, choice of responses is limited to yes, no, a number or name, etc, with possibly the option of replying "other", within some category fixed by the investigator. Such an approach, of course, eliminates the possibility of picking up any signs that the whole issue behind the investigation has been misdiagnosed, or that there are additional dimensions to it not realized by the investigator.

The second option was to choose a method from the family of open-ended techniques (structured interviewing, projective methods, ethnographic methods, etc). Smith (1987a), in a review of the range of applicability of a variety of survey techniques, concluded that the home range of closed questionnaires was the set of well-structured problems -- ie those where there is no doubt as to the definition of the problem, the best mode of solution, etc -- while that of open-ended instruments was the set of ill-structured problems. Groundwater management -- where there is doubt on both the diagnosis of the problem and the method of solution -- clearly is an ill-structured problem, and to accomodate this, it was initially decided to use a two-stage, open-ended technique. This was to consist of preliminary open-ended interviews, preparatory to an analysis using repertory grid methods (Stewart and Stewart 1981) on what seemed to be the most significant issue: farmers' perceptions regarding restraint and collaboration. Repertory grid methods were favored, because, of all the cognitive group, they seem to have the best-developed theoretical base (Bannister and Fransella 1986); work well in practice (Stewart and Stewart 1981); and are closely related to effective techniques in ethnography (Spradley 1979).

As events fell out, the preliminary open-ended interviews revealed that the nature of the problem was very different from what we had anticipated: farmers often did not see the problem of resource depletion as a real one at all. Also, they do not share researchers' and officials' perceptions of groundwater sources and mechanisms. This has serious implications for programs to remedy the problem apparent in falling water levels, such as the creation of village water management committes, or the imposition of more laws and controls. (The present ones are weakly enforced.) What follows is an account of the findings of this pilot study.

2.1.2 <u>Method</u>

As described above, the original intention was to lay the ground for a structured exploration of farmers' constructs of restraint and collaboration, in relation to groundwater use. (A construct is an axis of classification, developed by the "subject", in the light of his/her experience.)

A sample of 25 farmers was selected from approximately 80 with active irrigation wells in a 22 sq km study area south and west of Atareb, near Aleppo, Syria. The sample frame was a complete census of well owners, made by systematically touring the area to locate wells and identify their owners. A stratified random sampling scheme was used, the strata being the size of the pump owned (as indicated by outlet pipe diameter), which it was expected would be associated with other important variables, eg farm size, access to funds.

For about six months prior to the execution of this study, irrigation diaries were collected weekly from all members of the sample. These recorded hours of pumping, crop species and area watered, and the share of the pump output allocated to each crop. Pump outputs were checked, using a flowmeter coupled into the delivery pipe. (The object of this earlier work was to estimate total water abstraction for irrigation purposes, as part of the input to a groundwater model.) As a result, a reasonable degree of rapport had been established with all the members of the sample group; this is particularly important with open-ended techniques, and -- as here -- where there is some suspicion of the motives and official connections of investigators.

In addition to information on costs of irrigation installations, and sources of funds for the investment, the following questions were asked:

- what different types of groundwater are there?
- for each type, what is its source?
- for each type, is its level dropping? (It is, of course, difficult for farmers to distinguish falling levels of groundwater (and declining flow rates towards their well within the aquifer) from declining pump performance, either as a result of wear and tear, or, more importantly, working against an increasing head as the pump is lowered in an attempt to maintain discharge rates.
- for each type, is its quality deteriorating?
- what are the reasons for any decline in quality or quantity?

In addition, the evidence supporting assertions about the classification of groundwater, its source, etc were asked for. Responses to all the above were recorded on checklists, for subsequent analysis; as far as possible, this was done without breaking up the flow of conversation. The analysis was done by organizing the responses into dendrogram form (Figure 2.1.1). The classifications farmers offered were branched into the sources they claimed supply those classes, with the sources branching in turn into units that differ according to whether a particular combination of classification and source is affected by declining groundwater or not, and the reason offered for such decline. The key position given here to classification reflects its importance in cognitive theories of behavior and behavior change.

As an example of the organization of the data, the first block in Figure 2.1.1 shows that some farmers classify groundwater as being "shallow" or "deep"; the sources they suggested for the latter -- each a branch in the dendrogram -- are "unknown","sea (or sea-like)", and "rain"; and these lead on to branches identified with different responses on decline.

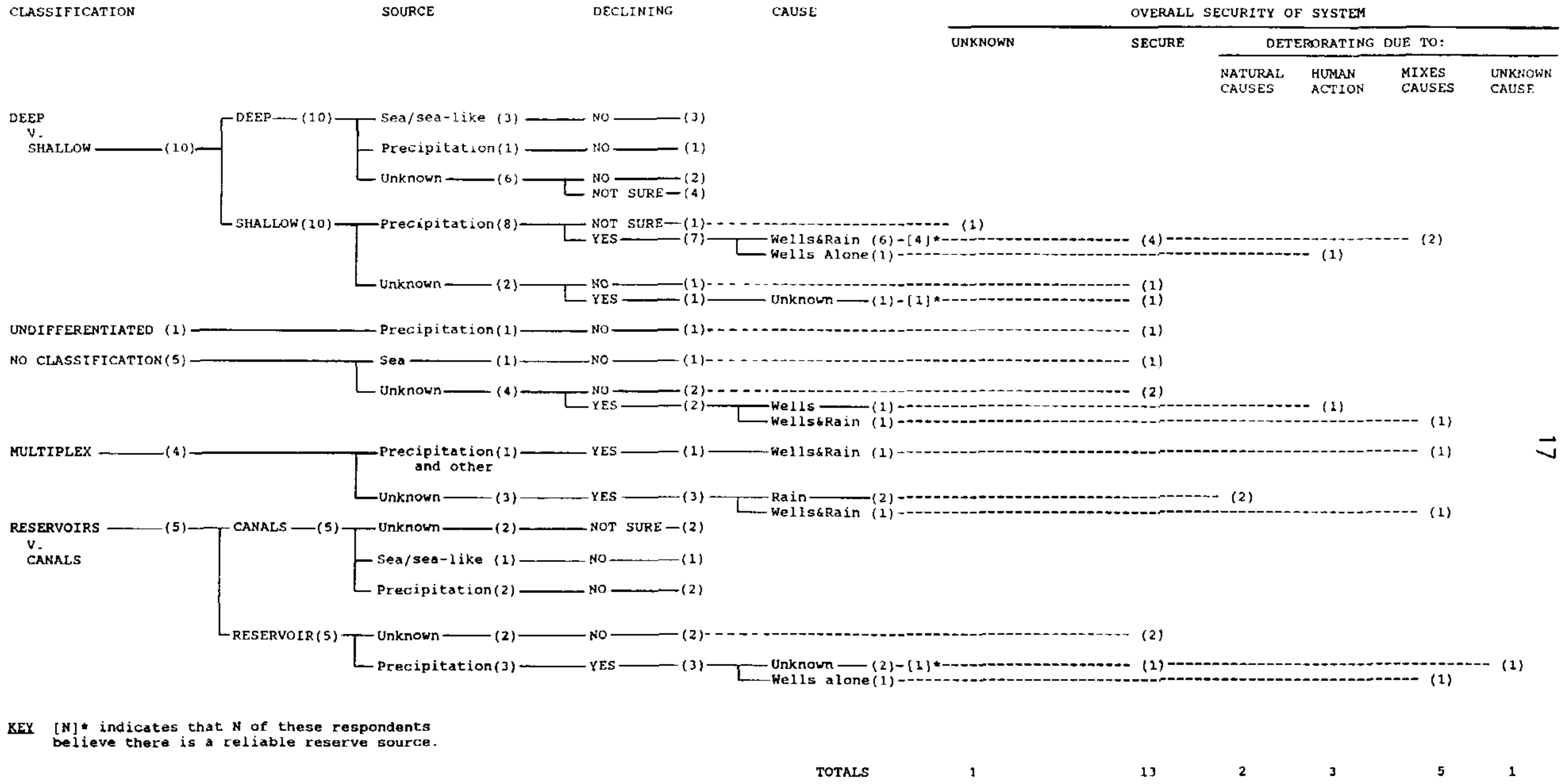

Figure 2.1.1 Dendogram of responses of 25 farmers expressing their concepts of the nature of the groundwater they are utilising

2.1.3 <u>Results</u>

Five separate typologies of groundwater were found:

- shallow versus deep groundwater; this was the commonest (10 farmers)
- water in underground reservoirs versus that in underground canals (5 farmers)
- multiplex, ie a large variety of undergound waters was identified (4)
- uniform, ie only one type (1)
- unclassified, respondents puzzled or unsure (5).

Each of these was supported by evidence. For example, those using reservoirs vs. canals as an axis of classification cite the different behavior of material (oil, straw) spilt into wells (either accidentally, or deliberately, to identify which sort of source a particular well is tapping) and the way different sources deplete at dramatically different rates. The deep vs. shallow classifiers cite the marked differences in taste, smell, and -- often -- maximum attainable flow rates between wells completed at 250m or less, and those going to 400m. (The farmers seem to use as a standard test for water quality, the question, "how good tea does it make?") The sole unitary classifier managed to dismiss all these differences as trivial ("if it only affects tea-making, well, that's not very important, is it?"); and the multiplex classifiers used both axes of classification cited by the first two groups to support their position. The same richness of evidence simply produced confusion among the non-classifiers.

It is important to note that -- with the exception of this last group -- all of those interviewed seemed confident of their grasp of reality. In Thomas Kuhn's significant phrase, they did not see the world (of groundwater) <u>as</u> <u>*if*</u> *it consisted of deep* and shallow; they <u>saw</u> a world of deep and shallow groundwaters.

When the farmers were asked what sources supplied the (various) groundwaters, two groups each showed an interesting internal contrast (Figure 2.1.1): both the deep vs. shallow and canal vs. reservoir classifiers tended to contrast a labile category (shallow in the one case, reservoir in the other) with a robust one (deep, canal). In many cases, the robust source of supply is seen as priveleged or secure. Sometimes this is because it is claimed to originate in distant rain/snow (usually in Turkey), which is believed to be highly reliable, and/or subject to some sort of buffering in the underground route it follows to the area. Alternatively, its origin is claimed to be the sea (desalinized by passage through the intevening rock) or a sea-like, undepletable body of water in the Earth's interior.

The undifferentiated, multiplex, and non-classifying groups showed much less of a pattern, with the commonest response being "don't know"; seven out of 10 gave this reply, the remaining three opting for the sea, distant rain, and local rain as the main source.

No-one thought that the quality of any groundwater source was declining, but opinions on levels were very varied. Looking at the non-classifying, undifferentiated, and multiplex groups' responses, and those of the other two groups responses about their labile sources (ie shallow water, and reservoir water), 17 out of 25 respondents thought that levels in at least one of their categories were dropping. Of this number, 3 could not give a reason; 2 blamed decreasing rainfall, 3 blamed increasing irrigation abstraction, and 9, some combination of increased abstraction and declining rainfall. Three of the last group thought that a reversal of the perceived decline in rainfall would overcome the effect of increased abstraction.

Regarding the robust sources (reservoirs, deep groundwater), 8 of the 15 respondents in the two relevant groups could not give an opinion, because of lack of experience; 7 said either that it was not falling, or, in effect <u>could</u> <u>not</u> fall. The effect of this latter set of perceptions is that several people who accept that labile groundwater is disappearing, nevertheless believe that the overall supply is secure, regardless of farmers behavior, because of the existence of a reliable reserve. As a result of this and other factors, 13 (of 25) respondents believe that the situation is non-problematic. Eleven believe that there is a problem, but only 3 of them accept the official explanation, that the sole cause is overuse. Even some of those who agree that overuse contributes to the apparent decline think that a change in rainfall could reverse the effect. (This last point provided one of the few cases in which the farmers could not cite evidence for the views they held.)

2.1.4 <u>Discussion</u>

The results presented above show that most farmers in the study area have a set of well-formed perceptions about the nature and origins of groundwater; and that these perceptions are such that the majority of them do not accept the official view that groundwater levels are declining solely because of excessive abstraction. The explanations they offer are naturalistic, and, with only one exception, do not rely on mystical or religious mechanisms. Neither do they embody absurd physics; indeed, the idea that the source of groundwater is the sea was the standard scientific explanation in Europe, before the pioneer work on the hydrological cycle in the last century (Freeze and Cherry 1988:Ch 1).

This phenomenon -- the existence of alternative, internally consistent interpretations of the state of an important resource -- raises several questions, which, as a group, demonstrate the strong interaction that can occur between fairly abstract theoretical considerations and practice. It also indicates that many accepted approaches to managing change are based on unconscious choices among radically different alternative views of mental functioning and motivation. The author's belief is that practice would be improved if practitioners were aware of these choices, even when there is litle hope of deciding which alternative is "best".

The questions raised are:

- Should we be accepting models of the change process that incorporate such perceptions and/or use an image of behavior and behavior change that assumes people are goal-directed?
- How is it that different interpretations of the same circumstances arise, and is there any sense in which they are equally "valid"?
- If we do accept that we should work with a model of change that relies on goal-directedness and admits the possibility of alternative interpretations of the physical (or social) world, then how does this affect our change management practice, particularly in situations in which we, the experts, think we have a better perception of some natural resource management issue than landusers, whether it be in soil conservation, rangelands, or water resources?

These questions are addressed in what follows

The choice of a model of change: Theories of behavior and behavior change that postulate that people are goal-directed come in two varieties, according to whether or not they imply that there is only one set of human desires and a single interpretation of how to go about satisfying them; or whether it is possible that different groups can "construe" the world in different ways -- as the farmers in this survey seem to have done. (There is a further type: the behaviorist theories, in which reflexes are established as a result of the reinforcement, by reward, of appropriate behavior, with no input from the mental processes of the changee. The commonest managerial application of these has been in the design of incentive schemes. Such theories also postulate some variation in the amount of inertia and in the sources of resistance to change. For reviews of this field, see Kanfer and Goldstein (1985) and Zaltman and Duncan (1977).)

The cognitive/goal-directed group of theories underly the best of farming systems research methods (Shaner et al. 1984) and modern approaches to project identification and intervention design (Smith 1987b). They are also the basis of a school of psychology, personal construct theory, which has produced successful methods of behavior change both in therapy and practical management (Bannister and Fransella 1986; Stewart and Stewart 1981). In many ways, these work, and they are certainly the most academically respectable set of theories. It is therefore surprising that they have not swept the board, with everyone converting to using them. There seem to be two sets of problems here.

Paradigms and the persistence of models of change: The first grows out of the subtle issue of paradigms. In its technical usage, this word means the set of images which form the foundation of peoples' ideas on how we get to know about the world, what sorts of things are in it to be known, the nature of social and physical processes, etc. Thus, a socio-economist might attempt to evaluate a project intervention exclusively by crop cutting or by head counts of adopters and non-adopters of some new technology, characterized by their externally visible attributes (age, education, etc). Such an investigator is working from a very different image of what sorts of entities (other!) people are, what sorts of information constitute admissible data, and how you satisfy colleagues that your conclusions are valid, than is, say, an action researcher. Action research (again, in the narrow technical sense) places emphasis on building a local set of understandings of motives and social mechanisms, as a route to untangling institutional problems (Zuber-Skerritt 1990). The <u>image</u> here is a very different one: of a world in which success and failure are highly dependent on social and political factors, and that these develop flexibly, and are emergent -- ie not fully determined by the physical and biological constraints of the situation.

While some dust still hangs over the debate about paradigms, the picture seems to be that no discipline does or can operate without a set of such images; that they are pre-scientific and largely beyond empirical comparison, because of their divergent stipulations on what is admissible data; and that they tend to distort the criteria for empirical success in their own favor. One result of this last feature is that both the head-counting socio-economist and the action researcher see the performance of their methods as confirming the rightness of their basic assumptions!

Smith (1992) discusses the history and current status of the paradigm issue in the context of development policy. It does appear that, particularly in any context with a large social content, the idea of a "best" choice of imagery is illusory: each set enables some problems to be addressed more potently than others, but always at a cost of weakness elsewhere. That different paradigms selectively enable/disable effective action in different contexts is very well demonstrated by Morgan's (1986) work on the images of institutions and organizations.

Practitioners who favor one or other of the great groups of change theory do seem to inhabit different paradigms. This means that, commonly, they will assume that all (right-minded) people <u>must</u> think as they do, and that they are not in a learning situation -- they already have an effective set of theories and practices, within the limits of an imperfect world. This obviously has implications for the most neglected sort of change management: not changing them out there (the farmers) but changing our colleagues, the old hands in the extension offices, for instance. We certainly will not succeed in this area by attempting to prove our approach is right and theirs wrong, given the extreme divergence between us on what constitutes evidence. Indeed, the only sort of change theory which can readily be shown to be wrong, in the simple sense, is the primitive and atheoretical blank sheet model, in which farmers sit there, waiting for experts to come and inscribe knowledge upon their minds. (Regrettably, this does still seem to be in use in some of the danker corners of the research community.)

Complexity, lay-theories, and the persistence of models: The other reason why major theoretical choices are made unconsciously is that the complexities of development work cut across many disciplines, and it is easy for the practitioner to be forced to operate in areas for which a rich choice of theoretical frameworks exist in <u>someone else's</u> discipline. For example, the economist who theorizes about the behavior of people in relation to the allocation of CPRs inevitably runs the risk of becoming a naive psychologist/anthropologist; the applied anthroplogist who is interested in resource conservation runs a similar risk of becoming a naive hydrogeologist/range ecologist/systems analyst, and so on. (Quite a lot is known about these naive sciences and "lay-theories" -- see Furnham (1988).) We do not seem to have in our professional training good mechanisms for instilling an appreciation of the menu of choices available in other disciplines. Getting access to relevant expertise, once you have identified what is relevant, is relatively easy, of course.

2.1.5 <u>The emergence of alternative interpretations</u>

Our model of the normal relationship between evidence on the one hand, and policy-making and action on the other, is that of the natural sciences: one collects data, analyses it, possibly formulates new hypotheses, tests them, and <u>then</u> decides what to do. Unfortunately, real life is an on-line, real-time activity, and many serious decisions in administration and management have to be made before the answers are known. Smith (1990b) reviews this problem, and discusses the families of techniques available to deal with it.

An important consequence of using the natural sciences model is that it accustoms us to assuming that we <u>should</u> always be operating with a single, confirmed view of the rules and processes that govern the behavior of the things (or people) we are working with. The on-line/real-time restriction ensures that this assumption is usually wrong. The main sources of multiple diagnoses, theories, and classifications of phenomena that arise in these circumstances are:

i) The partial, local, and specific nature of experience, which is often the only source of evidence landusers have. (For example, it is possible that, if we knew all the details of what appears to be a very complex hydrogeological situation, we might be able to explain all the variation in farmers opinions about it).

ii) Time series effects: most evidence of practical interest arises as a series of observations, taken in some sort of sequence (eg histories of water levels in wells, over a period of years). There are considerable theoretical difficulties in analysing such series, because they breach some of the assumptions needed for the validity of the usual least-squares estimators. Such breaches are often dealt with by applying conventional assumptions about the form of the underlying distributions (Kennedy 1988), but these may have more to do with convenience and tractability than reality. Conclusions may be dramatically affected by the <u>ad hoc</u> procedures usually used to deal with apparent outliers. Advocates of robust statistics (eg Hoaglin <u>et al.</u> 1988) criticise users of the standard least-squares approach for ignoring the vulnerability of their methods to outliers, <u>ad hoc</u> treatment of outliers, errors of observation, and to mis-specification of model; but they admit that robust time series methods still require much development (Hampel <u>et al.</u> 1986:416ff). The advocates of Bayesian methods (eg Phillips 1987) continue to infuriate or puzzle most users of classical significance tests by wanting to replace arbitrary significance levels with non-arbitrary but subjective probabilities. Finally, many series of interest in hydrology and meteorology display the Hurst effect, with the time-trace showing prolonged excursions both above and below the mean (Feder 1988:149ff). This is highly inconvenient to practitioners with relatively short runs of data (ie a decade or two, in the case of rainfall), and creates ferocious difficulties of analysis (Feder 1988; Hampel <u>et al.</u> 1986:387ff). The latter is not made any easier by voices (eg Potter 1976) claiming that the Hurst effect is not a real one anyway!

The upshot of all this is that <u>even</u> <u>if</u> it were possible to switch the whole debate about most major natural resource management questions into the off-line mode, and attempt to resolve it by accumulating long series of data, doing controlled experimentation, etc, we might still not come to a consensus on what was to be taken as the truth. This certainly applies to the reality, extent and direction of climate change, and to the reality of the desertification phenomenon (as distinct from severe erosion and vegetation depletion) -- see Hellden (1988) and Thomas and Middleton (1994).

iii) The sequence in which observations are acquired -- usually experientially, rather than experimentally -- matters. As a result of earlier experiences, concepts and categories are formed, and these affect the interpretation of subsequent events. This effect seems to occur even in artificial intelligence (AI) systems, both those that use the more traditional expert mode (Schank 1987) and the less prominent alternative, the genetic algorithms mode, one of whose roots was the hope of explaining emergent behavior in intelligent systems (Goldberg 1989:221ff). This is interesting: before AI, the idea that the categories into which natural phenomena are fitted might be neither "real", and somehow programmed into all (non-defective) minds, nor uniquely determined by external reality, was exclusively the property of psychologists and ethnographers -- at least, among the scientific community. (Benedict (1934) is still worth reading as the best exposition of the ethnographers' position on this.)

iv) Complexity: many fields, of which groundwater is one, are well understood in principle, but in practice, formulating good stable models of specific situations, which perform well when used outside of the range of data against which they were calibrated, often requires impractical amounts of data. (Freeze and Cherry (1988: 352ff) give a good introduction to the problems of modelling.) Very little attention is given to the question of what qualifies a model of complex (and recursively generated) system -- such as an aqifer/farmer system -- as being a "good" one, in relation to resource management and policy making; Casti (1992) is an exception.

Implications for change management in the natural resources field: The central problem is that of changing minds that see no reason to expose themselves to the possibility of change. This is a common problem in adult education, eg in relation to educating practitioners of various sorts in management science: learners already have their own theories, categories, etc, which they hold confidently -- occasionally, aggressively. These, for example, may define certain sorts of technique as irrelevant, or impractical, so the learner avoids them, usually in the process of pursuing other matters which his/her perceptions identify as more promising.

Subsidiary questions are: how to alert those we wish to change to the existence of a menu of ideas which they are not aware of; and how to overcome effects of their imageries and paradigms, even if we gain their interest?

Methods of adult education that take the above points into account usually rely on experiential learning, in which experiences are constructed, or reconstructed, and then analysed by the learners, with varying degrees of input by the teacher; or they use differences (between disciplines, between groups of farmers, etc) to explore how it is that different people come to see the "same" phenomenon in radically differently ways (Churchman 1971:188).

These imply something very different from the traditional linkage between science and action, in which the establishment of pure and uncontestable knowledge precedes its incorporation into recommendations for practice, which are then disseminated to a respectful and compliant audience. It aims to involve the changees in diagnosis and data gathering; to analyse their perceptions of the situation; and, ideally, to produce a synthesis which explains the origin of the deviations, <u>before</u> trying to formulate a remedy.

There is a slight twist in the tail of this account: official pronouncements on groundwater issues in the region seem to be based on a model in which aquifers are rather like a tank of fixed size, filled with some granular material, into which water has been poured. In such an aquifer, a 10 percent reduction in the depth to which the pores are filled represents a 10 percent depletion of the resource. Real aquifers are generally not like this: the "tank" may not be fixed in size, the effective catchment expanding under the influence of increasing hydraulic gradients created by lowering the water level; the tank may actually be a pressurized system (or even a leaky pressurized system), so that the observed decline in water levels reflects a pressure drop, rather than de-watering; drawing water from certain sorts of geological formations may result in their irreversible shrinkage; and, as water levels fall, both the critically important <u>transmissivity</u> and the quality of the water may decline. As a result of all this, a marked decline in levels may mean anything between impending disaster and the beginning of a process of re-equilibration (Freeze 1971). As a result of such a re-equilibration, increased abstraction and/or decreased recharge could come into balance but at lower water levels (with increased pumping costs, and possibly other side effects, eg reduced streamflow).

In the location studied, there is scope for most of these effects to occur; and the overall picture emerging from the farmers' accounts, of a complex and highly differentiated situation, is probably nearer the truth -- as indicated by the hydrogeological study made shortly after this survey (see 2.2) -- than is the naive hydrogeology of many resource administrators and extensionists.

Similar remarks apply to the farmers' assertion that the rainfall has changed. A staid statistical perspective suggests that such an effect could not be detected and confirmed with available data, and that it should therefore be discounted. If however, one is prepared to accept the possibility of the Hurst effect, data on rolling averages of total annual rainfall suddenly become pertinent, and these do suggest a real effect, through which rainfall at one station in the area was consistently high for a period of years (above 550mm), and then consistently low for another such period (around 400mm), within the last three decades (2.2 below).

2.1.6 Conclusions

In any situation in which an exhaustible or fragile natural resource appears to us, the experts, to be under threat, three sets of perceptions influence the likelihood of finding and implementing an effective remedy:

a) Naive and informal classifications and theories developed by landusers, broad in scope, and heavily influenced by at least the superficial appearance of reality.

b) Naive and simplistic classifications, theories and recipes acquired by administators, extensionists, and -- outside their special fields -- researchers, mainly during the course of their training. Often, the content of these is constrained neither by rigorous science, nor by field experience. These are broad enough in scope to support recipes for action in most areas of working life; their weakest areas are probably the social and management fields.

c) Formal classifications and theories, held for rigorous scientific reasons, by researchers and technical specialists operating within their area of expertise. These are very powerful, but narrow in scope, and may require time or inputs which are not available in practice.

The first two sets of perceptions matter: they influence the effectiveness of interventions of all types, by controlling landusers reactions, and by deciding which methods development staff will see as sufficiently effective to be worth finding out about and applying carefully. This is particularly relevant to the groundwater situation we have here, in which there is a growing debate over whether traditional models of the CPR problem are effective, and whether they should be supplanted by promising newer alternatives.

A wide variety of techniques exist for exploring these perceptions; while some are highly sophisticated, a structured, conversational investigation can sometimes be very effective. Closed instruments, such as the ever-popular questionnaire, have a dangerous tendency to supress evidence about divergences between the frames of reference of the investigators and the investigated, and probably should not be used in this sort of work. In the present study, these would almost certainly have failed to pick up a very important divergence. On the one hand, officials and researchers believe groundwater use is (at best) a zero-sum game, whose rules and procedures are in urgent need of reform. On the other hand, most farmers believe either that the situation is a positive sum game (all can have all they could reasonably want, without affecting each other) or that the total value of the resource is shrinking, but that this is not the (exclusive) result of their own actions. The significance of this for extension and intervention should be obvious.

Finally, methods for working with groups with divergent perceptions of resource management issues would benefit from the introduction of techniques from adult education, to replace some of the more conservative extension methods still in use in the field, some of which seem to assume that farmers have non-functioning minds and sense organs. [***Peter Smith, with major assistance from Hisham Salahieh in all aspects of the fieldwork***]

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2.2 An Investigation into the Shallow Groundwater Resources of Part of North-West Syria (Aleppo-Atarib-Idleb area)

2.2.1 The problem

Groundwater levels appear to have been falling consistently at an average rate of approximately 1m per annum; groundwater levels today (January 1994) are some 30m below those reported in the early 1960s (GSFRG, 1967).

The rate of installation of abstraction wells is increasing in areas suited to irrigated agriculture, and the total installed capacity has increased greatly in recent years (Table 2.2.1). In addition, farmers report the need to lower pumps deeper into existing wells and, when installing new wells, to go progressively deeper, to maintain adequate yields of water -- in both cases at a rate generally consistent with the one metre fall per year.

The life expectancy of this shallow groundwater resource is thought to be limited if this pattern of abstraction is continued. Key questions considered in this study therefore were:

- Can the system maintain current water (and crop) yields?

Table 2.2.1 Annual and cumulative pumping capacity in intensive study area (total cross-section area, cm^2, of delivery pipe)

Year	For year	Cum. from 1970
1970	139	139
1971	-	139
1972	-	139
1973	138	277
1974	81	358
1975	-	358
1976	46	404
1977	-	404
1978	91	495
1979	-	495
1980	-	495
1981	81	576
1982	133	709
1983	184	893
1984	183	1075
1985	479	1554
1986	126	1681
1987	380	2060
1988	334	2395
1989	351	2746
1990	461	3206
1991	786	3993
1992	863	4855

Figures are effectively net: where wells have been resited, the equipment was moved, in all cases; increased size of equipment recorded net. Note: study area is the same as that for the work described above in 2.1 and is approximately defined by the square drawn on the map in Figure 2.2.1

- If not, how and when will it fail?
- What would be the indicators of this impending failure? (Indicators of use to planners/decision makers would be particularly interesting).
- Is a mathematical model of the aquifer essential or helpful to answer the above questions? (Are there simple methods of deriving early warnings for policy makers, which do not require heavy loads of data collection and the intensive use of professional manpower?)

- What other information/data should be collected?
- What can be learned from a detailed study of a small area?
- How far can the above questions be answered by reference to a small sample area?

2.2.2 General description of area

Figure 2.2.1 shows the general topography: to the west, lies a rift feature, defining the valleys of the Aasi and Afrin rivers, bounded on its east side by high and largely rocky ground with pronounced relief. This occupies most of the triangle Afrin/Aleppo/Bab-el-Hawa and then extends southward alongside the rift in a relatively narrow band to near Idleb. Valleys and depressions -- the largest being at Dana -- occur in this rocky zone, and contain the red clay soils typical of the area. Karstic features are commomn. A north-eastward branch of the rift feature penetrates the rocky area, terminating near Armanaz. South of Idleb, the rocky zone broadens eastward, towards Ma'aret El Noman.

North of Aleppo, and east of the rocky zone, there are extensive cultivated plains; the southern part of these is intensively irrigated, but groundwater is scarce or absent in the northern parts. The course of the Quek River passes through this area. Flows in it appear to have diminished in recent years, and it now flows for only a few days, in one or two episodes, each winter. Similarly, levels in the Al Shahiba flood control dam (which is at the outflow of a natural wetland) have also been dropping: the pond has been dry for the last two winters. There do not appear to be any major abstaction works on the headwaters of the Quek in Turkey, but rainfall has been markedly less over the last few years (Table 2.2.2). These plains are bounded on the east by rising ground.

South of Aleppo, and east of the rocky area, a major depression runs from near Atarib south-eastwards; this is in intensive agricultural use, with considerable irrigation. The special study area (SSA) of the present investigation lies in the upper part of this depression. Rocky knolls are quite common. The River Quek emerges considerably augmented by waste from Aleppo (mainly with Euphrates water?), and flows southwards across this depression, ending in a shallow lake east of Abul Thuhor. Farmers report that this lake has also receded considerably over the last few years, and that springs near its margins have disappeared. The eastern edge of the depression is marked by a line of flat-topped hills, of which Jebel Hass is the most conspicuous.

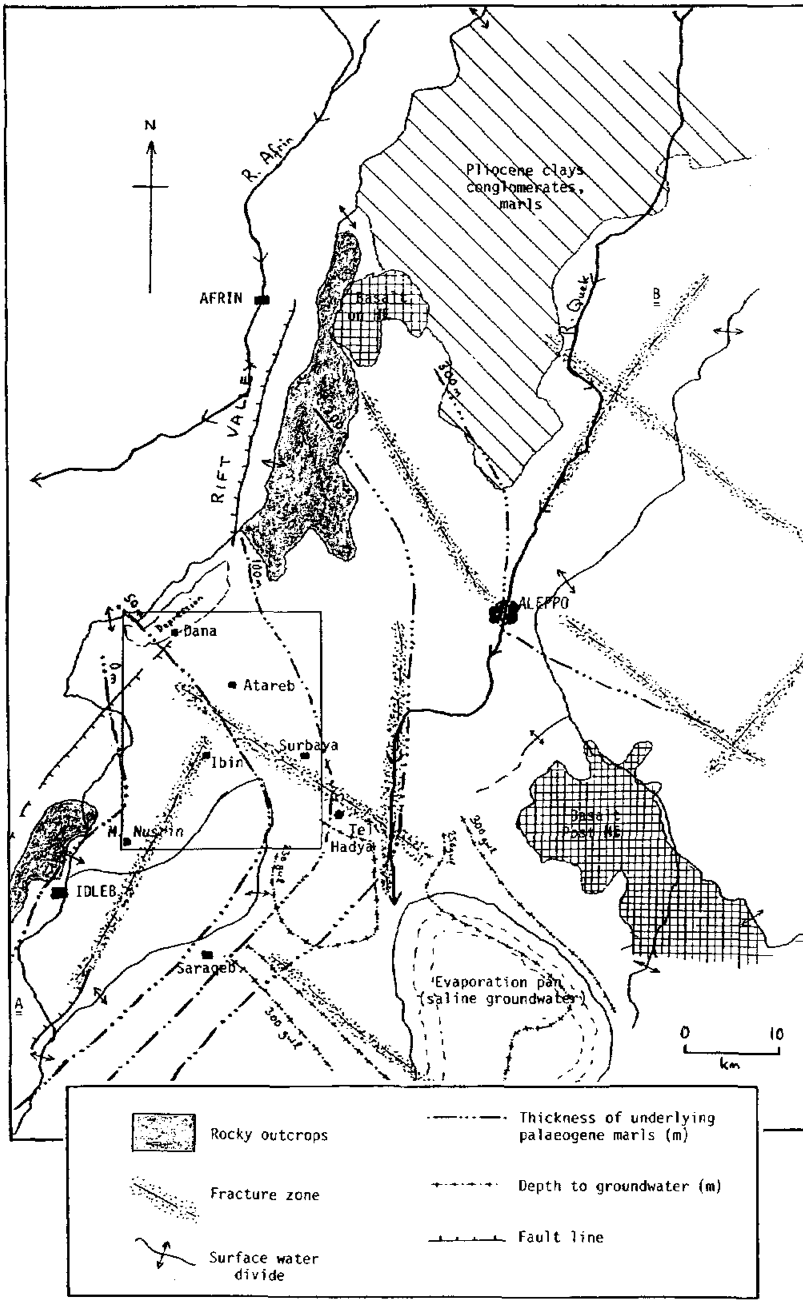


Figure 2.2.1 Map of Aleppo-Afrin-Idleb area, indicating some relevant topographical, geological and hydrological features and locating special study area (rectangle, centre-left). (HE - Helvetian Limestone; A and B approximately indicate the ends of the section shown in Figure 2.2.2)

Table 2.2.2 Long-range variation in rainfall (mm) at Jindiress

	Syrian met		ICARDA	
Year	Amount total	5-year rolling average	Amount total	5-year rolling average
1960	364.6			
1961	522.6			
1962	542.3			
1963	701.2			
1964	404.4	507.0		
1965	524.2	538.9		
1966	496.0	533.6		
1967	684.6	562.1		
1968	716.3	565.1		
1969	505.2	585.3		
1970	329.5	456.3		
1971	512.8	549.7		
1972	290.9	470.9		
1973	321.4	391.9		
1974	458.2	382.6		
1975	398.7	396.4		
1976	479.2	389.7		
1977	397.7	411.0		
1978	475.3	441.8		
1979	362.0	422.6		
1980	423.3	427.5	420.2	
1981	516.5	435.0	511.3	
1982	309.2	417.3	317.8	
1983	418.4	405.9	430.7	
1984	353.6	404.2	372.9	410.6
1985	369.5	393.4	390.5	404.6
1986	479.9	386.1	489.3	400.2
1987			633.1	463.3
1988			751.1	527.4
1989			232.9	499.4
1990			286.1	478.5
1991			510.8	482.8
1992			342.2	424.6
1993			311.3	336.7

2.2.3 Hydrogeology

The report (GSFRG 1967) of a German geological mission in this area identified two major aquifers. The deeper was termed the

General Hydraulic System (referred to in this report as the **Deep Aquifer**). It is made up of Cenomanian & Turonian limestones of the Upper Cretaceous and (separated from the former by 105-130m of Albian/Aptian marls) Jurassic limestones. These appear to vary in thickness from several hundred to a thousand metres and are presumed to underlie the entire area. They do not outcrop in the general area of the study; and in this area, ie east of the rift, there appears to be no current recharge into the system. Wells that seem to penetrate into this deep groundwater reportedly yield poor quality, saline water. The farmers' standard test is tea-making qualities of the water!, but one sample from this depth (Al. Ibrahim II) was included in the analyses made by the FRMP Soils Laboratory (Table 2.2.3). It may be noted that the quality of the water in the aquifer is probably worse than the sample, since -- like all the wells seen -- it is unlined for most of its length, and there is therefore some mixing with upper, better quality water. The saline spring at 'Ain Zurqa, away to the southeast, in an area where Cretaceous rocks do outcrop, is probably an upflow of this water.

The **Shallow Aquifer System** consists of younger (Miocene) Helvetian and Eocene limestones (the former are conspicuous in the rocky areas referred to above). The water is generally believed by farmers to be of good quality and the analyses in Table 2.2.3 confirm this.

The two aquifer systems are separated by Palaeocene and Upper Cretaceous strata which comprise limestones, clayey limestones, flinty horizons, and most significantly up to 450m of "dark grey <u>marls</u> and clayey limestones, with thin layers and lenses of flints" (GSFRG 1967). A hydraulic connection between the two aquifer systems may be provided by major faults (associated with the rifting), but elsewhere the intervening materials, especially the marls, were thought to be impermeable (but see below).

A number of zones of fissuring are noted in the German report. One of these runs NW from Aleppo, and the monitored well at Hareytan appears to be located in it. Comparisons of the comments of well owners in this locality suggest rapid lateral changes in the ground conditions encountered during drilling. This zone appears to consist of a down-faulted elongated block, which -- as is apparent from sub-surface mapping (GSFRG 1967) -- forms a buried trench-like feature, striking northwestwards from Aleppo city. This structure may effectively separate groundwater from the north and north-east from that to the south of the faults, acting as a cut-off drain or at least diverting the flow southwards. Maps also show an important fracture zone striking due south, accounting (further south) for the line of the Quek River; this may well be a preferential flow path for the groundwater.

Table 2.2.3 Water quality analyses from intensive study area, July 1993

Location	Well Dept. m	Surface elevation, m	Bottom of well, ASL	Na meq/1	Ca+Mg meq/1	SAR 1:1	pH ms/cm	E.C.	Boron
Atareb-Bricks	110	311	201	3.5	5.09	2.19	8.27	0.73	0.021
Kafr Noran I	200	305	105	2.5	4.43	1.68	7.53	0.57	1.132
Surbaya	195	280	85	1.5	3.77	1.09	8.37	0.38	0.372
At. Ibrahim I	200	291	91	2.5	4.76	1.62	8.07	0.62	0.026
At. Ibrahim II	410	291	-119	4.0	7.97	2.00	8.22	1.05	0.030
Hareytan	200	384	184	1.0	3.77	0.73	7.73	0.38	0.046
Jineh-Martini	250	293	43	2.0	5.05	1.26	8.40	0.59	0.258
Ibin	220	294	74	3.5	5.38	2.13	8.21	0.73	0.156
M. Nusrin	320	350	30	3.0	6.56	1.66	7.90	0.86	0.063
Armanaz	100	365	265	1.1	6.37	0.62	7.57	0.62	0.197
Dana	235	384	149	2.3	5.89	1.34	8.20	0.69	0.024
Jineh-Bakour	150	301	151	1.8	6.04	1.04	7.55	0.64	0.505
Kafr Noran II	150	305	155	2.7	3.87	1.94	8.39	0.50	0.339

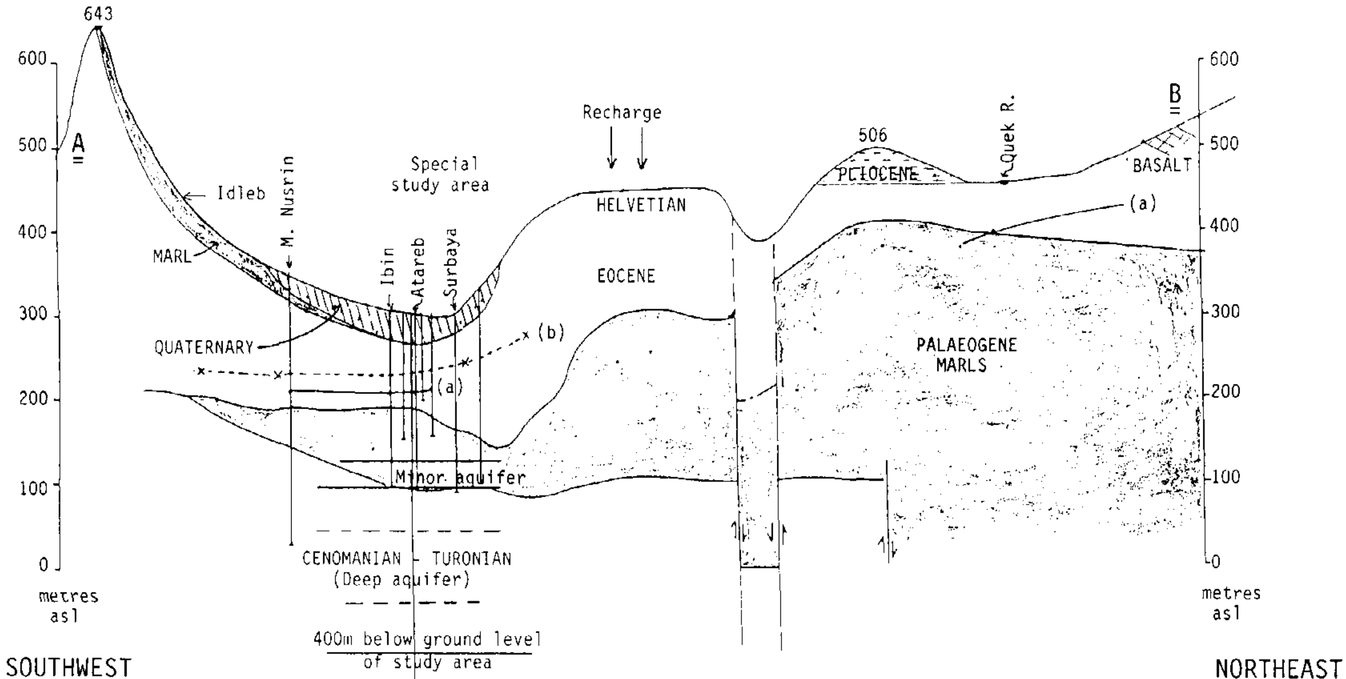
In the west of the area (eg immediately west of Idlib) the Palaeocene and Upper Cretaceous strata wedge out, as shown in the cross-section (Figure 2.2.2, which is an interpretation of Plates 5 & 6 of GSFRG 1967). Wells in the monitoring programme which lie on or near the plane of section are shown, and it is apparent that the current generation of wells draw much of their water from inside what appears to be an "impermeable" layer in the earlier published work. For the purposes of this study, the complex of water-yielding strata in this material has been labelled **"The Minor Aquifer"**. Its presence complicates the production of a numerical model of the water resources of this area.

Further north the marls extend westwards as far as the major fault line forming the east side of the rift, so that the Shallow Aquifer drains directly via springs in the Afrin Valley.

In the absence of an aquiclude [impermeable stratum], water may percolate downwards (since the water table in the Shallow Aquifer is probably higher than the piezometric surface of the Deep Aquifer), draining from the Shallow Aquifer System, recharging the Deep Aquifer, and interacting in complicated ways with the Minor Aquifer. Depending on the hydraulic gradient this water may then flow westwards and contribute to the springflow in the rift valley. Flow within the shallow aquifer is probably mainly south-easterly, along the line of the depression, but some of it may also diverge towards the rift. The reason for the uncertainty is that groundwater levels are deep; the water itself has few, if any, surface manifestations; and surface levels are not yet known with sufficient accuracy to enable a completely unambiguous set of groundwater contours to be drawn.

2.2.4 Recharge

The clayey soils and deeper Quaternary deposits which cover much of the Shallow Aquifer's "outcrop area" seem to be relatively impermeable. The amount of deep percolation -- and hence recharge -- in these areas is uncertain and has been presumed to be small, except (possibly) for some rapid recharge following the first heavy rains on previously dry and heavily cracked soils; and also in the valley of the Quek, where significant seepage may occur during prolonged flooding. (In the past such flooding may have been more frequent and more widespread, and may have been a more important source of groundwater recharge.) However, experience elsewhere has suggested that deep percolation through "impermeable" material can be much greater than is often assumed. The presence of a substantial number of rocky knolls, and areas of relatively stony soils, resulting from the considerable variability in soil depth, may also affect the issue.



(a) ground-water level, January 1994
(b) ground-water level, CSFRG, 1967
(some distance from line of section)

Figure 2.2.2 Simplified hydrogeological cross-section from southwest to northeast across study area, with vertical scale relatively exaggerted by a factor of 80. (Points A and B may be located on map in Figure 2.2.1)

However, about 12% of the outcrop area of the Helvetian Limestone (including the area overlain by Quaternary deposits) consists of rocky outcrops with no soil cover or with soil confined to pockets between bare rock. In addition, the rock is highly fractured and weathered, so that any precipitation and local runoff can be assumed to percolate into the underlying strata and subsequently to recharge the groundwater. It is this relatively small area that is thought to constitute the main recharge area of the Shallow Aquifer System for the area south of Aleppo. Its western boundary has been taken as the surface water divide; the rocky area west of Idlib probably contributes its groundwater recharge to springflow in the rift valley.

In the north of the area (Azaz and eastwards) the limestone is covered by thick Pliocene deposits, principally clays and marls with some conglomerates: this does not yield significant quantities of water. The limestone outcrops again in the Quek Valley to the east. In this northern section, groundwater levels are relatively high, reflecting the underlying geology and the presence of the Palaeogene marls at higher elevation.

2.2.5 Nature of groundwater flow

Geological structure is also important in controlling the flow path of the groundwater on a small scale. The Shallow Aquifer System consists principally of consolidated limestones whose hardness varies (because of differences in the degree of cementation) and in which secondary permeability is an important determinant of permeability, ie flow probably occurs principally in fissures. This may apply also to the minor aquifer. The main flow paths (seepage lines) probably correspond to bedding planes and vertical flows appear to be severely restricted. Particularly where more clayey limestone layers are present, flow may be (semi) confined within the more permeable horizons at depth; pumping will have the effect of reducing the pressure in these layers, rather than lowering a free water table. Also, wells are generally unlined (or have perforated linings), and so provide pathways for water from different horizons to mix; pumped water may be derived from several different layers simultaneously.

2.2.6 Aquifer properties

The transmissivity and storativity values do not seem to be known for any aquifer in the area. This is surprising; it is a major factor limiting our understanding of the hydrogeology. A transmissivity value of 240 m^2 per day was tentatively suggested by analysis of recovery data from Umar Ibrahim's well at Atarib. However, little confidence is placed in the general applicability of this figure, as there is evidence that the transmissivity/

hydraulic conductivity is very variable (for example, the marked local variation in yields of wells at similar depths).

Data from Tel Hadya show an increase in the annual range of groundwater levels from 4m in 1984 to 7m in 1992. This suggests that the storativity (specific yield) decreases with depth in the aquifer -- a common phenomenon.

2.2.7 Current groundwater abstraction in the special study area

Comparison of the depths of wells (data available for approx 30 wells out of 86 in the study area = 35%) and subsurface geology inferred from GSFRG (1967) suggests that the wells do not consistently tap the same aquiferous layers. Figure 2.2.3 is a plot of well depth vs average hourly discharge (measured by the FRMP team) for 25 pumped wells. The elevations of the wells are not known precisely, but they occupy an area of low relief with the ground surface at 300m ± 10m. As mentioned above, most wells appear to penetrate the Helvetian/Eocene limestones (Shallow Aquifer System) and have been drilled some way into the underlying strata, formerly thought to be the confining layer above the Deep Aquifer. Discussion with well owners and drillers suggests that well depths are determined by the presence of either a high yielding horizon or a notably impermeable/ unproductive layer underlying strata with a reasonable yield. It is the clustering of wells at particular depths which suggests the presence of distinct productive horizons within the material labelled "Palaeogene marls", ie the components of the Minor Aquifer complex.

Differences in well yields may, of course, be a reflection of pump characteristics and condition; but it is also likely that they show that aquifer characteristics vary over short distances, This is consistent with fissure flow being the main type of water transmission (see above).

2.2.8 Water balance for the study area

If all inflows and outflows can be identified and quantified, then calculation of the water balance for an area gives an indication of the contribution from storage. For the Special Study Area the following assumptions were made:

* no net run-off/run-on
* no net increase or decrease in storage resulting from deep groundwater flow.

So then, for inflows and outflows one has simply:

Inflows: Recharge from precipitation;
Pecharge from (over) irrigation.

<u>Outflows</u>: Irrigation abstractions;
Domestic water supply abstractions;
Possible (net) downward leakage to deep aquifer via deep boreholes.

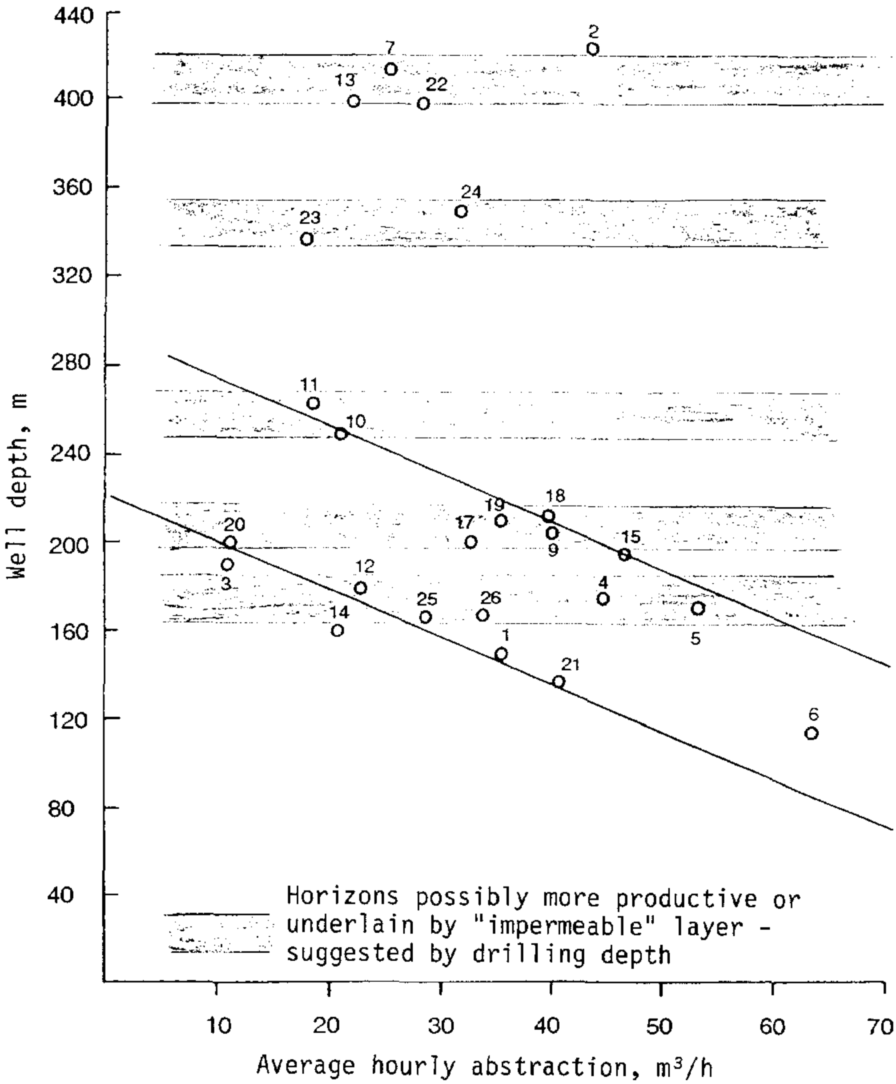


Figure 2.2.3 Relation between well depth and hourly rate of abstraction from it. (Interpretation: deeper wells tend to have lower yields, either due to pump characteristics or to increasing difficulty of abstracting water from stratum.)

But considerable problems remain:

1. How to estimate the recharge area supplying the discharge area (ie the well field). For this, more groundwater level information would permit the groundwater gradient to be determined and enable a flow net to be drawn for a preliminary estimate of inflow from the recharge area.
2. An average groundwater level decline of 1m p.a. has been observed, but to convert this to an equivalent depth of water, you need an estimate of storativity, which is not available. Storativity is probably in the range 2-20% (ie a fall in head of 1m releases 20-200mm water).
3. Before attempting to build a groundwater model, it is necessary to check that the water balance does, in fact, balance; the conventional tolerance is 10% either way. Because of the problems outlined above (unexpected goelogical complication, difficulties in estimating recharge, and non-availability of aquifer parameter estimates), this cannot be done without further work.

2.2.9 Conclusions

This preliminary study has demonstrated the importance of the subsurface geological structures in controlling the presence and movement of groundwater in the Shallow and Minor Aquifers. It suggests that groundwater may be effectively isolated into distinct blocks. A major implication for the groundwater resources in the main agricultural/irrigated area is the limited recharge source for each "block", limited by the relatively small permeable catchment area. If the abstraction rate exceeds the rate of recharge then groundwater levels will decline. The rate of decline observed depends upon the aquifer characteristics -- principally the storage properties.

The geological framework of this area is complex which makes it difficult to determine the hydrogeology with a high degree of confidence. Consequently, building an aquifer model is not straightforward. A severe limitation in devising a model with the long-term goal of use for groundwater management, to predict the outcome of future possible operating strategies, is the dearth of historic data. A model must be carefully calibrated against historic data before it can be extended into the future. Even then predictions which fall outside previous experience must be viewed with caution.

An aquifer model amounts to a boundary value problem: all boundaries need to be located and the condition at each boundary described in terms of groundwater head and/or flow. The recognition of the down-faulted block running north-west from Aleppo, means that it may be valid to consider modelling only a southern "block", defining the north-eastern boundary by this feature.

Given some continuing input to fill some of the data gaps, it should be possible to get closer to a quantitative prediction of the behavior of the resource, which will, however, always be conditional on scenarios about changes in the rate of installation of new wells, etc. The study's main aim, of relating technical work to policy-makers needs for advice, is a useful one, and should be pursued.

Turning to more specific questions, the shallow aquifer is very near to "failure": at the lowest levels in mid '93, the water level in the only well to draw water exclusively from this source was very close to the level of the bottom of the aquifer. However, the position in the minor aquifer is not yet as serious, and, because of its complex structure, it is much less likely that a sudden collapse in the availability of water from it will occur. There is a strong case for restricting the installation of wells in the deep aquifer, because of the poorer water quality, and the risk of such wells acting as vertical drains from the shallow and minor aquifers. [*Kate Ward, University of Southampton, UK, and Peter Smith*]

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2.3 Underground Water for Supplemental Irrigation in Syria: Quantity and Quality

2.3.1 Location of supplemental irrigation zone in Syria

Supplemental irrigation can be defined as "the provision of irrigation water to an area normally cultivated under rainfed farming in order to supplement rainfall and to satisfy crop water requirements". Under the agroclimatic conditions of Syria, the zone that can be considered as potentially suitable for supplemental irrigation lies between the 250mm isohyet (considered as the minimum required rainfall for rainfed farming) and 600mm (which represents the full wheat crop water requirement, (ET_C), Figure 2.3.1). This zone is spread over five hydrological watersheds: the Khabur, Euphrates, Aleppo, Orontes (Al-Assi) and Yarmuk basins, with a total area estimated at about 4,500,000 ha (25% of Syria), of which 80% is considered cultivable (3,550,000 ha).

In 1991, due to the limited water resources, only 450,000 ha of this zone was under irrigation (full and supplemental) while 2,500,000 ha was rainfed. Irrigated areas are dispersed over the supplemental irrigation zone, being located in limited areas around the different water resource points (Figures 2.3.2, 2.3.3 and 2.3.4).

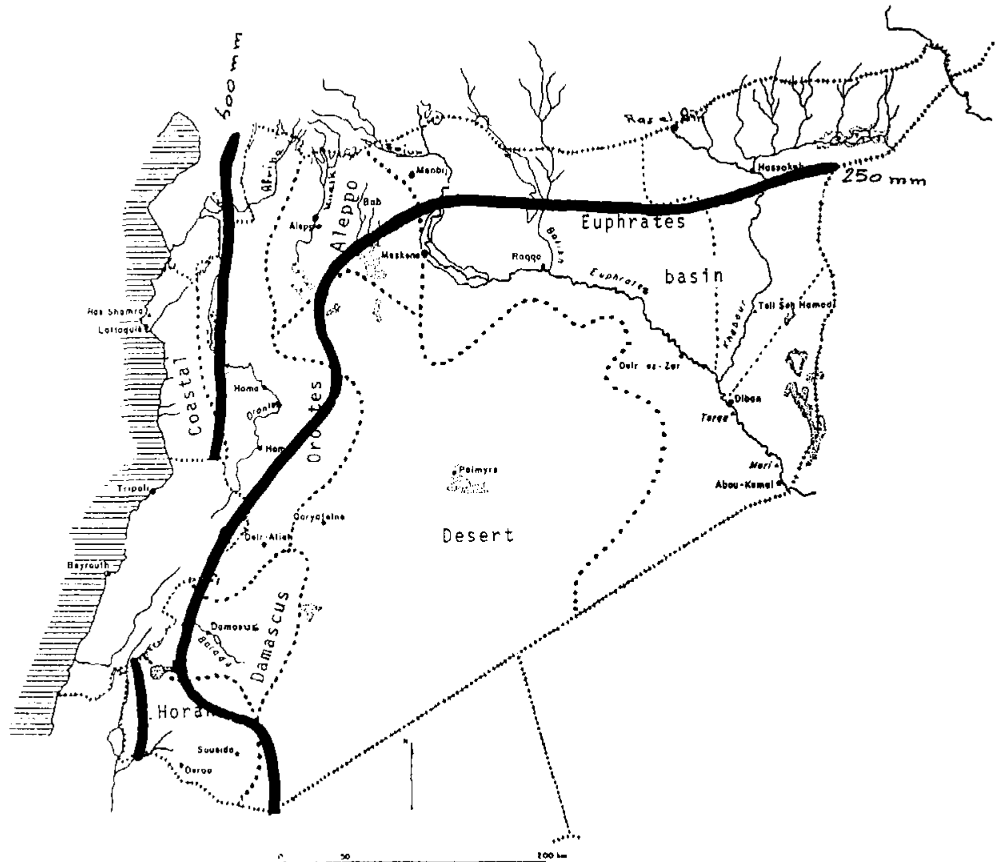

Figure 2.3.1 Zone potentially suitable for supplemental irrigation in Syria

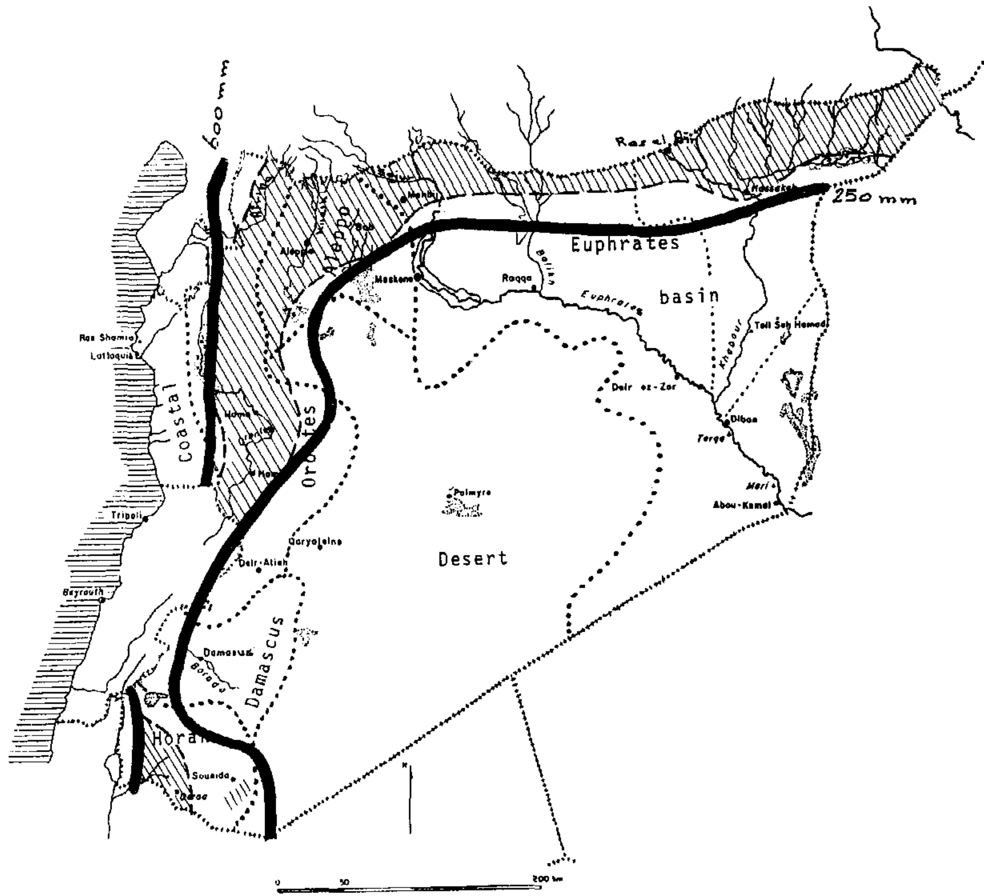

Figure 2.3.2 Areas of Syria where supplemental irrigation is used (shown by hatching)

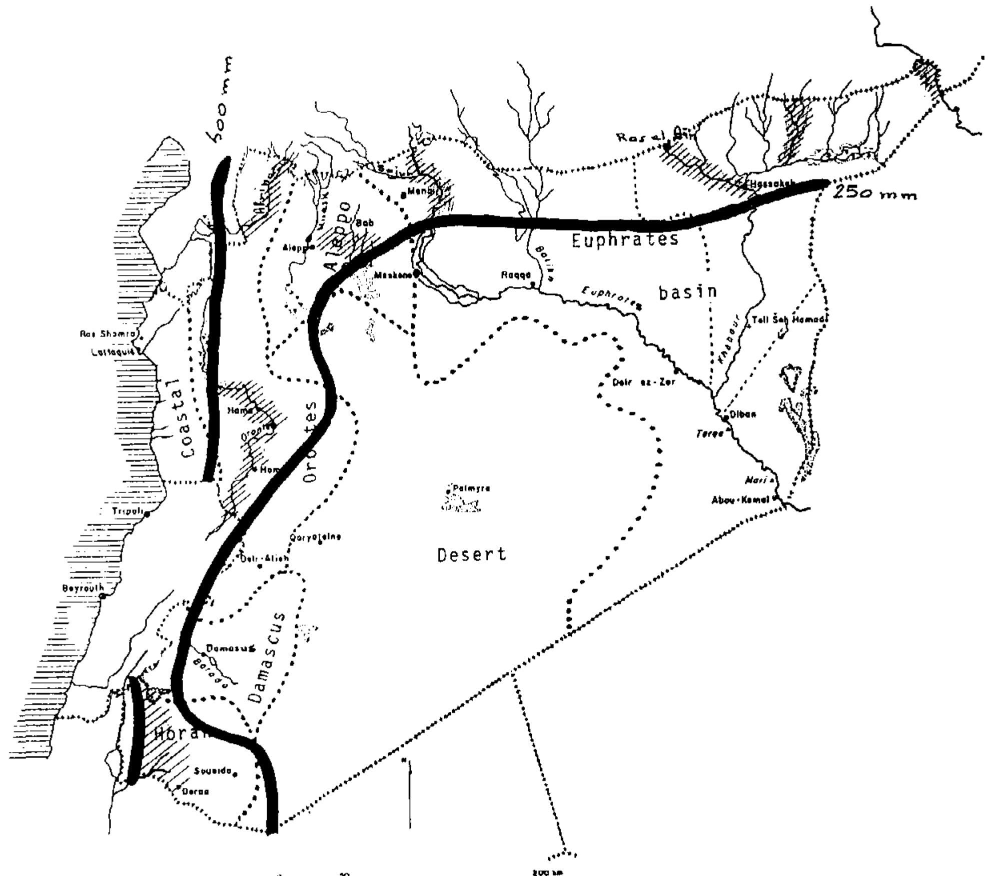

Figure 2.3.3 Supplemental irrigation areas using surface water (rivers)

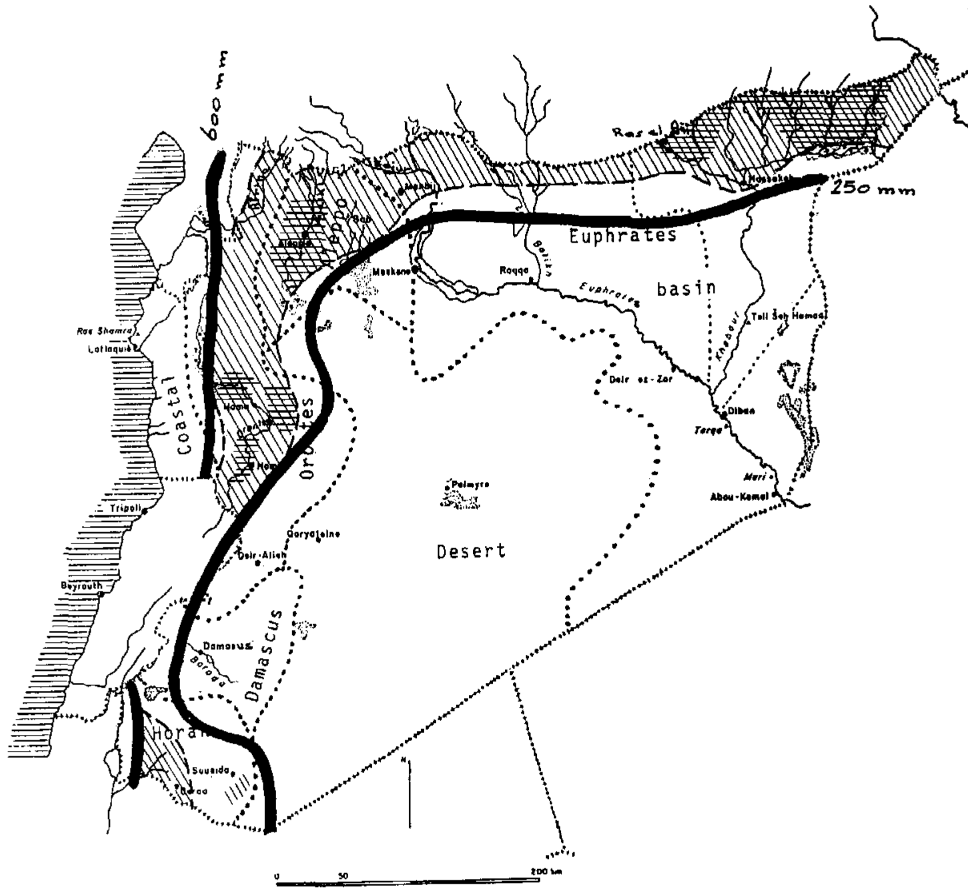

Figure 2.3.4 Supplemental irrigation areas using underground water

2.3.2 Water resources in the supplemental irrigation zone

The Syrian supplemental irrigation zone contains 70% of the country's water resources, including the largest rivers: Khabur, Euphrates, Afrine, Orontes and Yarmuk. The total water resource in this zone is estimated at about 6,000 million m^3/yr (not including Euphrates river flow), 23% of which (1350 million m^3/yr) is underground water (Table 2.3.1). The most important aquifers are in the Khabur, Orontes and Aleppo basins.

Table 2.3.1 Water resources (million m^3/yr) in supplemental irrigation zone

Basin	Surface water	Underground water
Khabur	1695	650
Euphrates *	13000	25
Aleppo	497	303
Orontes	2509	356
Yarmuk	429	18
Total	17630	1352

* Assumed Syrian share
Source: Ministry of Irrigation, Syria

Khabur basin: The Khabur basin has the largest volume of stored underground water in the supplemental irrigation zone. It contains two important aquifers: Al-Rad aquifer in the north east of the basin and Ras-El-Ain aquifer in the north west. In addition, there are some small isolated aquifers, especially in the north (Figure 2.3.4).

The annual "safe yield" of the Khabur basin aquifers was estimated at about 650 million m^3/yr by FAO (1966), but recent hydrological information obtained from newly drilled wells indicate that actual hydraulic productivity may be higher. The 1992-1993 annual withdrawal from different aquifers for irrigation purposes has been estimated at about 2700 million m^3 (Wakil 1993).

Well productivity varies greatly even within the same aquifer. In general, aquifer productivity is high in the north, especially in the Ras-El-Ain aquifer (where well discharge exceeds 150 m^3/hr), but decreases southwards. It can reach a very low value (around 20 m^3/hr) in some unconfined aquifers. Water quality shows a similar pattern. It is good in northern parts of the basin (EL_C <0.7 mmhos/cm), but salinity of aquifer water increases southwards (Figure 2.3.5) and reaches a high value in

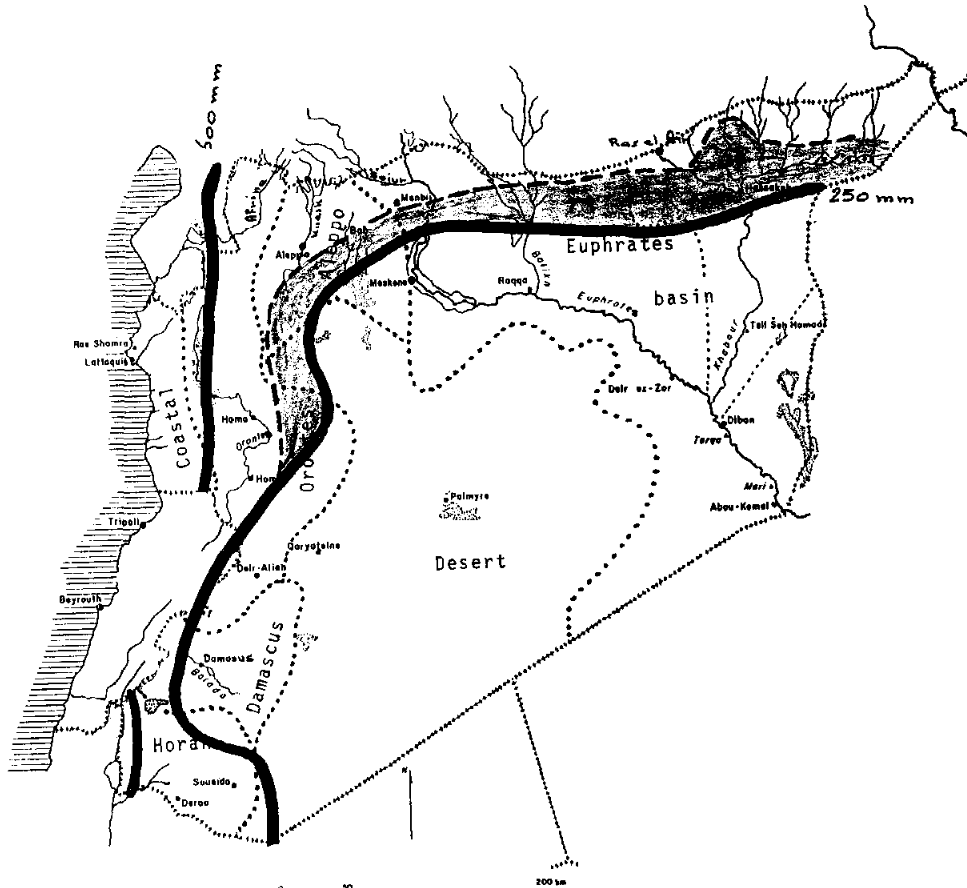

Figure 2.3.5 Saline aquifer zone (shaded)

the southern El-Rad aquifer (>5 mmhos/cm) (Table 2.3.2). It is estimated that around 30% of actual (1991/1992) irrigated areas in the Khabur basin are using saline underground water. This water tends also to have a high boron content (>0.75 mg/l). As with salinity, the boron content increases southwards.

Table 2.3.2 Electrical conductivity and boron content of underground water in some locations in Khabur basin

Location	Boron ppm	EC mS/cm	Na meq/l	Ca+Mg meq/l	SAR
Kh. Alas Kar	0.75	0.54	1.00	5.66	0.59
Tel Albarda	0.76	1.02	5.7	6.98	3.05
Tel Hamis	0.76	2.26	14.2	26.89	3.87
Bougha	1.47	3.84	15.0	33.02	3.69
Abou Ghazale	-	5.03	18.0	41.9	3.93
Al-Husseinieh	1.25	6.14	33.5	47.41	6.88
Al-Hudiebieh	2.20	9.35	53.4	62.50	9.55
Homs	3.676	12.25	83.4	65.09	14.62

Orontes basin: The annual hydraulic productivity of the Orontes basin aquifer is estimated at about 356 million m^3/yr, 70% of which is located in Al-Abharneh and Al-Ghab areas (MIR 1982). Some unconfined aquifers exist in the Salamieh area and in the east of the basin, with an estimated productivity of about 70 million m^3/yr.

Water quality is good in Al-Asharneh and Al-Ghab, but saline water occurs in the eastern part of the basin, in Salamieh (Dneibe, Sneide) and in the Maara area (Figure 2.3.5), with conductivity values varying between 1.5 and 3 mmhos/cm.

Aleppo basin: Underground water in the Aleppo basin is distributed between 4 main aquifers around Aleppo city. Hydraulic productivity of each aquifer varies between 50 and 90 million m^3/year (MIR 1982). In general, well productivity in all aquifers is medium to low (30-80 m^3/hr). Water in the southern aquifer and part of south-eastern aquifer is saline, with salinity increasing southwards and eastwards across the basin (Figure 2.3.5).

2.3.3 Extent of supplemental irrigation

Traditionally, river water (surface water) was the main source for irrigation (including supplemental irrigation of winter crops). However, all of the low river-valley plains suitable for irrigation were fully exploited before 1980; and the large increase in the supplemental irrigation area in recent years, eg from 130,000 ha in 1980 to 363,000 ha in 1990 (Table 2.3.3) has been based on groundwater. This rapid expansion was a result of two main factors:

- Official policy aiming to enhance national cereal crop production to counteract the country's growing food deficit. In this regard, two incentives have been offered: a crop price increase, and loans to farmers for well drilling and water pumping installation.
- Farmers observation of the dramatic increase in yield and yield stability arising from supplemental irrigation.

Table 2.3.3 Evolution of supplemental irrigation areas (ha) growing winter crops during the period, 1979-1993*

	1979/80	1986/87	1992/93
Wheat	111920	189937	290747
Other winter crops	18160	46290	72500
Total	130080	216228	363247

* Not including irrigated areas in the Euphrates project.
Source: Ag Abstracts, MAAR

The main expansion was accomplished in areas relying on underground water for irrigation, especially in the Khabur basin where, during the last five years, the number of drilled wells has increased from 3977 in 1988 to more than 23,000 (1993). The area in this basin irrigated from underground water is estimated at about 240,000 ha, about 60% of which is actually under supplemental irrigation systems. This represents about 40% of Syria's total area of supplemental irrigation. The Orontes basin, with around 110,000 ha, provides for about another 30%. The total area under supplemental irrigation from underground water is estimated at about 260,000 ha, or about 70% of the total supplementally irrigated area (Tables 2.3.3 and 2.3.4).

2.3.4 Cropping pattern

The main crop grown is wheat. In 1991/1992, wheat occupied 290,750 ha, which represents 75% of the total supplemental irrigation area (Table 2.3.4). The remaining 25% was mainly occupied by legumes, beans and forage crops. Crop rotation and cropping intensity in these areas depend largely on water availability and water quality.

Table 2.3.4 Actual areas of wheat under supplemental irrigation (1992/1993)

Basin	Underground water (ha)	Surface water (ha)	Total (ha)
Al-Khabur	118411	21797	140208
Euphrates	19790	3789	23768
Aleppo	23123	6259	29382
Orontes	47468	38991	86459
Yarmuk	2280	8650	10930
Total	211072	79675	290747

Source: Ag Abstracts, MAAR

Water availability. In general, the proportion of supplementally irrigated crops in the cropping pattern increases as water becomes more scarce. This situation is very clear in irrigated areas using unconfined aquifers of low well productivity (10-30 m^3/hr), as in the southern part of Al-Rad aquifer, in some isolated aquifers in the Euphrates basin, and in the south and northeast of the Aleppo basin. In these areas, cropping intensity varies between 80 and 100% depending on water availability. In some places wells dry up in summer, and the crop rotation is limited to winter crops, mainly wheat (Table 2.3.5).

Table 2.3.5 Crop rotation in limited water resource areas

	Springs	Unconfined acquifers		
Crop	Yarmuk	Orontes	Aleppo	Khabur
Wheat	61	66	95	80
Legumes	16	-	5	-
Beans	15	-	-	-
Peas	7	-	-	-
Spring potatoes	-	4	-	-
Barley	-	-	-	-
Summer crops	-	25	-	-
Total	100%	95%	100%	80%

Source: Ag Abstracts, MAAR

The same situation is observed in other areas with limited water resources, such as springs (Al-Yarmuk irrigation projects, 10,000 ha), non-perennial rivers (Koweik, Jagh Jagh) or small earth dams in wadis storing runoff flow from rainfall.

However, where the underground water is more available, farmers tend to incorporate "more valuable" crops, especially cotton and summer crops, into their rotation. Cropping intensity in these areas is higher and exceeds 100% (Table 2.3.6). And in places with the most abundant water resources, river plains (Khabur, Euphrates, Orontes) and areas of high productivity aquifers (more than 80 m^3/hr), cropping intensity is higher still and reaches an average of 135%, of which only about 60-70% is reserved for winter crops (Table 2.3.7).

Table 2.3.6 Cropping pattern in supplemental irrigation areas using underground water in Orontes and Khabur basins

Crop	Orontes [1]		Khabur [2]	
	Winter (%)	Summer (%)	Winter (%)	Summer (%)
Wheat	65		62	
Faba bean (seeds)	4		0.3	
Spring potato		4	0.5	
Sugar beet	6			
Lentil/chickpea			0.7	
Legumes	1	4	2	2.5
Forage crops		3		4.5
Cotton		15		36.5
Others		10		4.0
Sub-total	80	32	65.5	47.5
Total	112%		113%	

Source: 1) Hama Ag. Directorate, Ag. Abstracts, 1993
2) Hassakeh Ag. Directorate, Ag. Abstracts, 1993

Table 2.3.7 Cropping pattern in river valley plains (Orontes)

	Winter (%)	Summer (%)
Wheat	36	
Bean	7	9
Legumes	14	19
Cotton		25
Corn		24
Sub-total	57	68
Total	135%	

Source: Hama Agriculture Directorate Ag. Abstracts, 1993

Water salinity. The proportion of irrigated wheat in the crop rotation increases as the underground water becomes more saline. This was widely observed in the Al-Khabur basin. Farmers with saline well water reported fearing the large salt accumulation in their fields (loamy clay soil) that can build up rapidly when summer crops are grown. So, they tend towards the monocropping of wheat. This was reported in the Tal-Bourak, Assylem, Dabhayhieh and Tal-Zeitar areas, where water salinity exceeds 3 mmhos/cm (and in these areas, traces of salt accumulated from the irrigation only of wheat may already be seen on the soil surface).

The limitation of cropping to wheat in saline aquifer areas is also encouraged by the great sensitivity of winter legumes to salinity. They are considered as a non-salt tolerant crop (Maas and Hofman 1979). The maximum acceptable water salinity for different winter legumes is around 1.2 mmhos/cm, beyond which yield decreases sharply with increasing salinity of the irrigation water. Thus, in Salamieh, traditionally a legume growing area, farmers utilizing saline aquifers areas grow only wheat. A complete failure of legume productivity is observed when using water with an EC_e value of about 2.5 mmhos/cm.

2.3.5 Crop yield

Yields of supplementally irrigated wheat vary greatly according to such parameters as water availability, water quality, soil type, and human factors including farming system, irrigation and fertilizer management and wheat variety; but probably the most influential of these factors are the first two.

It was found that wheat yield varied between 3.5 and 7.0 t/ha in the different basins depending on water availability. Maximum yield is obtained in areas where water is available during the whole crop-growth period (November-mid June). This is the case in areas using surface water (river plains or irrigation project areas) or having abundant aquifers (e.g. north Al-Jazirah, Asharmeh). Low yields were observed in areas that have limited underground water and low well productivity. This is the case with some unconfined aquifers in the southern plains of Jazireh and the southeastern plains of Aleppo and Salamieh. In such areas the irrigation rate is less than the wheat water requirement (ET_C); and there are some locations where underground water is not available during the last two months of crop growth (April-May), especially in dry years. Lack of irrigation water during these two months has a major influence on wheat yield. Thus, the average yield in the Orontes basin (Hama directorate) depends on the nature of the water resource: 4.5 t/ha for confined aquifers, 4 t/ha for the Orontes river and 3.5 t/ha for unconfined aquifers (which in general have low-hydraulic productivity, Table 2.3.8).

Table 2.3.8 Average wheat yield in Orontes basin by water resource type

Type of water resource	Average wheat yield (t/ha)
Confined acquifer	4.5
Rivers	4.0
Unconfined acquifers	3.5
Springs	1.8

Source: Hama Agriculture Directorate Ag. Abstracts, 1993

Because of the scarcity of water resources, saline underground water is more and more used by farmers for irrigation. Thus, around 25% of the Khabur plains is irrigated with saline water. Underground saline water is also used for irrigation in the Euphrates, Aleppo and Orontes basins. None of the irrigated areas using underground water in these basins is provided with drainage networks. So, salt tends to accumulate rapidly in the soil. The actual rate and extent of this accumulation depends on the salinity of the water, the rainfall amount (which determines the rate of natural leaching), the soil type (which determines the natural drainage characteristics of the soil) and the irrigation history.

Previous studies of supplemental irrigation have tended to ignore the effect of water quality on the soil and crop yield, probably because it was assumed that a large portion of the crop water requirement would be provided by the rainfall. However, in Salamieh, winter legumes failed completely after three years using water with an EC of 1.85 mmhos/cm; and recent field research in the Al-Djezireh plains (loamy clay soil), north-eastern Syria, has shown that under semi-arid conditions, supplemental irrigation water even with low salt concentration can produce a rapid build-up of salt in the soil and hence lead to a decline in crop productivity.

Results from 20 farms using underground water of different salinity and having variable irrigation history indicated that salt started to accumulate in the soil from the first year of irrigation. The rate and extent of the salt accumulation were directly proportional to the salinity of the irrigation water (Figure 2.3.6). Due to the high rate of evaporation and low rainfall (average of the region is around 300mm/yr), salt continues to accumulate progressively in the soil with repeated applications of irrigation water (Figure 2.3.7). Thus, a saline soil media develops in the upper soil layer that affects plant growth and reduces crop productivity.

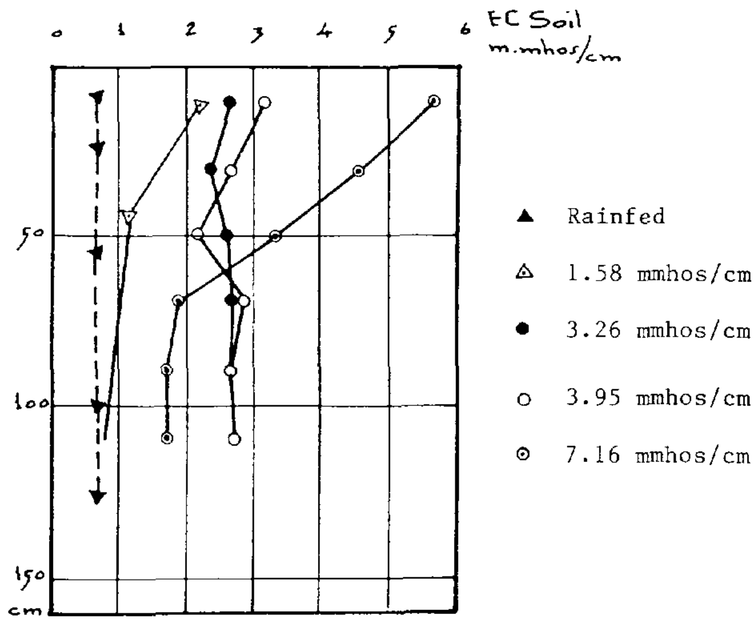

Figure 2.3.6 Effect of irrigation water salinity on soil salinity at various depths within the soil profile, after 1 year of using saline irrigation water

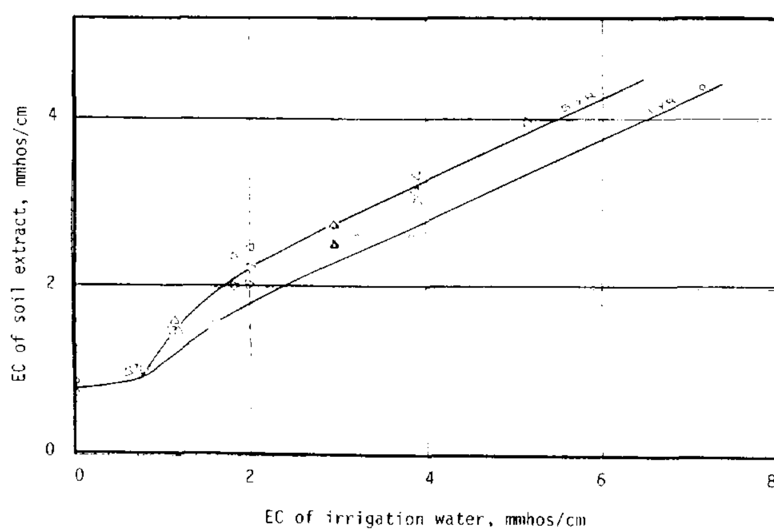

Figure 2.3.7 The relationship between average electrical conductivity of saturation extract of the soil upper layer (0-60 cm) with electrical conductivity of the irrigation water after 1 year and 5 years of using saline irrigation water

The combined effect of saline irrigation water and the resulting soil accumulation on wheat crop yield is illustrated in Figure 2.3.8 and Tables 2.3.9 and 2.3.10. Wheat yield declined increasingly as the water salinity and the resulting soil salt accumulation increased. An average yield decline of 50% was recorded after five years using irrigation water with an electrical conductivity between 3-4 mmhos/cm.

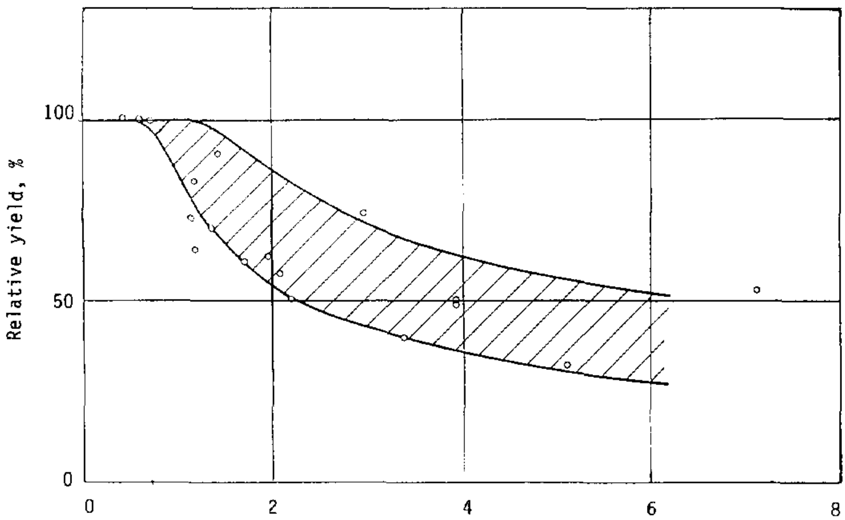

Figure 2.3.8 Relationship between irrigation water salinity and relative wheat yield

Table 2.3.9 Average wheat yield as a function of water salinity at different SYLICO farms (60 ha) in the Khabur basin after 5 years of irrigation with saline water

Farm	EC_e (mmhos/cm)	Yield (t/ha)	Relative yield %
N4	0.60	4.28	100
N1	0.63	3.28	86
H2	1.15	2.75	72
T2	1.20	3.125	82
B2	1.40	3.00	79
B1	1.70	-	-
B4	2.00	2.185	57
T1	2.00	2.38	63
B3	3.90	1.89	50

Table 2.3.10 Average wheat yield as a function of water salinity at different small farms in the Khabur basin

	EC_t (mmhos/cm)	Yield (t/ha)	Relative yield %	Irrigation history (years)
Bin Nouh	0.55	5.5	100	6
Bin Koko	0.55	5.5	100	6
Azizieh	1.58	3.6	65	1
Smehan Sh.	1.68	3.5	64	2
Khazouk	2.20	3.0	54	3
Dabbaghieh	2.95	4.5	82	5
Tal Zaitar	3.26	2.5	45	1
Assylem	3.60	3.0	54	1
Abou Arzaleh	5.05	2.0	36	5
Smehan Gh.	7.16	2.8	50	1

2.3.6 Possible future development of supplemental irrigation

The available water resources that exist in the supplemental irrigation zone are already completely exploited. In fact, most aquifers in this zone are subject to over-pumping. The annual water deficit of the Khabur basin is estimated at about 1500 million m^3 (Wakil 1993). In the Orontes basin, the water deficit of the Asharneh aquifer is estimated to be about 210 million m^3/yr. Mahmoud (1993) states that "temporary mining" is observed in all the major aquifers. This could lead to "permanent mining" if aquifer water withdrawal remains at the same rate.

Therefore, no horizontal expansion of supplemental irrigation utilizing new water resources can be expected. Any expansion can come only from a shift out of full irrigation. Such a shift could be dictated by the need to ease the "temporary mining" and to readjust the water balance of the particular aquifers. Thus, increasing the proportion of supplementally irrigated crops in the rotation has become an official "long-term" strategy in the Orontes basin, where the percentage of the irrigated winter crops has been officially increased from 55% to 80% (Mahmoud 1993). This has resulted in a saving of 75 million m^3/year, so helping to reduce the water deficit of Asharneh aquifer. Increasing the proportion of wheat in the rotation by 20% (from 60% to 80%) in the Khabur basin will result in a saving of 600 million m^3/yr (Wakil 1993).

It follows that what is badly needed at this stage is vertical expansion, achieved by improving the existing supplemental irrigation system. Most important is the improvement of water management at the farm level, including irrigation with the adequate rate and amount of water (which necessitates knowledge of the relationship, "ET_c-yield"), irrigation timing (scheduling) and improvement efficiency of water application. The completion of these improvements would result in water saving and so provide the opportunity to increase the irrigated areas and increase total production. [*Michel Wakil, University of Aleppo*]

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2.4 Optimizing Supplemental Irrigation for Wheat Production in Syria

2.4.1 Introduction

Wheat is Syria's principal food staple. It occupies about 1.2 million ha (30% of total area in crop production) of which 78% is rainfed. Due to the erratic rainfall pattern of the Mediterranean climate, rainfed yields are low and highly variable. In the last decade, however, the supplemental irrigation (SI) of wheat has dramatically increased, due to (i) the price factor effect, and (ii) the government's credit policy encouraging well-digging and groundwater utilization. Average yield on "rainfed" land has increased from 1.07 t/ha to over 3.5

t/ha, with SI being the most important contributing factor (Salkini 1992).

Farmers have realized large profits as a result of increased yields, successive wheat price increases and subsidized inputs. At the same time, ignorance of crop water requirements, poor water management practices, the low efficiency of many irrigation systems and the generally low cost of water have led to overpumping and excessive water use. In addition, the loss of fertilizer by leaching and the development of unfavorable rooting environments have started to occur. However, groundwater is a limited, scarce, and valuable resource at a national level. Optimal water-use efficiency is vital to Syria. It contributes to an expansion of the irrigated area, increasing national production, and the maintenance of the agricultural systems (Oweis et al. 1988).

Water resource planning and use should be viewed from a long-term perspective. At the national level, no acute water crisis has yet occurred in Syria, although localized crises have been experienced, especially where groundwater is the only source for irrigation. However, it has been projected that, by the year 2010, an ever-increasing water crisis at the national level will occur; and, by the year 2030, an estimated water deficit of about 5.5 billion m^3 (ie 26% of currently readily available water resources) is expected, entailing severe constraints to economic and social development (Wakil 1993). Measures to ensure the efficient and rational utilization of water resources are urgently needed.

In 1986, a research project to promote and transfer improved SI technologies was initiated by ICARDA in collaboration with the Ministry of Agriculture and Agrarian Reform (MAAR). Major objectives were to investigate under variable climatic and agro-economic conditions: (i) wheat requirements of SI; (ii) crop response to different application rates of water and nitrogen; and (iii) the impact of SI on wheat-based farming systems. The findings are reported in several publications of ICARDA[1]. The data from these experiments are used here to develop an optimization analysis of wheat production under prevailing conditions, to demonstrate optimal production levels of wheat under various input-output price situations, and to show the impact of water price fluctuation on the optimal rate of SI.

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1. See FRMP (1986-92); ICARDA/MAAR (1986-92); Perrier and Salkini (1991); and Salkini (1992).

2.4.2 Methodology

2.4.2.1 Data source

The optimization analysis for SI wheat requires the following information: (a) the supplemental irrigation production functions, (b) the market price of the output, and (c) the total cost of SI and other inputs. Actual prices of inputs and outputs were obtained from a farm survey conducted in 1988, but some assumptions had to be made. The total cost of a cubic meter of water was taken to be the sum of the annual investment, operation and maintenance costs of the well and of the irrigation systems of the farm. Production functions were derived from the research of the ICARDA/MAAR SI project described below.

2.4.2.2 Experimental work

Three different trials to examine wheat response to several combinations of water and fertilizer N were conducted at Tel Hadya during the period 1986-1992. SI scheduling was determined by the climatic water balance method in the first trial (1985-89), and from soil water measurements by neutron probe in the second (1986-90) and third (1991-92).

First trial: the treatments and the irrigation method used varied over the 4-year period. In 1985-86 and 1986-87, there were (a) four SI treatments: rainfed (no irrigation); and irrigated, to replenish 1/3rd, 2/3rd and 3/3rd of the water requirement, determined when 50% of the available soil moisture has been depleted; (b) 4 rates of nitrogen (zero, 70, 140, 210 kg/ha) in 1986; and (c) 4 wheat varieties in 1987 (bread wheat, Cham 4 and Mexipak; and, durum, Sebou and Cham 1). There was 80 kg P_2O_5/ha basal fertilization, and an establishment irrigation of 30mm on all plots in 1985-86 and 20mm on the SI treatments only in 1986-87.

During 1987-88 and 1988-89 a line-source sprinkler system was used to give six SI treatments: rainfed (no irrigation); irrigation to replenish 20%, 40%, 60%, 80% and 100% of water balance deficit. Spring wheat varieties Cham 1 and Cham 4 were sown. There were four rates of nitrogen, zero, 50, 100, 150 kg/ha of N and a uniform rate of 100 kg P_2O_5/ha at sowing time.

The **second trial** was uniformly duplicated over four years. Treatments were: (i) nitrogen rates of 0, 50, 100, 150 kg N/ha; and (ii) irrigation to replenish available soil water to 100% after it had been depleted to 80, 70, and 60% of moisture content at field capacity.

The **third trial** involved only SI treatments on Cham 1: applying 0, 40, 60, 80, and 100% of depleted soil moisture when it had fallen to 50% of the available moisture. Nitrogen, 100 kg N/ha, was applied in two equal doses at planting and tillering.

2.4.2.3 Response functions and optimization analysis

Production functions were determined to model yield response to various rates of SI, to assess the productivity coefficients of these variables, and to identify optimum rates of water under various input-output price scenarios. Simple and multiple regression analysis, using the least squares method, were used. Polynomial functions were found to give the best capture of the relationship between wheat yield and SI rate, in agreement with most reports in the literature of crop-water response functions (Salkini 1992). On the other hand, the rainfed wheat production function was found to be linear within the range of rainfall that occurred during the experimental period.

Modelling Profit Maximization of Wheat Production: Any crop response process involves gains and losses. The gains are the outputs produced, the losses are the inputs consumed. With gains and losses measured relative to some specified normative goal, best operating conditions occur when net gains are maximized. For this purpose, it is necessary for output gains and input losses to be measured in comparable units. These conversion factors are not determined within the response process. They must be chosen **a priori** by the researcher according to his purpose (Dillon and Anderson 1990). Since the purpose of response analysis in this research is to maximize the net gain of wheat production from supplemental irrigation, input and output prices are used as conversion factors.

Denoting the net gain from the response process by π, output price by P_y, and input price for the variable input X_i by P_i, the **unconstrained objective function** can be written as:

$$\pi = P_y Y - \Sigma P_i X_i \quad ; \quad (P_y, P_i > 0)$$

The production function for wheat yield with respect to water is:

$$Y = f(W) \tag{1}$$

where Y = grain yield in kg/ha, W = water received in m^3/ha, and for the unconstrained objective function we have:

$$\pi = P_y Y - P_w W \tag{2}$$

where π = net gain; P_y = grain price; P_w = water cost. Taking the first derivative of the objective function (2), we have

$$\partial \pi / \partial W = P_y (\partial Y / \partial W) - P_w \tag{3}$$

To maximize profit, we set the first derivative of the objective function, $\partial \pi / \partial W$, equal to zero and solve for W. The necessary second-order condition ($\partial^2\pi/\partial W^2 < 0$) holds automatically from the assumption of diminishing returns. Therefore, **the profit maximizing conditions for one variable (water)** is:

$$\partial Y/\partial W = P_w/P_y \qquad (4)$$

Thus, with no constraints on the objective function, the optimum water rate occurs when the marginal product of the water equals the inverse price ratio P_w/P_y. Since P_w and P_y must be non-negative, equation (4) implies $\partial Y/\partial W$ can never be negative at the value of W that maximizes profit. Regardless of the size of P_w and P_y, any value of W where MP_w (the marginal product of water $\partial Y/\partial W$) is negative will be irrational since a higher level of output could be achieved with less water.

2.4.3 Results of the optimization analysis

The total water (rainfall and SI) production function for wheat was found to be polynominal:

$$Y_T = \underset{***}{-\ 9336} + \underset{***}{5.0\ WT} - \underset{***}{0.0004\ (WT)^2} \qquad (5)$$

$$R = 0.86,\ R^2 = 0.73,\ R^2_a = 0.73,\ \overset{***}{F = 197.9}$$

where Y_T= total grain yield in kg/ha; WT = total water received (rain + SI) in m^3/ha; R = correlation coefficient; R^2 = coefficient determination; R^2_a = adjusted determination coefficient; *** = highly significant at <0.001.

The rainfall production function was found to be linear within the rainfall range of the experiment period (250-500mm):

$$Y_R = -\ 3550 + 1.8\ WR \qquad (6)$$

where Y_R is the grain yield in kg/ha produced under rainfed conditions (no SI); WR is the amount of rainfall in m^3/ha. Both total and the rainfed production functions are plotted in Figure 2.4.1.

The SI production function is the difference between the total water production function (SI + rain) and the rainfall one. Since that difference is a function of the seasonal rainfall, the following SI production functions are developed for various values of seasonal rainfall by subtracting the appropriate two curves for that rainfall. The resulting production functions for 250, 300, 350, 400, 450 and 500mm rainfall (plotted in Figure 2.4.2) are as follows:

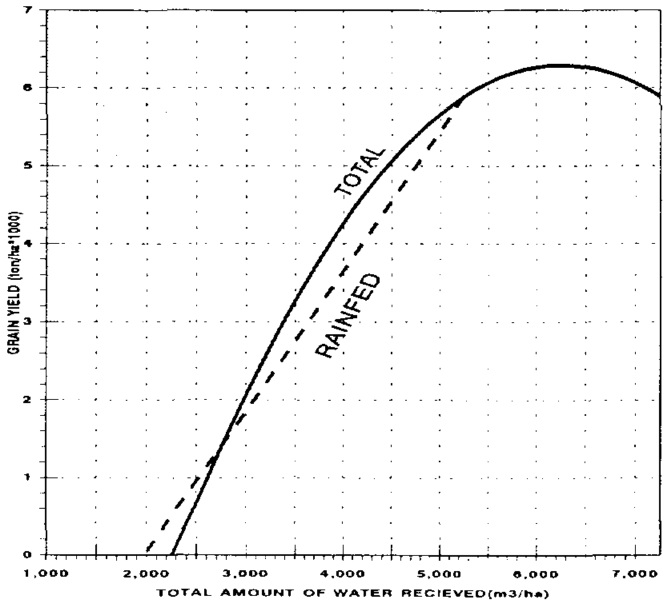

Figure 2.4.1. Rainfed and total water production functions of wheat for Aleppo

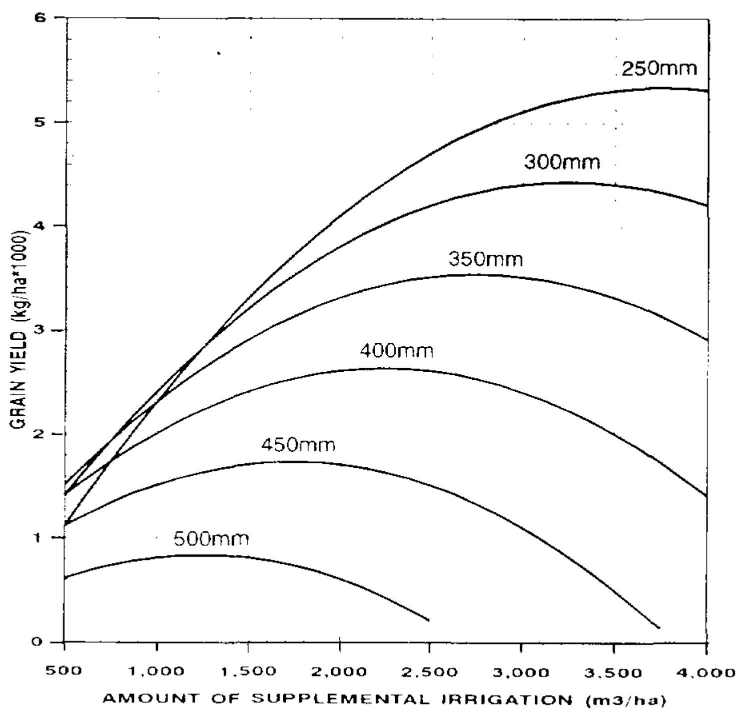

Figure 2.4.2 Supplemental irrigation production functions of wheat for Aleppo

$$YS_{250} = -286 + 3.0\ WS - 0.0004\ WS^2 \quad (7)$$
$$YS_{300} = 214 + 2.6\ WS - 0.0004\ WS^2 \quad (8)$$
$$YS_{350} = 514 + 2.2\ WS - 0.0004\ WS^2 \quad (9)$$
$$YS_{400} = 614 + 1.8\ WS - 0.0004\ WS^2 \quad (10)$$
$$YS_{450} = 514 + 1.4\ WS - 0.0004\ WS^2 \quad (11)$$
$$YS_{500} = 214 + 1.0\ WS - 0.0004\ WS^2 \quad (12)$$

where YS_n is the grain yield in kg/ha produced by supplemental irrigation when seasonal rainfall is n. WS is the amount of SI applied in m^3/ha.

Farmers maximum profit occurs when the marginal product for water equals the inverse price ratio; that is when $\partial Y/\partial W = P_W/P_Y$, where P_W is the total cost of 1 m^3 of SI and P_Y is the market price of 1 kg of grain yield assuming negligible value for straw. For equation 7 (n=250):

$$\frac{\partial Y}{\partial W} = 3 - 2(0.0004)W = \frac{P_W}{P_Y} \quad (13)$$

which simplifies to: $W_{250} = 3750 - 1250\ P_W/P_Y$ (14)
Similarly, for other rainfall values:

$$W_{300} = 3250 - 1250\ P_W/P_Y \quad (15)$$
$$W_{350} = 2750 - 1250\ P_W/P_Y \quad (16)$$
$$W_{400} = 2250 - 1250\ P_W/P_Y \quad (17)$$
$$W_{450} = 1750 - 1250\ P_W/P_Y \quad (18)$$
$$W_{500} = 1250 - 1250\ P_W/P_Y \quad (19)$$

Equations 14-19 are plotted in Figure 2.4.3 for direct use. The optimal rate of supplemental irrigation can be found for any rainfall value and ratio P_W/P_Y. Thus, when the cost of water is zero, which means that P_W/P_Y = zero, then the rates of 3750, 3250, 2750, 2250, 1750, and 1250 m^3/ha SI water may be given for annual rainfall of 250, 300, 350, 400, 450 and 500mm, respectively. On the other hand, when 1 m^3 of SI water costs 3.0, 2.6, 2.2, 1.8, 1.4 and 1.0 times the cost of 1 kg of wheat gain at the 250, 300, 350, 400, 450, and 500mm rainfall, respectively, then SI becomes economically prohibited, and rainfed production becomes the optimal practice.

It is interesting here to calculate examples from actual values. In 1988, the total cost of irrigation was 1.23 SL/m^3 and the market price for wheat was 3.9 SL/kg (Salkini 1992), giving $P_W/P_Y = 0.32$; since rainfall in that season was about 500mm, the optimal amount of SI is calculated to be 856 m^3/ha (85.6mm), increasing the yield from rainfed production, 5450 kg/ha, by 777 kg/ha. In contrast, in 1992, the total cost of SI water was 2.0 SL/m^3, the price of wheat was 10 SL/kg ($P_W/P_Y = 0.2$), and rainfall was about 350mm. From these values, we find that optimal SI is

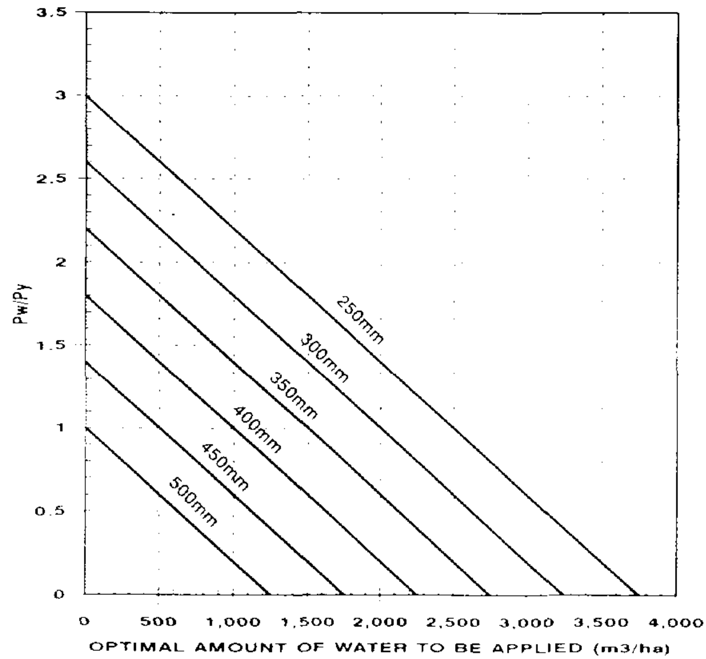

Figure 2.4.3 Optimization chart for supplemental irrigation of wheat in Aleppo in terms of the ratio of water cost (SL per m^3) to grain-yield price (SL per kg)

2500m^3/ha, which would increase the yield from 2750 kg/ha (rainfed) to 6264 kg/ha under optimal management conditions.

It can be seen that improving the wheat price encourages the use of more water unless the rate of increase in the cost of water exceeds that of wheat. Figure 2.4.4 shows the effect of increasing the cost of irrigation water on the size of optimal application assuming a constant wheat price of 10 SL/kg.

2.4.4 Conclusions

1. Optimal applications of SI are not determined by the input/output price ratio only, but also by weather conditions. In a specific price situation, different SI amounts are defined for different rainfalls.
2. Production functions and optimization analyses can be used to identify optimal rates of inputs, given actual or predicted input-output price conditions. In situations where the pricing and marketing conditions are determined by the government, as in Syria, the analysis can be used to help: (a) farmers attain optimal production for the prices

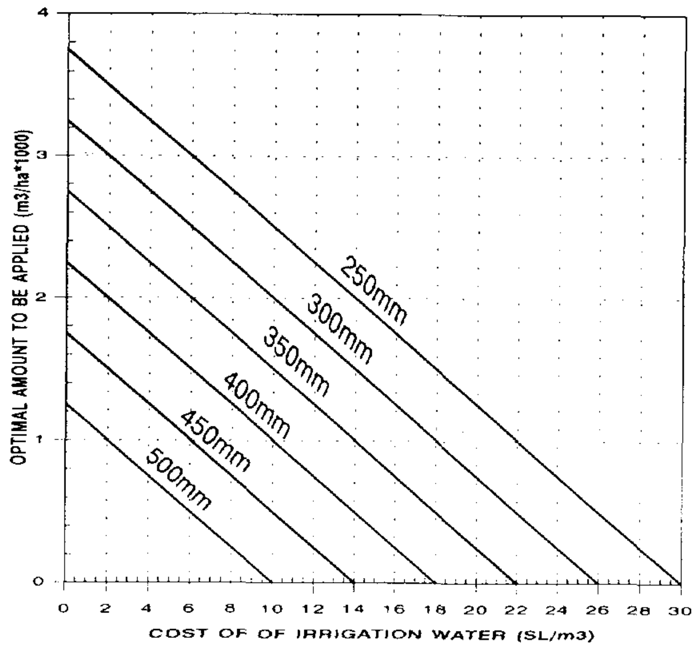

Figure 2.4.4 Optimization chart for supplemental irrigation of wheat in Aleppo in terms of the cost of irrigation water

offered; (b) policy makers to take decisions to achieve government goals. These might be maximum production per unit area or maximum water-use efficiency (and consequently more rational use of groundwater resources). Whereas subsidies support the achievement of the first goal, taxation and control measures would encourage the latter.

3. Currently in Syria, water from public (surface) irrigation schemes is given (almost) free to users; and groundwater costs do not reflect their real value because the energy required for pumping is obtained at a subsidized price. As a result, most farmers tend to over-irrigate. ICARDA/MAAR research has shown that the SI amounts for wheat reported by farmers is up to three times the optimal rate defined by research trials. It is common to see sprinklers operating on wheat in December, January and February, when the probability of rain is high, even though the crop water requirement in these months is low and the crop not very sensitive to water stress.

   With the drying up of some aquifers and the continuous lowering of many others, effective measures to control the overpumping of groundwater need to be identified and adopted urgently. Such measures could be (i) control of unlicensed well digging; (ii) modification of the price subsidy system, (iii) taxation of water pumped in excess of a specified quota; (iv) improvement of the irrigation efficiency by reducing water losses; and (v) demonstration to farmers of simple scientific methods of SI scheduling. The latter has been a major technology transfer objective of ICARDA/MAAR supplemental irrigation project which is now being implementated. [*A.B. Salkini and T. Oweis*]

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3. AGROECOLOGICAL CHARACTERIZATION FOR RESOURCE MANAGEMENT

Introduction

The purpose of agroecological characterization (AEC) is to describe the resources of the agricultural environment, both as a guide generally to other research and the effective extension of its results and to promote the efficient and sustainable utilization of those resources. It involves, first, the acquisition of data bases of environmental parameters and then their (usually) computerized manipulation to provide models of aspects of that environment, both spatially referenced and described in terms of temporal probabilities.

Meteorological data tend to be the initial focus of this activity, but as attempts are made to utilize output for practical ends -- eg as input to drive crop production models and predict patterns of yield distribution in time and space -- the need to include other information, such as that from soil maps and their associated profile descriptions, becomes urgent. At a later stage one might expect to bring in mapped data of relevant socio-economic characteristics in order to describe farming systems and their resource utilization and productivity in a spatial and temporal manner (with convergence and linkage towards whole-farm modelling and systems analysis activities). For the present, however, the farming systems dimension of agroecological characterization is still at the descriptive level.

The first section of this chapter (3.1) summarizes the logic of a stochastic regional model (STORM). This "integrating shell" links crop-growth simulation models to spatially referenced soil data (with sample profile information) and long sequences of simulated weather data (from the spatial weather generator model) to provide, in statistical or GIS format, yield descriptions in the form of long-term means, ranges and probabilities according to soil type and input use. The report goes on to provide an example of the use of this model to evaluate the performance and to verify the applicability of the FAO "length of growing period" concept for the rapid appraisal of climatic land suitability. This example is drawn from work forming part of a major AEC project conducted in Morocco over the last five yers. (A much wider range of results from this project will be published later as the proceedings of a workshop conducted at Tel Hadya in April 1994.)

The second section (3.2) provides an example of how the consideration of the efficient use of resources can provide a guide to research. It notes that plant-breeding aims for enhancing drought tolerance include increased plant access to water by means of more extensive root systems and osmoregulation. However, examination of moisture profile records from a long-term crop rotation at Tel Hadya indicate there is effectively no more water to extract. Some water is held at depth at tensions lower than the laboratory-determined 'permanent wilting point', but any that was removed by a 'more efficient' crop would have to be replaced by rainwater the following season. There would thus be no net gain to the rotation as a whole. Plant mechanisms to increase water uptake would be advantageous only where the supply (rainfall) frequently exceeds the water-holding capacity of the soil, leading to losses by through-drainage. On the deeper and heavier soils (like Tel Hadya) for which ICARDA designs many of its cultivars, such losses occur only where rainfall appreciably exceeds 400mm. Except on sandy soils, enhanced crop mechanisms to extract more water seem unlikely to be appropriate for lower-rainfall areas.

A review of descriptive studies of dry rangelands in five WANA countries (3.3) identifies problems common to all of them: increasing numbers of sheep on decreasing areas of range (due to cultivation expansion) and decreasing contributions of range grazing to nutritional requirements. Biomass production is well below potential and declining, as demographic pressures drive over-utilization and natural "feed-back" control is lost as modern technology (wells, feed concentrates and, above all, easy transport) buffers resource users against the consequences of their actions. However, the biggest single cause of the present crisis is seen as the collapse of the traditional systems of control over access to grazing previously exercised by an (often tribally-based) community of users with a long-term interest in the preservation of the range. There are no easy answers to the question: can a new management system emerge that will halt the present trend towards destruction?

3.1 Adding Stochasticity to GIS: Stochastic Regional Models

3.1.1 GIS and the time dimension

Geographic Information Systems (GIS) are powerful tools for the analysis and visualization of data with spatial dimensions, typically digital maps. In a raster system, where maps are represented by a grid of regularly spaced cells, the possible operations can be grouped into two basic types, point operations and area operations.

In the first type of operation, out of values of one or more layers of attributes for one cell the value of a new attribute for the same cell is obtained through a transformation (Figure 3.1.1); this step is then repeated for all other cells sequentially. An example of this type would be the preparation of a map of surface air temperature from maps of air temperature reduced to sea level, the temperature gradient and a digital elevation model.

The second basic type of operation makes use of the values of an attribute across a range of cells with different coordinates to

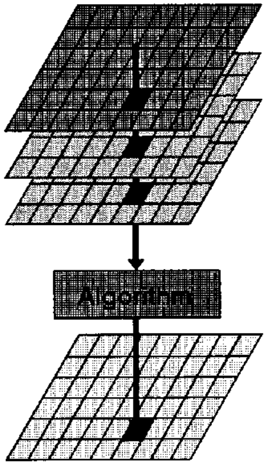


Figure 3.1.1
Point operations in a raster GIS-environment. The value of a cell in the new attribute layer is a function of values of cells with the same coordinates in other attribute layers

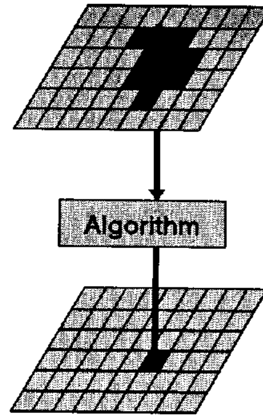


Figure 3.1.2
Area operations in a raster GIS-environment. The value of a cell in the new attribute layer is a function of values of cells with different coordinates (more than one per layer) in one or more other attribute layers

obtain the value of a new attribute for a single cell or for a group of cells (Figure 3.1.2); and this process is repeated to obtain values for the other cells of the output map. An example would be the construction of a map of reduced air temperature from station data through kriging.

For vector systems, where spatial information is stored in the form of boundaries between different mapping units, the same distinction can be made between operations which use the values of input attributes at one point in space to generate output for the same point and operations which use the values of an input attribute across an area to determine the output for a point or for an area, although demonstration is not as straightforward as for raster systems.

While GIS are geared to deal with variability across space, variability over time is not so easily handled, because the maps managed by GIS are fundamentally static structures. In some cases, eg in the case of weather satellite imagery, data are a priori available in the form of sets of inter-temporal maps depicting development over time. In other cases, temporal variability can be represented by means of maps of statistical descriptors of attribute distributions over time, eg the coefficient of variation or deciles. While for some applications, this may be an adequate summary of temporal variability, the sequence of events in time is not represented.

3.1.2 Stochastic regional models

Another way to introduce a time dimension is through random number generators. Random number generators can be devised in such a way that, through appropriate modifications to a series of uniformly distributed random numbers, they are able to emulate the stochasticity of any time series. The generated series will contain the same types and sequences of events with the same frequencies as the original series which it emulates, but within the restrictions inherent in the statistical model used to describe the original series and to compute the coefficients which drive the generator.

Probably best known are weather generators which generate synthetic series for climatic elements (for details see W. Göbel 1990 and 1991). Other examples include a crop yield generator (März 1987 and 1990), which generates series of crop yields maintaining the proper correlations between the yields of various crops, and a price generator for agricultural inputs and commodities currently being developed at ICARDA (Rodríguez, pers. comm.). The generated series can, in turn, be used to drive various types of models, eg crop simulation models or crop production functions, resulting in synthetic series of any variable computed by such models.

The synthetic series are not forecasts of what will happen in the future but rather samples of sequences of events which might happen that way. They are most useful for estimating the frequencies of events whose definitions may be simple or complex, involving several variables, or for obtaining frequency distributions of derived variables. Nevertheless, there is some scope for predictive applications, since the initial conditions of the generator, unless also randomly chosen, have an influence on the generated values (due to built-in serial correlations or stochastic processes such as Markov chains) which disappears only gradually with increasing length of the synthetic series. Repeatedly generating a series with the same initial conditions can therefore be used to determine the likely values and ranges of variables occurring after a given time.

The coefficients driving a generator may be mapped like any other variable with a spatial dimension. It is thus possible to generate location specific synthetic series for any point (or grid cell in a raster system) and overlay these, or statistical descriptors of the series, with other attributes. A weather generator used in this fashion becomes what is termed a spatial weather generator. An otherwise static model of a region, consisting of a GIS with various layers of attributes, through the inclusion of generator coefficient maps, a generator module and, optionally, other associated models and modules, is turned into a STOchastic Regional Model, or STORM for short. Figure 3.1.3 shows the basic setup of a STORM with the generator and an optional generator-driven model integrated with a raster GIS.

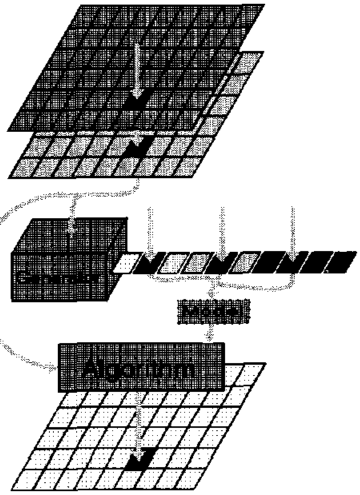


Figure 3.1.3 Point operations in a raster GIS-environment involving a random number generator. The random number generator obtains its coefficients from some of the attribute layers. The numbers generated form a stack of attribute layers, each one representing a different time horizon, limited in spatial extent to a single cell. They can be transformed and condensed into statistical descriptors by a model and are combined with values from other attribute layers to define the value of the new layer

The setup shown in Figure 3.1.3 corresponds to GIS point operations as defined in section 3.1.1 above. The process of generating a synthetic data series and overlaying it with other attributes is repeated cell by cell across the grid. However, it must be noted that spatial correlations of individual values of the generated series are not maintained between cells by this sequential spatial generation method. Area operations requiring simultaneous generation across a range of cells, eg the calculation of runoff from a catchment after a storm, require generators which maintain spatial correlations of individual values. The generation has to be simultaneous for at least that group of cells from which the output value is calculated (Figure 3.1.4). Unfortunately such simultaneous spatial generation methods are computationally very demanding.

3.1.3 The STORM shell

The STORM shell was conceived to permit the efficient integration of generator modules, crop and other simulation models, statistics modules, GIS- and other application modules into a single executable

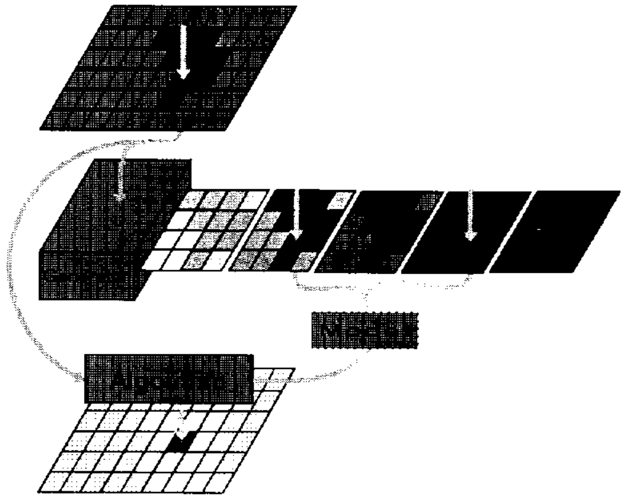


Figure 3.1.4 Area operations in a raster GIS-environment involving a random number generator. The set-up is similar to the one for point operations (cf Figure 3.1.3) except that the generator has to be capable to generate attribute values for an area consisting of more than one cell simultaneously

program. Its strength lies in its flexibility; the 'executable' (program) is custom-made for each specific task. The integration of the application modules into a single program makes the data exchange between the different modules extremely efficient; input and output to files is reduced to a minimum. The drawback is that application modules should be available in source code so that they can be modified to interface with the shell and conform to certain rules which this imposes. Programs for which the source code is not available can still be interfaced in many cases, but this reduces the computational efficiency. For example, most modules of the SURFER and IDRISI software packages can be interfaced. However, they cannot exchange data dynamically with other modules; the data to be exchanged with them must be written to and read from a disk.

The shell consists of two major parts, the interactive configuration part and the execution part (Figure 3.1.5). The configuration part itself is again divided into three sections. A first section configures the main body of the configuration part according to which application modules are to be linked with the shell into the execution part, reminiscent of the way in which a MKMF-utility makes makefiles. The main section of the configuration part does three things. It sets up the run-time parameters for the execution part and each of the application modules linked into it,

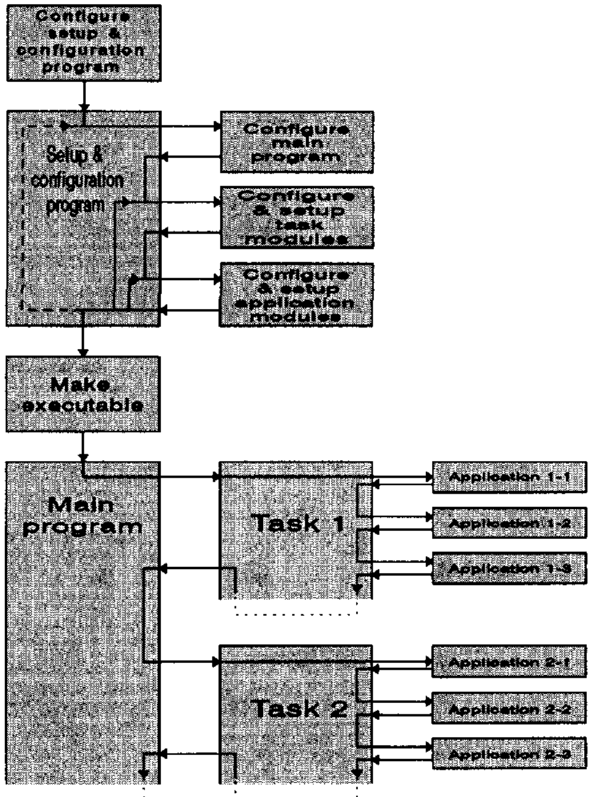


Figure 3.1.5 Flowchart of the STORM shell. The shell consists of two parts:the configuration part including a make facility to compile the execution part, and the execution part consisting of main program with attached task and application modules

which are passed on in a parameter file. It then generates the source code of the main program of the execution part, setting the nesting depth of loops and the sequence in which application modules are called according to requirements. Thirdly, it contains a facility for creating or editing application modules. The last section of the configuration part makes the 'executable' of the execution part by compiling the self-generated source code, as well as any application modules which may be in source code form, and linking with object module libraries and application modules which are in object form.

The execution part is structured as a chain of so-called task modules. Each task module consists of one or more of nested loops, the innermost loop containing a series of calls to application modules. The number and sequence of task modules, the nesting depth of the loops in each of them, and the sequence of application module calls are defined during configuration and fixed when making the 'executable'.

Figure 3.1.6 shows a single task module and the linked application modules in greater detail. In a typical setup for point operations, the task module might contain three nested loops: innermost a "time loop" executed, for example, once for every day during a 100-year period; an "attribute loop" executed once for every value of an attribute, eg once for every soil type occuring in the mapping unit to which the current grid cell belongs, or for every meaningful combination of values of several attributes; and, outermost, a "location loop" which would be executed once for every grid cell. How often these loops are executed is controlled by separate sequencer and timer modules. Other loops or a different nesting order of loops are possible, all depending on the task to be performed. For predictive tasks, another loop could be inserted between time loop and attribute loop, which would repeat the generation of the time series for each location and attribute-value combination. For area operations involving simultaneous spatial generation, a time loop may be all that is needed.

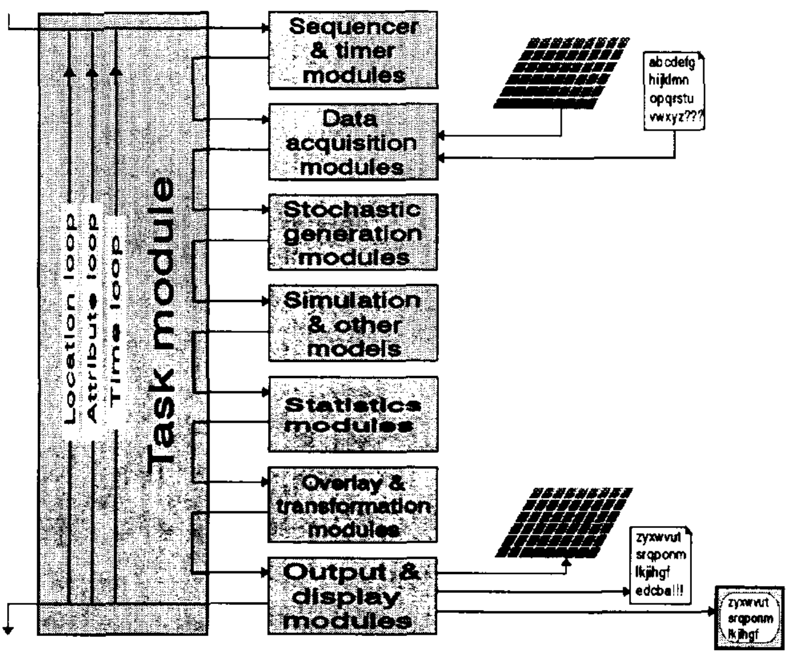


Figure 3.1.6 Flowchart of a task module with attached application modules in typical sequence

In a typical sequence of application modules, the sequencer and timer modules would be followed by data acquisition modules, retrieving input data for the current location from maps and other data files. Then follow stochastic generation modules, simulation models driven by the generated data, statistics modules to extract meaningful statistics from the generated and simulated data, overlay and transformation modules to perform overlays with data from other maps and other GIS-operations, and finally output and display modules which ensure the coordinated output to files and screen. Of all of these types of modules, there can be as many as available memory permits. It is, for example, possible to simulate simultaneously several different crops, different treatments, or crop rotations by linking several crop models or several copies of one crop model (which must, however, use different names for all subroutines and commons).

3.1.4 An example application. The relationship between LGP (Length of the Growing Period) and wheat yield in central Morocco

The purpose of this investigation was to evaluate the performance and to verify the applicability of the LGP-concept as a method for the rapid appraisal of climatic land suitability in central Morocco.

The LGP-concept was developed by FAO during the 1960's as a tool for land evaluation and agro-ecological zoning following earlier pioneering work by Cochemé and Franquin (1967) and others. It was and is the heart of FAO's AEZ-methodology which was first applied on a world-wide scale in the AEZ-project (FAO 1978-1981). A program to compute LGP is contained in APT, the Agricultural Planning Toolkit (FAO 1990). The principle is simple: a water balance is calculated from precipitation, soil moisture storage and potential evapotranspiration. The growing period is assumed to start when precipitation exceeds 50% of the potential evapotranspiration; it ends when precipitation plus soil storage fall again below that threshold. All periods with a mean air temperature of below +5°C are subtracted.

Since it is technically not possible to link the program from APT to the STORM shell, a custom module has been written for the LGP computation. It differs from the APT program by using the method proposed by Sivakumar (1986) to determine the end of the growing period, ie utilizing potential evapotranspiration calculated by the SIMTAG wheat model instead of the Penman formula, and daily water balance calculations instead of decadal data. To avoid excessive fragmentation into short growing periods separated by dry spells, a consequence of using daily instead of decadal data, dry periods of up to five days in length were assumed not to break a growing period. Minor growing periods separated by more than five dry days from the major growing period of a season were discarded. This way, LGP's were obtained which are similar to those given by APT from historical data of a selected number of weather stations.

Wheat yields were simulated using the SIMTAG wheat model developed by Stapper (1984) and validated for central Morocco by El Mourid (1988). It simulates wheat growth and development on a daily time-step driven by precipitation, air temperature and solar radiation. Nutrients were assumed to be non-limiting. The variety Nasma, one of the most widespread and best-adapted local varieties was "planted" on 15 November, with planting depth set at 4cm and plant density at 300 plants/m^2.

The study area in central Morocco covers approximately 4000 km^2, and, within it, 40 typical soil profiles were identified from 13 soil mapping units, the number of profiles per unit varying between 1 and 12. Profile water-holding capacities range from 18 to about 250mm, profile depths from 15 to 220 cm, and elevations from sea level to about 600m. Mean annual rainfall decreases from about 550mm along the coast to below 250mm inland. The climate is under the maritime influence of the Atlantic Ocean, but a distinctly continental component becomes noticeable as one moves inland.

One hundred and one years (=100 crop seasons) of daily weather were generated for the central points of grid cells spaced 2' by 2' apart and fed into the SIMTAG and LGPSUB modules. The modules for the generation of precipitation, air temperature and global radiation were adapted from the spatial weather generator described by Göbel (1990, 1991). The same weather series was repeated for, profiles representing each soil unit within the cell. Out of the computed grain yields and growing period lengths, various statistics were calculated and mapped, making use (among other things) of various program modules from SURFER and IDRISI.

The setup for this study contains four task modules executed in succession (Figure 3.1.7). The first of these modules generates and simulates the data cell by cell. Its output consists of maps (means, standard deviations and deciles) of LGP and grain yield separate for each soil profile. The other task modules are non-stochastic and serve to modify the output produced the first module through area operations. The second task module creates maps of average LGP and grain yield through averaging the results for the different soil profiles in each cell (averages of the means and of the deciles). The third module computes regressions between LGP and grain yield, and the final module creates maps of predicted grain yield based on these regressions and of the error relative to the yields simulated by SIMTAG.

The first task module contains three nested loops, controlled by three sequencer modules for time, soil type and location. The attached application modules are therefore called every day for 101 years. This is then repeated for each soil profile belonging to the soil unit at the present location and for each grid cell. The block of sequencer modules is followed in the calling sequence by a block of data acquisition modules, reading values from weather generator

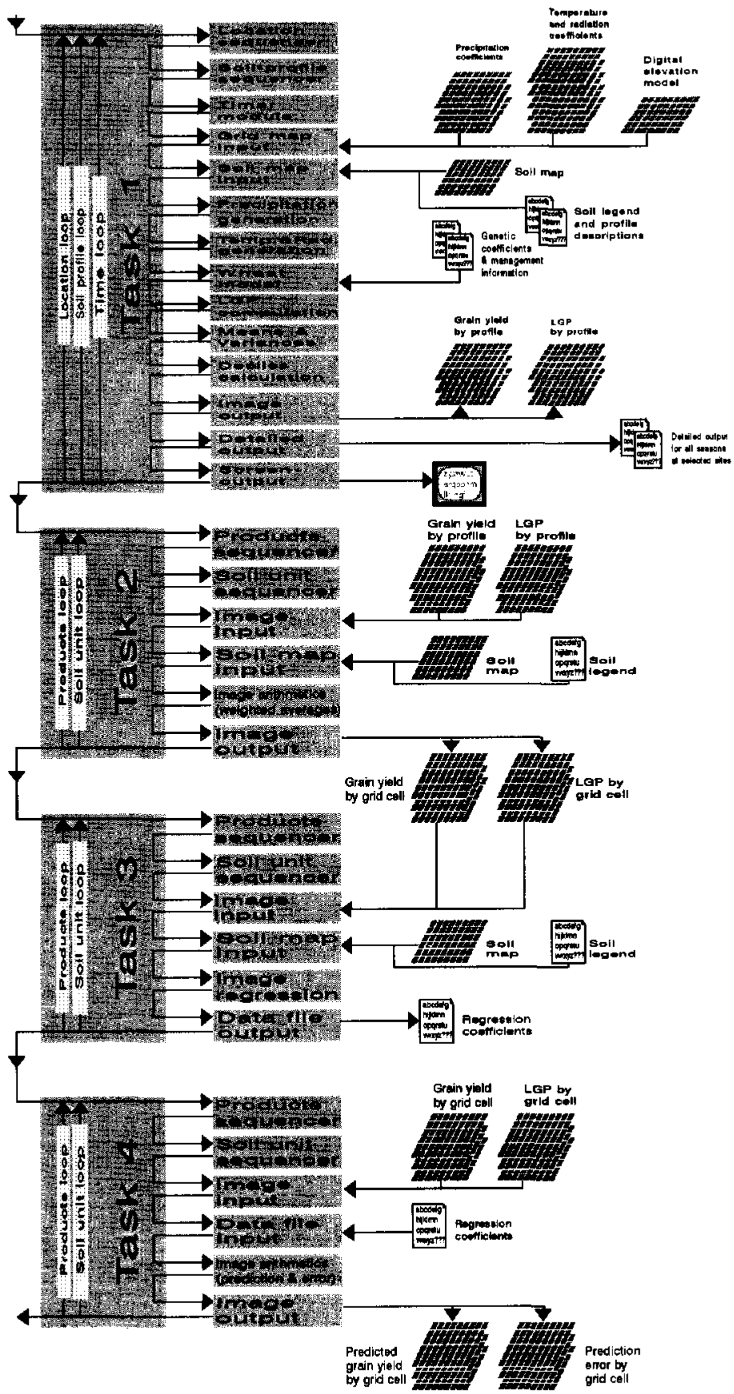


Figure 3.1.7 Section of flowchart of an example application of the STORM shell. For details see text

coefficient maps (which are in SURFER format), from the soil map (which is in IDRISI format), and from the soil legend every time the location changes; a soil profile is read or reread at the start of each cycle of the attribute loop. The data acquisition section is followed by the stochastic generation modules, in this case consisting of a precipitation generator and a temperature and solar radiation generator. The generated weather series differ from cell to cell, but for each cell the same sequence is repeated for each of the soil profiles. After the generator modules, the simulation modules are called, first the SIMTAG wheat model, then the LGP-module. The simulated crop yields and LGP's vary in spite of identical weather series due to the different depths and water holding capacities of the different soil profiles. Next in the chain are statistics modules which compute means, standard deviations and deciles for selected variables. These statistics are then written to IDRISI-type map files and displayed on the screen by output modules which conclude the chain of application modules called during each cycle through the loops. For selected cells, detailed year-to-year output is written to separate files.

There are two reasons for saving the data on disk at this point: to maintain data safety throughout the often very long time which is needed for the computations; and passing the data to the second task module in memory is not possible since several of the application modules of that task are taken from IDRISI and can only accept input from disk.

Figure 3.1.8 is an example of maps in the format produced by task 1; the attribute values have, however, been classified for better visualization. The maps of average LGP and grain yield for a 150 cm deep inceptisol with 155mm water holding capacity show the distinct granularity of the 2' by 2' cell size. They contain values for all those grid cells which have a soil of that type represented within them. No values are shown for the rest of the cells.

The second task module contains only two nested loops controlled by two attribute sequencer modules: one for type of output variable (mean and deciles, each for LGP and grain yield) and one for soil unit. The absence of generator modules obviates the need for a time loop; and the fact that all application modules making up this task perform area operations on the entire map surface makes a location loop also unnecessary. (Although the modules may work internally in point operation fashion, this is not visible to the calling task module.) This task accomplishes the following: the maps produced by the first task are overlaid with a soil map of the same resolution to obtain maps of LGP and of yields, averaged across all the relevant profiles in a weighted fashion according to the relative areas of the respective mapping units. Examples of the resulting regional maps (Figure 3.1.9) show LGP and grain yield values, averaged across all representative soil profiles in each cell and across 100 growing seasons.

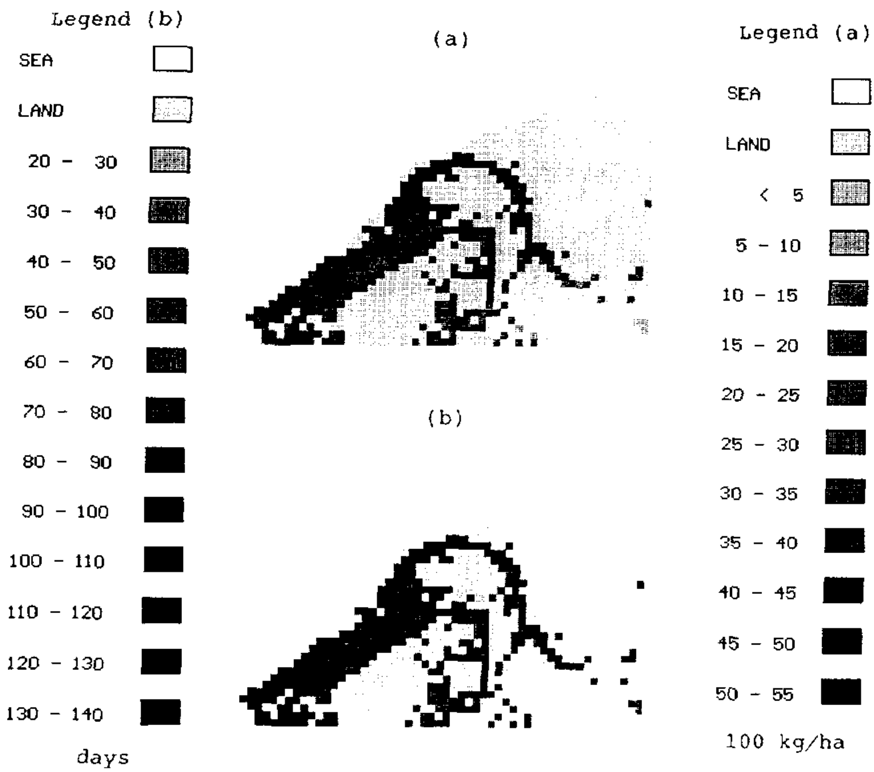


Figure 3.1.8 Mean wheat grain yield (a) and mean LGP (b) on a selected soil profile (150 cm deep inceptisol). Only those grid cells show values which belong to one of the soil units for which the selected profile is considered representative (it may be representative of the main soil type, an associated soil or an inclusion). The size of each grid cell is 2' by 2'. The area is part of central Morocco, Casablanca being at the top right corner

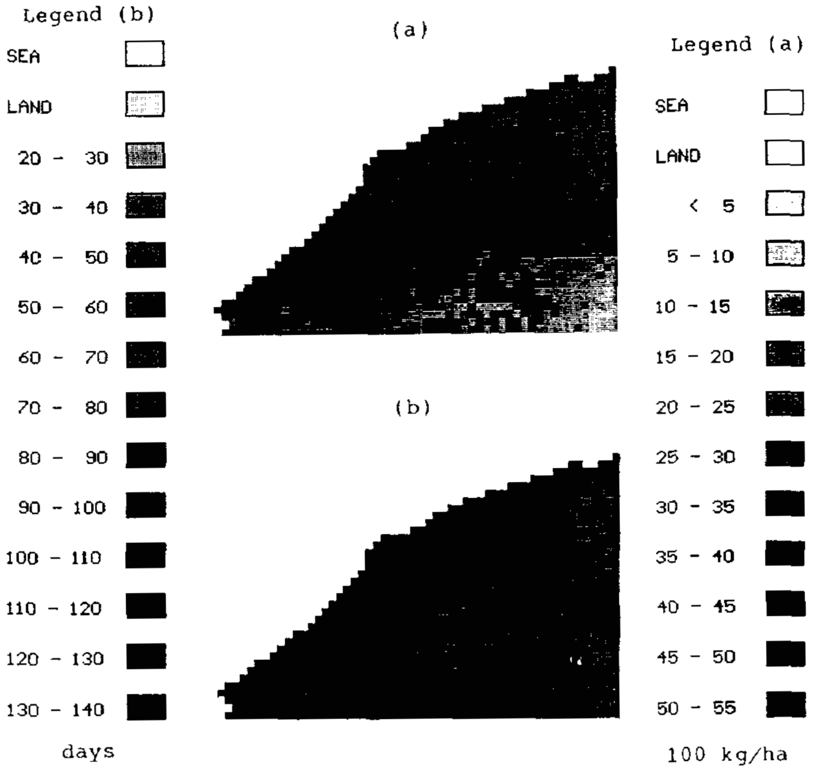


Figure 3.1.9 Mean wheat grain yield *(a)* and mean LGP *(b)*. Weighted averages for each grid cell of values for all soil profiles representing soils in the mapping unit to which the grid cell belongs

The third and fourth task modules contain loop structures similar to the second one, one loop for the type of output variable (mean and deciles, but this time not separately for LGP and grain yield) and one for soil unit. There is only a single application module in task 3, which computes a linear regression between each of the corresponding pair of values of LGP and grain yield. The fourth and last task module uses the regression coefficients to compute grain yield from LGP and then to create maps of the predicted yields, of the absolute prediction error (obtained by subtracting the corresponding yield values simulated by SIMTAG), and of the relative prediction error (obtained by dividing the yield by the absolute error).

After the generation of the output described above, the next step was to analyze the detailed output for a grid cell in the central coastal area. As an example, an inceptisol of 150 cm depth with 155mm plant-useable, moisture-storing capacity was chosen, but results for all other profiles are quite similar, except for a higher incidence of crop failures on shallow soils. For the selected profile, Figure 3.1.10 compares the LGP's calculated for the 100 growing seasons with the growing period lengths (GPL) from germination to maturity simulated by SIMTAG. While the GPL shows little variation from year to year with the exception of those

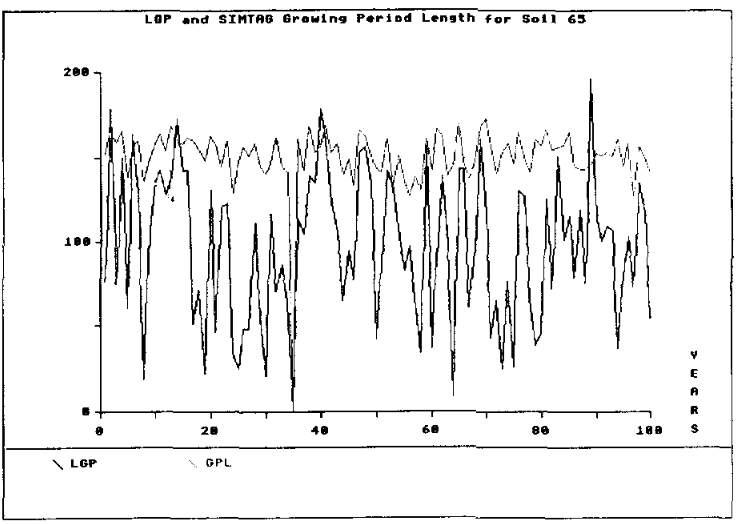


Figure 3.1.10 LGP (solid line) and growing period length predicted by the SIMTAG wheat model (dotted line) in days for 100 crop seasons. The simulation was done for a grid cell in the central coastal area using the same soil as that for Figure 3.1.8

seasons with crop failures, the LGP varies widely, being short in seasons with low rainfall and long in seasons with high rainfall. Ground evidence and the results of El Mourid (1988) show that the SIMTAG GPL is a correct representation of the true length of the life cycle of wheat. LGP, therefore, cannot be used as a measure of the growth-period length of individual growing seasons. However, as Figure 3.1.11 shows, reductions in LGP run parallel with reductions in grain yield, while GPL remains unaffected. The reason for this is that LGP is terminated by dry spells of more than five days, whereas GPL continues, depending on the development stage and previous exposure of the crop to moisture stress, across dry spells which may last more than ten or even twenty days. Since such prolonged dry spells usually affect yield negatively, LGP and grain yield are related (R^2=0.65), while GPL and grain yield are not (R^2=0.19).

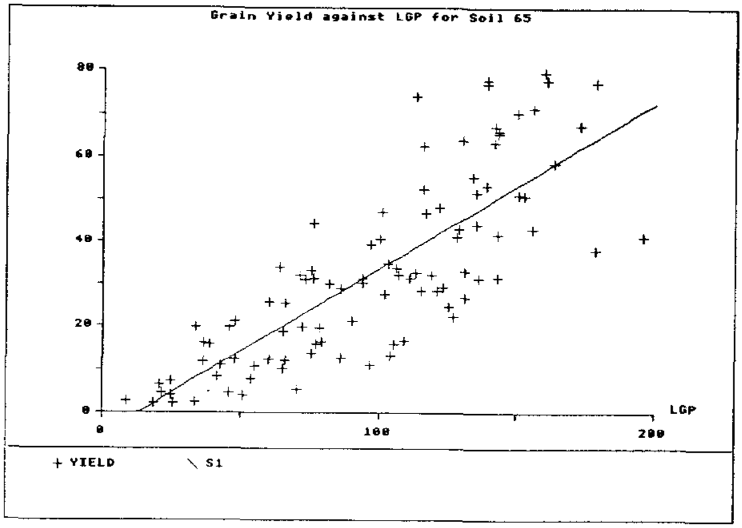
The close relationship between LGP and grain yield can be further demonstrated by a regression across all grid cells represented by a particular mapping units. Figure 3.1.12 shows the extraordinarily good correlation (R^2=0.97) between the averages of LGP and grain yield for the 100 simulated growing seasons mapped in Figure 3.1.8. Even considering that spatial autocorrelation contributes to this high value of R^2, the high degree of correlation is remarkable. It is furthermore stable across different types of soil, the R^2 value dropping only marginally to 0.94 for a shallow soil with 36mm moisture holding capacity, as a result of the increased number of crop failures.

A repetition of this type of regression for average LGP and grain yield across all soils, ie between the two maps of Figure 3.1.9, gives an R^2 value of 0.93 (Figure 3.1.13). An even better fit would be achievable with non-linear regression, because of the bias introduced by crop failures on shallow soils during poor seasons.

Figure 3.1.14 shows the histograms of the absolute and relative error of using LGP as predictor of mean grain yield (averages of 100 growing seasons across all soil types of each mapping unit), constructed from the error maps created by the last task module. The standard deviation of the absolute error is 223 kg/ha, and, for most of the grid cells, the relative error is less than 20% of the yield. The histograms are slightly skewed, again because there can be neither negative yields nor negative LGP's, so that the underlying assumption of normality of the distributions for the regression is not strictly correct.

From Figures 3.1.12 to 3.1.14 it is evident that LGP is an excellent estimator for mean grain yield in central Morocco, for individual soil profiles as well as for mapping units containing several soil types. It reaches its limits, however, in situations where the yield level is very low. This becomes apparent if, instead of mean LGP and mean grain yield, we look at LGP and yield

A



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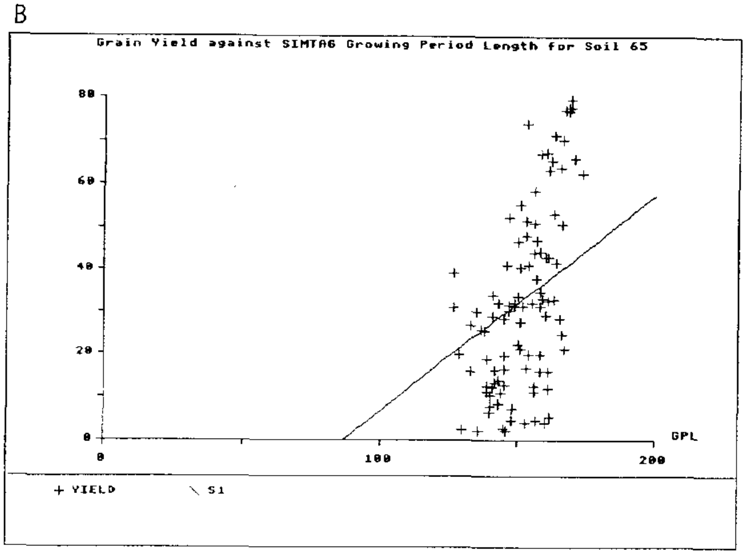


Figure 3.1.11 (a) LGP (days) against grain yield (100 kg/ha) for the same 100 simulated crop seasons as in Figure 3.1.10. $R^2=0.65$.
(b) Growing period length predicted by SIMTAG (days) against grain yield (100 kg/ha). $R^2=0.19$. The direction of the regression line is determined by a data point which coincides with the origin

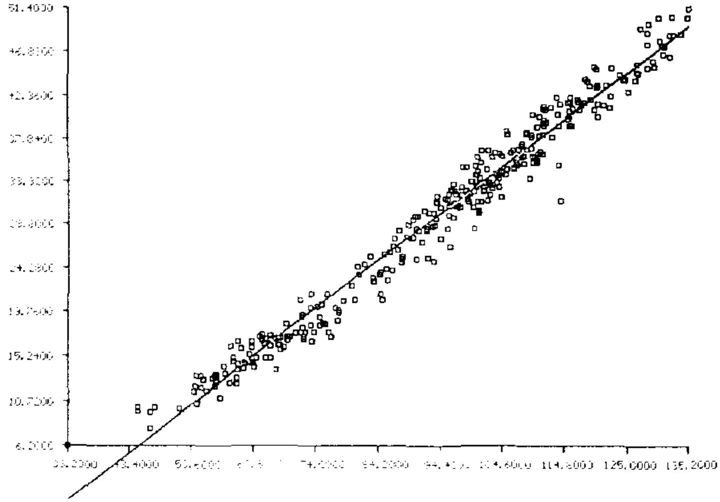


Figure 3.1.12 Average LGP over 100 crop seasons (in days on x-axis) against grain yield (in 100 kg/ha on y-axis) for single selected soil profile. Each point represents one grid cell of the maps in Figure 3.1.8. R^2=0.97 (not corrected for spatial autocorrelation)

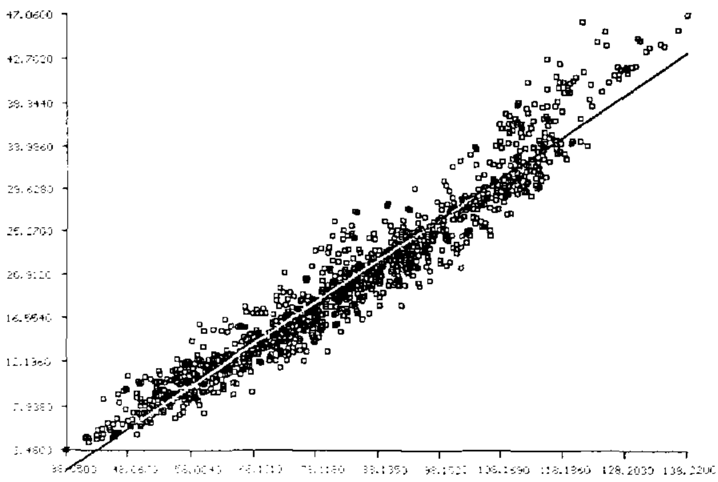


Figure 3.1.13 Average LGP over 100 crop seasons and across all soil profiles of each grid cell (in days on x-axis) against grain yield (in 100 kg/ha on y-axis). Each point represents one grid cell of the maps in figure 3.1.9. R^2=0.93 (not corrected for spatial autocorrelation)

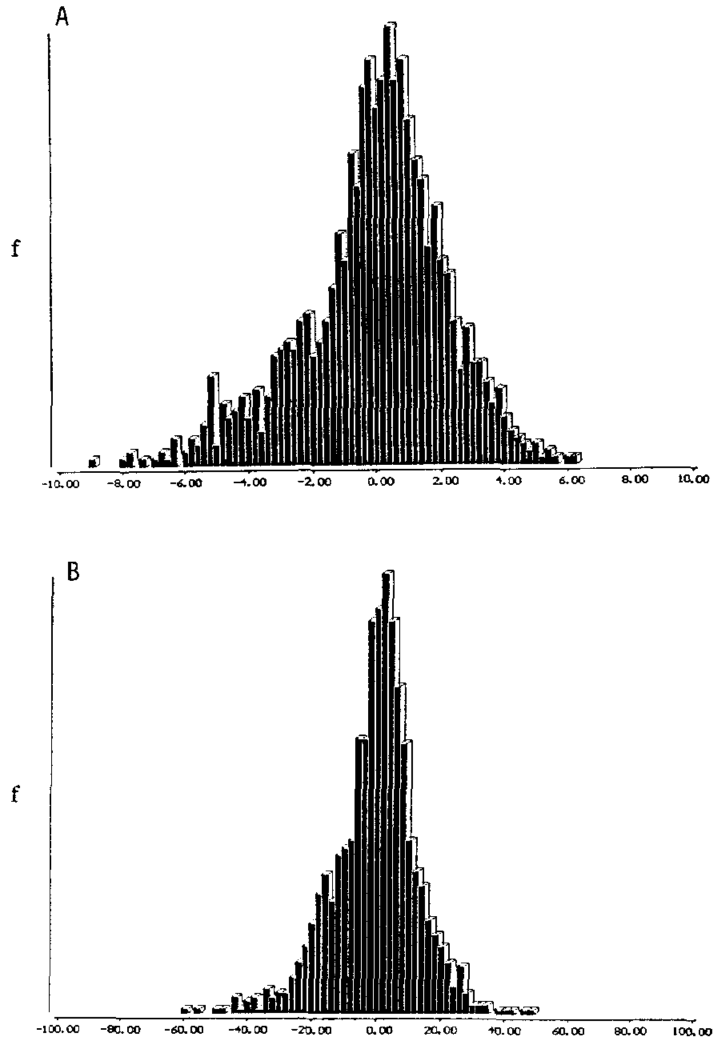


Figure 3.1.14 (a) Histogram of absolute error of prediction (in 100 kg/ha) of average grain yield from average LGP (averaged over 100 seasons and across all soil profiles of each grid cell).
(b) Corresponding histogram of relative error of prediction (in %)

exceeded in four years out of five, ie the second decile of LGP and yield. Figure 3.1.15 shows the corresponding regression across all soil types per mapping unit (comparable to Figure 3.1.13 for the means). With 0.85, the R^2 is still quite high. Using the regression to construct maps of absolute and relative error of the prediction, the histograms in Figure 3.1.16 are obtained. While the absolute error predicting the second decile of yield is of the same magnitude as the one for predicting the mean, the relative error becomes very large due to the low yield level. [***Wolfgang Göbel with Abdelillah Ambri, Mohammed El Oumri and Abdelaziz El Ouali, Morocco***]

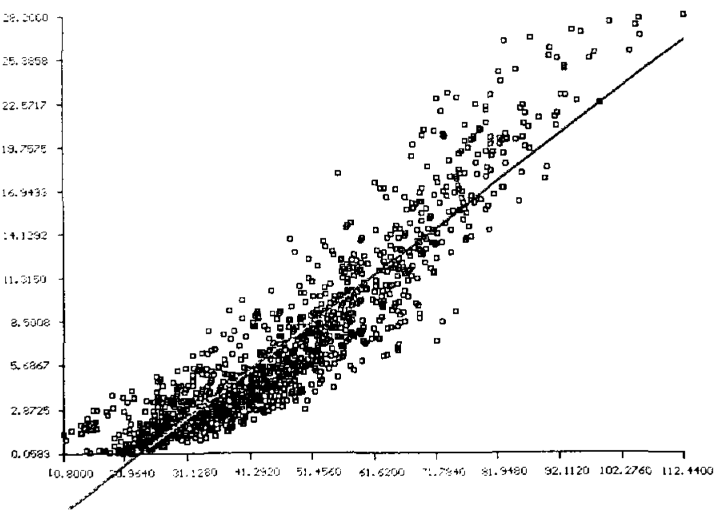
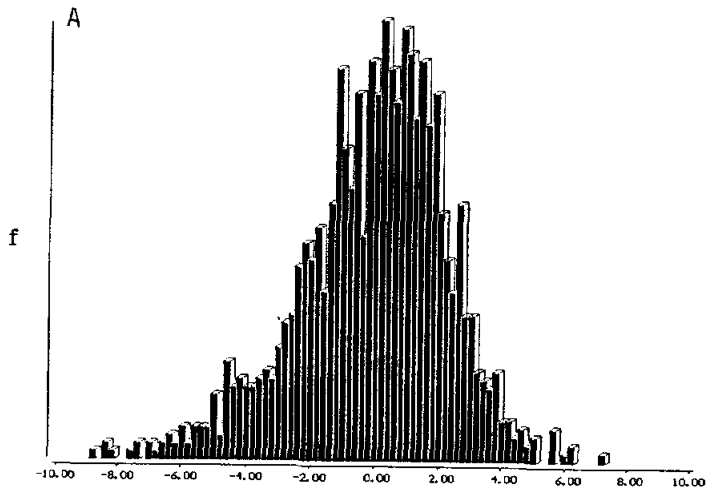


Figure 3.1.15 LGP reached in 80 of 100 crop seasons averaged across all soil profiles of each grid cell (in days on x-axis) against grain yield (in 100 kg/ha on y-axis). R^2=0.85 (not corrected for spatial autocorrelation)



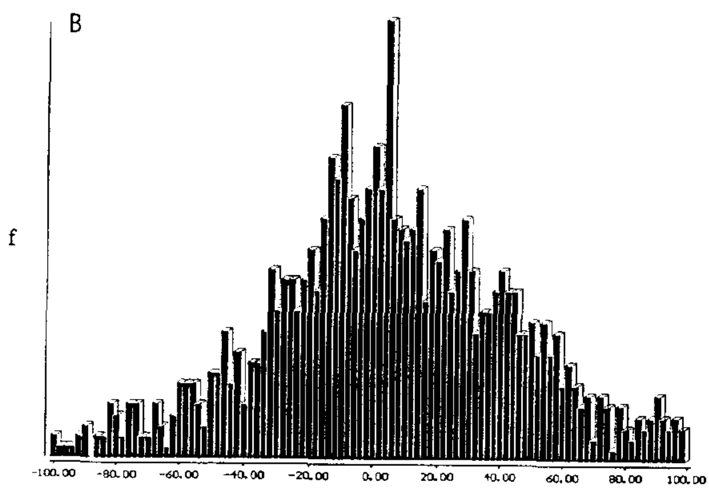


Figure 3.1.16 (a) Histogram of absolute error of prediction (in 100 kg/ha) of grain yield achieved in 80 of 100 crop seasons from LGP reached in 80 of 100 seasons (averaged across all soil profiles of each grid cell).
(b) Corresponding histogram of relative error of prediction (in %)

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3.2 Greater Root Growth and Osmoregulation for Drought Resistance: Where?

3.2.1 Background

The areas in which ICARDA works have a single rainy season during which crops are grown. However, because the rains terminate before the end of their life cycle, rainfed crops depend, during grain or seed development, on water stored in the soil from earlier rainfall, and they almost inevitably suffer drought stress at this crucial stage.

A major objective of plant breeding in the Center is to incorporate into new cultivars traits that impart drought tolerance. Such traits may be thought of as falling into two groups: those which enhance the efficiency with which water is used in the production of economic yield; and those which allow a plant to access more water. Amongst the first, we can think of traits such as earliness, early growth vigour, and the greater cold tolerance which both of these necessitate. The second group includes more extensive root systems and osmoregulation.

This note attempts a preliminary examination of where the second group might be usefully targetted.

Figure 3.2.1 shows lines representing field-determined wet and dry profiles of water content in the swelling clay soil (Calcixerollic Xerochrept) at Tel Hadya. The wet profile (right hand line ≡ field capacity) comes from a fallowed plot in a year with 480mm of rain, when drainage through the profile was recorded under fallows. The dry profile (left line) is measured, very repeatably, at the end of the summer (September) following the growth of wheat and chickpea crops in the previous season (November to June). In the surface layers this line represents air dryness, but below about 60 cm there is little loss of water over the summer and it thus represents the lower limit of plant extractable water. The dashed line is a laboratory-determined permanent wilting point (-15 kPa).

Divergence of the line for the lower limit of plant extractable water from that for the permanent wilting point at depth is partly due to increased resistances to water flow in the soil-root system, but is also attributable to reduced root density at depth (Brown *et al.* 1987; 1989). The result is that there appears to be water remaining in the soil (hatched area of Figure 3.2.1) which a plant with an enhanced root system might be expected to exploit. We can postulate that, if we could design plants with greater density of roots at these depths, they should be able to take up some of this apparently unused water (Taylor and Yamauchi, 1991). This would have the effect of moving the lower limit line to the left, and so increasing the volume of plant available water that the soil can store.

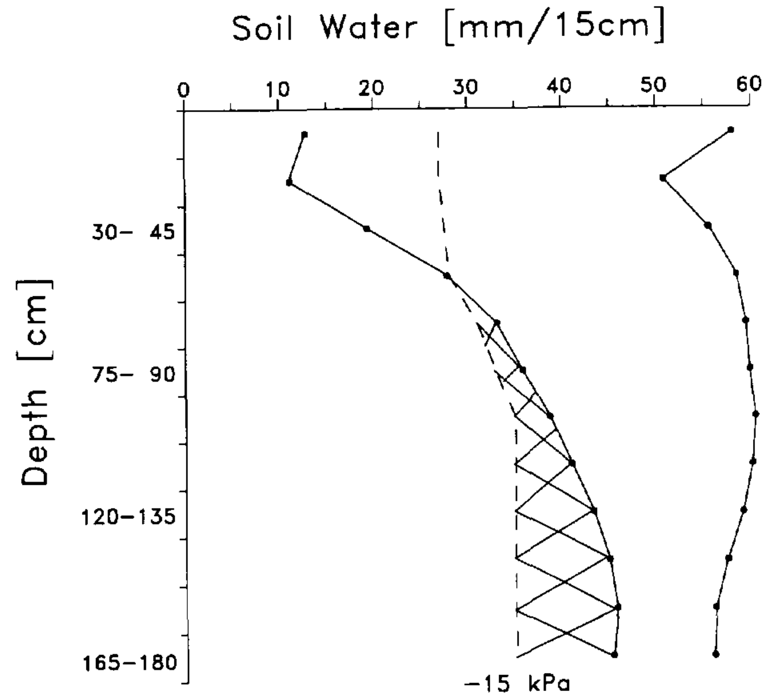

Figure 3.2.1 Field determined upper limit (field capacity; right hand line) and lower limit (left hand line) of soil water, and laboratory determined permanent wilting point (dashed line) for Tel Hadya soil.

A similar argument applies to the trait for osmoregulation. A decrease in plant water potential arising from osmotic adjustment would also have the effect of moving the lower limit line to the left, with the same result.

Let us look at circumstances where it may be of advantage to increase the volume of plant extractable soil water in these ways.

3.2.2 Field water balances

Figure 3.2.2 shows the pattern of wetting of a deep profile in a swelling clay soil (data from Tel Hadya in 1987-88 with 480mm of rain). Water entering the soil is redistributed to depth according to the balance between the supply and the force of gravity, the permeability of the soil, and the water potential gradients existing within the profile. At some point, providing the supply is sufficient, much of the profile will become saturated and water will

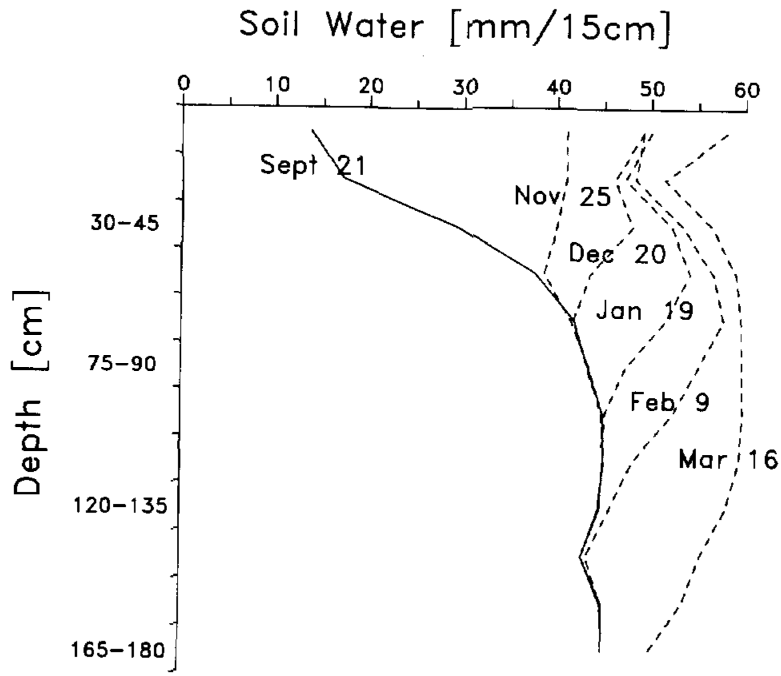

Figure 3.2.2 The pattern of wetting, under fallow, of the Tel Hadya deep clay soil during a season with 480mm of rainfall.

begin to drain from the bottom, depending on the permeability of the subtending stratum. Throughout the process there are also losses from the surface in the form of evaporation, possibly runoff, and transpiration if plants are present.

Figure 3.2.3 shows the maximum soil water profiles measured in the field under wheat and chickpea crops in the past seven years at Tel Hadya, together with the rainfall for each season. Only in the wet year (1987-88, 480mm rain; estimated as a 1 in 30-years event) was the profile almost filled. With rainfall near the average for the site (330mm), the depth of wetting was of the order of 120 to 135 cm, depending on the distribution of the rain through the season. A contrast exists between the 1990-91 and 1992-93 seasons, both with very similar below-average total rainfall. In 1992-93 much of the rain fell early in the season, allowing a build-up of stored water to a depth of ≈ 105 cm and storage, at the maximum, of about 40% of the total rainfall. In 1990-91 smaller falls were distributed throughout the season, the wetting front did not extend below 60 cm and only 25% of the rainfall was stored at the maximum

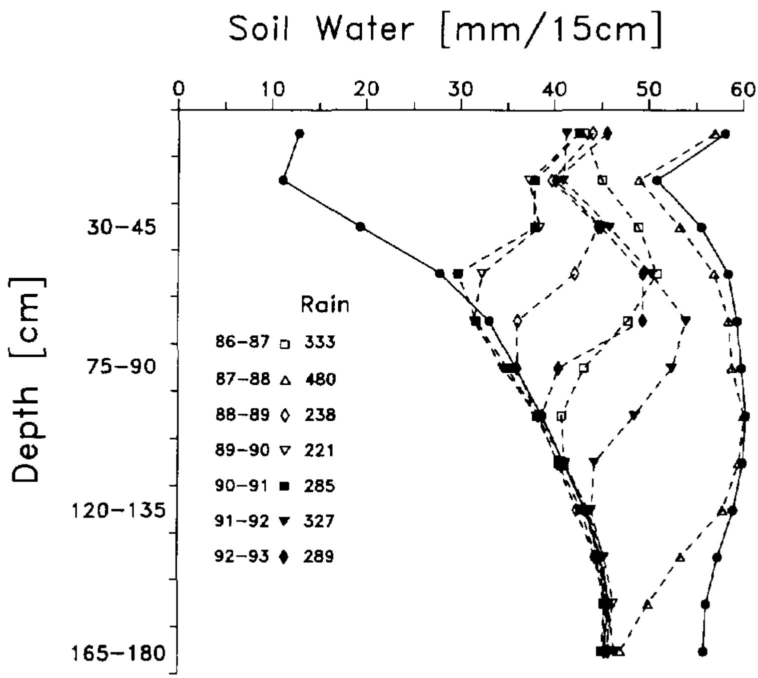

Figure 3.2.3 Maximum soil water profiles measured under wheat and chickpea crops, and total seasonal rainfall, in the past seven years at Tel Hadya. Solid lines are the upper and lower limit.

point. Over the seven seasons, the proportion of the season's rainfall stored at maximum storage ranged from 25 to 50% (the time-course of these extremes is shown in Figure 3.2.4), and in most years a considerable volume of the soil remained dry.

Figure 3.2.5 illustrates the pattern of uptake, by the wheat and chickpea crops, of the water stored in the wet year (1987-88). Both crops dried the soil virtually to the lower limit line (also shown, Figure 3.2.5), even though the supply of water was so much greater in this year. Thus both crops possess an ability to expand their root systems to explore the full volume of this soil when water is available.

What would have been the effect of having crops with an ability to take up more water in these years ? If, in any one year, the lower limit line had been moved to the left, on no occasion would the extra water removed have been replenished in the next season.

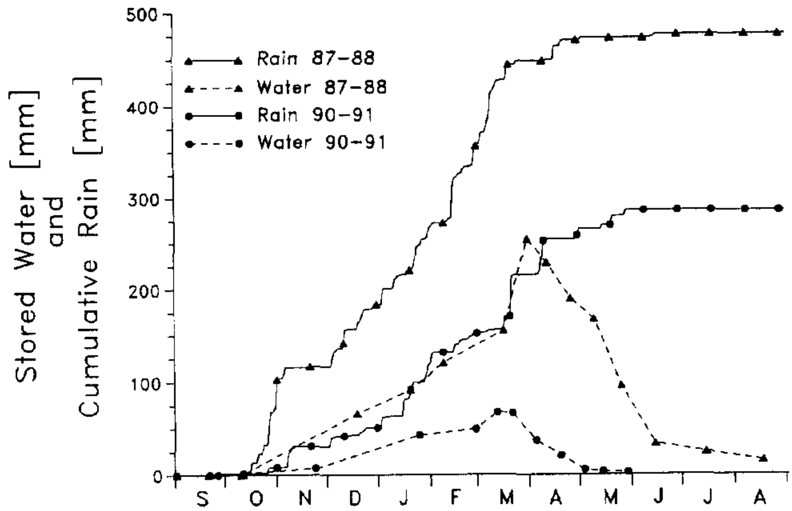

Figure 3.2.4 The time-course of rainfall accumulation, and storage and use of soil water in contrasting seasons at Tel Hadya.

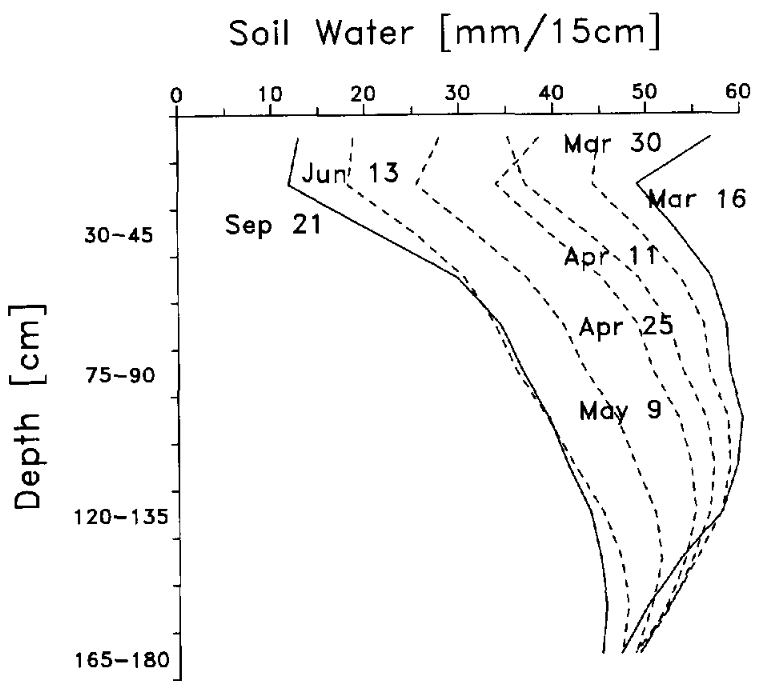

Figure 3.2.5 The pattern of drying of the soil profile by wheat and chickpea crops in 1987-88 when the profile was almost fully wet at maximum water storage.

Incontrovertibly, the limitation in this situation is the supply of water and not the ability of crops to take it up.

3.2.3 Targetting the traits

From the preceding, it can be argued that plant mechanisms to increase water uptake would be of advantage only very rarely in this environment. And to generalize, they would be of advantage only where there is a reasonable probability that the water supply (rainfall in this context) will be in excess of the water holding capacity of the soil. Or, to put it another way, they would be of advantage only in situations where there is regular drainage of water through the soil profile.

In the example from the wet year (Figure 3.2.2), at the time of maximum storage amounts equal to approximately 165, 210 and 250mm had been stored in the top 75 cm of soil, the top 105 cm, and the whole profile (180 cm), respectively. These represent 35, 40 and 50 percent of the total rainfall of that season. If we can use these as rules of thumb, and taking into consideration the fact that losses from the soil surface will be similar regardless of the depth of the profile, then it can be crudely estimated that rainfall totals of at least 415mm, 460mm and 500mm of rain would be needed to cause drainage from profiles of the same depths, ie 75, 105 and 180 cm. Obviously, these are very broad generalizations and can take no account of the distribution of the rain through the season which, as has been noted, markedly affects the proportion that is stored. Also, these values are of relevance only to well-structured heavy clay soils, although these are widely prevalent in the arable areas of the region. The values would differ for soils having slower infiltration rates, or soils of a coarser texture with faster infiltration rates and less water storage capacity.

However, despite the uncertainties, the point to be made is that rainfall values in excess of 400mm are in the upper range of those towards ICARDA directs its major effort. Provided we are clear in our minds that mechanisms, such as enhanced root growth at depth and osmoregulation, that contribute to greater water use are of most relevance to the wetter end of the spectrum, then they can be used to target cultivars for the better rainfall zones. They are unlikely to be appropriate for the drier zones, except, possibly, where soils are sandy. [*H.C. Harris, with technical support from Hassan Jokhadar, Issam Halimeh and Ali Haj Dibo*]

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3.3 Present Situation and Future Prospects of the Dry Rangelands in WANA: A Review of Five Countries

Funds provided to ICARDA under a special grant were used to commission case study reports on the "marginal areas" in five West Asia and North Africa (WANA) countries: Syria, Jordan, Egypt, Tunisia, and Morocco. National scientists with extensive experience in the drier areas were contracted in each country. In both Jordan and Egypt, two scientists were contracted and divided the case study terms of reference between them. In each country, the objectives were (1) to provide a local assessment of the situation of the dry rangeland areas and (2) to define research and training needs and priorities for those areas.

The consulting national scientists all struggled with defining geographically and economically the concept "marginal areas". Ultimately, each country study settled on its own definition, but there was a general recognition that rainfall regime and natural plant cover were the two most defining variables. Thus, a winter rainfall of between 50 and 250mm and a ground cover of grass and/or shrubs characterize the areas described in each report. The terms dry rangelands and steppe are used interchangeably with marginal areas.

The dominant use pattern is unimproved grazing (or rangeland), although there are pockets of rainfed and irrigated crop production. It is recognized in all five countries that the area cultivated within the marginal areas has increased dramatically over the last twenty years, mostly as mechanized dryland barley but also including significant areas of fruit trees (principally olives, figs, and some nuts). There are considerable year-to-year fluctuations in cultivated area, but the trend is towards a loss of the better rangeland as cultivation encroaches on it. If land receiving less than a 50mm yearly average is excluded, then the five countries contain about 40m ha of steppe used for rangeland and intermittent barley production. This represents a land surface and productive resource far larger in extent than the rainfed arable and irrigated areas combined. The percentage of the countries' populations living in and/or deriving income from the steppe varies from about 25% in

Tunisia to less than 1% (of a much larger national base) in Egypt. Other than Egypt, the average is probably around 10% if the largest oases are excluded.

It is very difficult to estimate the contribution of the steppe areas to the various national economies. Tourism has recently become an important dimension, especially in Tunisia and Egypt where the steppe runs directly along the Mediterranean shore. If we exclude extractive industries such as petroleum, natural gas, and rock mineral mining, then the basic productive activity is animal husbandry, primarily sheep and goats. The bulk of crop production in the steppe and along the steppe margins contributes to animal production through the provision of feed supplies (barley grain and crop residues). It is estimated in Syria and Jordan that the majority of the national sheep flock spends at least part of the year in the steppe. Similarly, the steppe has traditionally been the center of small ruminant production in North Africa, along with camel raising.

Despite the only very rough estimates of steppe-based flock numbers available, two basic trends seem common to all the countries: increasing numbers of sheep on shrinking ranges and decreasing contribution of steppe grazing to their nutritional requirements. It is generally agreed that the nutritional contribution of steppe grazing to the national flocks is now less that half of what it was twenty years ago in proportional terms. Despite heavier stocking rates and more complete coverage, the absolute contribution in terms of biomass has probably also declined. All the authors reported "overgrazing", "deterioration", and "degradation" of the rangeland plant resources.

Rangeland degradation is, of course, the most important issue, and information about the current situation and prospects for the future are the reasons why the case studies were commissioned. Unfortunately, none of the authors provides a detailed definition of range degradation, nor even of range deterioration. It is assumed that the reader is familiar with the concepts, and that it is not necessary to produce quantitative measures of either. Some experimental results are given in the Syrian, Jordanian, and Egyptian studies. These show that current biomass production on the open range is well below the potential as indicated in controlled experiments.

The authors are unanimous in stating that degradation is increasing and that the long-term productivity of the steppe is seriously threatened by the phenomenon. Each author advances a diagnostic explanation for deterioration, and each provides the outline of a solution for the country in question. The general explanation is the same in every case. An increasing human population needing to provide itself with a livelihood has few easy alternatives to intensifying its exploitation of the very limited (and fragile) rangeland vegetation. The demographic pressure of people and animals is heightened by the introduction of modern technology in the form of motor transport, deep wells, and feed concentrates and by economic policies and market structures that encourage livestock production in quantitative rather than qualitative terms. Not only are there more animals, but the flocks have greater mobility. The result has been uncontrolled overgrazing. Plant communities are not given sufficient time to rest and recover from grazing, and many desirable species are not even allowed the opportunity to reproduce themselves. The following points are common to all five countries:

1. Decreased area of range due to encroaching cultivation.
2. Increased intensity of grazing due to various factors, among them greater mobility of flocks, lack of control over access to rangeland, provision of water in the steppe, and higher stocking rates.
3. Subsidy programs for livestock feed, encouraging larger flocks but not higher quality animals. Often linked with support prices for barley production.
4. Flows of merchant and speculative capital to finance livestock and/or barley production in the steppe.
5. Short-term deterioration or irreversible degradation of plant and soil resources. Desertification, with formation and encroachment of sand dunes noted.

Although the general trend towards destruction of range resources would appear distressingly similar in each country, various authors provide slightly different diagnoses of the national problems, as well as slightly different prescriptions for overcoming them.

In terms of causes of degradation, the authors' assertions can be grouped under three basic headings: climate change, collapse of user control, and economic forces. The first of these may be seen as an external force of nature beyond human influence. Essentially, the argument is that human exploitation is not responsible for resource degradation. Rather, the climate-supplied factor of rainfall has ceased to be available, and drought has killed the plants. Continued drought (a long-term change in climate since the 1970s) has destroyed the range forever, or at least until the climate becomes more humid. None of the authors actually subscribe to this view, although a few indicate that policy makers in their countries might do so. However, at least in the cases of Algeria and Jordan, low rainfall in the 1970s and 1980s was a factor aggravating the overgrazing problem.

The second general cause is sociocultural and involves formal and informal relationships among people and the land. Essentially, the argument is that in times past ("traditionally") tribal groups controlled access to and use of steppe grazing resources. Each group controlled an area of the steppe and regulated grazing of the natural pastures through various mechanisms, including the use of coercion or the threat of force. The tribal group was careful to preserve and conserve the productivity of its rangeland simply because of economic necessity. To allow the destruction of the patrimonial resource would be to jeopardize the continued existence of the group that relied upon its animals for its livelihood. Outsiders were excluded from grazing except by agreement of the group. The reasoning is that those dependent on the range have the greatest stake in conserving range resources and, therefore, will do what is necessary to maintain the plant communities.

Two authors, Masri and Abaab, argue that for their countries tribal communal control over the steppe rangelands was disrupted during the colonial period, and that user control over steppe resources has not been restored since. In both countries former tribal territory has become the object of squatters seeking to establish private ownership through cultivation. The steppe itself has become a "no man's land" nominally under the jurisdiction of the state, but effectively access is not controlled and is open to unlimited grazing.

The question of land tenure is addressed in all the studies, but no clear picture emerges. It would seem that all five countries have a very strong tribal heritage in the steppe areas. All (with the possible exception of Egypt) have a notable history of colonial intervention in tribal affairs and in the steppe itself. All the authors indicate that the uncultivated steppe is at least nominally in the state's domain, but that in some cases tribal groups still have at least residual rights (in Jordan, Egypt, Algeria, at least). In other situations, a modern cooperative society may overlap with tribal membership and perform at least nominally some of the old tribal functions. Both Masri and Abaab argue either explicitly or implicitly that the collapse of control over access to grazing resources by a community of users was the single most important factor contributing to the present disastrous state of affairs.

In terms of a solution to the pattern of resource degradation, both Masri and Abaab stress the importance of empowering those people who have the most to lose from the disappearance of the rangeland plant communities. It is suggested that the formation of cooperatives under the control of the members and with control over designated rangelands is a viable replacement for the traditional forms of tribal control. In terms of past experience with common property resource management, the responsible involvement of a homogenous user community is essential for success.

The other authors do not feel as strongly about communal control and the demise of traditional management arrangements. Rather, they lay the blame on the rangeland users becoming incorporated in a wider market economy. Bedrani develops this argument in the most detailed and explicit fashion, but it is very much present also in the Jordanian and Egyptian studies. The resource destruction can be traced in the evolution of the production systems practised by steppe inhabitants and their neighbors. All authors stress the significance of the introduction of motor transport. Distance, and the time to move from one grazing area to another, is no longer a limiting factor. Similarly, with tank trucks and/or drilled wells, water is no longer a limiting factor. Finally, trucks and government feed programs have eliminated the destruction of the rangeland itself as a limiting factor. Livestock producers no longer need the range for their very existence. The natural range has become simply an alternative source of feed among others. It happens to be the cheapest because it is free, and the open access, if it exists, ensures that it is the first resource to be completely exhausted before producers turn to purchased feeds or rented stubble fields.

Those who lay the blame for the degradation of the steppe at the feet of the economic system, rather than the political and social institutional arrangements per se, suggest a broad range of possible solutions, and they acknowledge that no single solution in isolation from other measures is likely to be successful in reversing the perceived trend towards the total destruction of steppe rangelands.

The solutions may be grouped under at least four headings. First, there is the recognition that the steppe is not (and never was) a closed system. Tadros, Nesheiwat, and Naggar each stress the importance of developing non-livestock economic alternatives for steppe inhabitants. Tadros, Ayyad, and Bedrani concur with Masri and Abaab on the importance of social institutions to regulate the use of range resources, and all mention the desirability of cooperative organizations based on local membership and control. Abaab, Ayyad, Bedrani, and Nesheiwat all call into question the wisdom of present pricing policies and feed supply programs, believing that while they may result in short-term gains in animal production, they jeopardize the long-term ability of national economies to sustain production using domestic resources.

The least controversial of the suggested solutions is the introduction of improved technologies. Without exception, the authors believe that research should be undertaken to introduce more productive rangeland species and to develop more efficient production techniques in dryland cropping systems, including such measures as water harvesting. Improved and adapted varieties of the shrubs atriplex and salsola are the most commonly cited examples of new technologies, but no one is actually able to cite an example of the successful introduction and use of these shrubs. Of course, if new technologies are indeed successful in raising the level of biomass available for sheep, their success begs the question of whether or not the number of livestock would simply increase until a new crisis would arise.

To their credit, all authors express extreme caution regarding the concept of range rehabilitation if this is restricted to reseeding rangeland, whether or not new species are introduced in the process. The point here is that rangeland rehabilitation is not simply a physical or biological question of what has potential to grow and flourish in the ecological circumstances. The authors cite numerous examples of protected experimental sites where ground cover has been (re)established, but from which there has been no productive, economic benefit in terms of livestock grazing. Technical inputs without proper use are useless, and we are warned that control of grazing access needs to be established and organized before rehabilitation can happen.

This leads the authors back to the basic question facing the steppe rangelands of WANA: can or will a management system emerge that will allow the continued high level of exploitation of grazing resources but prevent or discourage the present trend towards destruction of those resources because of over-exploitation? It should be no surprise to anyone that the authors cannot provide an easy solution to this apparent contradiction in marginal land development. [*Rick Tutwiler, based on the individual country studies of A. Masri (Syria), K. Nesheiwat and K. Tadros (Jordan), M. Ayyad and S. El-Naggar (Egypt), A. Abaab (Tunisia) and S. Bedrani (Algeria)*]

4. MANAGEMENT OF SOIL, WATER AND NUTRIENTS

Introduction

The 'project' reported in this chapter embraces both traditional agronomy, including, where appropriate, the economic as well as technical appraisal of field-trial results, and technical studies of soil and water management problems. Several of the reports on water highlighted as a special topic in chapter 2 would normally be placed here; but even without that material the scope of activities covered is wide: from wind erosion (4.1) and soil fertility and analysis (4.2, 4.3 and 4.4) to oilseed crops (4.5), rotations (4.6 and 4.7) and wheat varietal response to supplemental irrigation (4.8). The unifying theme is the management of crops and the agricultural resources supporting them for higher and more sustainable production.

The results of wind erosion studies reported this year (4.1) come largely from FRMP-supported work conducted by colleagues from the Syrian Soils Directorate on farmers' fields in northeastern Syria. Appreciable movement of soil was recorded at only one of the three experimental sites, illustrating again the patchy incidence of wind erosion in both time and space found in previous years. Conservation tillage (soil roughening in strips transverse to the prevailing wind direction), which successfully reduced erosion at one site in Aleppo Province in 1992, appeared actually to promote erosion at the erosive site in northeastern Syria this year. It seems likely that this technique will be successful only where the soil has a reasonably high clay content and some inherent structure.

Until recently, soil fertility research had concentrated largely on the major nutrients, nitrogen and phosphorus. Work on these elements continues, but attention is now also being given to certain minor elements. Reports of toxicity symptoms from a number of sites have prompted a new interest in boron; and the systematic sampling of soils at Bouider station reported here (4.2) shows great variability over very short distances and with depth, with individual point values of soluble boron in the soil ranging from adequate to potentially toxic. It is not yet known how widespread such patchiness is, but even within the confines of a small research station it is liable to interfere with cultivar screening.

Most previous work on soil phosphorus has focussed on inorganic forms and those inorganic processes in calcareous soils that tend over time to reduce the availability of added fertilizer P. In contrast, and in contrast also to work on nitrogen, little account has been taken of organic forms of phosphorus in the soil. Now, new studies (4.3) of the behavior of phosphate added to the soil in organic form (manure), with and without inorganic sources, indicate that the organic material reduced the sorption of phosphate on mineral surfaces and promoted later desorption. The implication, that manuring and other management techniques that add and maintain organic matter in the soil encourage greater availability and more efficient utilization of soil phosphorus, needs to be followed up.

All soil fertility studies depend on the support of reliable analytical laboratories. Reliability of the results provided is particularly important where research findings are collated and compared between research groups in different countries, as in the ICARDA-led soil fertility network. Results recently reported from 22 regional laboratories participating in a network exercise (4.4) showed quite wide divergencies in values for standard analyses of identical soil samples sent to each of them. The reasons for this will be followed up.

Studies on oilseed crops (4.5) have their rationale in FRMP's broader interest in crop rotation and farming systems. The range of commodity options currently open to most rainfed crop farmers is narrow, and it is anticipated that broadening their choice with an appropriate oilseed cash crop could in many situations be beneficial. Macro-economic benefits may also be expected, since at the present time most WANA countries import a considerable proportion of their edible oils. In our trials in the 1992/93 season:

- Rapeseed and mustard yields were disappointing at Tel Hadya, where the rains started late and were below average, but were large enough (around 1.5 t/ha) at Jindiress to be economically interesting.
- Safflower yields were impressive (2-3 t/ha) at Tel Hadya, but less so at Jindiress (around 1 t/ha), where insect pests posed a problem.
- Some open-pollinated sunflower varieties performed as well as the best hybrids, indicating that the production of cheap seed for this crop need not be a problem in Syria. At Tel Hadya, the crop needed supplemental irrigation, 40mm at the early flowering stage, to complete the growth cycle and yield around 2 t/ha. Except where bird damage intervened, Jindiress yields tended to be a little higher than this from completely rainfed growth.

FRMP maintains a number of long-term crop rotation trials at Tel Hadya and Breda, and results are summarized in the Program annual report as and when multi-year runs of data have been recently summarized to monitor trends in yields and soil conditions. This year, two trials are reported. First, the productivity of barley in rotation with a _medicago_ pasture at Breda (4.6). Previous results from Tel Hadya have shown medic to be a disadvantageous alternate crop for wheat, compared with annual forage legumes like vetch, because it dries out the soil profile more thoroughly and so leaves the following wheat crop totally dependent on incident rainfall. At Breda, over five years, barley following medic yielded as well as barley following the legume forage, _lathyrus sativus_, indicating no relative disadvantage to the cereal crop from medic in this environment. This is almost certainly because, under the drier conditions at Breda, very little water is left in the soil by any crop, and -- except sometimes after bare fallow -- all cereal crops depend entirely on incident rainfall.

Results from the two-course wheat rotation trial at Tel Hadya have been given in previous reports. This year, the focus is on the economics of the nitrogen applied to the wheat course in five of the seven rotations in the trial (4.7). As before, the new analysis (of 8 season's data) shows wheat-lentil to be the most profitable rotation, followed by wheat-water melon, with wheat-wheat the least profitable. However, returns to nitrogen on wheat were considerable (in all rotations) up to 60 kg N/ha, declined between 60 and 90 kg N/ha, and appear low and very risky above 90 kg N/ha. The extent to which water may be stored in the soil profile over the summer for use by the wheat crop is important in this trial also. The amount stored depends on the nature of the preceding crop (wheat, chickpea, lentil, water melon or fallow) and the preceding season's rainfall. Ex-post analysis indicates that adaptive management (ie N-fertilizer rates adjusted annually to take account of preceding rainfall) would have increased gross margins by a mean of 13% over the 'optimum' rate based on a simple eight-season average. Greatest increases (22 and 36%, respectively) were in wheat-chickpea and wheat-wheat, rotations that are most likely to suffer water limitations.

While it is well known that, under suboptimal rainfall conditions, wheat responds well to supplemental irrigation, in WANA most wheat varieties have been developed either for drought-resistance in rainfed farming or for maximum yield in fully irrigated farming; and none have been characterized for their suitability for supplemental irrigation. Two trials initiated at Tel Hadya in 1992 compare four promising varieties each of bread wheat and durum wheat, under different planting dates, N-fertilizer rates and supplemental irrigation regimes (4.8). It is intended that these trials, continued over several years, will also provide a detailed, systematic data set to aid the construction of a supplemental irrigation model. The first season's results indicate real differences between wheat varieties in their response to supplemental irrigation; and important interactions, between water and nitrogen rates and between these two treatments and planting time, are evident.

4.1 Wind Erosion in Northeast Syria

4.1.1 Introduction

Through the efforts of staff of the Syrian Soils Directorate, wind erosion studies, previously limited to Aleppo Province (FRMP 1992, 1993), were extended to Raqqa and Deirezzor Provinces for the erosive season of 1993. This report presents measurements at three locations, where soil type and surface conditions were quite different from those that had been studied in Aleppo.

The main aim of the study was to quantify the relationships between erosion and climatological conditions, soil type and surface conditions, land use and land management practices; but, to evaluate the potential for simple soil conservation measures that could be used by local farmers, a conservation tillage treatment was included at two of the sites.

4.1.2 Materials and methods

Wind erosion was studied at Resaffeh, Mezile and Gezira (Table 4.1.1), locations in the marginal area where mean rainfall is close to 200mm. Surface cover, crusting and roughness were measured on a 20 x 10 grid ($1m^2$). Surface cover and crusting were then calculated as area percentages, and surface roughness as the standard deviation of the heights (cm). Aggregate size was obtained by gentle hand sieving of the surface soil using laboratory test sieves.

Table 4.1.1 Wind erosion study sites, 1993 in Deirezzor - Raqqa Province

No.	Location	Field	Prev. crop	Harvest/tillage details
1	Ressafeh	ERBG	Barley	Not harvested, not grazed
2	Ressafeh	ERNV	Natural veg.	Grazed
3	Mezile	EMBC	Barley	Combine harvested, then grazed
4	Mezile	EMBT	Barley	As 3, then ducksfoot tillage (20%)
5	Gezira	EGBC	Barley	Combine harvested, then grazed
6	Gezira	EGBT	Barley	As 5, then ducksfoot tillage (20%)

Ducksfoot tillage (20%) is one pass of a ducksfoot cultivator every 10m, disturbing about 20% of the total surface.

For wind erosion measurements, modified BSNE-samplers were used. The samplers are designed to collect airborne material under natural field conditions, at 5, 10, 20, 50 and 100 cm above the soil surface. On each field, three samplers were installed in a downwind direction, 100 meters apart. In front (upwind) of the first sampler, a 10m wide non-erodible boundary was created by roughening the soil with a ducksfoot cultivator. At this sampler no local erosion occurred, providing a background value for airborne material derived from other areas. Vertical integration of the data from the five heights was used to calculate the total quantity of soil passing the samplers.

4.1.3 Results

Wind speed and soil surface conditions: During the erosive season of 1993, wind speeds at Tel Hadya were above average (Table 4.1.2). In July, the month with the highest wind speeds, values were slightly below average. For Raqqa, no long term wind data were available, but wind speeds during the 1993 season were similar to those at Tel Hadya. Soil surface conditions were measured at the beginning and end of the erosive season. The conditions at the six studied fields are shown in Table 4.1.3.

Table 4.1.2 Average wind speed (m/s) at 2m height at Tel Hadya and Raqqa

		June	July	August	September	**Average**
1981-1992	T.H	3.2	5.2	4.3	3.0	**3.9**
1993	T.H	3.7	5.0	4.7	3.3	**4.2**
1993	Raqqa	2.9	4.9	5.1	-	

Table 4.1.3 Vegetation cover (%), surface crusting (%), surface roughness, aggregate size (%) at the beginning and the end of the erosive season

					Aggregate size		
No.	Field	Veg.	Cru.	Rou.	>1mm	0.1-1	<0.1mm
(A) Beginning erosive season: June 1993							
1	ERBG	**15**[a]	**90**	0.8	19.3	62.4	18.3
2	ERNV	**30**	**30**	**1.5**	1.6	83.7	14.7
3	EMBC	5	0	0.5	9.9	73.1	17.0
4	EMBT	5	0	**T**[b]	14.8	69.5	15.7
5	EGBC	**15**	**10**	0.8	15.5	71.2	13.3
6	EGBT	**15**	**10**	0.8	**23.9**	64.2	11.9
(B) End erosive season: September 1993							
3	EMBC	5	0	0.5	8.5	73.1	18.4
4	EMBT	5	0	**T**[b]	12.6	70.1	17.3
4b	EMNEB	0	0	**2.8**	16.0	65.9	18.1
5	EGBC	8	2	0.8	19.1	68.5	12.4
6	EGBT	4	2	0.8	18.0	68.9	13.1

a) Bold face values indicate conditions that provided protection against wind erosion; b) T means conservation tillage

Wind erosion measurements. The measuring period and total amounts of collected soil are shown in Table 4.1.4. An increase of collected soil at the second and third sampler indicates that local erosion occurred downwind from the first sampler.

Table 4.1.4 Total amount of collected soil (kg/100m width) at three pins in down-wind direction, for the six fields (1993)

Field	Period	Pin 1	Pin 2	Pin 3
ERBG (1)	21/6-28/9	100	35	36
ERNV (2)	-	53	45	78
EMBC (3)	22/6-28/9	1192	552	2993
EMBT (4)	-	1797	9112	7026
EGBC (5)	24/6-27/9	185	176	183
EGBT (6)	-	186	246	267

Local erosion occurred from the fields at Mezile (3 and 4). In both fields a similar amount of soil was collected at the first sampler (background value) and larger amounts downwind. The absence of a clear lateral increase was probably due to the high variability of vegetation cover and crusting in the two fields.

In the grazed field (EMBC) the amount of collected soil increased from the second to the third sampler. The erodibility here, with transportable aggregates (<1mm) over 85%, was very high (Table 4.1.3), and the vegetation cover and crusting were too limited to protect the fine particles from movement.

In the neighboring field, where conservation tillage covered 20% of the surface (EMBT), much more local erosion occurred. Most soil was collected at the second sampler, with a slight reduction at the third sampler. In this field, erodible conditions were similar to those in the grazed field (Table 4.1.3), and, apparently, the conservation tillage increased rather than reduced the amount of erosion. Measurements made in the tillage lines (EMNEB in Table 4.1.3) showed 84% transportable soil aggregates, indicating that only a few non-erodible clods had been brought to the soil surface by the tillage. Also, the tillage lines had no vegetation cover or crusting. Further, the increased surface roughness may have increased the turbulence of the airflow; and, since the tilled surface was very erodible, this may explain the higher soil loss.

At Ressafeh, no local erosion occurred in the barley field (ERBG). At the beginning of the erosive season, the percentage of crusted surface was very high. The plan was that the barley would be grazed in June, gradually increasing the erodibility of the field; but the farmer, afraid that the sheep might damage the samplers, did not graze the field. The field was therefore very well protected against erosion by the vegetation cover and the surface crusting. In the natural vegetation (ERNV) little erosion occurred. Grazing and sheep movement was limited because the vegetation consisted largely of non-palatable species. The combined effect of vegetation cover and surface crusting was adequate to prevent any wind erosion.

In the barley field at Gezira (EGBC) similar amounts of soil were collected in all three samplers, indicating that no local erosion occurred. In the neighboring field with conservation tillage (EGBT) there was a minor lateral increase in collected soil towards the third sampler. At the beginning of the erosive season the fields had been well protected by a surface cover of 15% and surface crusting of 10%, but conditions became more erodible towards the end of the season as a result of grazing (Table 4.1.3). Probably, highest wind speeds occurred when the fields were still protected, explaining the limited total erosion. The slightly greater amounts of soil collected in the field with conservation tillage may be explained in a similar way to the findings at Mezile.

Local erosion from the grazed barley field at Mezile. During the erosive season of 1993 nearly 2.5 tons/ha of soil was lost from the grazed barley field (EMBC) and over 7 tons/ha from the field with conservation tillage (EMBC). Amounts of soil collected during individual recording periods are shown in Table 4.1.5. At both fields most soil was collected in the last week of August. For the field with conservation tillage this was 46% of the season's total; for the grazed field 37%. Highest average daily wind speed in this period was 6.1 m/s. In the second week of July, similarly large quantities were collected. Highest average daily wind speed was 6.9 m/s. Other periods that showed some lateral increase are also shown in Table 4.1.5. In general, local erosion occurred in those recording periods where the highest average daily wind speed exceeded 6 m/s.

Size distribution (Table 4.1.6) and chemical composition (Table 4.1.7) were determined on samples of soil collected during different recording periods. For both fields and all periods the material collected at the first (upwind) sampler was very fine. Near the soil surface (5 cm), around 70% of the soil was in aggregates smaller than 0.1mm, rapidly increasing to over 90% at 50 cm height (Table 4.1.6). For each field the vertical distribution of aggregate sizes was similar for the different recording periods. The saltation fractions (>0.1mm) in the large samples collected during the last week of August were similar to those of the smaller combined samples collected over several less windy weeks (Table 4.1.6). For all recording periods the field with conservation tillage (EMBT) gave a larger fraction of saltation material at all heights above the ground (Table 4.1.6). At the second sampler of

Table 4.1.5 Measuring period and amount of collected soil (kg/100m width) from the barley field (a) and conservation tillage field (b) at Mezile (1993)

a) Field EMBC (3)

Period		Pin 1	Pin 2	Pin 3
10	26- 1/9	224	195	1137
3	8-14/7	377	155	935
4	15-21/7	22	14	114
7	5-11/8	74	33	188
8	12-18/8	28	20	68
9	19-25/8	20	17	41
		144	**83**	**410**

b) Field EMBT (4)

Period		Pin 1	Pin 2	Pin 3
10	26- 1/9	706	4186	2549
3	8-14/7	608	2950	2289
4	15-21/7	34	445	177
7	5-11/8	69	532	621
8	12-18/8	68	329	362
9	19-25/8	31	107	73
		202	1486	1233

the grazed field (EMBC) very little soil was collected at all (Table 4.1.5), and this is reflected in the fine size of this material (Table 4.1.6).

Table 4.1.7 shows the chemical composition of the airborne material collected during the last week of August (10), the second week of July (3) and during several smaller storm events (4789) in the two fields at Mezile. For both fields, the organic matter content of this material was highest in samples collected at the first sampler, the background value. Organic C increased only slightly with height and the average enrichment compared to the field soil was 2.7. At both fields, locally eroded soil (samplers 2 and 3) showed a clear increase in organic C with height. Vertical distribution was similar for the different recording periods. On average, enrichment ranged from 1.7 at 5 cm above the soil surface to 2.4 at 100 cm (grazed barley field) and from 1.4 to 2.4 (field with conservation tillage).

Table 4.1.6 Size distribution (%) of airborne material sampled at heights of 5, 10, 20, 50 and 100 cm from the barley field (EMBC) and conservation tillage field (EMBT) at Mezile (1993) during different weeks of the erosive season

	Pin 1					Pin 2					Pin 3				
	5	10	20	50	100	5	10	20	50	100	5	10	20	50	100
EMBC10: 26/8 - 1/9															
0.1-1mm	22	17	7	4	3	15	10	5	3	2	58	50	22	11	3
< 0.1mm	78	83	93	96	97	85	90	95	97	98	42	50	78	89	97
EMBT10: 26/8 - 1/9															
0.1-1mm	19	14	9	6	3	67	67	44	19	7	70	68	51	15	3
<0.1mm	81	86	91	94	97	33	33	56	81	93	30	32	49	85	97
EMBC3: 8-14/7															
0.1-1mm	33	29	16	7	4	13	17	6	3	2	48	41	25	7	3
< 0.1mm	67	71	84	93	96	87	83	94	97	98	52	59	75	93	97
EMBT3: 8-14/7															
0.1-1mm	18	14	16	7	3	65	69	43	12	5	68	67	48	16	7
< 0.1mm	82	86	84	93	97	35	31	57	88	95	32	33	52	84	93
EMBC4789*															
0.1-1mm	36	30	14	9	4	32	17	11	5	5	56	45	29	7	4
< 0.1mm	64	70	86	91	96	68	83	89	95	95	44	55	71	93	96
EMBT4789*															
0.1-1mm	29	19	11	33	4	66	59	48	11	5	68	67	43	13	7
< 0.1mm	71	81	89	67	96	34	41	52	89	95	32	33	57	87	93

(Pin 1 in upwind; pin 3 downwind; pin 2 in between)
* 4789 indicates weeks 4,7,8 and 9 (ie 15-21/5 and 5-25/8)

Olsen-P values were highest in material collected at the first sampler, with an average enrichment of 1.4. Locally eroded soil from the grazed barley field showed a similarly modest increase with height for both recording periods, with enrichment ranging from 1.2 at 5 cm to 1.5 at 100 cm. For conservation tillage, there was no clear increase in enrichment with height, and the average value was 1.3.

4.1.4 Discussion

Conservation tillage, that is roughening about 20% of the soil surface with a ducksfoot cultivator in a direction transverse to that of the prevailing wind, was tested in a hand-harvested barley field at Urdjl (UBH), Aleppo Province in 1992; and it reduced a soil loss of nearly 1 t/ha to almost zero (UHT). In 1993, it was tested at Mezile and Gezira in barley fields where combine harvesting had been followed by grazing. However, at these locations different soil surface conditions obtained, and at Mezile and to a lesser

Table 4.1.7 Organic matter content (%) and Olsen-P (ppm) at Mezile, grazed barley field (EMBC) and conservation tillage (EMBT) (airborne material collected at 5, 10, 20, 50 and 100 cm for three samplers in down-wind direction) during different means of the erosive season

	Sampling height (cm)				
	5	10	20	50	100
Organic matter (%)					
Field soil: 0.81					
EMBC (10) sampler 1	2.08	2.06	2.27	2.28	2.27
EMBC (10) sampler 3	1.24	1.44	1.80	2.02	1.81
EMBC (3) sampler 3	1.41	1.54	1.95	2.09	2.12
EMBC (4789) sampler 3	1.46	1.54	1.85	2.12	2.00
EMBT (10) sampler 1	2.13	2.27	2.33	2.33	2.06
EMBT (10) sampler 2	1.00	0.98	1.36	1.75	1.82
EMBT (3) sampler 2	1.30	1.06	1.48	2.01	1.97
EMBT (4789) sampler 2	1.10	1.27	1.27	2.03	2.27
Olsen-P (ppm)					
Field soil: 6.5					
EMBC (10) sampler 3	8.4	8.9	9.4	10.1	-
EMBC (3) sampler 3	7.6	8.6	9.0	9.9	-
EMBT (10) sampler 1	-	9.6	9.5	12.3	9.1
EMBT (10) sampler 2	8.6	7.2	8.9	8.8	-
EMBT (3) sampler 2	7.9	7.3	8.0	8.6	-
EMBT (4789) sampler 2	9.7	7.5	8.5	-	-

extent Gezira, conservation tillage did not prevent local wind erosion but rather accelerated it.

Differences in the effectiveness of conservation tillage in preventing local wind erosion can be explained by differences in the soil surface conditions (Table 4.1.8). Both at Urdjl (UBH) and Mezile (EMBC) there was very little vegetation cover, surface crusting or surface roughness. At Mezile, there were more transportable particles at the soil surface, especially in the suspension fraction (<0.1mm). The major differences were in the surface conditions that resulted from the tillage operation. At Urdjl, the roughness in the tillage lines was extremely high as large non-erodible clods had been brought to the soil surface (Table

4.1.8). These clods protected the small aggregates from surface exposure. At Mezile, conservation tillage increased the surface roughness significantly, but the exposed material was just as erodible as the field soil (Table 4.1.8). The tillage lines provided shelter and reduced the wind speed but increased the turbulence of the airflow. Since transportable particles were available in these tillage lines soil loss actually increased.

Table 4.1.8 Vegetation cover (%), surface crusting (%), surface roughness, aggregate size (%) in the hand-harvested barley field (UBH) at Urdjl (1992), the grazed barley field (EMBC) at Mezile (1993) and the tillage lines in these two fields

No.	Field	Veg.	Crust	Roughness	>1mm	0.1-1	<0.1mm
1	UBH	1	9	1.0	27.0	69.0	4.0
2	UBHTIL	0	0	**5.5**	-	-	-
3	EMBC	5	0	0.5	13.0	70.0	17.0
4	EMBCTIL	0	0	2.8	16.0	65.0	18.0

At Urdjl, 80% of the locally eroded soil collected at 5 cm height was in the saltation fraction (0.1-1mm) reducing to 34% at 100 cm. At Mezile, corresponding values were 60% at 5 cm and 3% at 100 cm, reflecting the composition of the material at the soil surface. The enrichment of the airborne material relative to field soil ranged for organic matter from 1.3 to 2.8 at Urdjl and from 1.7 to 2.4 at Mezile, and for Olsen-P values from 1.2 to 2.4 at Urdjl and 1.2 to 1.5 at Mezile. The percentage of non-erodible particles at the soil surface was larger at Urdjl than at Mezile. The removal of soil by wind erosion was therefore more selective than at Mezile, explaining the more distinct vertical gradient in particle size, organic C and Olsen-P in the airborne material at Urdjl.

4.1.5 Conclusions

Conservation tillage, as applied in this study, does not provide a simple and straightforward solution to the problem of wind erosion all over Syria. Its effectiveness depends on the creation of strips with surface erodibility lower than that of the untilled soil. The technique could be useful in marginal areas with heavy soils that are subject to pulverization each summer when flocks of sheep graze off all the stubble. Here, conservation tillage would bring large non-erodible clods to the soil surface that reduce wind erosion and trap eroded soil. In areas where lighter soils with little or no aggregation occur, conservation tillage will not be effective and may even accelerate wind erosion.

At Gezira, where quite erodible conditions occurred, a limited vegetation cover of 15% already provided substantial protection. For these highly erodible soils, future research should focus on developing and testing conservation measures that include establishing or maintaining a vegetative cover during the erosive season. Almost certainly, this would require more effort from the farmers than a simple tillage operation; and such a vegetative cover, unless unpalatable, would be difficult to maintain in a dry year when feed for the sheep was in short supply. [***Ben Timmerman with major technical assistance from Pierre Hayek, FRMP, and Messrs Maher Tawil and Bashar Akkad from the Soils Directorate, MAAR***]

4.2 Implications of Soluble Soil Boron at Boueidar Station

4.2.1 Introduction

Boron is an essential trace element needed in small amounts for crop growth. As with other micronutrients, problems with B nutrition, whether deficiency or toxicity, are widespread. Indeed, B is unique in that the range between deficient and toxic levels is narrow. While deficiency, generally indicated by less than 0.5 ppm hot water-soluble B in the soil, is the more common problem globally, the limited soil and plant analysis data suggest that deficiency may not be common in West Asia and North Africa (WANA) (Khan et al. 1979; Sillanpaa and Vlek 1985). However, excess B is increasingly being recognized as a problem, especially in semi-arid and arid areas and where irrigation is practiced. Soil B concentrations of just a few ppm, whether naturally occurring in the soil or added in irrigation water, can be toxic to the plant (Ryan et al. 1977).

Boron toxicity, recognized as a serious and widespread problem in dry areas of South Australia with a Mediterranean climate (Cartwright 1986), may also be a widespread problem in dryland areas of WANA. In a world survey of tropical and subtropical countries, the Mediterranean was the region with the highest B concentration in the topsoil (Sillanpaa and Vlek 1985). So far, apparent B toxicity symptoms in winter cereals and/or high soil B have been found near Aleppo, Syria, near Eskisehir and Konya, Turkey, and on the northwest coast of Egypt. Toxicity symptoms in barley have also been observed near Mosul in northern Iraq.

Boron toxicity can cause substantial reductions in grain and straw yield (Cartwright et al. 1984; Moody et al. 1993). Since treating the soil to remove or reduce the effect of B, e.g. by leaching, is difficult, selecting or breeding crop cultivars with high tolerance/resistance to B toxicity is the most promising approach. In fact, the variability of B distribution, vertically with soil depth and horizontally, often makes reliable field screening of breeding lines difficult, but large numbers of entries can be screened in the greenhouse with B-amended soil. Dr S. Yau of the Germplasm Program has recently initiated studies of this type to evaluate the tolerance of ICARDA'S advanced international nursery lines (Yau et al. 1994).

Soil fertility research and chemical analysis at ICARDA has so far concentrated on nitrogen and phosphorus, but concern that micronutients may also pose crop growth constraints is increasing. Since B toxicity has been identified as a cause of reduced growth and specific symptoms in barley in similar semi-arid environments, it was postulated that high soil B might be the cause of similar symptoms in barley at Boueidar station. As this site is used for barley trials, it was important to establish if soil B concentrations were higher than normal and how variable B was throughout the field.

4.2.2 Procedure

The Boueidar site (about 10 ha) is the driest of ICARDA'S arable experimental sites (mean annual rainfall, 225mm) and is used almost exclusively for work on barley. In any one year, half of the site is cropped with cereal and the other half left fallow. In the fall of 1992, we selected an area of 250 x 160m in the area cropped the previous season. Surface samples of soil were taken by augur to a depth of 20 cm every 10m in each direction (north-south; east-west) in a rectangular sampling grid. Depthwise samples were taken in a systematic manner to represent as far as possible the experimental area. The samples were subsequently analyzed for water-soluble B using the Azomethine-H colorimetric method.

4.2.3 Results and Discussion

The surface spatial distribution of water-soluble B at the experimental site is depicted in three dimensions in Figure 4.2.1 and by contouring in Figure 4.2.2. Currently, we are using kriging to describe the variability patterns. It is evident that, even within this small site, much variability exists, shown by peaks in Figure 4.2.1 and "islands" in Figure 4.2.2. Values ranged from a low value of 0.87 ppm -- just above what is considered adequate for crop growth -- to 6.6 ppm, which is potentially toxic.

As B is believed to be passively absorbed by the plant and to accumulate in the plant tissue in proportion to the transpiration, the growth of sensitive species such as barley could be adversely affected at the higher B concentrations found. (The implications of B uptake in high-B soil in relation to temperature and transpiration is currently being investigated by Dr M. Mahalakshmi of the Germplasm Program.) This probably accounts for the erratic distribution of apparent B-toxicity symptoms observed at Boueidar.

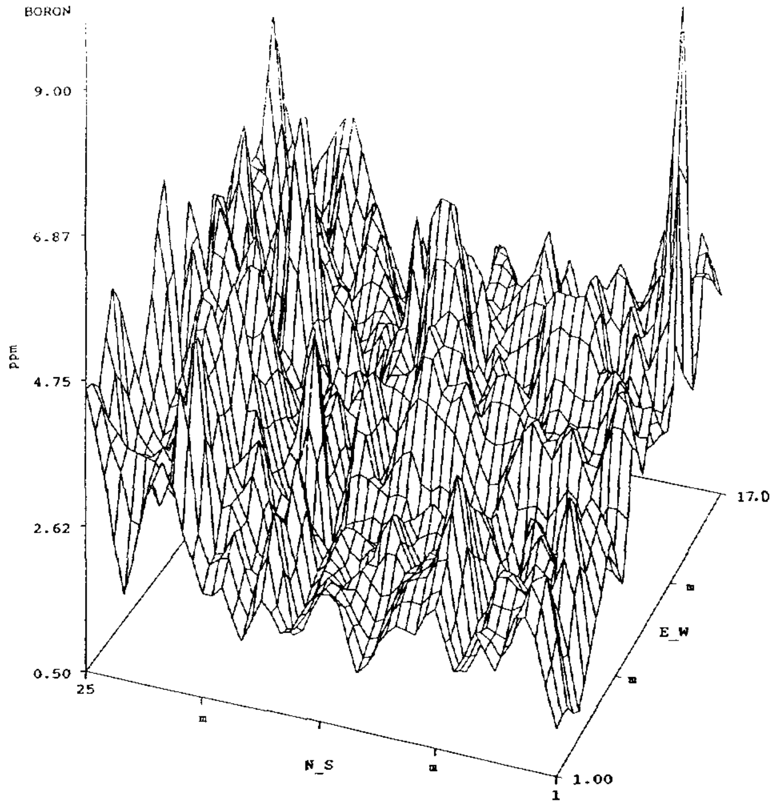

Figure 4.2.1 Three-dimensional representation of spatial variability of water-soluble boron in the surface soil of a field at Boueidar, Aleppo Province

The variable topsoil distribution of soluble B has to be considered in the design of field trials involving B-sensitive crops, but surface differences may be compounded by variations with depth. Surprisingly, depthwise distribution of soluble B at Boueidar exhibited, not one, but three distinct patterns (Figure 4.2.3). Profiles 5, 8 and 9 showed consistent B increases with depth in contrast to profiles 3 and 7, which were uniform with depth. In drier areas such as Boueidar, one might anticipate increased B with depth due to the limited depth of natural leaching environment, and most profiles (1, 2, 4, 6, 10) showed B accumulation at depths from 20 to 60 cm. In view of the fact that plant roots are in contact with this B-rich layer, the issue of variability of B toxicity is even more complex.

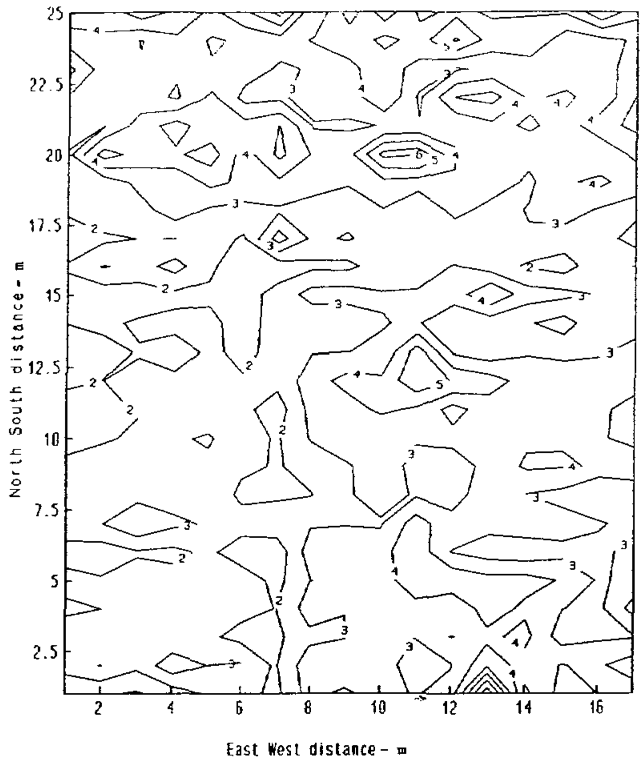

Figure 4.2.2 Representation of spatial variability of boron by isograms of water-soluble content (ppm B) of surface soil of field at Boueidar

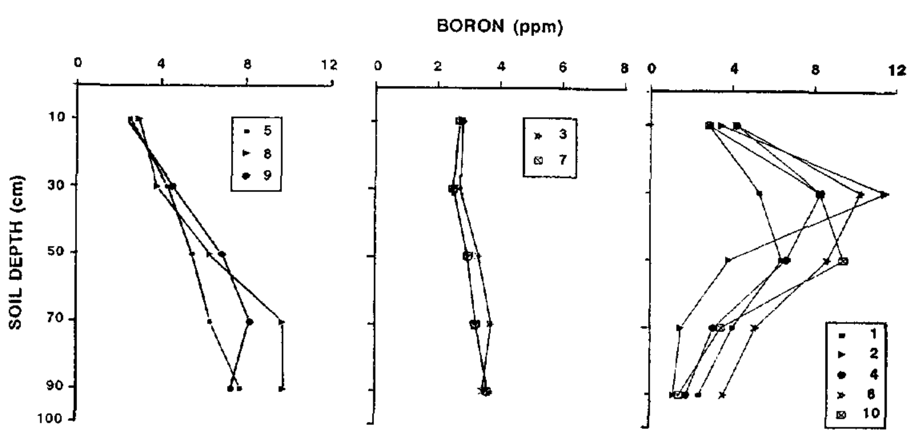

Figure 4.2.3 Patterns of depthwise distribution of water-soluble boron in various profiles at Boueidar

This brief study has signalled the potential importance of B in drier areas of WANA and has served as a catalyst for related screening and physiological investigations which are currently under way. [*J. Ryan and M. Singh (CBSU), with the technical assistance of S. Masri*]

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4.3 Phosphorus Solubility Changes with Time in Organically Amended Soil

4.3.1 Introduction

The mainly calcareous agricultural soils of the Mediterranean region are often seriously deficient in available phosphate (Matar et al. 1992), and efforts to improve native P availability and enhance fertilizer efficiency continue to dominate the research agendas of soil fertility scientists. However, studies of the dynamics of soil P have largely centered around the inorganic forms which are seen to control the complex soil chemistry of this element. Organic forms have received much less attention.

When a soluble P compound is added to soil the reactions that follow mainly involve surface adsorption and precipitation. Phosphorus sorption is affected by ambient conditions and soil properties. Sorption in calcareous soils is rapid during the initial contact phase (Ryan et al. 1985a). Subsequently, the availability of this sorbed phosphate decreases with time (Ryan et al. 1985b) because of slow reactions, which are also affected by soil and environmental conditions (Barrow 1974; Sharpley 1985). The outcome of both short and long-term reactions affects plant P recovery; the more P that is "fixed" in insoluble form, the less is available for plant uptake.

In contrast to the wide interest in organic nitrogen and its mineralization, remarkably little consideration has been given to organic P mineralization even though organic forms may constitute from 15 to 80% of the total amount of P in soils (Thien and Myers 1992) and in soil extracts. There is a need to consider the organic fraction in such tests for P availability as the Olsen *M* $NaHCO_3$ method, which measures only inorganic P but extracts both organic and inorganic P fractions.

The use of organic fertilizers has a long history. Now, increasing urbanization and environmental concerns have stimulated interest in the agricultural use of sewage sludge and municipal wastes, particularly in the Middle East. In addition to supplying N, organic fertilizers supply soils with available P and maintain P concentrations in the soil solution for a longer time than similar applications of inorganic sources (Abbott and Tucker 1973). Sharpley (1985) showed the importance of organic P as a source of available P, particularly the more labile fraction.

While P sorption by soils fertilized with inorganic P fertilizers has been extensively investigated, sorption by soil amended by organic materials alone or in combination with inorganic fertilizers is less clearly documented. As the effect of fertilizers is time-dependent, it is important to examine such changes in P with time. In one of the few such studies, Majid and Nielsen (1992) showed that inorganic P in a soil extract was lowest in winter and highest in spring, while the converse was true for soluble organic P. However, seasonal P variation was dominated by physico-chemical processes which masked the biological P transformations.

4.3.2 Materials and Methods

Soil: The calcareous soil used was from 0-20 cm surface layer at the Faculty of Agriculture Farm of Tishreen University in Lattakia on the north-west coastal plain of Syria. Its properties were: sand, silt and clay, 8, 31, and 61%, respectively; pH, 7.9; organic matter, 2.6%; electrical conductivity, 0.13 mS/cm; exchangeable Ca and Mg, 20 and 0.8 meq/100 g, respectively; total $CaCO_3$, 60%; and 12 ppm $NaHCO_3$-P.

Treatments: 5 kg samples of sieved soil were placed in 5 l pots, with 3 replicates each of: (1) untreated control, (2) farmyard manure added at 5% of the soil weight; (3) inorganic P as triple superphosphate added at 100 mg/kg soil, and (4) organic and inorganic materials (5% farmyard manure + 100 mg P/kg soil) both added.

The pots were placed in the open air for 19 months, from October 1990 to May 1992, and experienced typical Mediterranean (Xeric) climate conditions, winter rainfall and lower temperatures, and summer dryness with higher temperatures (Figure 4.3.1). Samples were removed from the pots every 2 months for the determination of available P by the Olsen method.

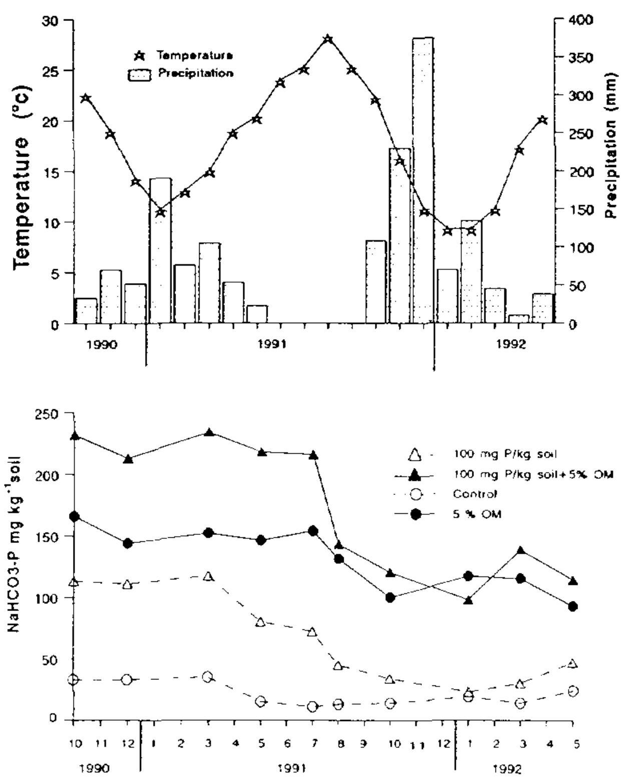

Figure 4.3.1 Change in $NaHCO_3$-extractable soil P (Olsen) over time with monthly precipitation and temperature data

Adsorption, Desorption: At the end of the incubation period, duplicate 2 g samples of soil representing each treatment were equilibrated with 25 ppm P solution (0-100 mg/l as KH_2PO_4) by shaking for 22 h. Samples were subsequently centrifuged and filtered, and P determined colorimetrically. The amount of P sorbed by the soil was considered as the difference between that added and that in the equilibrium solution. The data were used to construct an adsorption isotherm according to the conventional Langmuir equation. For desorption, the samples of soil which had been equilibrated with 80 ppm P (as KH_2PO_4) were extracted daily with 25 ml dionized water by shaking for 22h, followed by centrifigation and P determination; the process was repeated daily for 20 consecutive days.

4.3.3 Results

As might be anticipated, the addition of manure increased the carbon content of the soil, from 1.36% to 1.91%. Similarly, addition of manure increased water-soluble P from 1.8 ppm in the control soil to 17.9 ppm, whereas the 100 mg P/kg soil treatment raised soluble P to only 5.3 ppm. Soluble P in the combined treatment was 23 ppm, essentially an additive effect.

The different rates of P, added in organic or inorganic form, led to widely different available P values at the initial sampling in October 1990: from 33 ppm in the control to 113 ppm after superphosphate, 160 ppm after manure and 232 ppm after both (Figure 4.3.1). The most notable feature, however, was the pattern of seasonal change. During the late fall and winter period until March, there was, in essence, no change in the content of extractable P with time in either amended or unfertilized pots. This period coincided with that of winter rainfall and decreasing air and soil temperatures. After March, while rainfall decreased and ambient temperatures increased, P values for the control and the superphosphate-treated pots began a steady decline. However, where superphosphate had been added with manure, extractable P declined to the same level as that from manure alone, and then values from both treatments remained at a similar plateau till the end of the observation period in May 1992.

Thus, *while soluble fertilizer P reverted over time to more stable and therefore less available forms, the rate of this change was influenced by the presence of added organic material*. When the relative percentage change in extractable P was plotted against time, the rate of change was less for the manure-amended soil with and without superphosphate than for that amended only with superphosphate (Figure 4.3.2). This clearly shows the greater residual value of manure in supplying P. It raises the question as to what beneficial effect the organic material had on the residual value of the inorganic P alone and how it might affect P sorption.

Not surprisingly, sorption curves for the soils residual from each treatment at the end of the observation period showed clear

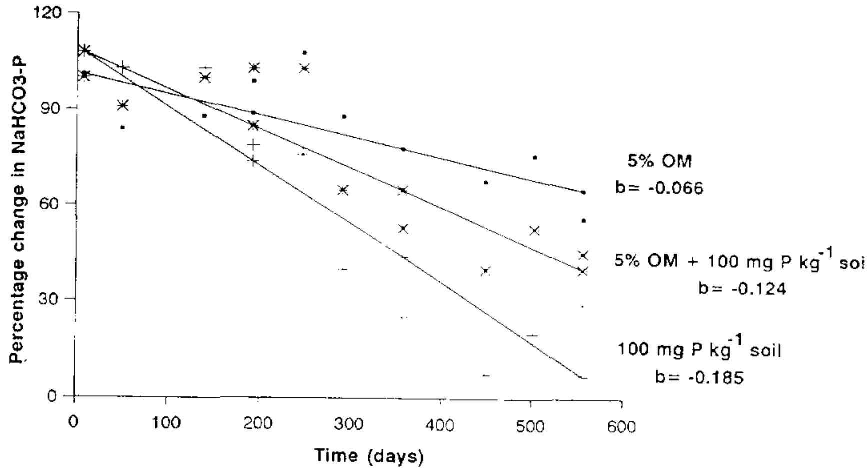

Figure 4.3.2 Rate of change in $NaHCO_3$-extractable soil P (Olsen) as function of time

differences due to initial treatment (Figure 4.3.3). Adsorption was significantly less in manure-amended soils for any given level of P in the equilibrium solution; the curves for manure with or without P were similar. When plotted according to the Langmuir equation, straight-line isotherms resulted. Adsorption maxima were highest for the control and the superphosphate-treated soil, 465 and 446 mg/kg, respectively. Corresponding values for the manured soil were 420 and 424 mg/kg for manure alone and combined with P, respectively. Bonding energy values were also lower for the manured treatments (0.033 and 0.030) compared with the control (0.052) and the superphosphate (0.038) treatment.

The prior addition of manure, alone or in combination with inorganic P, reduced the total amount of P sorbed. The amounts desorbed and the desorption/sorption ratio were accordingly also reduced. However, nearly 100% of the P added to manured soil was desorbed over a period of 20 days with daily extraction. The initial extraction removed 40-50% of sorbed, dropping to 15-25% at the second extraction and gradually decreasing thereafter. After the second extraction, the relative amounts of P removed were similar for samples of manured and unmanured soils.

4.3.4 Discussion

This preliminary study highlighted aspects of the behavior of P from both organic and inorganic sources applied to soil under typical Mediterranean climatic conditions. In contrast to the initially

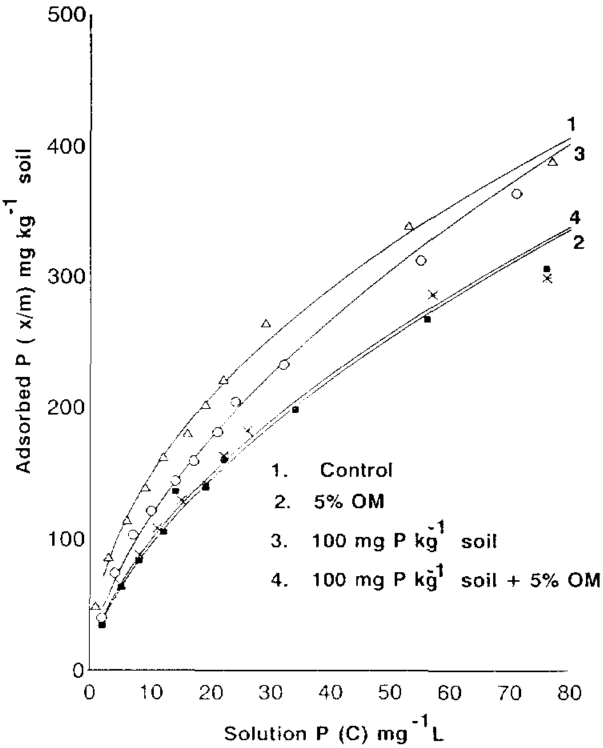

Figure 4.3.3 Phosphorus adsorption isotherms

rapid and subsequently gradual reversion rate of applied inorganic P (Ryan et al. 1985b), availability of P from organic sources appeared as two "plateaux": no significant change in extractable P during the cool wet season (late fall to early summer), followed by a precipitous drop to a lower level with the onset of the drier hot summer season. This was probably due to conditions favoring chemical precipitation. The presence of organic matter should mitigate this effect, and the extraction data suggest that dry-season P availability would be lower in the control soil.

Although the levels of organic matter used in this pot study were higher than normally used in the field, except perhaps in greenhouses, and the levels of $NaHCO_3$-P higher, it is clear that the seasonal effect on P is dominant. Given the negative interaction between inorganic P and soil moisture, it is likely that the seasonal effects on inorganic and organic P observed by Majid and Nielsen (1992) for temperate region soils would be more pronounced in the Mediterranean area, where summer and winter conditions show greater difference.

Of particular interest in this study was the fact that manure reduced P sorption. The likely reason is that organic anions from organic decomposition formed complexes with mineral components of exposed clay surfaces that would normally attract and retain phosphate ions. One could speculate that, in the field, this effect would reduce the rate of reversion to insoluble P compounds and so promote more efficient plant utilization of P fertilizer. Despite the time-of-soil-contact differences between laboratory shaking and field conditions, it appears that manure also promotes the release of sorbed P.

The changes in the relative proportion of inorganic and organic P fractions in soil extracts highlight the issue of organic P mineralization and immobilization. However, little information is available on the relative proportion of soil P in organic forms or on seasonal variations in P availability in Mediterranean soils. This has implications for soil sampling and testing; the dilemma is that samples are usually taken in the dry season prior to cropping. Actual availability may change with the onset of cooler, moist conditions and thus invalidate whatever recommendations were made from the soil test.

As organic matter contents of Mediterranean soils are low, improved soil management practices should aim to increase them, for example through reduced tillage and better rotations. Long-term trials at ICARDA have shown that rotations in which *Medicago* spp alternate with wheat (*Triticum turgidum* var durum) increased topsoil OM from 0.8% to 1.3% over an 8-year period (Harris et al. 1994). Normally, benefits of increased soil OM are expressed in terms of reduced erosion, through improved aggregation, and improved water-holding capacity. The present study suggests that the improved soil OM status would also impact favorably on P-use efficiency and promote a continuous supply of P to the soil solution through gradual mineralization. The practical implications need to be evaluated in the field through frequent monitoring both of soil moisture and temperature conditions and of the more labile organic and inorganic P forms. [*Leila Habib, Tichreen University, and John Ryan, with grateful acknowledgement to IMPHOS, Casablanca, Morocco, for partial support of this work*]

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4.4 Regional Standardization of Soil Analysis

4.4.1 Introduction

Laboratories in the WANA region which perform soil analysis for available nutrients are operated by Ministries of Agriculture, other state bodies, or by universities. There are very few commercial laboratories. Based on our observations and the diversity that exists in the region, soil testing is variable. In the only study of laboratory procedures in the WANA region that we are aware of, Matar (1985) showed that, although all participating laboratories used the $NaHCO_3$ method for available phosphorus (Olsen et al. 1954), results varied widely. This was attributed to modifications introduced by the operators and conditions specific to individual laboratories.

In view of efforts at ICARDA to coordinate soil and fertilizer use research in the WANA region, our objectives in the present exercise were twofold: (1) to ascertain the range of routine tests performed in soil analysis laboratories, and (2) to compare analytical data for these tests on a reference soil sample supplied by ICARDA to cooperators in these laboratories.

4.4.2 Materials and Methods

A bulk sample of soil, representing the dominant soil type (Vertic Xerochrept) at ICARDA's Tel Hadya station, was prepared by air-drying and sieving through a 2mm screen. Sub-samples (0.5 kg) were sent in plastic containers to government and university soil testing laboratories (one commercial laboratory was included) in the following countries: Syria, Jordan, Iran, Iraq, Pakistan, Yemen, Saudi Arabia, Ethiopia, Lebanon, Turkey, Cyprus, Egypt, Libya, Algeria, Tunisia, Morocco, and, additionally, Spain. A sample was also sent to the USDA-SCS Soil Laboratory in Lincoln, Nebraska, for complete analytical characterization. The data from this laboratory and ICARDA's own laboratory will serve as the reference standards.

Respondents were asked to submit the sample to routine tests performed in their laboratories and report the results on an accompanying questionnaire, coded to preserve anonymity. The following tests were specified in the questionnaire: pH, electrical conductivity (EC), Kjeldahl N, ammonium-N and nitrate-N, organic matter (OM), calcium carbonate ($CaCO_3$), extractable phosphorus (P), total P, cation exchange capacity (CEC), exchangeable cations, extractable micronutrients, and sulfate.

Respondents were also asked to list any other tests which they routinely performed, and whether they did isotope analysis, ie ^{15}N or ^{32}P, or mineralogical analysis, or made recommendations to clients based on soil tests. For each test performed, procedural details were requested, ie air- or oven-drying, soil/solution ratio, shaking time, specific extractant and molarity, determination procedures, instrumentation, units of measurement, and reference methods.

When all questionnaires are returned and the data summarized, a report will be sent to all respondents. It is hoped that this will help laboratories to eliminate unacceptable deviations from "true" test values, where such variation exists.

4.4.3 Results

Of the 50 laboratories contacted, 22 have so far responded. (It is anticipated that 10 to 15 more will respond later, including SCS-USDA at Lincoln). The results presented are based on these 22 respondents. Actual test results are presented in Figures 4.4.1 to 4.4.5, while variations in the analytical methods used are summarized in Tables 4.4.1 and 4.4.2. The highlights of each test or group of tests are summarized here.

Soil Preparation: The samples were prepared by air-drying in all except one laboratory, which used oven-drying (35°C).

pH, EC, $CaCO_3$, CEC (Figure 4.4.1): All laboratories used water to extract the sample except one which used KCl or $CaCl_2$. The soil/solution ratio was mainly 1:2.5 or a saturated paste. With a mean of 8.0, pH values obtained ranged from 7.2 to 8.9. Similarly, with a mean of 0.37 mS/cm, EC values ranged from 0.10 to 1.20.

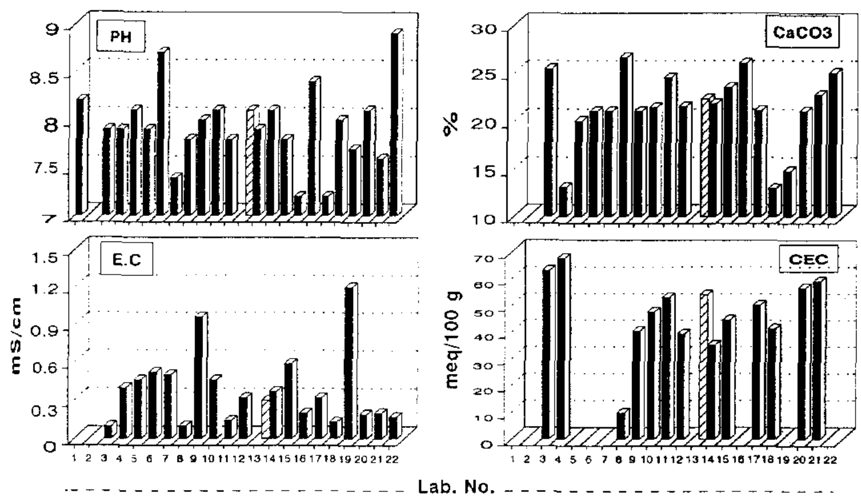

Figure 4.4.1 Laboratory test values for pH, electrical conductivity, calcium carbonate, and cation exchange capacity

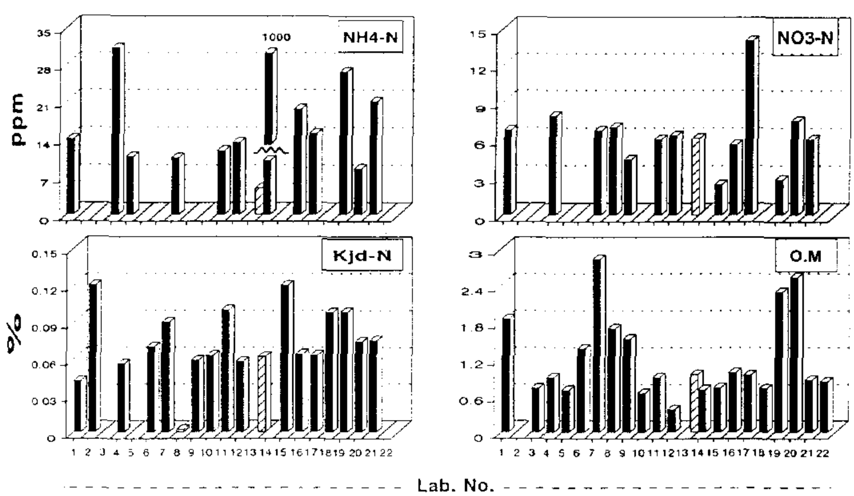

Figure 4.4.2 Laboratory test values for organic matter and various nitrogen forms

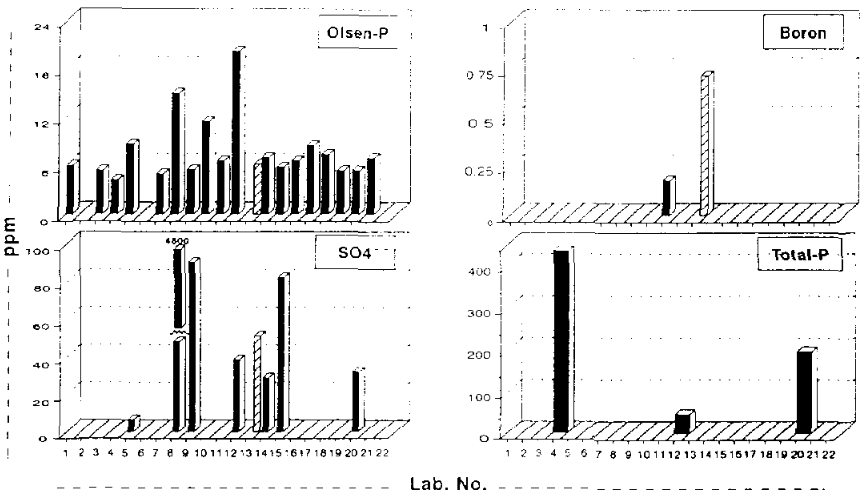

Figure 4.4.3 Laboratory test values for sulfate, boron, and available and total phosphorus

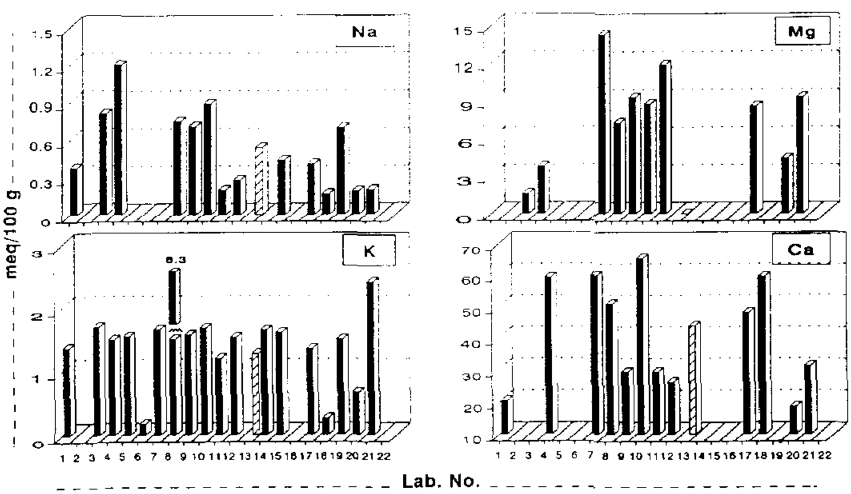

Figure 4.4.4 Laboratory test values for extractable cations

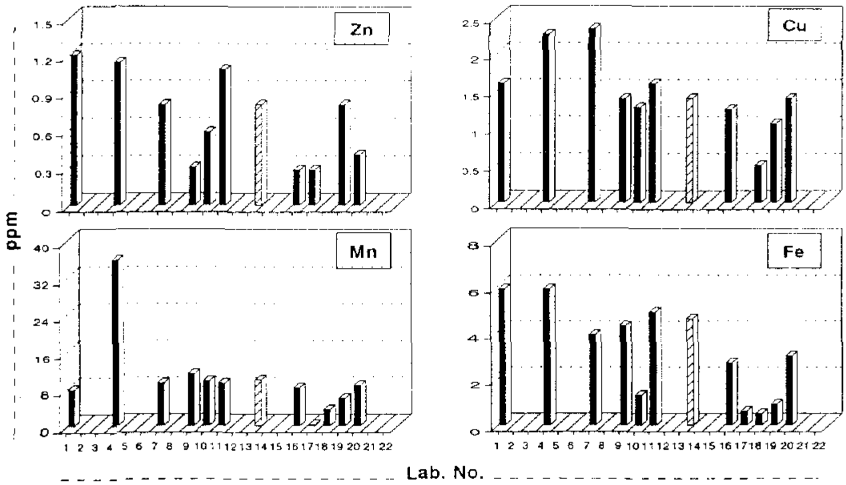

Figure 4.4.5 Laboratory test values for extractable micronutrients

Table 4.4.1 Determination variables for general soil properties

Measurement	Procedure details (No. of labs in parentheses)	
pH, EC	Extractant:	Water (22)
	Soil/solution:	1:1(5), 1:2(1), 1:2.5(7), 1:5(3), 1:10(1), Paste(6)
Organic matter	Wet oxidation:	Potassium dichromate (21)
	Titration:	Ferrous Sulfate (12), Ferrous ammonium sulfate (9)
Calcium Carbonate	Extractant:	0.1*N* HCL (1); 0.5*N* HCL (4); 6*N* HCL (3)
	Determine:	Weight loss (2); Acid Neutralization (11), Calcimeter (9)
Cation exchange	Saturation:	1*N* NaOAc, pH 8.2 (9); 0.4*M* NaOAc -0.1*M* NaCl pH 8.2 - 60% ethanol (4)
	Displacement:	1*N* NH_4OAc, pH 7.0 (0): 1*M* $Mg(NO_3)_2$, pH 7.0 (4)

Table 4.4.2 Determination variables for soil nutrients

Measurement	Procedure details (No. of labs in parentheses)	
Mineral Nitrogen	Extractant:	2*M* KCL (10), 1*M* KCL (1),
	Soil/solution:	1:10(10); 1.5(4);1:4(2), Paste (1)
	Shaking time:	60 min (10), 15 min (2), 30 min (1), 45 min (1), 10 min (1)
	Determination:	Distillation (13); Colorimetric (3)
Kjeldahl Nitrogen	Preparation:	Digestion (19)
	Digestion time:	5 min to 1 hr (3); 2 to 5 hr (5); 6 to 8 hr (3)
	Determination:	Distillation (16), Colorimetric (2)
Extractable Phosphorus	Extractant:	0.5*N* $NaHCO_3$ (20); 1*M* $NaHCO_3$ (2)
	Soil/solution:	1:20 (22)
	Shaking time:	30 min (22)
	Determination:	Colorimetric-Ascorbic Acid (13), Stannous chloride (5)
Exchangeable Cations	Extractant:	Ammonium acetate pH 7.0 (20, pH 8.5 (2)
	Soil/solution	1:5 (5); 1:20 (10); 1:45 (1)
	Shaking time:	15 min (1); 30 min (11); 60 min (3)
Extractable Micronutrients	Extractant:	NH_4HCO_3 - DTPA (1): DTPA (12)
	pH:	7.2 (2); 7.3 (10); 7.6 (1)
	Soil/solution:	1:2 (12); 1.5 (1)
Sulfate	Barium sulfate:	Precipitation (3); Turbidimetric (4)

Twelve reported as mmhos/cm and the remainder as dS/m or mS/cm.

For $CaCO_3$, most laboratories used acid neutralization with 1.0*N* HCl or 6.0*N* HCl, followed by either titration with 0.5 or 1.0*N* NaOH or CO_2 evolution as measured by a Bernard, Collins or Scheiber calcimeter. Some laboratories used 4 or 6N HCl, while a few used gravimetric loss from CO_2 evolution. Values ranged from 13 to 27%. However, most were clustered around the mean value (22%).

Most laboratories that measured cation exchange capacity (CEC) used the standard 1*N* NaOAc, pH 8.2 saturation procedure, followed by washing and displacement of exchangeable Na by 1*N* NH_4OAc, pH 7.0. Four laboratories used 0.4 *M* NaCl, pH 8.2 - 60% ethanol, followed by 1M $Mg(NO_3)_2$ at pH 7.0. While most values were around 47.2 meq/100 g, four were near 60 and one less than 10.

Organic Matter - Nitrogen Fractions (Figure 4.4.2): All laboratories used wet oxidation with 1*N* potassium dichromate for organic matter determination followed by titration with 0.5 M ferrous sulfate or ferrous ammonium sulfate. Values ranged from 0.37 to 2.82% with about 50% around the mean (1.18%).

While the Kjeldahl procedure, using concentrated H_2SO_4 with a catalyst mixture of K_2SO_4, $CuSO_4$, Se (100:10:1), is commonly used for measuring organic N, there was no consistency in digestion time among laboratories, with a range of 5 minutes to 8 hours. Most used distillation followed by titration with H_2SO_4 rather than colorimetry. Not surprisingly, many values were considerably above the modal (0.07%) and mean (0.11%) values.

Mineral N, ie ammonium (NH_4) or nitrate (NO_3), was measured by 13 laboratories, most of which used KCl (*1M* or *2M*) as an extractant. Most used a soil/solution ratio of 1:10, a shaking time of 1 hr, and distillation. However, a range of shaking time and ratios was reported (Table 4.4.2). For ammonium, four laboratories were considerably above the modal (14 ppm) and the mean (16 ppm) values, excluding the abnormal 1000 ppm value, while only one was markedly higher in the case of nitrate.

Available and Total Phosphorus, Boron, Sulfate (Figure 4.4.3): Virtually all laboratories measured available P using the standard Olsen method with 0.5*N* $NaHCO_3$. Most used ascorbic acid for color development, while others used stannous chloride as a reducing agent. Most values were close to the mean (7.4 ppm) but with the extremes, 3.8 and 20.2 ppm. Total P was measured in three laboratories. These used digestion with perchloric acid and color determination with ammonium metavanadate, molybdenum blue, or ascorbic acid. Values ranged from 46 to 435 ppm.

Boron was measured in only two laboratories, both using the hot water extraction procedure. However, the values obtained were widely different, 0.18 and 0.72 ppm. Sulfate was measured in eight laboratories by barium sulfate precipitation or turbidimetry. Values were expressed as S or SO_4. Again, results varied widely, from 10 to 100 ppm, with one extreme value of 4800 ppm SO_4.

Extractable Cations (Figure 4.4.4): Most labs used 1*N* NH_4OAc, pH 7.0, to extract K, Ca, Mg and Na. Most labs determined K, while relatively few did Mg. The K values were generally close to the mean value, with some low values. Variation in values for the other cations was considerably greater. Most reported determination with flame photometry and a few used atomic absorption spectrophotometry.

Micronutrient Cations (Figure 4.4.5): Several laboratories determined micronutrients, all using the simultaneous extraction DTPA procedure of Lindsay and Norvell (1978) or its modification using NH_4HCO_3-DTPA (Soltanpour and Swab 1977), with measurement of the extracted micronutrients by atomic absorption spectrophotometry. Values for Mn were uniform except for one laboratory, while there was greater variation for Fe, Zn, and Cu.

Miscellaneous Information: Five laboratories reported doing analysis for gypsum, and two of them for ESP (exchangeable sodium percentage) also. Particle-size distribution was also determined by five laboratories. One reported doing "active" carbonate determination, and another was involved with fertilizer analysis. Only one laboratory surveyed did ^{15}N analysis and two measured ^{32}P. A total of eight laboratories indicated that they did mineralogical analysis. All but three laboratories reported some interpretation of results, giving practical recommendations to users based on soil and other test results.

4.4.4 Conclusion

While most laboratories used standard reference procedures for the tests they performed, ie USDA Handbook 60 (Richards 1954) for pH, EC. and $CaCO_3$; N in Black et al. (1965); the Olsen procedure for P (Olsen et al. 1954); and that of Lindsay and Norvell (1978) for micronutrients, the variation in the results suggested that modifications had been introduced by the operators or there were other unspecified factors. Previously, the present authors had observed large differences between Olsen-P values of identical samples according to whether they were analyzed during summer or winter. This difference was attributed to the higher temperatures of the water used to make the extracting solution during the summer. Sharing the findings of this study with the various laboratories involved should help to identify causes of unusual deviations from true values. At the same time, the survey will promote cooperation between ICARDA and the various national research programs in the countries of WANA region. It should also provide a basis for scientific communication within the regional Soil Fertility Network under ICARDA's mandate. [*John Ryan and Sonia Garabet*]

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4.5 Oilseed Crops

4.5.1 Introduction

World population in 1992 was 5.47 billion, of which 9.93% resided in WANA countries (FAO 1992a). In the same year about 122 million ha worldwide were planted with edible oilseed crops (sunflower, rapeseed and mustard, safflower, sesame, soybean and groundnut). These produced 189 million tons of oilseeds. The WANA share in area and production was 3.3% and 1.5%.

In 1992 WANA countries imported 4.994 million tons of vegetable oil, about 80% of their needs, at a cost of 2.6 billion US dollars (FAO 1992b). The chronic shortage of edible oils in the region, due to lack of area or production, needs research and development, to assess oilseed crop potential and management requirements and to integrate suitable crops into the farming systems. In this third year of oilseed crops research at ICARDA, expanded varietal increase and selection and agronomic research were conducted on rapeseed and mustard (Brassica rapa syn B. campestris, B. napus, B. juncea), safflower (Carthamus tinctorius) and sunflower (Helianthus annuus) at three ICARDA research stations in Syria.

4.5.2 Rapeseed and mustard

Oilseed brassicas account for 14 to 15% of the total world edible vegetable oil production and are destined to play an ever-increasing role in supplying future world food, feed and industrial needs. Not only do these crops offer the best opportunity to meet the increasing oil requirement of many developing nations, they also offer the chance for crop diversification in predominantly cereal producing countries (Downey and Rimmer 1993). These crops are still little grown in the WANA region, so that research is needed to assist their successful introduction.

4.5.2.1 Location x seeding date x variety trial

Materials and methods: This trial involved fourteen cultivars of B. napus ($ACSN_1$, $ACSN_3$, Ceres, Cobra, Eureka, Maluka, Pivot, Regent, Shiralee, Taparo, Wesree, Wesroona, Westar and Wesway), five of B. campestris (Jumbuck, Parkland, Rex, Titan and Tabin) and one B. Juncea (Cutlass), bred in Australia, Canada or Germany. All the rapeseeds are "double low" in quality (that is, low in erucic acid and glucosinolate), while Cutlass is a conventional quality mustard. A split-split plot randomised block design with three replicates was used, with locations as the main plots, seeding dates as sub-plots and cultivars as sub-sub plots. Individual plots had 15 rows, 5m long, spaced 15 cm apart. Trials were seeded at Tel Hadya and Jindiress, on three dates, 15 and 16 November, 28 and 30 November and 15 and 16 December 1992. The previous crop at Tel Hadya was lentil and at Jindiress chickpea. Fertilizer, 20 kg N/ha, was applied before sowing with a row planter at a seed rate of 10 kg/ha and depth of approximately 3-4 cm. Weeding was done manually.

Results and Discussions: Average seed yield at Jindiress, 1345 kg/ha (Table 4.5.1), was much higher than that at Tel Hadya (421 kg/ha). First (930 kg/ha) and third (925 kg/ha) seeding dates had similar and significantly higher seed yield than the second seeding date (793 kg/ha), mainly due to low temperature and frost events faced by the second-seeded crop after germination and emergence. B. juncea, var. Cutlass, yielded the highest (1887 kg/ha). Yield range in napus cultivars was 529 kg/ha (Cobra) to 1047 kg/ha (Shiralee). Varieties of B. napa had a close range of 711 kg/ha (Parkland) to 1005 kg/ha (Jumbuck). A comparison of the yields of seven high-yielding cultivars representing each species across locations and seeding dates is made in Table 4.5.2. Varieties Cutlass (2763, 2541, 3657 kg/ha), Shiralee (1638, 1299, 2155 kg/ha), Wesroona (1527, 1472, 1477 kg/ha), Maluka (1598, 1279, 1592 kg/ha), Jumbuck (1697, 1316, 1860 kg/ha) and Rex (1338, 1649, 1852 kg/ha) consistently gave higher yields at Jindiress. At Tel Hadya, Cutlass (713, 644, 1005 kg/ha) was the highest yielding for each planting date, the yields of other varieties being consistently low and differing little due to date or genotype. This was because rainfall was low and late. Early sowing with supplementary irrigation (25 October to 5 November) might improve yields, as reported earlier (FRMP 1993). In contrast, the yields obtained at Jindiress are economically interesting. Cutlass, notably, is suitable for early as well as late sowing, is cold tolerant, does not shatter or lodge, and in the present trial was free from disease and insects. It is therefore very significant that a "double zero" mustard (that is, free of erucic acid and glucosinolate) will soon be commercially available.

4.5.2.2 Seed rate influence on yield and yield components of B. napus cv Westar

Seed rates of 4.5-6.5 kg/ha are recommended for B. napus in Canada (Downey et al. 1974). Vulloid (1974) in Switzerland found 6-8 kg/ha

Table 4.5.1 Seed yield and yield component means of rapeseed and mustard for locations, seeding dates and genotypes, ICARDA, 1992-93

Factors	Seed yield kg/ha	1000-seed wt (g)	No. of pods/ plant	No. of seeds/ pod	Plants/ meter row	Plant height (cm)
Locations						
1. Tel Hadya	421	2.98	39	23	51	74
2. Jindiress	1345	3.31	71	24	44	96
S.E.	60	0.054	3.37	0.82	1.88	0.234
L.S.D. 5%	257	0.234	14.53	N.S.	N.S.	1.00
Dates						
1. Mid Nov	930	2.99	49	23	59	87
2. End Nov	793	3.26	43	23	47	85
3. Mid Dec	925	3.18	73	25	36	83
S.E.	27	0.036	1.99	0.69	1.46	0.78
L.S.D. 5%	67	0.084	4.6	1.58	3	1.8
Genotypes						
<u>B. campestris</u>						
1. Jumbuck	1005	2.67	66	21	38	84
2. Rex	992	2.54	54	24	53	91
3. Titan	928	2.60	54	26	45	87
4. Tobin	866	2.32	50	21	51	78
5. Parkland	711	2.28	55	22	38	81
Average	900	2.48	56	23	45	84
<u>B. napus</u>						
1. Shiralee	1047	3.34	47	25	58	82
2. Wesroona	940	3.35	43	26	44	82
3. Westar	907	3.80	45	25	47	87
4. Maluka	906	3.32	46	24	49	80
5. Pivot	887	3.34	47	25	43	80
6. Regent	853	3.62	54	23	53	87
7. Wesway	834	3.71	44	25	42	84
8. Taparo	812	3.55	56	23	43	78
9. Eureka	800	3.46	48	24	52	80
10. Wesree	782	3.35	43	24	59	83
11. $ACSN_3$	707	3.33	56	24	35	80
12. $ACSN_1$	694	3.16	47	29	49	86
13. Ceres	571	3.15	59	25	41	79
14. Cobra	529	3.40	58	25	40	88
Average	805	3.42	49	25	47	82
<u>B. juncea</u>						
Cutlass	1887	2.60	125	15	67	124
S.E.	83	0.077	5.81	1.89	4.33	1.91
L.S.D. 5%	162	0.15	11.40	3.71	8	3.74

Table 4.5.2 Yield performance of major rapeseed and mustard varieties from three seeding dates at Tel Hadya and Jindiress, 1992/93

Varieties	Tel Hadya				Jindiress			
	Seeding dates				Seeding dates			
	15 Nov	28 Nov	15 Dec	Average	16 Nov	30 Nov	15 Dec	Average
	kg/ha							
B. campestris								
1. Jumbuck	530	369	257	385	1697	1316	1860	1624
2. Rex	433	411	269	371	1338	1649	1852	1613
Average camp.	481	390	263	378	1517	1482	1856	1618
B. napus								
1. Shiralee	455	378	355	396	1638	1299	2155	1697
2. Wesroona	481	380	300	387	1527	1472	1477	1492
3. Westar	486	403	454	448	1727	1091	1280	1366
4. Maluka	455	478	330	421	1461	1255	1455	1390
Average napus	469	410	360	413	1588	1279	1592	1486
B. juncea								
1. Cutlass	713	644	1005	787	2763	2541	3657	2987
Overall Ave.	507	437	424	456	1736	1517	1962	1738
S.E.	52.5	55.8	78.4		304.1	237.8	292.6	
LSD 5%	106.3	113.0	158.7		615.8	481.4	592.5	

was best for winter B. napus. A seed rate of 20 kg/ha for summer B. napus was highest yielding in Sweden (Ohlsson 1972; quoted by Clarke and Simpson 1978). Rapeseed-mustard introduction in WANA will need information on agronomic practices, including the optimum seed rate. This trial was conducted at Tel Hadya using the double zero variety Westar (B. napus). It was laid out in a RCB design, with three replications, and sown (late) on 26 December. The seeding rate ranged at 1 kg/ha intervals between 5 and 24 kg/ha. The plots consisted of 12 rows 5m long with 15 cm between rows. Areas of 4.5 x 1.5m were harvested from each plot for grain yield.

Results and discussion: Although no clear trends were evident in 1000-seed weights, numbers of pods per plant or of seeds per pod, high seed rates, 23 and 24 kg/ha, gave significantly the highest yields (Table 4.5.3) and seed rates, 11, 16, 19, 20, 21 kg/ha had similar seed yield (420 to 458 kg/ha), which was significantly higher than that from some lower seed-rates. These results indicate an advantage from the use of high seed rates to cover the risk of cold and frost, but before definitive recommendations on seed rate can be made more trials are needed.

Table 4.5.3 Effects of seeding rates on seed yield and yield component of Westar variety of rapeseed (B. napus) at Tel Hadya, 1992/93

Seed rates kg/ha	Yield kg/ha	1000-seed wt (g)	Pods/ plant	Seeds/ pod	Plant height, cm
1. 5	248	3.90	42	27	75
2. 6	238	4.24	38	23	80
3. 7	259	3.79	41	26	80
4. 8	280	4.07	35	24	73
5. 9	289	3.96	51	25	85
6. 10	398	3.60	46	23	79
7. 11	434	4.31	48	31	76
8. 12	361	4.59	57	26	82
9. 13	368	3.56	46	25	80
10. 14	366	3.61	44	23	88
11. 15	338	4.58	46	31	78
12. 16	428	4.30	60	28	80
13. 17	349	4.21	33	22	82
14. 18	346	4.03	34	27	83
15. 19	449	4.18	51	27	80
16. 20	458	3.96	37	24	85
17. 21	420	4.08	48	25	78
18. 22	444	1.51	41	26	82
19. 23	736	4.37	54	28	80
20. 24	766	4.05	37	23	80
S.E.	85	0.38	4.99	0.49	1.94
L.S.D. 5%	173	N.S.	10.12	1.00	3.93

4.5.3 Safflower

Safflower is valued for its high poly-unsaturated fatty acid content level. A health-conscious population in developed countries has created a significant market for its oil as salad oil, margarine and cooking oil. It is a drought-tolerant crop and yields more than 2t grain/ha in dry hot areas with rainfall as low as 300mm, with grain oil contents in the range 38 to 44%. And it can be seeded and harvested with the same equipment as for cereal crops.

4.5.3.1 Location x seeding date x variety trial

Trials involving eight safflower cultivars, two from USA (CW4440, CW74), one from Syria, four from Pakistan (209287, 250539, 250835 and 252041) and one from Turkey (Dinger) were laid out in a split-

split plot complete RBD design with three replications at Tel Hadya (previous crop, lentil) and Jindiress (chickpea). Plots had 6 rows, 5m long, spaced 30 cm apart. Seeding dates were 15/16 November, 28/30 November and 15/16 December, the earlier date in each case being for Tel Hadya; 20 kg/ha N/ha was applied before seeding; the seed rate was 30 kg/ha; and weeding was done manually.

Results and discussion: Grain yield at Tel Hadya (1810 kg/ha) was significantly higher (Table 4.5.4) than at Jindiress (1124 kg/ha) where chickpea pod borer (Heliothis armigera) and semilooper (Plusia orichalcea) attacked safflower heads at the seed development stage, reducing yields even though the crop was sprayed with Decis and disulphan. Across the three sowing dates at both sites, the two USA cultivars (1.2 t/ha) were outyielded, in most cases significantly, by the other six cultivars, which averaged about 1.5 t/ha.

A yield comparison between sites and sowing dates, and including two later sowings at Tel Hadya, is given in Table 4.5.5. Later seeding (30 December) gave the highest yields (2655 kg), improving the Tel Hadya average to 2013 kg/ha. All 8 varieties gave better yields in this late planting, with Syrian and 250835 exceeding 3 t/ha and 5 of the other six varieties producing around 2.5 t/ha. The pattern of the seeding date effect on mean yield is given in Figure 4.5.1.

Plant heights and the various yield parameters (Table 4.5.4) showed no major differences between locations, planting dates or

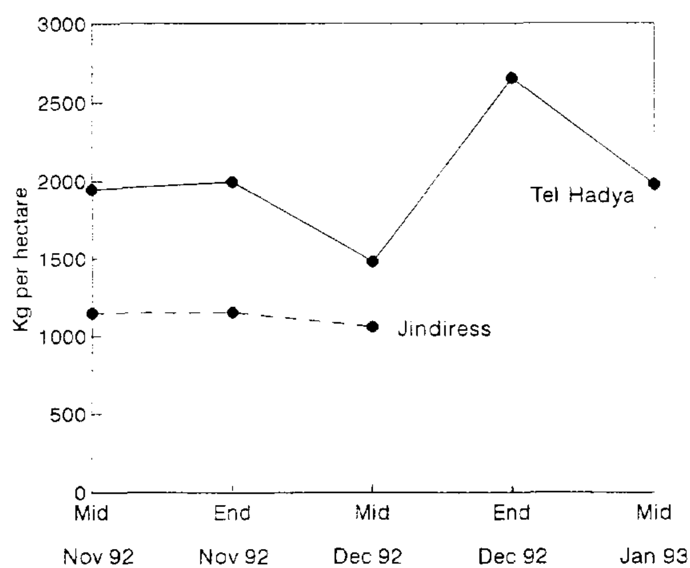

Figure 4.5.1 Seeding date effect on seed yield of safflower (average of 8 var), for 5 dates at Tel Hadya (solid line) and 3 dates at Jindiress (broken line)

Table 4.5.4 Safflower yield and yield components as affected by location, seeding date and genotype

Factors	Yield in kg/ha	Heads per plant	Seeds per plant	Seed wt/ plant (g)	100-seed weight (g)	Hull %	No. of plants/ m	Height in cm
Locations								
1. Tel Hadya	1810	8	254	11.0	4.44	46.88	17	92
2. Jindires	1124	10	331	16.0	4.69	48.27	17	104
S.E.	184.57	0.26	7.13	0.53	.065	2.28	0.61	1.778
L.S.D.	794	1.12	30.69	2.28	n.s.	n.s.	n.s.	7.649
Seeding dates								
D1 Mid Nov	1549	9	258	12	4.54	48.54	17	98
D2 End Nov	1561	9	341	15	4.49	47.48	14	98
D3 Mid Dec	1274	9	278	13	4.68	47.52	18	98
S.E.	114.03	0.46	22.40	1.091	.031	0.704	0.93	1.129
L.S.D.	n.s.	n.s.	51.66	2.51	.07	n.s.	2.146	n.s.
Genotypes								
1. CW4440	1163	8	245	11	4.07	44.55	20	95
2. CW74	1157	8	295	12	4.48	44.28	18	95
3. Dinger	1571	9	214	10	4.67	52.83	16	96
4. Syrian	1734	8	350	18	5.66	48.50	17	99
5. 209287	1433	9	284	14	4.31	50.83	14	100
6. 250539	1642	10	349	17	4.07	44.77	17	97
7. 250835	1418	10	252	11	4.75	48.16	14	99
8. 252041	1573	11	351	14	4.56	49.83	15	105
S.E.	144.65	0.697	31.09	1.51	.075	1.58	1.32	1.705
L.S.D.	287	1.38	61.67	3	0.15	3.13	2.625	3.381

genotypes, although, interestingly, the Syrian variety had significantly greater 100-seed weight than all the others.

Hull percentage, which is usually inversely related to oil and protein percentage is an important value. In the present case, locations and seeding dates showed little effect, but differences between varieties were quite large: CW74 had the lowest value (44.5%) and Dinger the highest (52.8%). Hull percentages in this study are similar to those found by Lakshminarayana and Azeemadin (1991). Oil content coupled with oil yield per unit area may be a good criterion for the selection of a locally suitable variety.

4.5.3.2 Varietal performance at Breda

Nine varieties, S-541, 250539, 250838, 252041, Dinger, Yenice, Syrian 209287 and Thori 78, were planted in three replicates at Breda on 11 December, in plots 27m long, each with 6 rows 30 cm apart. Final plant population (7-13 plants/ha) was low because of poor emergence due to poor moisture conditions. The yield range was

Table 4.5.5 Safflower variety performance from 5 seeding dates at TH and 3 seeding dates at Jindiress, ICARDA, Syria, 1992/93

Varieties	Tel Hadya Seeding dates 15 Nov	28 Nov	15 Dec	30 Dec	15 Jan	Average	Jindiress Seeding dates 16 Nov	30 Nov	16 Dec	Average	Average Hull %	100-seed W
	yield / kg/ha											
1. CW4440	2091	1457	888	2163	1649	1650	932	877	733	847	42.5	3.99
2. CW74	1548	1612	1150	2641	1807	1752	1006	1048	840	965	43.7	4.28
3. Dinger	2156	2147	1531	2718	1871	2085	1254	1048	1289	1197	51.9	4.83
4. Syrian	2889	1904	1742	3047	2952	2507	1524	1071	1275	1290	47.8	5.11
5. 209287	1987	1524	1224	2591	1622	1790	1124	1511	1226	1287	47.9	4.17
6. 250539	1807	2880	1592	2619	2256	2231	1180	1187	1208	1192	47.9	4.08
7. 250835	1654	1983	1714	3010	1656	2003	1022	1182	955	1053	47.3	4.37
8. 252041	1441	2477	2033	2454	2045	2090	1171	1332	985	1163	49.6	4.38
Average	1947	1998	1484	2655	1982	2013	1152	1157	1064	1124	47.3	4.40
S.E.	445.1	501.6	359.5	242.37	353.5		175.5	210.5	201.0			
LSD 5%	915.1	1015.6	728.0	498.31	726.9		358.4	426.2	407.1			

from 240 (Thori 78) to 409 (250539) and 412 kg/ha (S-541). These two varieties were also among the high-yielding cultivars at Tel Hadya and Jindiress. The 100-seed weight range was 3.41 g (Yenice) to 5.34 g (Syrian) and the number of heads per plant ranged from 5 (252041) to 11 (Syrian). Hull percentage ranged from 44.3 (250539) to 56.3% (Dinger). To obtain a better assessment of performance at this site early planting into moist soil will be essential in future trials.

4.5.3.3 Safflower seed rate trial

This trial, planted on 26 December, compared eight seed-rate treatments, 15, 20, 25, 30, 35, 40, 45, and 50 kg/ha, of the high-yielding, early-maturing spring Turkish variety, S.541, in six 30 cm-wide rows plots, 5m long, with three replications.

Results and discussion: 5-12 kg/ha seed rates are used in Pakistan and India for mixed cropping, 18-22 kg/ha for strip farming, and 30-60 kg/ha for large communal planting, depending on variety and whether rain-grown or irrigated (Weiss 1983). In this trial, highest yield (2580 kg/ha) was obtained from a 40 kg/ha seed rate, but differences across the wide yield range of 1346 kg/ha to 2580 kg/ha (Table 4.5.6) were not statistically different due to a large experimental error. However, the average yield, 2119 kg/ha, from a late planting, is encouraging.

Table 4.5.6 Seed rate effects on yield and other characteristics of safflower at Tel Hadya, 1992/93

Seed rate kg/ha	Yield kg/ha	100-seed wt (g)	No. of plant/m	Height cm	Heads/ plant	Seeds/ plant	Seed wt/ plant, g	Hull %
1. 15	2049	3.7	14	77	7	95	4	45.6
2. 20	1346	3.7	19	70	10	156	6	41.3
3. 25	2258	3.7	21	77	6	219	9	47.0
4. 30	1934	3.7	26	67	7	286	13	55.0
5. 35	2269	3.5	26	73	4	186	7	40.0
6. 40	2579	3.5	28	75	5	214	7	43.3
7. 45	2179	3.5	29	72	5	68	2	54.3
8. 50	2339	3.5	31	75	5	135	6	48.6
Average	2119	3.6	24	73	6	170	7	47
S.E.	444.96	0.08	3.29	6.03	1.48	39.20	1.6	3.69
L.S.D.	n.s.	0.17	7	13	3.19	84.1	3.4	7.9

4.5.3.4 Safflower nitrogen fertilizer trial

This trial was conducted at Tel Hadya and Jindiress with variety S.541. Plot size was 10 x 1.8m, 6 rows per plot 30 cm apart.

Fertilizer was applied immediately before sowing on 8 December at Tel Hadya and 11 December at Jindiress. Nitrogen treatments ranged from 10 to 150 kg/ha, in 10 kg/ha increments.

Results and discussion: The mean yield at Jindiress (1530 kg/ha) was significantly higher than that at Tel Hadya (1136 kg/ha) (Table 4.5.7). Although N-treatment values ranged from 933 to 1582 kg/ha, there was no consistent trend. This is a surprising result, as safflower is usually considered to have a relatively high nitrogen requirement for maximum yield (Weiss 1983). There may be some relationship here to the finding (above) that mid-December gave the lowest yields of safflower, although the reason for this is not clear.

Table 4.5.7 Effect of nitrogen on safflower yield and other characteristics at Tel Hadya and Jindiress, 1992/93

Factors	Yield kg/ha	Heads/ plant	Seed no./ plant	Seed wt/ plant, g	100-seed wt (g)	Yield/ plot, g	Hull %
Locations							
Tel Hadya	1136	9	202	6.72	3.05	1091	49.75
Jindiress	1530	10	154	6.97	4.13	1469	48.04
S.E.	34	0.52	13.4	0.50	0.09	32.5	0.63
L.S.D.	146	n.s.	n.s.	n.s.	0.38	140.1	n.s.
Fertilizer N kg/ha							
1. 10	1384	11	223	9	3.57	1330	47.3
2. 20	1582	8	94	4	3.62	1520	49.6
3. 30	1332	9	102	4	3.85	1279	51.8
4. 40	1308	10	253	9	3.59	1257	52.3
5. 50	1197	10	281	10	3.61	1150	50.8
6. 60	1536	10	206	8	3.66	1476	50.8
7. 70	933	10	152	6	3.50	896	52.0
8. 80	1321	9	147	5	3.65	1269	44.8
9. 90	1142	10	236	8	3.66	1097	43.6
10. 100	1412	10	122	4	3.56	1357	44.0
11. 110	1212	9	199	9	3.51	1164	51.8
12. 120	1275	9	164	7	3.61	1225	48.6
13. 130	1524	10	151	6	3.49	1464	47.6
14. 140	1298	10	147	5	3.45	1246	48.5
15. 150	1540	9	192	6	3.57	1479	49.5
Average	1333	9.6	178	6.6	3.59	1281	48.86
S.E.	166	0.92	20.2	0.76	0.11	160	2.9
L.S.D.	333	n.s.	40.6	1.53	n.s.	320	5.8

4.5.3.5 Conclusions from safflower trials

1. Safflower grain yields ranged from 0.7 to over 3 t/ha. Most varieties gave over 2 t/ha at Tel Hadya, and such yields under dry conditions, low rainfall and from late planting encourage the belief that this crop has a commercial future in Syria.
2. Safflower is prone to many diseases, but in the dry conditions of Tel Hadya it was totally disease- and insect-free.
3. Spineless varieties are needed by the smallholder, who harvests by hand. Our present collection has 5 spineless varieties giving yields comparable to those of the spiny varieties.
4. Safflower's drought tolerance is attributed to its long root system. Under low rainfall conditions its roots are not long, but it still gives high yields, indicating it has 'genetic' drought tolerance as well.
5. As the last 3 years' observations show, safflower can withstand cold (-6°C), frost and snow reasonably well without a reduction in stand or yield.

4.5.4 Sunflower

Cultivation of *sunflower* in the rainfed areas of WANA is a relatively recent innovation and information on the optimum production practices is lacking. Productivity may possibly be increased in various ways, by using improved varieties or more efficient production practices or a combination of both. Three variables that a farmer can, inter alia, manipulate to influence production are variety, plant population and row spacing. Trials were conducted at Tel Hadya and Jindiress to assess varietal performance, optimum plant population, row spacing and dates of sowing under low and high rainfall regimes.

4.5.4.1 Varietal evaluation

WANA countries that grow sunflower use imported hybrid seed, which is costly and usually not readily available. Good open-pollinated varieties (OPV) would be a useful alternative that could be easily produced locally, even by farmers, with less cost. Twenty-one cultivars, 11 OPV and 10 hybrids, were compared in field trials at Tel Hadya and Jindiress. The OPV were from Turkey (2), Kenya (2), Romania (2), Pakistan (3), and Russia (2). The hybrids were from Yugoslavia. Planting was on March 3 (Tel Hadya) and March 4 (Jindiress). A RCB design with three replications was used. Three rows 10m long plots, with 40 cm row and plant distances were used to obtain 62500 plants/ha. Weeding was done manually. To compensate for low rainfall, the crop at Tel Hadya was given a 40mm sprinkler irrigation on June 7, at the full bud stage.

Table 4.5.8 Performance of open-pollinated and hybrid sunflower varieties at Tel Hadya and Jindiress, 1993

Factors	Yield kg/ha	100-seed wt (g)	Kernel %	Head diameter cm	Height cm
<u>Location</u>					
Tel Hadya	2080	3.70	71.44	11	125
Jindiress	2207	3.62	70.77	12	145
S.E.	173	0.13	1.22	0.38	1.81
L.S.D.	n.s.	n.s.	n.s.	n.s	7.80
<u>Varieties</u>					
1. Ekis-1	1929	4.24	72	12	145
2. Ekis-2	2208	3.98	74	12	145
3. FEDHAK	2328	3.88	71	11	141
4. H01	2099	4.20	66	12	139
5. NSH 17	1945	3.30	75	12	136
26	1769	2.74	74	11	130
43	2292	3.74	71	12	150
97	2607	3.42	74	11	128
102	1322	3.14	71	12	129
104	2283	3.18	72	12	119
108B	2346	3.01	77	11	121
110	2362	3.42	75	12	124
111	2373	3.61	71	12	129
213	2908	4.05	66	13	134
15. Record/S	2176	3.84	73	12	139
16. Record/TH	2351	4.27	68	11	147
17. Shahba	2022	3.99	71	11	137
18. Shams	1415	2.75	62	11	121
19. SMT	1948	3.75	70	12	141
20. V8931	1871	3.79	75	11	140
21. VINIIMK	2466	4.66	67	12	144
S.E. 402	0.24	2.41	0.48	4.26	
L.S.D. 5%	n.s.	0.48	4.81	0.96	8.48

Results and discussion: There were no significant differences in yield due to locations or cultivars (Table 4.5.8). Across the two sites, the highest-yielding OPV was VINIIMK (2466 kg/ha) and the highest-yielding hybrid was NSH213 (2908 kg/ha). Some means and individual OPV and hybrid yields at each location are shown in Figure 4.5.2. Among OPV, varieties Record and Ekis-2 were outstanding at Tel Hadya and Jindiress, respectively. Among

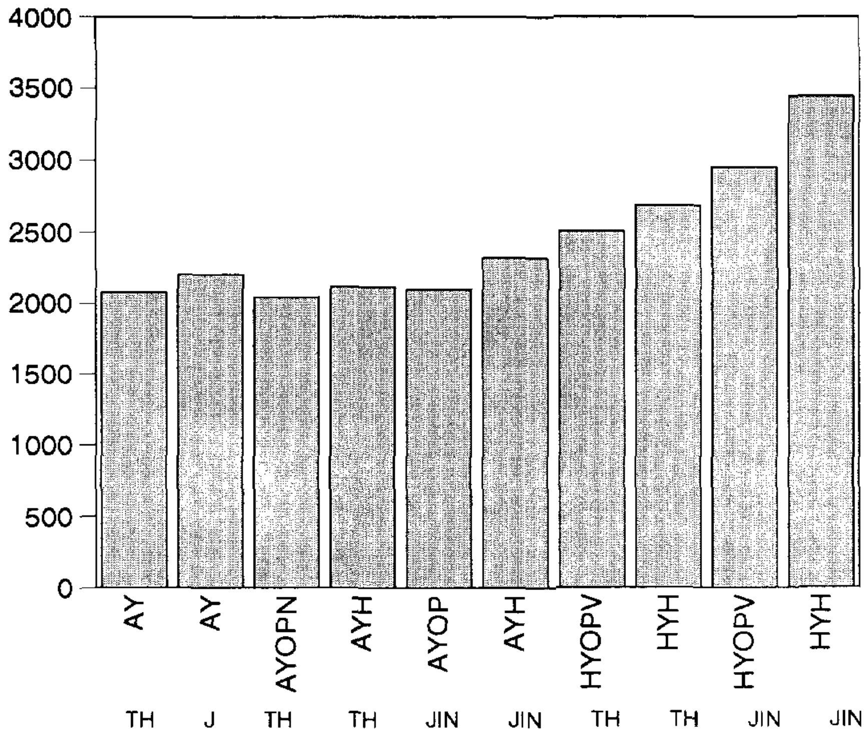

Figure 4.5.2 Average yield of open-pollinated and hybrid varieties of sunflower at Tel Hadya and Jindiress, 1993 (AY=average yield; OPV=open-pollinaed variety, Record and Ekis 2; AYH=average yield of hybrids; HYOPV=highest yielding OPV; HYH=highest yielding hybrid)

the hybrids, NSH 111 at Tel Hadya and NSH 213 at Jindiress were highest yielding. It is worth noting that the difference between the average yields of 11 OPV (2073 kg/ha) and 10 hybrids (2220 kg/ha) was non-significant and small (147 kg/ha) in relation to the yield ranges 1463 kg/ha (Ekis-2) to 2690 kg/ha (NSH 111) at Tel Hadya and 1013 kg/ha (NSH 102) to 3443/ha (NSH 213) at Jindiress. The mean 100-seed weight of OPV (3.94 g) was greater than that of the hybrids (3.36 g). However, hybrids had a slightly greater kernel percentage (72.6%) than the OPV (69.9%).

4.5.4.2 Row spacing x plant population trial

In trials at Tel Hadya and Jindiress, the OPV 'Record' was tested in the treatments: row spacings, 40, 50, 60, 70, 80, 90 and 100 cm apart, and plant populations, 40,000, 50,000, 60,000, 70,000, 80,000, 90,000 and 100,000 plants/ha. Main plots for row spacing were split into sub-plots 10m long for plant populations. Sowing was on March 22 at Tel Hadya and March 25 at Jindiress. High seed rates were used, and seedlings were thinned to the desired population when they were 5 cm tall. The harvest was on July 21 at Tel Hadya and on July 25 at Jindiress. All data were taken from the central 5m of the row in each plot.

Results and discussion: Yield at Tel Hadya (2610 kg/ha) was higher than at Jindiress (1142 kg/ha), for two reasons: the Tel Hadya trial was given a 40 mm irrigation on 7 June, and there was greater bird damage at Jindiress because of late bagging of the heads. The 40 cm row spacing outyielded the 50 cm spacing non-significantly but gave significantly higher yield than the 60 cm and all wider row spacings; and the high population of 90,000/ha significantly outyielded populations of 80,000/ha and less (Table 4.5.9). These results support the use of narrow rows and higher plant populations, which provide good soil cover to minimize moisture evaporation and intercept more radiation for photosynthesis. A two-way comparison of yields from plant population and rowspacing is given in Table 4.5.10.

4.5.4.3 Sunflower date of sowing trial

Two hybrids NSH 110 and NSH 213, and two OPV, 1101 and Record were compared at three sowing dates, 2 March, 22 March and 5 April at Tel Hadya. The crop was given one irrigation of 40 mm on 7 June. The average yield of the four cultivars was considerably reduced by delayed planting, from 2352 kg/ha for the earliest date to 833 kg/ha for the latest date (Figure 4.5.3). However, it would be useful to repeat this trial, starting with plantings from early February. The purpose would be to check whether, from sufficiently early planting, it would be possible to bring a sunflower crop to maturity in a relatively dry area, like Tel Hadya, without any supplemental irrigation.

It may be concluded that:

1. A good OPV is comparable in yield to a hybrid.
2. Supplemental irrigation in a dry season can improve yield when applied at the complete flowering stage.
3. The Tel Hadya type environment may need supplemental irrigation in a low rainfall year, although early planting may preclude this need. The Jindiress type environment and rainfall can give a yield equivalent to that of irrigated areas. [*Akhtar Beg, Visiting Scientist*]

Table 4.5.9 Sunflower performance under different row spacings and plant populations at Tel Hadya and Jindiress, 1993

Factors	Yield kg/ha	100-seed wt (g)	Kernel %	Head diameter cm	Plant height cm
<u>Location</u>					
1. Tel Hadya	2610	4.49	72	11.88	144
2. Jindiress	1142	3.62	69	11.38	151
Average	1876	4.05	70.5	11.63	147.5
S.E.	57	0.071	1.041	1.66	0.86
LSD 5%	727	n.s.	n.s.	n.s.	n.s.
<u>Rowspacings</u>					
1. 40 cm	2863	4.47	71	12.90	148
2. 50	2127	4.21	70	12.24	150
3. 60	1895	4.05	70	11.39	145
4. 70	1908	3.99	70	11.24	147
5. 80	1384	3.77	70	11.35	149
6. 90	1493	3.91	71	11.15	145
7. 100	1464	3.96	71	11.15	150
Average	1876	4.05	70.5	11.63	147.5
S.E.	411	0.315	1.085	0.55	4.05
L.S.D. 5%	896	n.s.	n.s.	1.97	n.s.
<u>Plant Pop/ha</u>					
1. 40000	1446	4.11	70	11.69	144
2. 50000	1692	4.18	70	11.97	146
3. 60000	1722	4.07	70	11.70	144
4. 70000	1948	4.11	71	11.65	152
5. 80000	1953	3.92	72	11.55	148
6. 90000	2207	4.01	71	11.70	152
7. 100000	2166	3.94	70	11.14	147
Average	1876	4.05	70.5	11.63	147.5
S.E.	127	0.126	0.738	0.196	1.77
L.S.D. 5%	252	n.s	n.s	0.389	3.52

Table 4.5.10. Sunflower, yield with varying row distances and plant population averaged over two locations, Tel Hadya and Jindiress

Row spacing cm	Plant population (000)/ha) 40	50	60	70	80	90	100	Aver.
	kg/ha							
40	1989	2685	2274	2789	3106	3729	3469	2863
50	1605	1873	2518	2413	2100	2295	2088	2127
60	1515	2102	1852	1882	2160	1943	1812	1895
70	1291	1598	1802	2351	1811	2336	2168	1908
80	1085	883	1241	1534	1351	1707	1887	1384
90	1518	1368	1157	1115	1759	1650	1882	1493
100	1122	1333	1212	1553	1382	1791	1854	1464
Average	1446	1692	1722	1948	1953	2207	2165	1876

	SE	LSD
Row spacing	411	896
Plant popln	127	252
Plant popln at same row spacing	336	668
Row spacing at same plant popln	516	1087

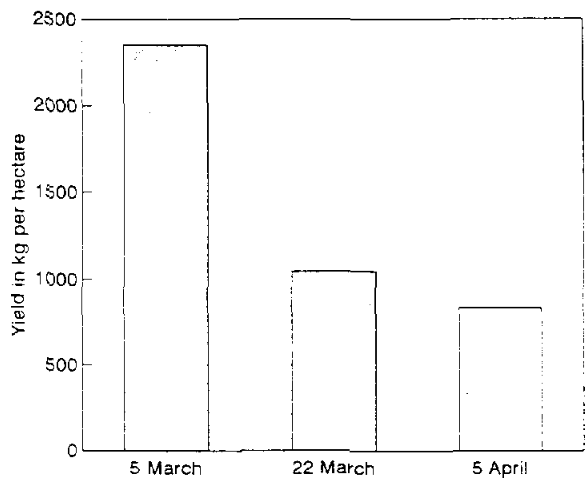

Figure 4.5.3 Sowing date effect on sunflower yield at Tel Hadya in 1993

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4.6 Barley productivity in the medic-barley rotation at Breda

Most ICARDA research on medic-cereal rotations has involved wheat as the cereal component. However, the possibility of utilizing barley instead of wheat, particularly in wheat-growing areas of only moderate rainfall (300-400mm), is beginning to attract more attention. Wheat has recently been replaced by barley in one of the long-term medic rotation trials at Tel Hadya (PFLP 1993, pp 110-118). The problem of wheat following medic in this environment is that its yield is often depressed relative to that of wheat following other crops. This is almost certainly due to the ability of medic to extract more water from the profile than shorter-season crops like lentils or vetch (FRMP 1993, pp 138-148), so that in the subsequent season the cereal is planted into a drier profile and, in total, has less water available to it for growth. Barley may be more suitable than wheat in this situation.

Ley farming systems of medics and barley need also to be considered for drier areas (<300mm mean rainfall), where barley/livestock systems prevail and barley-fallow rotations have largely given place to almost continuous barley growing. It might be argued that high-quality legume pastures should be more attractive to farmers here, where livestock products are the main source of agricultural income, than to those in areas of greater arable potential.

With this in mind, a joint FRMP/PFLP trial was set up at Breda in 1987 to compare a rotation of barley with annual medic (a mixture of annual Medicago species) with three alternative rotations, barley-fallow, barley-barley and barley-lathyrus (Lathyrus sativus, harvested at maturity). The trial comprises three replicates of both phases of each of the four rotations. In the barley-medic rotation, each plot is 1 ha in size to permit realistic grazing management. Plots in other rotations are each 0.36 ha, and all plots are divided into 2 subplots to carry two rates of topdressed nitrogen, 0 and 20 kg N/ha, in the barley phase. Phosphate, 60 kg P2O5/ha, is also added, biennially to the barley phase at planting time.

As noted earlier (FRMP 1991, pp 149-151), the main focus of interest is the barley-medic rotation, the other rotations serving as different forms of control. At that time, with two years of results, medic appeared to behave similarly to the other legume, lathyrus, in respect of its effect on the barley phase of the rotation. Three more years of the trial have elapsed, and this observation appears still to be valid. The present report summarizes the five seasons of barley data now available.

As would be expected, yields of grain and straw were consistently highest for barley following fallow and (except in 1991/2) consistently lowest for barley following barley (Table 4.6.1). Differences between barley following medic and following lathyrus were usually small, and the five-year means for these two treatments are virtually identical for both grain and straw. It should be mentioned that in the three alternate years, 1988/89, 1990/1 and 1992/3, the barley of the barley-medic rotation was preceded by good stands of medic - the result of good seed-bank establishment during the wet year of 1987/8. In contrast, the 1989/90 and 1991/2 barley crops were preceded by poor stands of medic, more accurately described as weedy fallow. (The initial year for medic in this phase, 1988/9, was very dry, and even re-seeding in 1990/1 was not very successful in establishing medic in these plots.) However, no clear phase differences are evident in the barley data in respect of yields following 'medic' and lathyrus.

Application of nitrogen fertilizer tended to decrease grain and increase straw yields, but these effects were very small and usually non-significant (Table 4.6.2). In two years (88/89 and 92/93), there were significant interactions between rotation and nitrogen fertilizer treatments, on grain yield only: nitrogen increased yield in the barley-barley rotation but consistently decreased it in each of the other three rotations.

Table 4.6.1 Barley grain and straw yields (t/ha) in four two-course rotations at Breda over five years, 1988-1993 (means over two N-fertilizer rates)

Year	Seasonal rainfall, mm		Alternate crop: Medic	Lathyrus	Fallow	Barley	SE of the mean, ±
GRAIN							
88/89†	181	**	0.87	0.96	1.30	0.61	0.075
89/90	178	***	0.20	0.15	0.71	0.28	0.046
90/91†	210	*	1.10	1.15	1.33	0.89	0.068
91/92	231	**	1.03	0.83	1.36	1.11	0.068
92/93†	283	***	1.88	2.17	2.70	1.38	0.106
Mean			1.02	1.05	1.48	0.85	
STRAW							
88/89†	181	***	2.14	2.36	2.63	1.24	0.084
89/90	178	***	1.30	1.42	2.80	1.34	0.068
90/91†	210	**	2.07	1.96	2.11	1.65	0.088
91/92	231	*	1.33	1.00	1.66	1.35	0.050
92/93†	283	**	2.51	2.64	3.05	1.72	0.109
Mean			1.87	1.88	2.45	1.46	

† Years in which barley was preceded by a good stand of medic
(*, **, *** — significant at 5, 1 and 0.1% levels, respectively)

Table 4.6.2 Mean effects of nitrogen fertilizer on barley grain and straw yields (t/ha) in four two-course rotations at Breda, 1988-1993

Year	kg N/ha:	Grain 0	Grain 20	SE of mean, ±		Straw 0	Straw 20	SE of mean, ±
88/89	ns	0.97	0.90	0.041	ns	2.04	2.14	0.084
89/90	*	0.39	0.28	0.030	*	1.58	1.85	0.068
90/91	ns	1.09	1.14	0.055	†	1.81	2.09	0.088
91/92	ns	1.08	1.08	0.033	ns	1.29	1.38	0.050
92/93	*	2.11	1.96	0.037	ns	2.47	2.49	0.109
Means		1.13	1.07			1.84	1.99	

(*, † — significant at 5 and 10% level, respectively)

For the three rotations, fallow-barley, lathyrus-barley and barley-barley, the relative magnitudes of the barley yields are similar to those found in the other (small-plot) barley rotation at Breda (FRMP 1993, pp 148-158). For the barley-medic rotation, the interesting comparison is with the wheat rotations at Tel Hadya. There, over the period 1985-92, mean wheat grain yield after medic (1.39 t/ha) was 24% lower than that after grazed vetch (1.84 t/ha), which for present purposes may be equated with lathyrus (FRMP 1993, pp 138-148). As noted earlier, this almost certainly reflected medic's superior ability to extract water from the soil profile.

The absence of any similar difference between medic and lathyrus precursors on barley yields at Breda might stem from a difference between wheat and barley. More probably, it stems from differences between Breda and Tel Hadya in rainfall and subsequent inter-seasonal water storage in the profile. Under the drier conditions that usually obtain at Breda, the profile is wetted to a shallower depth, and we may not expect either medic or lathyrus to leave much available water unutilized; and any small difference that might exist at harvest is likely to be lost before the following barley crop is planted. As data from the period 1983-88 showed, soil water storage even after a bare fallow is usually less than 10% of the previous season's rainfall by the end of the summer (FRMP 1989, pp 36-54). We may therefore provisionally conclude that as one moves into drier areas any disadvantage of medic relative to annual legumes in respect of subsequent cereal crop performance may be expected to decrease and disappear. [*Mike Jones with major technical assistance from Zuhair Arous*]

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4.7 Economics of nitrogen use in wheat-based two-course rotations at Tel Hadya

Crop rotations allow farmers to make efficient use of limited available water, to restore or sustain soil fertility, and to reduce the risks of pests and diseases. Weather and market price variability within and among seasons determine input allocation as well as decisions on how to combine alternative rotations to achieve farmers' goals.

The objective of this section is to assess the economic viability of nitrogen fertilizer use in different wheat-based two-course rotations in a trial at the Tel Hadya farm. Five of seven rotations investigated are: wheat/fallow, wheat/summer crop (melon), wheat/lentil, wheat/chickpea and wheat/wheat. The other rotations involve sheep grazing: wheat/vetch for lamb fattening and wheat/medic for supporting year-around sheep production. Their complexity deserves special attention elsewhere.

The experimental design and trial management description, seasonal conditions, crop yields, water balance for the last seven years, and economic interpretation for the first four seasons are available in FRMP (1990; 1993a). Each rotation treatment comprises two phases, one carrying wheat and the other 'non-wheat' in any given year. Nitrogen fertilizer is applied at 0, 30, 60 and 90 kg N/ha in the wheat-phase only, half being applied at planting and the rest at the tillering stage. Alternation of the crop, and, where relevant, of the fertilization treatment, in a cyclical fashion constitutes the essence of the rotation. Continuous wheat is a special case of this. Wheat is present in both phases but only one phase receives fertilizer.

The same budgeting procedures as outlined in FRMP (1990) were followed, using constant prices of 1990 for factors and products. Wholesale price indexes published by SAR (1986-1992) were used for the first seven seasons and used to extrapolate for the eighth season.

4.7.1 Sources of variability

Total seasonal rainfall in Block C at the Tel Hadya farm and 1990 prices for all commodities produced and harvested in eight seasons are shown in Figure 4.7.1. The 1987/88 season was extremely wet, followed by two dry seasons. Over eight seasons, rainfall averaged 313mm with a coefficient of variation of 24%. Wheat and lentil straw had low prices in the wet season and high prices in the first dry season. The increasing trend in wheat grain price was highly influenced by the government price control policy. While wheat and lentil straw and melon prices had high coefficients of variation (55-65%), those for wheat grain, lentil grain and chickpea were low (7-22%).

Some costs such as labor, fuel, fertilizer, herbicides and pesticides, and machinery rental are almost independent of weather conditions [although Saade (1990) elaborated a model where fertilizer price is dependent upon rainfall distribution]. Coefficients of variation of these costs were less than 10% over the eight seasons, except that of nitrogen fertilizer which was 28%. On the other hand, harvesting costs are heavily dependent upon crop yield which is a direct consequence of weather conditions.

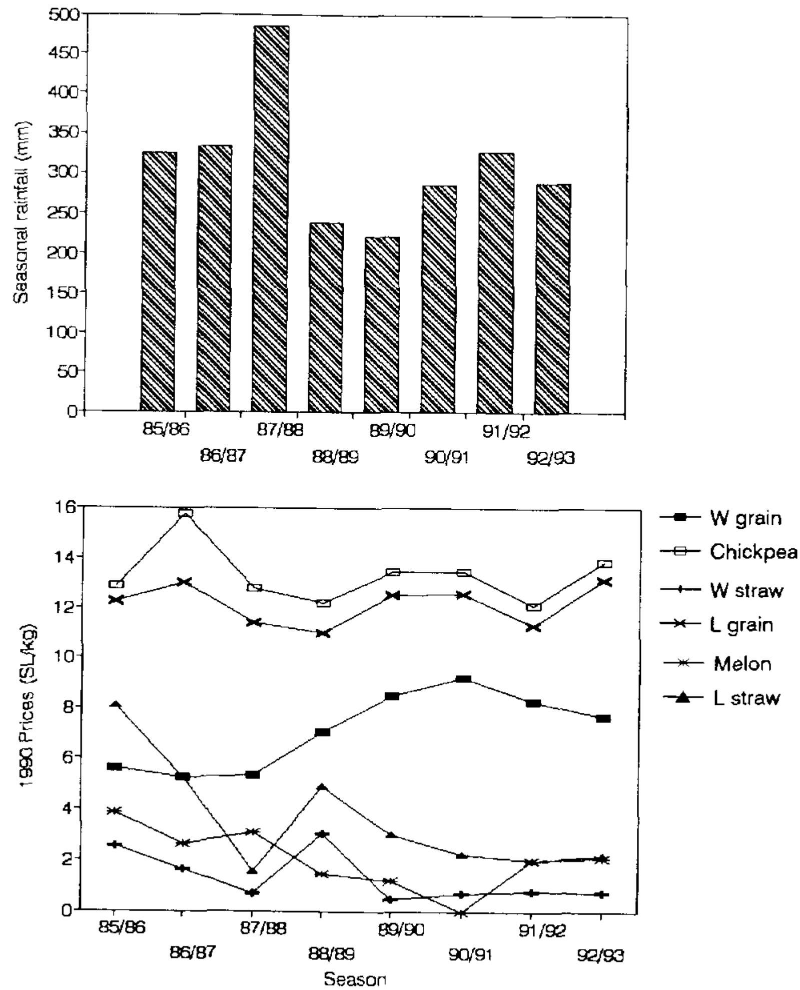

Figure 4.7.1 Rainfall and 1990 prices of commodities harvested during eight seasons in a two-course wheat rotation trial at Tel Hadya

Most of the variation embedded in the crop rotations stems from rainfall and market variability. Straw price is responsive to rainfall fluctuations in the short-run since it affects the liveweight gain expectations of the farmers' flocks. Rainfall also affects the price of melon which is a cash crop. Variations in market prices of cereals and legume grains depend on the weather conditions of the previous and current agricultural cycle and the national stock of staple commodities.

4.7.2 Crop yields

Yields of grain or fruit and straw in the five rotations are shown in Table 4.7.1. No straw was collected in the non-wheat phase of the wheat/fallow, wheat/summer crop or wheat/chickpea rotations. Variability in wheat yields arose from two sources: variation in seasonal rainfall, and variation in the amount of carry-over water from the alternate phase. Seasonal rainfall also strongly influenced the yield of the legumes, but in addition, yields, particularly of lentil, were reduced by low temperature in some years (FRMP 1990; 1993a). The Tel Hadya environment is marginal for chickpea production which, in northern Syria, is located mainly in areas with >350mm average rainfall.

Table 4.7.1 Yields of grain or fruit[1] and straw (kg/ha) in five wheat-based two-course rotations in Tel Hadya from 1985 to 1993 averaged across all nitrogen treatments

		Wheat phase					Non-wheat phase				
	Season	W/F	W/S	W/L	W/C	W/W	W/F	W/S	W/L	W/C	W/W
	1985/86	2574	2711	2041	2003	1379	0	2037	1257	1020	735
G	1986/87	1916	1958	1649	1351	1010	0	2165	1078	989	530
R	1987/88	4095	3609	3911	2938	943	0	3520	1224	990	528
A	1988/89	1844	1444	944	396	310	0	0	614	506	330
I	1989/90	1139	1600	728	623	553	0	0	205	373	475
N	1990/91	1563	1641	1249	759	968	0	0	1105	793	739
	1991/92	2703	2773	2206	2189	1923	0	1015	829	1404	1316
	1992/93	2636	2114	2463	1973	1143	0	1850	851	1230	770
	AVG[2]	2309	2181	1899	1529	1029	0	1323	895	913	678
	CV[3]	37	35	50	55	45	-	91	37	35	41
	1985/86	3951	3800	2966	3164	2283	0	0	2757	0	1385
S	1986/87	3333	3404	3285	2526	1856	0	0	1955	0	961
T	1987/88	7184	6195	6904	5006	1159	0	0	1650	0	573
R	1988/89	3521	2220	2071	1174	949	0	0	1248	0	917
A	1989/90	2551	2689	1724	1661	1711	0	0	1113	0	988
W	1990/91	3953	4438	3611	3698	2946	0	0	2504	0	1403
	1991/92	3743	3201	3503	3066	3278	0	0	1744	0	1991
	1992/93	4104	4746	2811	4141	3411	0	0	1454	0	1309
	AVG[2]	4042	3837	3359	3055	2199	0	0	1803	0	1191
	CV[3]	32	31	44	39	40	-	-	30	-	34

1) Melon in wheat/summer crop
2) Average
3) Coefficient of variation (%)

The coefficient of variation of yield: was greater for grain than for straw; was greater for wheat/lentil, wheat/chickpea and wheat/wheat than for wheat/fallow and wheat/summer crop; and was similar among the crops in the non-wheat phase, except for the melon where it was 91% as no crop was sown in three out of eight years because low rainfall led to insufficient soil water for planting.

Because of the heterogeneous nature of the output from the different rotations, productivity can be assessed and compared only by using nutritional, energetic or market values. Here we use market values.

4.7.3 Gross margins and optimal nitrogen applications

Partial budgets for each nitrogen treatment in each rotation permitted identification of the optimal N fertilizer rate (Table 4.7.2). The wheat/lentil rotation gave the highest mean gross margin, from an average of 60 kg N/ha applied to the wheat. Wheat/melon followed, with a 30% lower mean gross margin, from an average of 86 kg N/ha, and then wheat/chickpea and wheat/fallow, somewhat lower, from 49 and 56 kg N/ha, respectively. Continuous wheat yielded the lowest mean gross margins, from an average fertilizer rate of 45 kg N/ha. Zero N was the optimal rate in some rotations in low rainfall seasons, except in 88/89 which was preceded by the wettest season and, thus, benefitted from a large carry-over of soil moisture. More generally, soil water storage in the fallow had an effect on the requirement for fertilizer. Wheat/fallow called for an average of 30 kg/ha more nitrogen than the continuous wheat.

None of the optimal rates in Table 4.7.2 had a normal distribution. Distributions were either bimodal, as for wheat/lentil and continuous wheat, or they were negatively skewed. The shape of the distributions must be related to the nature of the crop rotations, the effect of rainfall and management. However, explicit cause-effect of these distributions is beyond of the scope of this report.

Gross margins of the five rotations averaged for the eight seasons were plotted against increasing quantities of nitrogen used on the wheat (Figure 4.7.2). These curves suggest that the expected returns to nitrogen are considerable up to 60 kg/ha and decline towards 90 kg/ha with the exception of wheat/melon. Returns to nitrogen fertilizer above 90 kg/ha are expected to be extremely low and very risky because of the low probability of large amounts of rainfall. It is of note that the lowest returns come from continuous wheat and wheat/fallow. Unfertilized wheat/fallow has been a traditional practice for centuries, while price distortions due to government policies in some countries are encouraging farmers to practice continuous wheat cultivation.

Table 4.7.2 Optimal nitrogen fertilizer applications to wheat in kg/ha (highlighted figures) and two crop 'rotational' gross margins (SL/ha), in five crop rotations at Tel Hadya

Rotation	Season									
	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	AVG[1]	CV[2]
W/F	**30**	**90**	**90**	**90**	**90**	**30**	**90**	**90**	**75**	**35**
	8166	641	8339	3705	-186	3071	7784	7653	4897	67
W/SC	**90**	**90**	**90**	**90**	**90**	**60**	**90**	**90**	**86**	**12**
	11546	5664	14638	828	2927	3314	9065	7202	6898	63
W/L	**60**	**90**	**90**	**90**	**0**	**0**	**90**	**60**	**60**	**61**
	21018	12277	12617	4190	-136	10150	8499	10597	9902	59
W/CHK	**60**	**90**	**90**	**30**	**0**	**0**	**90**	**30**	**49**	**75**
	10629	6114	9425	-2076	-858	3498	10598	10734	6008	82
W/W	**30**	**90**	**90**	**30**	**0**	**30**	**60**	**30**	**45**	**67**
	6432	803	-2996	-3143	-617	1208	7999	2921	1576	241
AVG[1]	**54**	**90**	**90**	**90**	**36**	**24**	**84**	**66**	**63**	-
CV[2]	**42**	**0**	**0**	**0**	**122**	**94**	**14**	**34**	-	-
Rain	325	333	485	238	221	285	327	289	313	24

1) Average 2) Coefficient of variation (%)

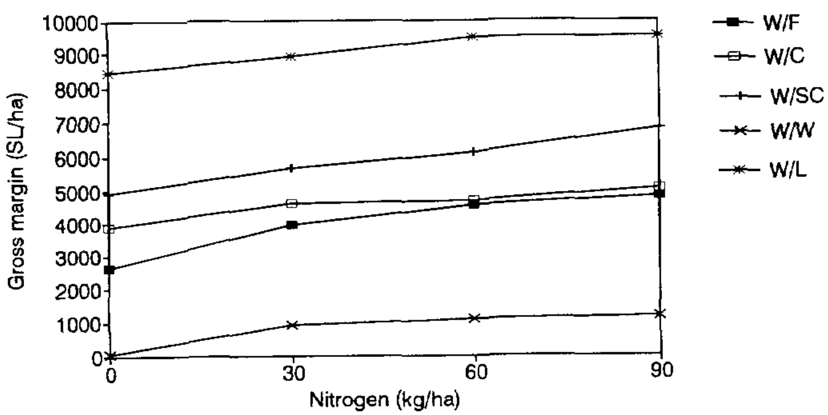

Figure 4.7.2 Gross margins in five rotations averaged for eight seasons with respect to increasing quantities of N fertilizer

In spite of the high profitability of the wheat/lentil rotation, lentil occupies much less than half the cultivated land in northwestern Syria. Limiting factors such as capital, labor and land fragmentation may explain this. It is very possible that the labor cost used in the budgets here does not represent its opportunity cost in the farmers' portfolio. Whole farm modeling could be used to examine the opportunity cost of limiting factors.

4.7.4 Adaptive and non-adaptive management

Eight seasons of available data constitute a small time series which allows us to make inferences about weather and market risk in the rotations commonly found in northwestern Syria. The average optimal rates in Table 4.7.2 are the *ex-post* maximization of gross margins. They show adjustment for rainfall in the current and previous seasons (adaptive management). If farmers fertilize with the average quantity (Table 4.7.2 column 9) they would receive lower gross margins compared with the adaptive scheme (Table 4.7.3). The benefits of adaptive management averaged 13% for all rotations, although this derived mostly from the wheat/chickpea and continuous wheat (22% and 33%, respectively). These are the rotations most likely to suffer water limitations.

Table 4.7.3 Comparison of expected gross margins (SL/ha) derived from adaptive and non-adaptive management policies

	Management policy		
Rotation	Non-adaptive[1]	Adaptive[2]	Benefit
	------- (SL/ha)	-------	(%)
Wheat/fallow	4675	4897	5
Wheat/melon	6697	6898	3
Wheat/lentil	9477	9902	4
Wheat/chickpea	4676	6008	22
Wheat/wheat	1004	1576	36
Average	5304	5856	14

1) Averages of N fertilizer in Table 4.7.2 were used to interpolate gross margins from data depicted in Figure 4.7.2
2) Averages of seasonal gross margins from column 9, Table 4.7.2

An adaptive policy whereby the fertilizer application is a function of the soil moisture carry-over and rainfall in the current season is desirable. Whitaker (1990) found that an adaptive, dynamic policy of nitrogen use on wheat rotations was 3-8% more profitable than a static policy based on the average of optimal policies. She benefitted from sets of 200 seasons of simulated weather and crop growth using two-stage production functions. Here, we estimated the non-adaptive management policy based on 8 seasons of data and also determined *ex-post* optimal adaptive management policies.

Sequential decision making in nitrogen applications has some potential as summarized in Table 4.7.3 and Whitaker (1990). It seems fruitful to devote resources to understand farmers' sequential allocation of capital and labor into alternative rotations on different plots of land. The challenge is to provide usable recommendations to farmers, which link past performance of the agricultural systems with expectations of weather events and market prices. [*Abelardo Rodríguez and Hazel Harris*]

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4.8 Response of Durum and Bread Wheat to Supplemental Irrigation and Management Practice

4.8.1 Introduction

That supplemental irrigation (SI) can have a significant positive impact on wheat yields under Mediterranean rainfed conditions has been established through research by ICARDA and others in many WANA wheat growing areas (Perrier and Salkini 1991). However, the local feasibility of practising SI depends on such factors as climate, management, and socio-economics.

Precipitation amount and distribution are the most important climatic parameters. Variation in both the amount and frequency of rainfall in time and in space greatly complicate SI management. On the other hand, SI may improve the utilization efficiency of rainfall by preventing crop failure due to drought during sensitive stages of crop growth. Management factors include the types, rates and timing of such inputs as irrigation water and fertilizer, and the choice of germplasm and planting date.

Previous studies have shown various relationships between wheat yield and the amount of supplemental irrigation, depending on seasonal rainfall and SI management (FRMP 1990, 1991, 1992). As water is limited in most WANA rainfed areas, applying SI for maximum production is not the optimal strategy; rather, it is logical that under such conditions the strategy should be to maximize water-use efficiency. However, in either case, production functions for crops grown under SI need to be determined before any optimization criteria can be defined.

Wheat varieties differ in their response to SI. Generally, most varieties have been developed for either resistance to drought under rainfed conditions or for fully irrigated conditions. They have not been characterized for response to various levels of SI. Proper selection of wheat varieties for the prevailing climate and management conditions could improve the feasibility of efficient use of SI.

Previous research at ICARDA showed that the application of nitrogen is vital to increasing wheat yields under SI. However, study was restricted to few varieties and standard planting dates. Few data are available on the interaction of N with varieties and planting dates at different rates of SI.

Planting date of wheat is difficult to control under rainfed conditions, but when SI is available it can easily be chosen. This may play an important role in reducing the cost of SI. Knowing the crop response to planting date, water-use efficiency can be maximized by selecting the appropriate planting date for the prevailing conditions. Furthermore, on large fields, the demand for a large discharge water supply and irrigation system can be reduced by spreading the dates of planting which, in turn, will spread the crop demand for water, thereby reducing the cost of the irrigation system.

Optimizing SI under all these variety, fertilizer and management parameters is not an easy task. It requires a comprehensive analysis that takes into account the contribution of each factor and the interactions between them. Understanding such systems and producing useful strategies and simple schedules is best done with simulation models; but this requires accurate and detailed field data for calibration and verification. Accordingly, the two experiments reported here were designed to provide detailed information on the direct and interaction effects of rates of SI and N, and of dates of planting, on the yields of four bread and four durum wheat varieties.

4.8.2 Methodology

Site: The two experiments are located in the B block of Tel Hadya station. A field of approximately four ha is divided into four parts, two under a cover crop in rotation with two carrying the annual wheat trials. The average 150 cm soil profile texture is clayey, with 62% clay, 29% silt and 9% sand. The soil is generally deep and well drained, with a water-holding capacity of 45% by volume and a basic infiltration rate of 11mm/hr.

Treatments:

a) Three dates of planting: D1=early, D2=normal, and D3=late.

b) Four wheat varieties:
In bread wheat expt. V1 = CHAM 4, V2 = GOMAM ,
V3 = CHAM 6, V4 = MEXIPAK 65
In durum wheat expt. V1 = CHAM 1, V2 = LAHN,
V3 = CHAM 3, V4 = OMRABI 5

c) Four SI application rates:
W1 = rainfed with no irrigation
W2 = irrigation to provide 1/3 of water applied in W4
W3 = irrigation to provide 2/3 of water applied in W4
W4 = full SI; water is applied to bring soil moisture back to field capacity when it has dropped to 50% of the available moisture (the difference between field capacity and wilting point)

d) Four nitrogen rates: N1=zero N; N2=50 kg N/ha; N3=100 kg N/ha; N4=150 kg N/ha, as urea.

Experimental Design: A split-split-split plot design with three replicates. Dates of planting, D1, D2, and D3, comprise the main plots; wheat varieties, V1, V2, V3, and V4, the subplots; irrigation rates, W1, W2, W3, and W4, the sub-sub plots; and the N rates, N1, N2, N3, and N4, are the sub-sub-sub plots.

Materials: A trickle irrigation system provides the SI treatments, giving full control over both time and amount (see FRMP 1993 for system design). Design parameters were selected to provide a uniform application similar to that of sprinkler and surface irrigation. Pressure compensating emitters, of approximate discharge rate 2l/hr, were installed along polyethylene lines 40m long and 20mm in diameter. Emitters are spaced along each lateral in four groups to provide automatically the four experimental SI treatments. Spacings between laterals were 70 cm and between emitters 17.5, 26.25, and 52.5 cm, corresponding to W4, W3, and W2, respectively. No emitters were installed in the W1 section. It may be noted here that the trickle irrigation system is only an experimental tool used to achieve precision. (It is unlikely that such a system would be economic for commercial fieldcrop production under these conditions.) Irrigation water is measured by a flowmeter and by calibrated emitter discharge.

Neutron probe access tubes were installed in one replicate of W1, W2, W3, and W4 treatments to a depth of 180 cm (a total of 48 tubes in each trial); and a probe is used to determine soil moisture frequently.

Germplasm materials were produced by ICARDA's Cereal Program in Tel Hadya. A uniform rate of phosphate was applied to all plots prior to planting. Fungicides and insecticides were used when necessary. Rainfall and other climatic parameters data are collected from a weather station located near the experiment site.

Procedure: Soil moisture content is estimated (weekly when conditions allow and also after each rain event and before and after each irrigation) by neutron probe measurements made at 15 cm intervals down the 150 cm soil profile. The gravimetric method is used for the top 15 cm layer. Measurements are made in one replicate at all rates of SI and nitrogen within varieties GOMAM and OMRABI.

Irrigation is applied to the treatments W2, W3, W4 at the same time. After sowing, 30mm is given to all treatments when rainfall is not adequate the day after sowing. Subsequently, when available soil moisture in the root zone of the W4 treatment is found to have dropped to 50% of its value, the amount of water required to bring soil moisture in the W4 root zone back to field capacity is calculated; and irrigation application time is then determined according to the system average discharge. Total volume of water is checked by a flowmeter installed at the head of the system. As the required amount of water for W4 is applied, then W3 and W2 receives 2/3 and 1/3 of that amount automatically, where rainfed treatment does not get any water.

Samples for soil chemical properties are taken before planting, and available N and P determined to indicate the fertilizer requirement. A nematicide is applied with the P fertilizer at the time of land preparation. Land preparation comprises a pre-planting cultivation using a ducks-foot cultivator with a harrow behind. A seed rate of approximately 300 seeds/m^2 in 17.5 cm rows is mechanically sown. Nitrogen fertilizer is applied in two doses, half immediately after planting, half topdressed at crop stage 22-25 (Zadoks).

Plant samples are taken at crop stages of 30, 45, 65, 85, and 94 (full maturity). Other measurements include: date of emergence, plant vigor, cold damage (if any), plant number, leaf area, dry matter, days to anthesis, tiller number at stage 65, number of grains per square meter, grain yield/m^2, total dry matter/m^2, weight of 1000 seeds, and days to maturity.

4.8.3 Highlights from the results of the first season

The 1992/1993 season rainfall, 277mm, was below average. The first rain was late, on November 15th. Subsequent rainfall was well distributed until early March when the last effective rain was received. Planting dates for bread wheat were 1/11/92, 10/12/92, and 16/1/93 (D1, D2, and D3, respectively), and for durum wheat, 10/11/92, 21/12/92, and 27/1/93. Three or four irrigations were needed (Tables 4.8.1 and 4.8.2).

It should be mentioned that the amounts of water listed in Table 4.8.2 do not represent actual crop consumptive use. Those values will be determined after the soil moisture data are analyzed and will be presented in the FRMP 1994 report. Only highlights of the first season grain yield responses to SI, rainfall, date of planting, and nitrogen are presented here.

Table 4.8.1 Dates of irrigations

	Bread wheat			Durum wheat		
Irrigation no.	D1	D2	D3	D1	D2	D3
1st	31/3	31/3	31/3	2/4	1/4	6/4
2nd	22/4	14/4	22/4	15/4	23/4	23/4
3rd	21/5	22/4	2/5	23/4	4/5	22/5
4th	—	22/5	22/5	21/5	21/5	—

Table 4.8.2 Total amounts of irrigation (mm)

	Bread wheat			Durum wheat		
Treatment	D1	D2	D3	D1	D2	D3
W4	425	411	408	548	441	276
W3	383	274	272	365	294	184
W2	142	137	136	183	147	92

4.8.3.1 Bread wheat variety comparison

All the improved bread wheat varieties significantly outyielded the local check (Mexipak) at each of the four irrigation rates and across the three planting dates (Figure 4.8.1). In the early

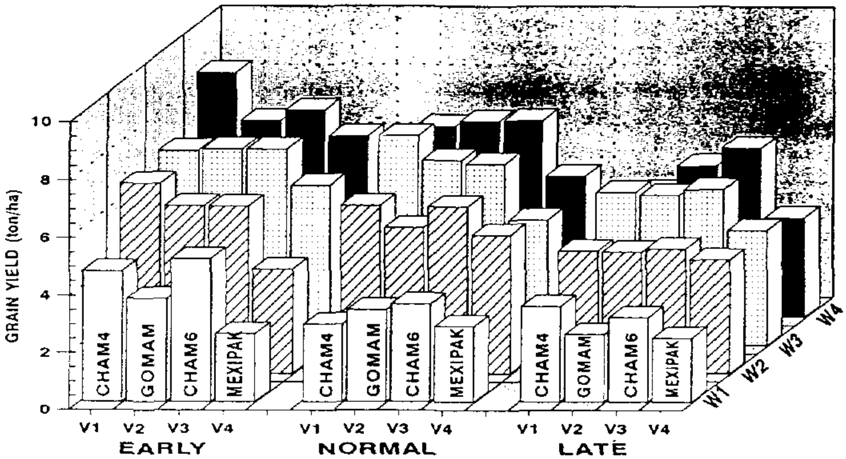

Figure 4.8.1 Bread wheat variety response to rates of supplemental irrigation and dates of planting

planting, Cham 6 gave the highest rainfed grain yield (more than 4.0 t/ha), reflecting its reported drought tolerance (Ortiz Ferrara 1992), while Cham 4 yielded most at the highest irrigation rate W4. This variety was released in Syria for commercial production in the high rainfall and irrigated areas. In the two later plantings, Cham 6 tended to equal or outyield Cham 4 under all water-rate treatments.

A provisional conclusion at this stage would be that Cham 6 may be recommended for early planting in the rainfed, low-rainfall areas, while Cham 4 would be expected to perform better under early planting and SI.

4.8.3.2 Durum wheat variety comparison

The grain yield of durum was generally lower than that of bread wheat, when compared across planting dates and SI treatments, and for each of the tested genotypes yield decreased slightly with later planting (Figure 4.8.2). All tested genotypes were improved varieties and produced similar grain yields (about 2.5 t/ha) under rainfed conditions (W1) across all planting dates. This could be attributed to the narrow variability between these genotypes. Responses to the first (and second) increments of SI (W2, W3) were generally greatest in the early-planted crop, but in both the later plantings OMRABI was clearly the most responsive variety. OMRABI was again one of the two highest-yielding varieties at the highest rate of SI, with Cham 3 in the early planting and with Cham 1 in the two later plantings.

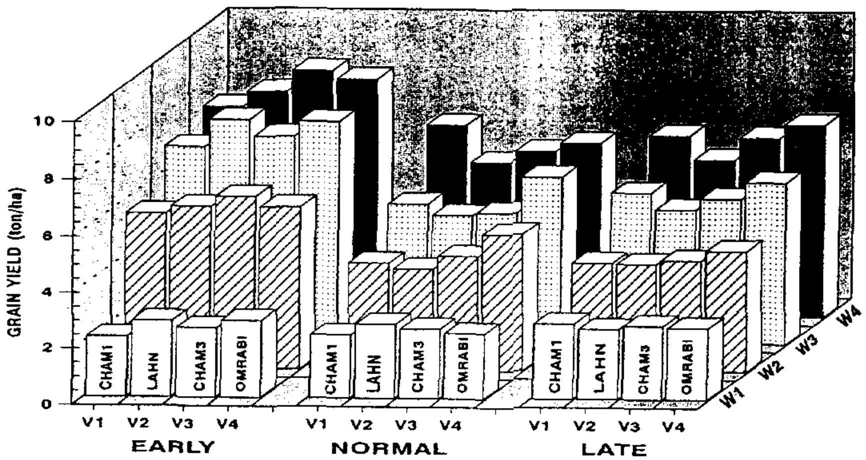

Figure 4.8.2 Durum wheat response to rates of supplemental irrigation and dates of planting

4.8.3.3 Wheat response to nitrogen

The response of bread and durum wheat to nitrogen under different water and date of planting regimes is summarized in Figures 4.8.3 and 4.8.4. For both bread and durum wheats the effect of increasing N rate was related to the water treatment: a small yield decline under rainfed conditions (and under W2 in the late planting) but an

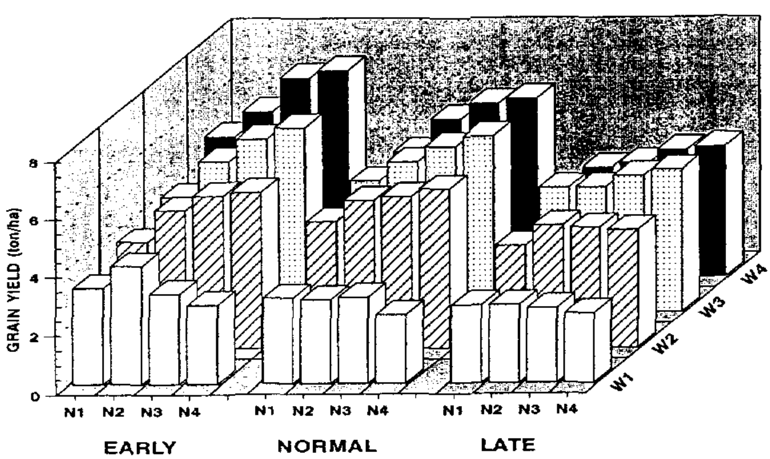

Figure 4.8.3 Bread wheat response to nitrogen and supplemental irrigation under various planting dates

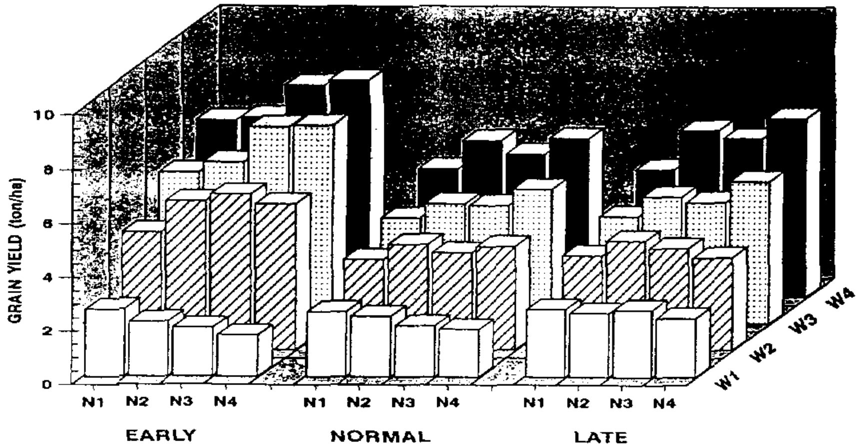

Figure 4.8.4 Durum wheat response to nitrogen and supplemental irrigation under various dates of planting

almost linear positive response under W3 and W4 treatments. Bread wheat appears to have been slightly more responsive to N than durum, at least in the two earlier plantings.

All these data await full statistical analysis, and in any case the trial is being repeated in the 1993/94 season. However, the importance of the interactions, both between water rate and nitrogen and between these two treatments and planting time, is already evident. Clearly, each of both SI and nitrogen is more effective when the other is present, and both tend to give greater yield increments with the earliest planting. [*Theib Oweis, M. Pala, H. Harris, J. Ryan, G. Ortiz, and M. Nachit with major support from S. Dehni*]

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5. ADOPTION AND IMPACT OF TECHNOLOGY

Introduction

The subject matter of this 'project' is broader than its title suggests and, at different times, its activities include economic studies of production techniques as well as farm surveys at different stages of the farming systems research approach. The present chapter comprises reports of diagnostic surveys (5.2 and 5.3), an appraisal of the economic viability and sustainability of cereal production under water harvesting conditions, and four adoption studies of various cereal production technologies (5.1, 5.5, 5.6 and 5.7).

FRMP scientists have studied and worked with barley farmers in northern Syria for more than ten years. A major diagnostic study in the early 1980s prompted a long program of on-farm fertilizer trials, which in turn led to a new government policy allocating fertilizer for the first time to barley growers in dry areas. By early 1993, 86.7% of farmers in zone 2 and 46.7% in the drier zone 3 were using fertilizer on their barley; and the follow-up study, reported in part here (5.1), examined the factors that had influenced farmers' adoption -- or non-adoption -- of the fertilizer recommendation. One important reason for non-adoption was a lack of access to credit, but 'psychological' (or personality) factors were also identified: the self-image of those who adopted was more progressive, flexible and scientifically orientated than that of non-adopters, and 34% of adopters said they liked the occupation of rainfed farming very much as against only 12.5% of non-adopters. Technology adoption is a function not only of economic and technical factors but of individual attitudes and lifestyle preferences.

The diagnostic studies were in Lebanon and Libya. The first (5.2), in collaboration with AUB, ARI (Lebanon) and ICARDA (Terbol), aimed to characterize wheat-production systems in Lebanon, to prioritize constraints to development and to identify research needs. It found that wheat, occupying around 36% of the farmed area, has good potential for increased production, particularly from the adoption of improved varieties. This is currently limited by the lack of a seed multiplication system. Findings also suggest that the use of supplemental irrigation could be increased and that more research is needed on fertilizer use and disease and pest control.

The Libyan study (by ARI, Libya, with FRMP backup) sought to evaluate the current cereal production situation in western Libya (5.3). Its results confirm that few wheat crops there are purely rainfed, and supplemental irrigation is essential for economic production. As in Lebanon, the lack of a proper mechanism for producing and distributing seed is a major constraint; further, a policy of subsidizing the wheat price paid by the consumer inhibits production development and is contrary to the aim of self-sufficiency.

Extra water is also needed to improve and stabilize cereal yields in highland Balochistan, but many farmers have no access to irrigation sources and their only option is to make the best use possible of the rainfall. The study reported here (5.4) was concerned with the viability of a system in which part of the area of each arable field is used as a rainwater catchment supplying extra water to crops grown rainfed on the rest of the field. Six years of wheat data and four of barley from agronomic trials at several sites were analysed. In fact, the data sets are insufficient for any firm conclusions to be drawn, but there is some evidence that for wheat a 1:1 division of the field (ie half catchment, half cropped area) is more productive than cropping the whole area.

The last three sections in this chapter report work conducted by Rockefeller post-doctoral fellows attached to FRMP for two-year periods to undertake specific research assignments, in Egypt (A. Aw-Hassan) and North Africa (M. Saade).

Over the last ten years, the Nile Valley Regional Project has had many successes in the transfer of improved crop production techniques to farmers in Egypt, Sudan and Ethiopia, and, specifically, has contributed to the impressive increase in wheat yields in Egypt. At the same time, farm-level economic and social issues have been relatively neglected. For Upper Egypt, the lag in technology adoption and yield improvement relative to Middle Egypt and the Delta has not been well understood. The present assignment (5.5) examined the adoption of modern wheat production technologies in two provinces of Upper Egypt and their impact on the profitability of wheat growing. Preliminary results indicate that some technologies (eg new varieties) have been quite widely adopted, while others (like rates of seeding and fertilizer application) have not -- due, it seems, to lack of farmer confidence in them. More farmer participation in technology evaluation activities is recommended.

The survey further noted that increases in the wheat price after policy changes in 1986 had greatly improved the profitability of wheat production, but this was later offset by the removal of subsidies on inputs. Nevertheless, net returns per hectare were higher (and the effects of costly inputs less detrimental on net return) for farmers adopting higher levels of technology.

Triticale was introduced to Tunisian farmers 10 years ago to reduce maize imports for poultry feed. Survey results (5.6) suggest that farmers liked the crop but hesitated to increase the area grown because of market uncertainties. Until 1990, utilization of triticale was depressed by the availability of cheaper maize and barley. Since then, the removal of subsidies on those commodities has made triticale the cheapest feed ingredient, dramatically increasing utilization; but more of it has gone to feed small ruminants than poultry. Prices now need to be modified to keep triticale cheaper than maize but more expensive than barley, to ensure that the limited triticale supplies are utilized most efficiently, that is as poultry feed.

Finally, a survey in Morocco to identify the reasons for the limited adoption of new barley varieties (5.7) found that adoption was greater than expected. However, it was restricted to the "semi-arid" zone and to two older varieties, favored because they give good yields of grain suitable for human consumption. In any case, low production and high price of certified barley seed seems likely to continue to constrain wide adoption. It is further concluded that future efforts, in both technology transfer and varietal improvement, should focus more on the "arid" zone, where more than half the barley area is located.

5.1 Preliminary Results of a Survey of the Adoption of Fertilizer Use on Rainfed Barley

5.1.1 Introduction

During March and April 1993, 105 producers of rainfed barley (60 in zone 2, 45 in zone 3) in Aleppo, Idleb, Hama, Hassekeh and Raqqa provinces were randomly selected and interviewed. The main objective was to identify the factors influencing their adoption of fertilizer use on barley, but other questions were also asked about the practice of continuous barley cropping.

5.1.2 Continuous barley cropping

Farmers were asked: when they had started cropping barley continuously; for what reasons; whether they had noticed any resulting problems; how long they intended to continue; and whether they thought growing barley continuously had any effect on the need for fertilizer.

Around 82% of the farmers interviewed now grow barley continuously (Table 5.1.1). This is a very big increase over the figure of 27% recorded in the barley survey of 1980 (Somel et al. 1984). The proportion doing so is rather higher in the northeast (98%) than in the northwest (70%), but in both locations the reason most commonly given was the small area of the farmer's land holding. Nevertheless, most farmers realise the drawbacks of the practice. Around 50% of those growing barley continuously noticed decreasing yields, and 41% referred to insect damage, especially from 'ground pearls' (Porphyrophora tritici). This insect is a particular problem in the northeast.

Comparisons for the 1991/92 season show that mean yields from continuous barley were 67% (zone 2) and 74% (zone 3) of those from barley following fallow or another crop. Differences were particularly large on farms of non-adopters of fertilizer, where the mean yield in continuous barley rotation was just 431 kg/ha, or 36%

of that obtained (1180 kg/ha) in other rotations. Despite these results, 51% of farmers said that they would continue growing barley continuously, 43% that they would continue for a few years, and only 6% that they would stop it next year.

Table 5.1.1 Continuous barley cropping in Syria (% of farmers)

	Zone		Region		Fertilizer		Total
	2	3	NW	NE	Adopters	Non-adopters	
Practice continuous barley cropping	78.3	86.7	70.0	97.8	78.1	90.6	81.9
Continuous barley cropping, effect on fertilizer use	100.0	75.9	97.6	84.1	98.2	75.9	90.7
Growing continuous barley:							
- will stop next year	4.3	7.7	7.1	4.5	3.5	10.0	5.8
- will continue for few years	27.6	61.7	40.5	45.5	38.7	51.6	43.0
- will continue	68.0	30.8	52.4	50.0	58.0	37.8	51.2
Barley yield (1991/92) kg/ha							
B-B	990	570	825	763	974	431	790
(CV) %	(56)	(69)	(66)	(68)	(55)	(63)	(67)
B-other crop	1473	763	1290	-	1280	1180	1274
(CV) %	(61)	(62)	(67)		(65)	(89)	(67)
Time since starting the practice							
1 year	4.3	-	4.8	-	3.5	-	2.3
2-5 years	29.8	38.5	28.6	38.6	29.8	41.4	33.7
6-10 years	46.8	25.6	45.2	29.5	42.1	27.6	37.2
10-19 years	17.0	17.9	19.0	15.9	21.1	10.3	17.4
More than 20 years	2.1	17.9	2.4	15.9	3.5	20.7	9.3
Reasons for the practice							
Small holding area	45.0	53.3	38.3	62.2	46.6	53.1	48.6
Higher income	20.0	28.9	21.7	26.7	17.8	37.5	23.8
Stopping fallow system	11.7	-	-	15.6	8.3	3.1	6.7
Fertilizer use	6.7	2.2	5.0	4.4	6.8	-	4.8
Shallow soil	5.0	6.7	8.3	2.2	6.8	3.1	5.7
As neighbor practice	8.0	-	5.0	4.4	6.8	-	4.8
Feed requirement	-	6.7	5.0	-	1.4	6.3	2.9
Other reasons	1.7	4.4	3.3	2.2	4.1	-	2.9
Problems noticed							
No problems	6.7	2.2	8.3	-	6.8	-	4.8
Low yield	50.0	71.1	50.0	71.1	52.1	75.0	59.0
Insects	35.0	48.9	13.3	77.8	34.2	56.3	41.0
Plant yellowish	5.0	-	5.0	-	4.1	-	2.9
Empty heads	6.7	-	6.7	-	5.5	-	3.8

5.1.3 Fertilizer adoption

According to most theories on the adoption and diffusion of agricultural innovations, adoption is not a sudden event but a process. Farmers do not accept an innovation immediately but need time to think it over. Various theoretical schemes have been proposed detailing the stages of the process, for instance: awareness, interest, evaluation, trial and adoption.

Research has shown that within populations of farmers the adoption of an innovation plotted against time often follows a bell-shaped or normal distribution curve (Figure 5.1.1); and sociologists have categorized adopters according to how long their act of adoption takes relative to that of other members of the same

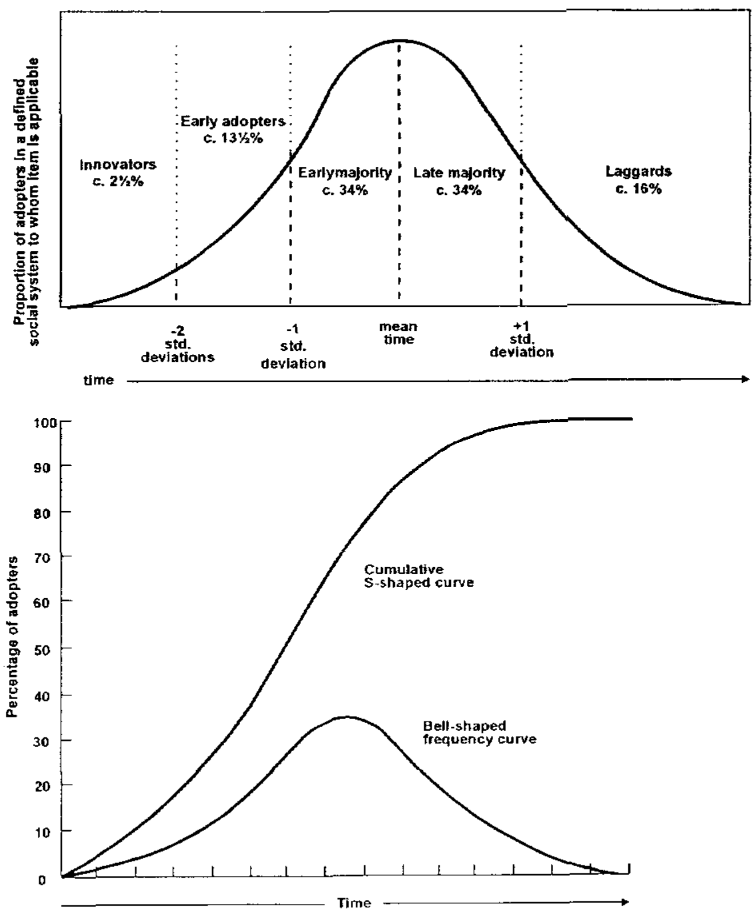

Figure 5.1.1 Categories of adopters (assuming a normal diffusion curve) [Rogers 1983]

social system. By calculating the average time of the adoption process and the standard deviation from it, they have divided adopters into five categories: innovators, early adopters, early majority, late majority and laggards.

Farmers interviewed in the present survey were asked: when they started using nitrogen fertilizer on their barley, at planting time and as a top dressing; when they started using phosphate; and their reasons for using or not using chemical fertilizer. Their answers are plotted as cumulative percentages in Figure 5.1.2. We may note that:

- Adoption of any type of fertilizer has been higher in zone 2 than zone 3 (86.7% versus 46.7%), with a greater total adoption of phosphate (65.7%) than of planting-time nitrogen (53.3%) or top-dressed nitrogen (49.5%).
- In both zones, the adoption rate and the percentage of farmers who adopted was greater for phosphate than for nitrogen. This could be related to an awareness of farmers that there is a risk associated with nitrogen, especially if there is a shortage of rain, that is not associated with phosphate.
- Adoption started later in zone 3 because the release of the innovation was later, but once fertilizer was made available (after a change in policy resulting from the FRMP/SD collaborative project), the <u>rate</u> of adoption (represented by the slope of the curve) was greater.

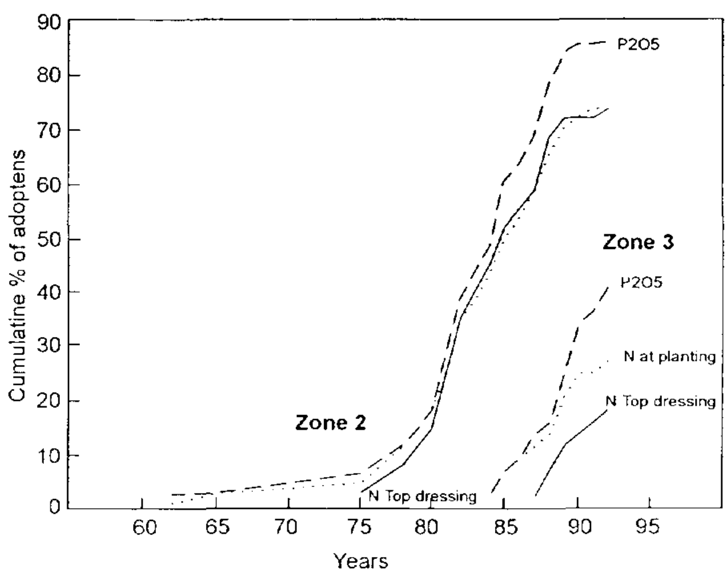

Figure 5.1.2 Actual diffusion curves of fertilizer use on rainfed barley in Syria

Some difficulty was experienced in classifying adopters into five classes, due to the incompleteness of the adoption process at the time of the survey. However, taking the classification into five simply as an ideal that may be modified in the practical situation, in the present case it was found more appropriate to use four categories:

- early adopters, who adopted before 1981
- early majority, who adopted between 1982 and 1988
- late majority, who adopted between 1989 and 1992
- laggards or non-adopters, who have not yet adopted.

Results are summarized in Table 5.1.2.

Table 5.1.2 Fertilizer adoption by categories of adopters and rainfall zones (% of farmers)

	Zone 2	Zone 3	Both zones
Adoption of N and/or P fertilizer	86.7	46.7	69.5
N and/or P fertilizer			
Early adopters (before 1981)	28.3	-	16.2
Early majority (1982-1988)	51.7	17.8	37.1
Late majority (1989-1992)	6.7	28.9	16.2
Non-adopters	13.3	53.3	30.5
P fertilizer			
Early adopters	28.3	-	16.2
Early majority	50.0	15.6	35.2
Late majority	6.7	24.4	14.3
Non-adopters	15.0	60.0	34.3
N at planting time			
Early adopters	25.0	-	14.3
Early majority	40.0	13.3	28.6
Late majority	8.3	13.3	10.5
Non-adopters	26.7	73.4	46.7
N top dressing			
Early adopters	25.0	-	14.3
Early majority	43.3	6.7	27.6
Late majority	5.0	11.1	7.6
Non-adopters	26.7	82.2	50.5

For each possible reason for using or not using fertilizer, the farmer's response was graded according to importance, viz. not important, of little importance, of medium importance, and important. The 'important' reasons given by adopters were to increase yield (95.7%), credit availability (46.4%) and 'the neighbors are using' (37.7%). Among reasons of medium importance were: to reduce the possibility of crop failure and 'fertilizer is not a risky practice' (Table 5.1.3).

About 61% of non-adopters gave the non-availability of credit as an important reason why they did not adopt, and this problem was greater in zone 3 than in zone 2 (Table 5.1.4). Another 36% said that fertilizer is risky to use; and 50% mentioned lack of awareness as a factor of medium importance behind their non-adoption.

Table 5.1.3 Reasons for using chemical fertilizer (% of adopters)

	Degree of importance			
	Not	Little	Medium	Important
Aware of its application	24.6	27.5	34.8	13.0
Its availability on time	63.8	21.7	11.6	2.9
Credit availability	23.2	4.3	26.1	46.4
Fertilizer not risky to use	34.8	29.0	34.8	1.4
Want to increase yield	2.9	-	1.4	95.7
Reduce the possibility of crop failure	14.5	13.0	46.4	26.1
Recommended by extensionists	84.1	8.7	1.4	5.8
The neighbors use it	24.6	13.0	24.6	37.7
Labor availability	97.1	2.9	-	-
Not expensive	91.3	5.8	2.9	-

Table 5.1.4 Reasons for not using chemical fertilizer (% of non-adopters)

	Degree of importance			
	Not	Little	Medium	Important
Not aware of its application	25.0	8.3	55.6	11.1
Fertilizer is not available	86.1	5.9	5.6	2.8
Credit is not available	16.7	13.9	8.3	61.1
Fertilizer is risky to use	50.0	2.8	11.1	36.1
No real benefit of using fert.	80.6	-	11.1	8.3
Lack of trust in Extension	94.4	2.8	-	2.8
Neighbor do not use it	27.8	8.3	16.7	47.2

5.1.4 Psychological factors affecting fertilizer adoption

While economic factors have an important influence, many non-economic factors may affect adoption (Figure 5.1.3); and their identification is necessary to an understanding of the process. Important among these factors is the individual's views, developed through time and experience, of himself or herself and of how he or she is seen by others. Such a 'self-concept' is a composite image of what we think we are and what we think we can achieve (cognized self), what we think others think of us (other self), and what we would like to be (idealized self); and many psychologists regard it as a major determinant of every individual's behavior.

In studying farmers' decision making and consequent behavior, it is important to identify these images. They create a frame of reference for every individual within the farming community to recognise himself or herself and to preselect both goals and behavior. The present research therefore assessed such aspects as farmers' attitudes, their beliefs about agriculture, and their self images. Each farmer was asked to state the degree to which he liked or disliked the following jobs: rainfed farming, irrigated farming, livestock raising, agricultural machinery, trade, government employment,and other self employment. Five categories of answer were allowed: like very much, like, neutral, dislike, and dislike very much.

At the same time, to assess self concept, each farmer was presented with eight 'dimensional' words and their definitions, one at a time:

* Progressive farmer - is always in front of others in taking up new ideas.
* Efficient farmer - looks to details, keeps records and considers things from an economic point of view.
* Innovative farmer - has the ability and self-confidence to try different ways to solve a problem.
* Experienced farmer - has had the time and opportunity to learn.
* Fortunate farmer - is a lucky farmer.
* Flexible farmer - has the ability to manage and adapt his practices to changing circumstances.
* Scientifically-oriented farmer - wants to know, either from researchers or extensionists or by testing the results of experiments himself.
* Risk-taking farmer - is prepared to take risks and believes that, sometimes, risk-taking is necessary to earn more money.

Each of these dimensions was scored on a five-point scale by the farmer. For example, for the first one, he was asked to identify his cognized self, his other self and his ideal self on the scale:

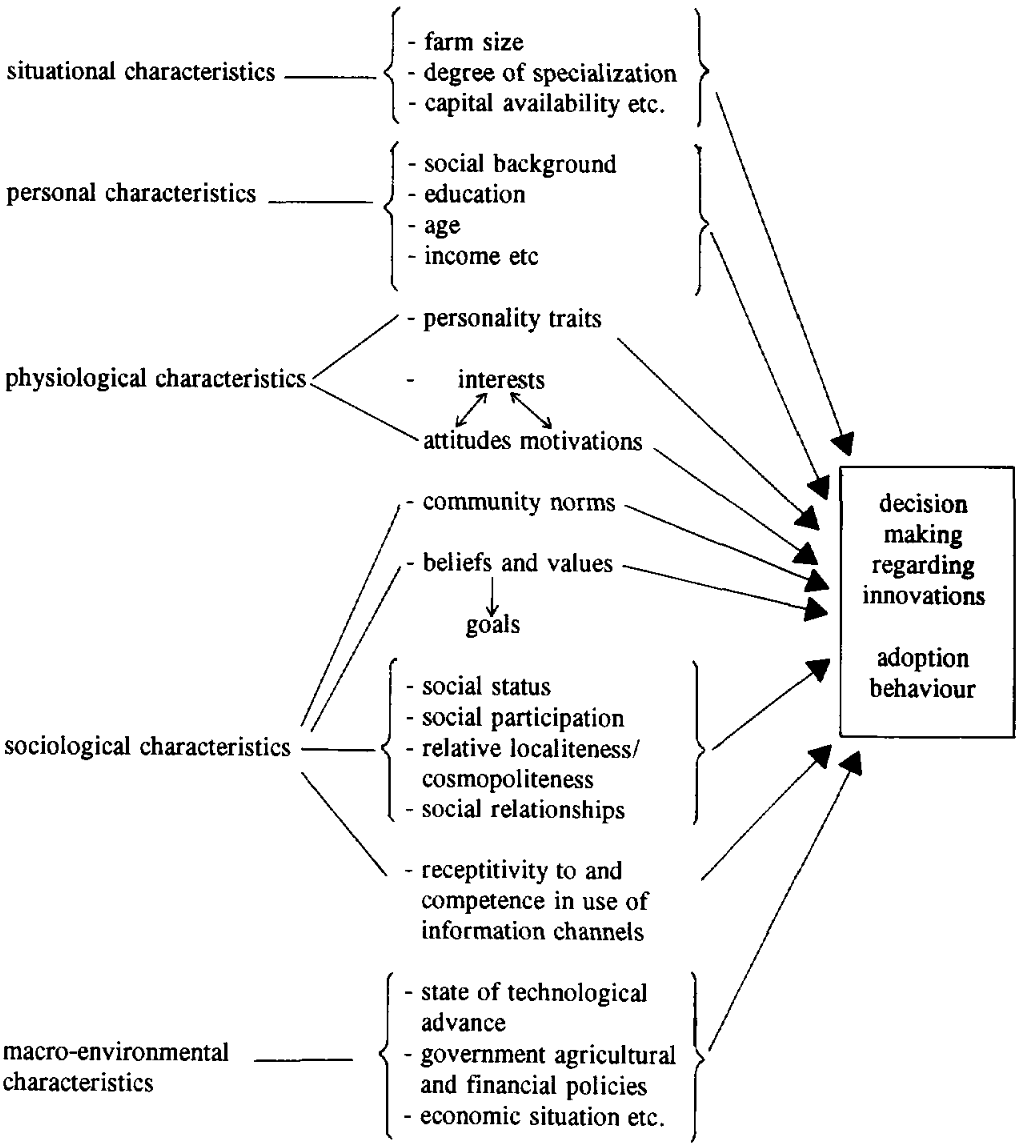

Figure 5.1.3 Factors affecting the diffusion of innovations among farmers (from Jones 1975)

I---------I	---------I	---------I	---------I	---------I
1	2	3	4	5
Very traditional	Traditional	Neutral	Progressive	Very progressive

Summarizing farmers' attitudes to job types, two significant differences emerge between fertilizer adopters and non-adopters (Table 5.1.5). About 34% of adopters reported that they like rainfed farming very much, as against only 12.5% of non-adopters; but, whereas only 16.5% adopters reported liking or liking very much a trade job, for non-adopters the figure was 48%. This attitude may reflect the low profitability of rainfed farming for non-adopters. Such results support the view that a relationship exists between farmers' attitudes to rainfed farming and the adoption/non-adoption of fertilizer.

Table 5.1.5 Farmers' attitude to some jobs (%)

	Dislike very much	Dislike	Neutral	Like	Like very much	P
Rainfed farming						
Adopters	-	-	5.5	60.3	34.2	<0.01
Non-adopters	-	-	25.0	62.3	12.5	
Irrigated farming						
Adopters	-	1.4	9.7	9.7	79.2	n.s.
Non-adopters	-	-	6.5	9.7	83.9	
Animal raising						
Adopters	1.4	13.7	37.0	34.2	13.7	<0.01
Non-adopters	-	-	53.1	28.1	18.8	
Trade						
Adopters	30.1	32.9	20.5	11.0	5.5	<0.05
Non-adopters	18.8	21.9	12.5	37.5	9.4	
Agri-machinery						
Adopters	2.7	1.4	20.5	43.8	31.5	n.s.
Non-adopters	3.1	9.4	21.9	46.9	18.8	
Government employment						
Adopters	52.1	30.1	9.6	8.2	-	n.s.
Non-adopters	65.6	18.8	3.1	12.5	-	
Other self employment						
Adopters (n=16)	6.3	12.5	56.3	6.3	18.8	n.s.
Non-adopters (n=4)	-	-	100.0	-	-	

Some of the findings of the 'self concept' study are presented in Tables 5.1.6, 5.1.7 and 5.1.8. The self-image of farmers who adopted fertilizer was more progressive, efficient, flexible and scientifically oriented than that of non-adopters, differences that

Table 5.1.6 Farmer's view of himself (cognized self) (%)

	5 Very progressive	4 Progressive	3 Neutral	2 Traditional	1 Very traditional	P
Progressive - Traditional						
Adopters	5.5	50.7	37.0	6.8	-	<0.01
Non-adopters	-	28.1	40.6	31.3	-	
Efficient - Not efficient						
Adopters	2.7	16.4	21.9	52.1	6.8	<0.01
Non-adopters	6.3	9.4	9.4	40.6	34.4	
Innovative - Not innovative						
Adopters	2.7	19.4	38.4	37.0	2.7	n.s.
Non-adopters	-	9.4	46.9	34.4	9.4	
Experienced - Not experienced						
Adopters	-	24.7	35.6	32.9	6.8	n.s.
Non-adopters	-	34.4	37.5	18.8	9.4	
Fortunate - Not fortunate						
Adopters	11.0	46.6	30.1	12.3	-	n.s.
Non-adopters	3.1	34.4	40.6	21.9	-	
Flexible - Not flexible						
Adopters	12.3	63.0	19.2	5.5	-	<0.05
Non-adopters	3.1	43.8	40.6	12.5	-	
Scientifically oriented - Not Scien.						
Adopters	1.4	12.3	34.2	45.2	6.8	<0.05
Non-adopters	-	9.4	9.4	56.2	25.0	
Likes to take risk - Does not like						
Adopters	1.4	27.4	28.8	34.2	8.2	n.s.
Non-adopters	3.1	28.1	18.8	37.5	12.5	

n.s. = not significant

Table 5.1.7 Farmer's view of how he is seen by others (other self) (%)

	5 Very progressive	4 Progressive	3 Neutral	2 Traditional	1 Very traditional	P
Progressive						
Adopters	5.5	41.1	43.8	9.6	-	<0.01
Non-adopters	-	25.0	40.6	34.4	-	
Efficient						
Adopters	2.7	16.4	19.2	54.8	6.8	<0.05
Non-adopters	3.1	12.5	9.4	43.8	31.3	
Innovative						
Adopters	5.5	13.7	39.7	38.4	2.7	n.s.
Non-adopters	3.1	3.1	50.0	34.4	9.4	
Experienced						
Adopters	-	17.8	39.7	34.2	8.2	n.s.
Non-adopters	-	21.9	50.0	18.8	9.4	
Fortunate						
Adopters	6.8	32.9	43.8	16.4	-	n.s.
Non-adopters	3.1	25.0	53.1	18.8	-	
Flexible						
Adopters	8.2	56.2	30.1	4.1	1.4	<0.01
Non-adopters	-	31.3	46.9	21.9	-	
Scientifically Oriented						
Adopters	2.7	8.2	31.5	50.7	6.8	<0.10
Non-adopters	3.1	3.1	15.6	53.1	25.0	
Likes to take risk						
Adopters	2.7	12.3	39.7	37.0	8.2	n.s.
Non-adopters	-	15.6	28.1	40.6	15.6	

n.s. = not significant

Table 5.1.8 Farmer's view of what he would like to be (ideal self) (%)

	5 Very progressive	4 Progressive	3 Neutral	2 Traditional	1 Very traditional	P
Progressive						
Adopters	20.5	58.9	19.2	1.4	-	n.s.
Non-adopters	12.5	53.1	34.4	-	-	
Efficient						
Adopters	9.6	23.3	39.7	26.0	1.4	n.s.
Non-adopters	6.3	25.0	28.1	31.3	9.4	
Innovative						
Adopters	8.2	20.5	42.5	28.8	-	<0.10
Non-adopters	3.1	12.5	59.4	18.8	6.3	
Experienced						
Adopters	9.6	39.7	34.2	13.7	2.7	n.s.
Non-adopters	12.5	37.5	34.4	12.5	3.1	
Fortunate						
Adopters	41.1	53.4	5.5	-	-	<0.10
Non-adopters	21.9	62.5	15.6	-	-	
Flexible						
Adopters	39.7	45.2	12.3	2.7	-	<0.01
Non-adopters	3.1	56.3	37.5	3.1	-	
Scientifically Oriented						
Adopters	9.6	17.8	43.8	26.0	2.7	n.s.
Non-adopters	9.4	9.4	40.6	34.4	6.3	
Likes to take risk						
Adopters	13.7	15.1	41.1	24.7	5.5	n.s.
Non-adopters	9.4	25.0	28.1	34.4	3.1	

n.s. = not significant

were significant at the 5% level. Similarly, with estimates of other self there were significant differences in the progressive, efficient and flexible dimensions. For ideal self, the only difference between adopters and non-adopters significant at the 5% level was for flexibility, although differences in the innovative and fortunate dimensions were significant at the 10% level.

These results broadly indicate that psychological factors have an influence on farmers'adoption behavior. However, they are only preliminary findings. It is recognised that psychological factors are also related in many ways to other personal and socio-economic factors, and it may be misleading to discuss individual factors separately. The next stage of the investigation is to bring the different factors together in a quantitative model, results of which will be given in a subsequent report. [*Ahmed Mazid, Elizabeth Bailey and Martin Seabrook (University of Nottingham)*]

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5.2 Wheat Production Systems in Lebanon: A Diagnostic Farm Survey

5.2.1 Introduction

Now that security and socio-political conditions in Lebanon have improved, the urgent need to enhance agricultural development and particularly the production of basic food crops (cereals, legumes, and animal products) can be addressed. Strengthening agricultural research and technology transfer should be a major contributor to such development. Nonetheless, efficient design and implementation of research plans and development policies require a good understanding of present farming systems and their problems and potential for improvement.

To achieve this understanding, the collaboration between ICARDA and Lebanese institutions on farming systems research and technology transfer has recently been enhanced. In 1992/93, a rapid rural appraisal (Salkini and Zaiter 1993) and two diagnostic farm surveys on wheat and livestock production were conducted. This report presents the main findings of the survey on wheat production systems. Findings of the livestock survey are reported by Hamadeh et al. (1993). A third survey on legume production will be carried out in 1994.

5.2.2 Objectives

Lebanon is a small country both in terms of area (about 1 million ha) and population (3 million). A rough estimate of total wheat area in 1990 was around 26000 ha, equivalent to 63% of total cereals and 12.5% of the total area in crop production (FAO 1990). In view of the smallness of the area, this research aimed mainly to answer two important questions: (i) what is the importance of wheat in Lebanese agriculture ? and (ii) is it worth it -- for ICARDA and Lebanon -- to invest in crop improvement ? Specific objectives were to:

1) characterize wheat production systems (biological, technical, and socio-economic);
2) identify and prioritize major constraints to development and give guidance to experimental research design; and
3) predict improvement potential.

5.2.3 Methodology

Diagnostic research has two complementary components: rapid appraisal and farm survey. The initial rapid appraisal (Salkini and Zaiter 1993) gave useful insights into Lebanon's wheat-based farming systems, providing preliminary identification of the problems and potential for improvement and guidance for the planning, design, and implementation of the farm survey.

This survey was conducted in the major wheat producing provinces in the Bekaa', and in the North and the South. A sample of 123 wheat producers was randomly selected from 74 villages in 12 districts. The sample was geographically distributed proportional to the provinces' relative contributions to national wheat production (70% for Bekaa', 20% and 10% for the North and the South, respectively). The sample also covered the agroclimatic variability of wheat production areas, from locations with rainfall little more than 300mm to over 1000mm, and from coastal plains to mountainous terraces of very high elevation (Figure 5.2.1).

Farm visits and farmer interviews were conducted by three teams (2 members each) from ICARDA-Terbol Research Station, ARI (Agricultural Research Institute), and AUB (American University of Beirut). A standardized precoded questionnaire of 369 variables was implemented (March-April 1993). A 2-day training course was conducted first to standardize interviewers' understanding of the questionnaire and to advise them on how to conduct a successful farmer interview. The data collected were processed and analysed at ICARDA's headquarters using SPSS.

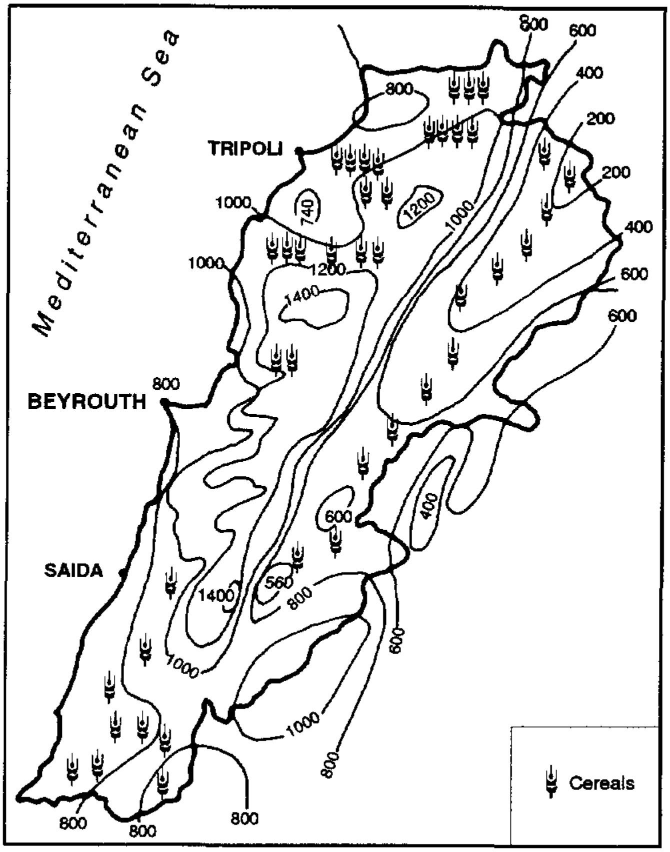

Figure 5.2.1 Mean annual rainfall isohyets (mm) and wheat production areas in Lebanon

5.2.4 Research results

5.2.4.1 Some socio-economic characteristics of the sample

Wheat is grown by the majority of farmers in Bekaa', and in the North and South provinces of Lebanon. The average wheat grower is 55 years old, educated (5-grade) and well-experienced in agriculture and wheat production. However, 20% of the sample farmers are illiterate (16% in Bekaa' compared with 28% and 33% for the North and the South, respectively). At the other extreme, while none of the southern farmers has secondary education, 24% of the northern farmers and 42% in Bekaa' have secondary or even university education.

Farmers of the Bekaa' are generally wealthier. They have larger land holdings with better soils. The average area owned is 14.0 ha compared with 5.3 ha and 1.9 ha in the North and South. In addition to owned land, Bekaa' farmers are more able to enlarge their land holdings by leasing or share-cropping (25.7, 8.5 and 8.3 ha for Bekaa', the North, and the South, respectively).

Livestock production is uncommon in the wheat-based farming systems; 82% of the sample farmers have no sheep, and 87% and 72% have no goats or cattle. The few farmers with animals raise relatively large herds in Bekaa' (50-400 sheep, 50-300 goats, 7-50 cattle). Only 12% of farmers keep poultry, in most cases just a few birds for home consumption. Only 2 farmers (in Bekaa') have large poultry production plants of 3000-4000 chickens.

Farm operations are highly mechanized, as 50% of the sample farmers have their own tractors. Seed drills and broadcasting machines are owned by 43%, plant protection equipment and transport vehicles by about 25%. Farmers who own no machinery obtain easy access to it through hiring from neighboring owners.

The average family consists of 7 members; 2 are involved full-time in farm management, one has part-time on-farm employment, 2 are in full-time off-farm employment, and 2 are unemployed. No significant differences were found between the three provinces, but unemployment was lowest in Bekaa'. Only 15% of the sample farmers were members of cooperative societies, most of which are established mainly for marketing.

Electricity, mainly from public network sources, is available for 98% of farmers. Only one farmer considered his water unsuitable for human consumption.

5.2.4.2 Importance of wheat in terms of area

Wheat is grown on all types of topography (plains to high elevation), on different soils, under a wide variety of agroclimatic environments, and under highly variable socio-economic conditions. It plays an important role under both rainfed and supplemental irrigation conditions. In 1991/92, wheat was assigned 36% of total farm area, followed by potatoes (21%), barley (14%), and other vegetables (7%) (Table 5.2.1).

Prices, crop production economics and marketing were reported by the majority (67%) of the sample farmers as the factors most affecting crop/land allocation, followed by capital availability (57%), soil type (47%), rotation requirements (43%), and water supply (42%). Labor availability, climatic conditions, technical and biological problems and time availability are less important.

At the time of the farm visits (March-April 1993), 53% of farmers had decided to increase their wheat area in the near future, 37% had not taken any decision yet and only 10% said they would reduce wheat area in 1993. Barley area will also be increased by

Table 5.2.1 Crop/land allocation in the study areas (% of total farm area)

Crop	Rainfed farms	Irrigated farms	Total sample
Wheat	38.9	34.5	36.3
Barley	22.6	7.5	13.8
Lentil	1.4	0.4	0.8
Chickpea	6.0	0.5	2.8
Faba bean	0.8	1.8	1.4
Potatoes	4.1	33.3	21.2
Other vegetables	3.3	10.1	7.3
Fruit trees	4.9	4.0	4.3
Other crops	1.5	5.3	3.7
Fallow	16.5	2.6	8.4
Total	100.0	100.0	100.0

48% of farmers, and to a lesser extent that of chickpea, lentil and faba bean as well.

5.2.4.3 Economic importance of wheat

Wheat is a multi-purpose crop, considered by most farmers as an important enterprise for both cash earning and subsistence. Wheat straw is fed to farm animals or sold in the market (at a value almost equal to that of grain). However, inter-seasonal yield variability is considerable for both rainfed and supplementally irrigated wheat, and net revenues were estimated as 900 $/ha for a good harvest, 500 $/ha for a normal year, but less than 60 $/ha for a poor harvest.

Wheat contributed 37% of farm income (30% in the North, and 40% in the South) and was reported as the most profitable crop by 40%, and as the second most profitable by 25%, of the sample farmers. Potatoes, because of recent marketing problems, was reported by only 6% of farmers as the most profitable crop, with other vegetables (14%) and fruit crops (14%). Barley and lentil are of special importance under rainfed conditions, and each was considered the most profitable crop by 8% of farmers. Barley had the highest scores as the second and third most profitable crop (25% and 19%, respectively).

Farm income contributed 66% of total family income, off-farm agricultural income 9%, and non-agricultural sources 25%. The latter assumed much higher values under rainfed farming conditions, especially in the South (48%). Of the farm income, 48% came from cereal production, 30% from fruit and vegetable production, 13% from animal production, and only 9% from legumes. No significant differences between the three provinces were found in the structure of farm income.

5.2.4.4 Farmers' wheat production practices

Soils and wheat plots. Most soils in the wheat-based farming areas have good depth, stoniness, slope, infiltration, and salinity characteristics. More than 68% of farmers considered their soils to be of good fertility, 24% moderate, and 6% poor.

Due to topography and land tenure (leasing and share-cropping), wheat is grown on a large number of plots. In 1992, only 29% of farmers grew wheat on one plot, 40% on 2-3 plots, 24% on 4-7 plots, and 7% on more than 7 plots. In the mountainous terraces of the north, wheat may be grown on 40 or 50 plots of a few square meters each. The mean area of each farmer's largest wheat plot in 1992 was 5.7 ha (CV 132%), with minimum and maximum values of 0.2 ha and 50 ha; 44% of them were owned by the farmer himself, 41% were leased and 15% share-cropped.

Crop rotation. Most farmers (53%) in the wheat-based system follow a two-course rotation of potatoes (and/or other vegetables)/wheat. Other rotations (especially in rainfed systems) include:

Legumes/wheat (or) legumes/wheat/fallow	(15% of farmers)
Wheat/fallow	(12% of farmers)
Wheat/wheat (or barley)	(7% of farmers)
Wheat/other crops	(13% of farmers)

Whereas 85% of farmers use the same rotation continuously, 15% of farmers may change their rotationss from time to time.

Seed-bed preparation and sowing. The number and timing of cultivations and the equipment used for seed-bed preparation, are variable, depending on soil type and topography, availability and cost of machinery, and preceding crop type and cultivation practices. About 28% of farmers grow wheat without any preplanting cultivation, a practice that is more common in the South than in the North and Bekaa' (50%, 28%, and 24% of farmers, respectively). Tractors are used for cultivation by 98% of farmers, and animal traction (2%) is used only on soils where mechanical traction is impossible.

The locally-made (Zahlawyya) moldboard plough is most commonly used for preplanting and seed-covering cultivations, but the ordinary (heavy or light) moldboard or different types of disc plow, chisel plow and duckfoot cultivator may also be used. Any preliminary preplanting cultivations are usually carried out many weeks (or months) ahead of planting. When only one preplanting cultivation is used, it is usually done directly before sowing.

Most farmers (70%) sow wheat in November, 13% sow earlier in October, and 17% sow later in December (15%) or January (2%). Whereas the timing of early-season rains affects the sowing date for 49% of farmers, 43% of farmers sow wheat at a predetermined (fixed) date regardless of early-season rains. Hand sowing is still the majority practice (59%). Broadcasting machines are used by 32% and drills by only 9% of farmers.

Seed source, variety and rate. In 1992, farmer's own stock (from previous harvest) was the main source of seed (70% of farmers), followed by market sources (22%), government sources (ARI) (5%). Very few farmers (4%) use specially-prepared storing facilities; but, even so, 41% of farmers reported no insect or rodent problems, and most of those who have such problems use pesticides to control them. Most farmers (60%) sow cleaned and pesticide dressed seed, 20% just clean and sieve their seed, while the rest use untreated seed.

Improved bread and durum varieties were grown by 42% of farmers in the 1991/92 season (Table 5.2.2). Adoption of new varieties is more evident in Bekaa', where farmers have easier access to improved seed sources (currently, ARI and ICARDA). Local varieties reported were Salmouni, Frensawi (the old Cite Siros), Bekaai, Hourani, Biadi, Baladi and Toliani (Senator Capelli).

Table 5.2.2 Wheat varieties by geographical location (1991/92)

Variety	% of farmers			
	Bekaa'	North	South	Total
Improved, durum				
Stork	24.4	0.0	0.0	17.1
Sibou	3.5	0.0	0.0	2.4
Improved, bread				
Mexipak	16.3	12.0	0.0	13.8
S.82	10.4	0.0	0.0	7.3
Cham 6	1.2	0.0	0.0	0.8
Baalbaki	1.2	0.0	0.0	0.8
Sub-total Improved	57.0	12.0	0.0	42.2
Sub-total local	43.0	88.0	100.0	57.8
Total	100.0	100.0	100.0	100.0

Farmers may change the variety and source of their seed in search of higher yield and marketability. Disease and insect susceptibility, seed availability, or simply a wish to experiment are other reasons for farmers to change variety and seed source. However, about 50% of the sample farmers did not change variety or source; 20% changed both within less than 3 years, 16% every 3-5 years, and 10% after more than 5 years.

Seed rate is highly variable. The sample mean is 170 kg/ha, but values ranged from 16 to 450 kg/ha. The impact of seed rate on yield could not be clearly assessed, but farmers may adjust rates according to soil type and fertility and, to a lesser extent, according to seed variety and quality. Changes in seed price and farming method have only a minor effect.

Fertilizer application. Manure was applied by 3% of farmers, one dose of N by 89%, two doses by 9%, and phosphate was applied by 9% of farmers. Application rates were variable (Table 5.2.3). The average rate for the first dose of N, for example, was 80 kg N/ha (SD 51 kg/ha), but the range was from zero to 230 kg/ha. The effect on yield was highly significant (<0.01).

It is interesting, however, that while most farmers applied N, only 9% applied P_2O_5. Main reasons given for not using P_2O_5 were lack of necessity (51%), cost (24%), unavailability (4%). It is also interesting that only 9% of N users split the fertilizer into two doses, whereas 91% top-dressed N in one dose at tillering. Soil type was reported as the main factor affecting N application rate by 56% of farmers, other factors being preceding crop, prices of N and wheat, rainfall, and water supply for supplemental irrigation.

Table 5.2.3 Fertilizer application rates (kg/ha)

Fertilizer type	Mean	SD	Range	n
1. For appliers only				
Manure	16250	8540	5000-25000	4
P_2O_5	60	40	27-162	11
N, first dose	90	45	17-230	110
N, second dose	101	57	47-230	11
2. For the whole sample collectively				
Manure	528	3189	0-25000	123
P_2O_5	5	21	0-162	123
N, first dose	80	51	0-230	123
N, second dose	9	33	0-230	123

(N supplied as ammonium nitrate, and P_2O_5 as single superphosphate)

Weed and pest control. Only 9% of farmers weeded by hand, while 45% used herbicides; and 21% of farmers applied pesticides, mainly for rodent control. There were significant effects on yield. When no control is used, it is either because it is not needed (ie low level of incidence or infestation) or because it is expensive, as in the case of hand weeding.

Supplemental irrigation. About 55% of the sampled farmers applied SI to their wheat in 1991/92, but there were large regional differences, viz. 74% of Bekaa' farmers, 12% of Northern farmers, but none of the Southern farmers). These probably reflect rainfall differences as much as diffrences in farmer resources; muchof the Bekaa' has relatively low rainfall (Figure 5.2.1). In Bekaa', 43% of irrigators irrigated from groundwater sources, 39% from surface water, 8% from both sources, and 10% purchased water from neighbors. No complaints were made by any of the irrigators concerning the quality and quantity of water.

The number of irrigations given is affected by geographic and climatic factors. In normal or good rainfall seasons, most farmers do not irrigate at all, or they may give one irrigation, most likely late in the season. However, in years of below-normal rainfall, 56% of farmers give 2-3 irrigations, and 20% may give four, according to site conditions. However, some farmers may not irrigate wheat even though water is available, either because it is costly or to avoid lodging and disease problems.

Harvest. Wheat is harvested mainly in July (73% of farmers) or June (18%), with some early-maturing wheats harvested around the end of May, and some late-maturing wheats in early August. Much of the harvesting is done mechanically, either by combine harvester or through a multi-stage mechanical harvesting process. Hand cutting (by 22% of farmers) is usually practised where machines cannot be used (very small holdings, stony soils and on narrow terraces). Threshing is done mechanically even when the crop is harvested manually. No problems were reported concerning machine availability and cost, nor for manual harvesting, since most of the work is undertaken by family labor.

5.2.4.5 Yields and yield gap

The climatic conditions in Lebanon's wheat-based farming systems are generally favorable for wheat production. The sample yield average for 1991/92 -- a season of normal weather -- was about 2.0 t/ha for rainfed wheat and 3.66 t/ha with supplemental irrigation. However, yields may vary widely depending on seasonal weather conditions (Table 5.2.4). Yields of both rainfed and SI wheat can be increased by 40% or decreased by 60% according to the favorability of the season.

The introduction of new improved varieties (by ARI and ICARDA) has substantially improved production (Table 5.2.5). Yields of the improved varieties surpassed the local ones by about 120%. Varieties Seri 82 (bread) and Stork (durum) were the highest yielding under both rainfed and SI conditions.

Table 5.2.4 Grain and straw yield of wheat according to seasonal weather conditions (t/ha)

		Normal (91/92)		Good		Bad	
		Rainfed	SI	Rainfed	SI	Rainfed	SI
Bread,	Grain	1.98	3.39	2.99	4.86	0.71	1.33
	Straw	2.36	3.18	3.12	4.78	0.80	1.42
Durum,	Grain	2.08	3.92	2.96	5.17	0.75	1.61
	Straw	2.72	2.91	3.87	4.58	1.18	1.51
Mean,	Grain	2.03	3.66	2.98	5.01	0.73	1.47
	Straw	2.54	3.05	3.50	4.65	0.99	1.46

Table 5.2.5 Grain yield of improved and local varieties in 1991/92 (t/ha)

Variety	Rainfed	Supp. Irrig.
Stork	3.50	4.72
Sibou	3.50	Not grown
Mexipak	2.39	3.68
S.82	4.30	5.00
Local, durum	1.30	2.70
Local, bread	1.90	3.00

Analysis of farmers' reported yield data indicate:

i) A yield gap (Figure 5.2.2) between improved and local varieties of about 2.0 t/ha for both rainfed and SI conditions. For the same variety (whether improved or local) SI increased mean grain yield by an average of about 1.3 t/ha:

Improved varieties, 3.5 t/ha for rainfed, and
4.7 t/ha with SI
Local varieties, 1.5 t/ha for rainfed, and
2.8 t/ha with SI

ii) There is great potential for further yield increases, as some farmers reported yields of 7.0-9.0 t/ha for grain and 10.0 t/ha for straw using improved varieties with SI. At the other extreme, yields as low as 200 kg/ha for rainfed wheat and 500 kg/ha with SI were also reported.

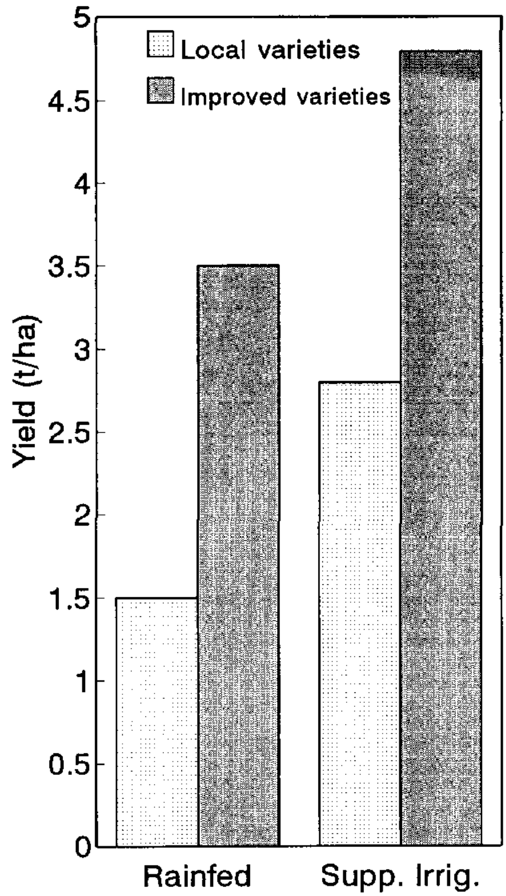

Figure 5.2.2 Yield gap between improved and local varieties of wheat under rainfed and supplemental irrigation conditions

5.2.4.6 Economics of wheat production

Economically, wheat production is a comparatively good farm enterprise. In years of normal weather conditions (as in 1991/92), a profit margin of 692,000 LL/ha (equivalent to 407 US$/ha) can be realized from rainfed wheat. With SI, this figure increases to 1,268,000 LL/ha (746 US$/ha). However, profitability can be seriously affected by the weather (Table 5.2.6). The profit margin of a rainfed crop, as high as 724 US$/ha under good conditions, can turn into a net loss under unfavorable conditions. Even with SI, profitability varies widely with the weather (Figure 5.2.3).

Table 5.2.6 Effect of weather conditions on wheat production economics (000 LL/ha)

Weather conditions	System	Gross revenue	Cost	Net revenue
Normal (1991/92)	Rainfed	1268	576	692
	Supp. irrig.	1924	656	1268
Good	Rainfed	1807	576	1231
	Supp. irrig.	2752	656	2096
Bad	Rainfed	474	576	-102
	Supp. irrig.	831	656	175

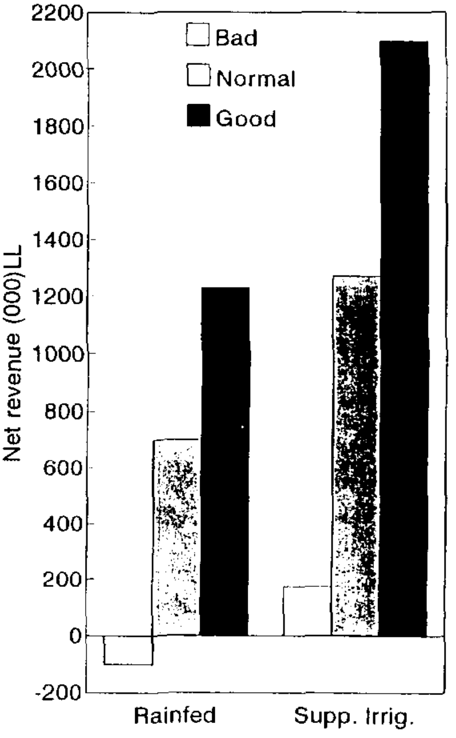

Figure 5.2.3 Effect of climatic conditions on wheat production economics under rainfed and supplemental irrigation conditions

5.2.5 Conclusion

1. Wheat is an important crop in both rainfed and SI wheat-based farming systems in Lebanon. It covers about 36% of total farm area, and contributes to 37% of total agricultural income of the household.
2. There is a great potential for wheat production improvement, especially with the adoption of new improved varieties. The Lebanese farmer is an excellent technology adopter when he has access to the technology. However, the lack of a seed multiplication system has limited the adoption of new varieties, especially in the North and the South. It is probable that adoption rate would be enhanced dramatically if more new improved seed were made available to farmers.
3. Increasing the adoption of SI also has good potential for improving wheat production. However, "when and how much to irrigate" remains a question research needs to answer.
4. An increase in wheat area provides further potential for greater production. Due to marketing and economic problems faced by other crops (especially fruits, potatoes, and other vegetables), and the recent strong control of the cultivation of illicit crops, it is predicted that wheat (and barley and legumes) will soon assume greater importance in the farming systems of Lebanon.
5. Some technical problems (particularly fertilizer use and disease and pest control) require more research and more efforts in the transfer of technology.
6. ICARDA/ARC/AUB and LU joint efforts in designing and implementing a technology transfer project on farmers' fields may greatly contribute to enhanced wheat production in Lebanon. A good start would be to find a suitable system for improved seed multiplication and distribution, further on-farm evaluation of improved varieties and a package of recommendations for fertilizer and SI.
7. A farm survey to characterize and assess the current (and potential) importance of legumes is also needed to improve our understanding of arable farming systems in Lebanon.

[*Abdul Bari Salkini, ICARDA; Haytham Zaiter, AUB; Michel Abi Antoon, ARI, in cooperation with Nicolas Rebeiz and Munir Sughayyar (ICARDA, Terbol)*]

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5.3 Cereal Production Systems in the Western Zone of Libya

5.3.1 Introduction

Cereals (wheat, barley and oats) are strategic food and feed crops for Libya, and the government has made strenuous efforts to increase their production in an attempt to achieve self-sufficiency. Very expensive irrigation schemes, implementing sophisticated technologies of pumping and center-pivot sprinkler systems, have been established to utilize the deep, fossil groundwater of abundant aquifers lying beneath the desert; and the "man-made river" conveys huge amounts of water all the way from the southern deserts to the better environmental conditions of coastal regions.

The important role of agricultural research and technology transfer in the development process has been recognized by Libyan policy makers, but due support has not yet been provided. Collaboration between ICARDA and Libya's Agricultural Research Center (ARC) has recently been strengthened, with the major goal of enhancing research activities in crop improvement and farming systems. Emphasis has been given to improving rainfed cereal production utilizing SI and to adopting a farming systems approach to research and technology transfer. This report summarizes the findings of a diagnosis of cereal production systems in the western zone of Libya where SI application is particularly important. Its aims were: (i) to evaluate the current cereal production situation, focussing particularly on the use of supplemental irrigation; (ii) to identify major constraints to crop improvement; and (iii) to give guidance to experimental research and policy makers for crop production development. The economics of crop production, particularly the economics of water use, were emphasized in view of the scarcity of groundwater resources.

5.3.2 Methodology

A sample of 109 farmers was selected, at random, from the western coastal zone -- Libya's main area of wheat production under SI (Figure 5.3.1). The sample was geographically distributed between 2 provinces (Tripoli and Al-Zawya) and 9 districts, in proportion to their relative importance for cereal production. These districts were: Janzour, Karabolli, Haira, Souk of Houma'a, Aziz'ya, Al Khoums, Sebrata, Al Ojaylat and Al Zawya. Mean annual rainfall ranges from about 380mm in Tripoli city to around 150mm inless favoured locations away from the coast.

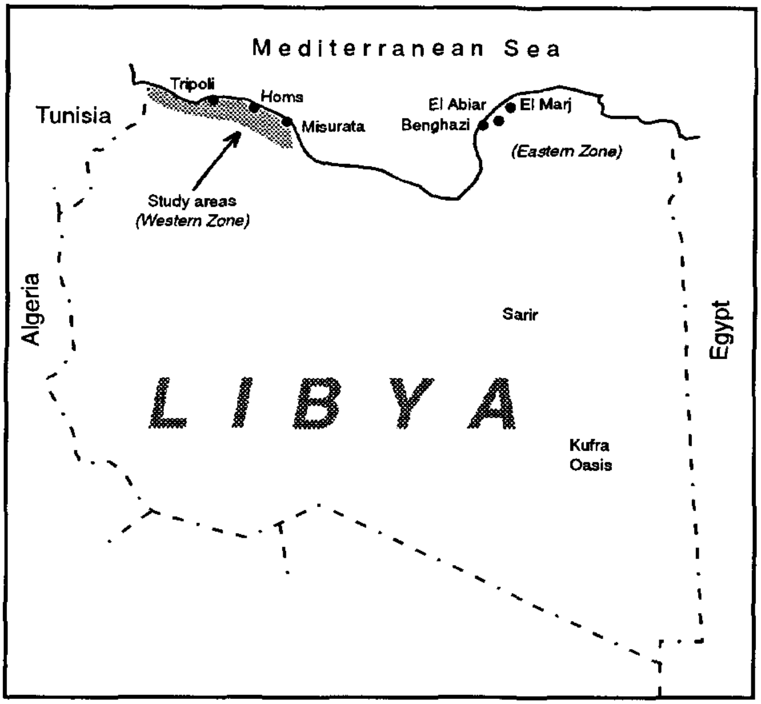

Figure 5.3.1 Areas of cereal production under SI conditions in the Western Zone of Libya

Using a structured, pretested questionnaire, data on crop production (farmer practices, yields, economics, etc.) were collected for the 1989/90 cropping season; but preliminary analysis, in 1991, revealed unreliability in the data and findings concerning SI application and costs. So, a second survey was conducted in 1992, and 51 farmers were interviewed to verify the data on SI and water management.

5.3.3 Major findings

Farm area and crop/land allocation. The three cereal crops (wheat, barley, oats) covered a mean of 40% of the total farm area, followed by vegetables (9%), other crops (14%), with 36% of the farm area under fallow. The average farm area was 8.1 ha (SD 6.5 ha), of which only 0.5 ha was rainfed. The high proportion of land fallowed and the low proportion of land assigned to rainfed farming indicate the unsuitability of the environment for rainfed agriculture, and the scarcity of water for SI. Barley is the most important cereal crop in terms of area (56% of total cereal area), followed by oats (31%) and wheat (13%).

Crop rotations were reported as follows (% of farmers):

Cereals/vegetables (50%)
Cereals/fallow (25%)
Cereals/other crops (20%)
Cereals/cereals (5%)

Seedbed preparation. Most farmers cultivate twice for cereals: a preplanting cultivation, usually done during August-September, and a seed-covering cultivation in October-November. A disc plow is the most commonly used (64% and 87% of farmers, for pre-planting cultivations and seed covering, respectively).

Seed rate and variety. Cereals are sown in October or November at average seed rates of 80 kg/ha (SD 44 kg/ha) for wheat, 96 kg/ha (SD 40 kg/ha) for barley, and 114 kg/ha (SD 41 kg/ha) for oats; but under rainfed conditions the rates are lower by 10%, 50% and 30%, respectively. Standard deviations are high; many farmers (44% of the sample) use very low rates (45 kg/ha or less) for wheat, while 26% use high rates (150-200 kg/ha) for oats.

Improved varieties are still uncommon, with adoption rates of 15% for wheat and barley, and 24% for oats. Corresponding figures for rainfed conditions were lower: 9% for wheat, 6% for barley, and zero for oats. On being asked the reasons for non-adoption, about 25% of farmers reported no knowledge of such varieties, 53% preferred the local varieties because of their better adaptation to the harsh environment, and 5% did not like to change traditional practices.

Fertilizer application. Only 3% of the sample farmers grew cereals without using any kind of fertilizer. The rest used compound fertilizers (12:24:12 or 16:48:0); 59% of farmers applied additional N in the form of ammonium sulphate (21% N), and 18% used organic fertilizer. Application rates were highly variable (Table 5.3.1), and there were large differences between geographical locations.

Table 5.3.1 Fertilizer application rates (kg/ha)*

Crop	N	N-P	N-P-K	Manure
Wheat	86	165	68	36
	(87)	(129)	(102)	(189)
Barley	122	298	88	53
	(129)	(242)	(170)	(290)
Oat	156	332	67	4
	(149)	(275)	(142)	(27)

* kg of trade material; ( ) SD values

Plant protection. Weeds and birds were reported as a constraint to cereal improvement by 86% and 69% of farmers, respectively. Insects, diseases, and rodent were problems of less importance (43% of farmers). However, only 9% of cereals growers applied control measures, 14% and 4% in Tripoli and Al Zawya districts, respectively.

Supplemental irrigation. It appears that cereals cannot be grown successfully without SI in most of the western zone of Libya, as only 6% of the crop area was found under rainfed conditions. This small rainfed area is most likely to have specific topographic characteristics, giving run-on water from nearby areas.

Groundwater is the only source of irrigation. Such water is not abundant, and seawater intrusion is a problem in many locations. Average well depth is 60m (SD 35m), with a range of 18-178m. Electrically-powered pumps with an outlet diameter of 63.5 - 76.2mm are most commonly used to supply the easily movable, line-source, sprinkler irrigation systems used by all farmers. In most cases, the system consists of 10 nozzles with an outlet capacity of 1.3m^3/hr each.

Farmers' decisions on irrigation timing are determined by soil and plant conditions. Basically, the number of irrigations per month are: November-January, 1; February, 1-2; March-May, 2-3; and June, 1 irrigation, but much depends on the rainfall pattern (volume and distribution). Thus, cereals are given 4-5 irrigations in wet years, and perhaps 7-10 and 13-15 irrigations in average and dry years. It seems that Libyan farmers are well aware of the low water-holding capacity of their sandy soils and prefer to irrigate very frequently, giving relatively small quantities of water each time. This conclusion was supported by the estimates of total water given for cereal crops (Table 5.3.2), which imply rational water use (Ismail, personal communication).

Table 5.3.2 Irrigation applications on cereal crops

Crop	Water application (m^3/ha) in year			
	Wet	Normal	Dry	1991/92
Wheat	1120	2800	4480	1680
Barley	880	1760	2860	2420
Oats	1150	1600	2980	2980

Economic considerations affect water use. Comparing the amounts of water actually applied in 1991/92 (a dry year) with the corresponding theoretical figures reported by farmers for a dry year

(Table 5.3.2), we found a discrepancy. Wheat received less water than barley or oats. This reflects the availability of subsidized wheat flour for consumers and a large demand for oats and barley in the market.

Total irrigation cost was estimated at 0.12 LD/m^3 (officially, 1 LD=3.33$)[1], based on yearly pumping of 1642 hours and a total cost of LD 2560 (of which 84% is variable costs, energy, labor, maintenance, etc. and 16% is depreciation of capital assets). Annual pumping capacity was estimated according to the formula:

$$AW = HRY * NN * NR$$

where AW = annual water withdrawal in m^3/yr; HRY = pumping hours per year; NN = number of nozzles in the irrigation system; NR = nozzle capacity in m^3/hr.

Yields. These are generally low and fluctuate widely even with SI. Average values in an average year were about 1500 kg/ha for wheat and oats and 1800 kg/ha for barley. Yields can decrease or increase by 25-70% depending on rainfall and other weather conditions (Figure 5.3.2). Yield variability within the sample was extremely high. Under average weather conditions, yield ranges were 250-3000 kg/ha for wheat and oats, and 400-5000 kg/ha for barley (Table 5.3.3). Straw yield was almost equal to that of grain for wheat and barley but was 40% higher for oats, with inter- and intra seasonal variability similar to that of grain.

Table 5.3.3 Distribution (%) of cereal grain yields among sample farmers

Yield (kg/ha)	Wheat	Barley	Oats
<1000	28	15	27
1000 - 1500	22	38	23
1600 - 2000	25	20	27
2100 - 2500	19	11	13
2600 - 3000	6	7	10
3100 - 4000	-	7	-
4100 - 5000	-	2	-

The major causes of low, unstable and variable yields, appear

1. The exchange rate in neighboring countries was LD 1 = 0.50$

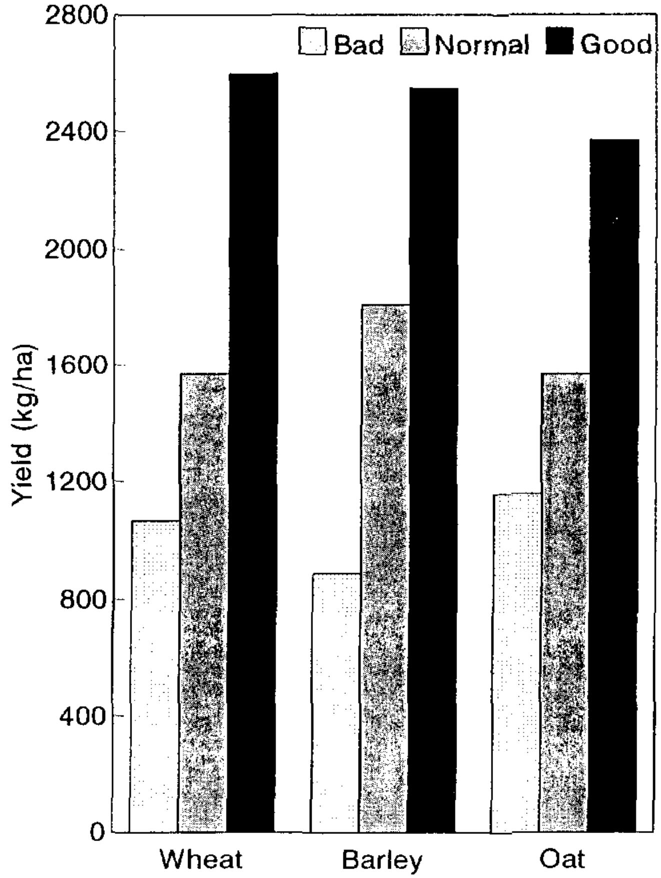

Figure 5.3.2 Effect of climatic conditions on cereal yields in western Libya

to be: (i) the low adoption of new improved varieties; (ii) inappropriate SI scheduling; (iii) the high incidence of weeds, birds, rodents and other pests; and (iv) the harsh environmental conditions, particularly the low and ill-distributed rainfall and spells of hot wind at anthesis.

However, a good potential for improved crop production has been identified. Although low yields, of 1500 kg/ha or below, were obtained by 50% of the sample farmers, at the same time yields of 3000 kg/ha for wheat and oats and 4000-5000 kg/ha for barley were reported by other farmers, who may represent an achievable potential.

Economics of crop production. To be an economic enterprise, cereal production needs good growing conditions. Then, profit margins of 1385 LD/ha for oats, 702 LD/ha for wheat, and 521 LS/ha for barley can be realized. However, in years of poor harvest, oats may achieve a very small profit margin of, say, 75 LD/ha, and wheat and barley may show a net loss (Figure 5.3.3).

Total production costs in 1990/91 were 933 LD/ha for oats, 702 LD/ha for barley and 557 LD/ha for wheat. Differences between crops arose mainly from the greater care given to oats in terms of irrigation and fertilizer rates, and from different seed prices.

Straw is of equal importance to grain. For barley, revenue from straw was higher than from grain, irrespective of weather conditions and variable yields. It is also higher for wheat in dry years and equal to 70% of grain revenue in average and wet years. Revenue from oat straw was 62-82% of grain revenue depending on weather conditions and the yields obtained.

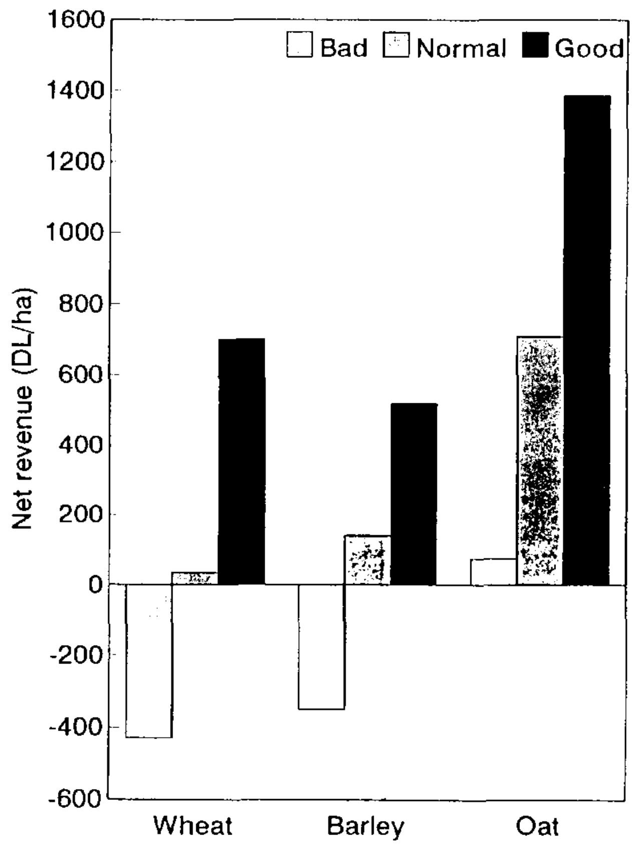

Figure 5.3.3 Effect of climatic conditions on cereal production economics in western Libya

5.3.4 Conclusions

1. Environmental conditions especially low rainfall (less than 300 mm in most years) and sandy soils, do not favor rainfed cereal production in western Libya, and *SI* is required for economic crop production. But "when and how much water to give?" is still an essential question for research to answer.
2. Lack of a proper mechanism for producing and distributing improved seed is another major constraint.
3. A consumer-subsidized wheat price inhibits crop production development. This subsidy should be stopped if the government is aiming at self-sufficiency in wheat.
4. The effects both of weed and pest control on cereal production and of legume (food and feed) crops in cereal rotations should be demonstrated to farmers.

[*A.B. Salkini, ICARDA; Salih Hamali and Sais Haraga, ARI, Libya*].

5.4 Economic Viability and Sustainability of Cereal Production under Water Harvesting in Highland Balochistan, Pakistan

5.4.1 Introduction

Wide rainfall variability between and within years makes rainfed crop production in highland Balochistan, a limited and risky practice. Annual rainfall averages from 175 to 200mm in the southern areas and from 300 to 350mm in the northern areas (Kidd et al. 1988). The minimum water requirement for wheat grain production is about 300mm and the probability of receiving more than this amount varies from 10 to 50% (Rees et al. 1989). In contrast, the minimum requirement for barley is 225mm (Rees et al. 1989), and consequently there is a higher probability of meeting this requirement. Wheat is grown by most farmers as a dual-purpose crop, the grain being used for human consumption and the straw for animal feed (Buzdar et al. 1989). Barley is not widely grown. Farmers grow wheat instead of barley for food security reasons, because they perceive that there is a poor market for barley and there are land shortages in certain areas (Nagy et al. 1989).

As an attempt to demonstrate more efficient use of rainwater, the Arid Zone Research Institute (AZRI) has, since 1986, been testing small catchment basin water-harvesting techniques, to grow cereals, lentils and forage legumes. The preparation of small catchment basins in rainfed valley bottom fields represents a low-cost method of generating run-off and increasing crop yields within the cropped areas. The proportions of water catchment area to cropped area investigated by AZRI have been: 1:1, half the area is water catchment, half is planted; 2:1, two thirds is water catchment, one third is planted; and, as the control, the entire area is planted, which is the traditional practice (Rees et al. 1991). However, rainfall variability has made it difficult to ascertain the sustainability, economic viability and potential adoption of these technologies (Rodríguez et al. 1993). One issue raised by researchers is the number of seasons needed to determine sustainability. This paper attempts to assess the sustainability and economic viability of wheat and barley cultivation under different water-harvesting treatments in highland Balochistan, using intertemporal and interspatial total factor productivity (TFP) indices.

5.4.2 The economics of water-harvesting and total factor productivity

Water-harvesting can increase soil moisture by holding run-off water from the catchment area within the cropped area, thereby increasing plant growth potential. However, its economic feasibility depends on the following inter-related questions:

1) Whether or not the cropped area receiving harvested water produces more than would the total area (crop and catchment) under traditional practice. Specifically, per unit area, does the 1:1 treatment yield more than double that of traditional practice or does the 2:1 treatment yield more than triple that of traditional practice?
2) Whether or not there are differences in the fixed and variable costs associated with differences in the proportions of crop and catchment area. For example, is field preparation and crop production less expensive in the 1:1 and 2:1 treatments than for the same total area under traditional practice?

Changes in the price of outputs (grain and straw) relative to the cost of inputs or a decrease in the cost of inputs relative to the price of outputs need to be incorporated into the evaluation of agricultural innovations. Bilateral and multilateral total factor productivity (TFP) index numbers have been used to measure productivity of regional agricultural sectors (Hazilla and Kopp 1988) or agricultural systems (Ehui and Spencer 1993; Whitaker 1991). The underlying assumption behind the use of index numbers is that they adequately represent the production and cost functions, and it is therefore possible to quantify intertemporal changes in productivity as well as comparisons of productivity across space. Further, Ehui and Spencer (1993) showed that it is feasible also to incorporate resource flows, as a means to ascertain the sustainability and economic viability of tropical agroecosystems. However, using the production concepts embedded in the TFP indices, results of station and on-farm trials can be appraised beyond conventional partial budgeting analysis regardless of the availability of any measurements of resource flows (eg soil nutrients, soil biomass, species diversity, etc.).

The bilateral Tornquist index of TFP (Denny and Fuss 1983) for two consecutive periods (intertemporal TFP) is defined as:

(1) $\ln T_{vu}=(1/2)\ \Sigma_k(OS_{kv}+OS_{ku})(\ln Q_{kv}-\ln Q_{ku})-(1/2)\ \Sigma_j(IS_{jv}+IS_{ju})(\ln Q_{jv}-\ln Q_{ju})$

where T_{vu} is the TFP in the v period over the TFP in the u period, or TFP_v/TFP_u, and $\ln T_{vu}>0$. OS_{kv} and OS_{ku} are the kth output shares of periods v and u, respectively. The output share is the proportion of revenue of output k in the total revenue of period v or u. Q_{kv} and Q_{ku} are the quantities of output k produced in periods v and u, respectively. IS_{jv} and IS_{ju} are the input shares of periods v and u, respectively. The input share is the proportion of the cost of input j in the total costs of a period. Q_{jv} and Q_{ju} are the quantities of input j used in periods v and u, respectively. If $0<\ln T_{vu}<1$, the productivity in period v is below that of period u (with the same input quantities and costs of period u). If $T_{vu}\geq 1$, the productivity in period v is equal to or higher than the productivity in period u. A system may be considered economically sustainable when the trend of TFP is non-decreasing (Lynam and Herdt 1989; Whitaker 1991; and Ehui and Spencer 1993). The bilateral TFP index can be used for interspatial comparisons, where v and u in equation (1) represent a system in space v and u, respectively. Interspatial comparisons are useful to evaluate the economic viability of alternative treatments (eg, fertilizer, water-harvesting methods, alternative crops, etc.) at the same location or of the same treatment at different locations.

5.4.3 <u>The trials, total factor productivity and trend estimations</u>

Six seasons of wheat data (1986/87 to 1991/92) and four seasons of barley data (1988/89 to 1991/92) from trials located in farmers' fields in the Quetta valley were used in this study. Yields for the 1:1 and 2:1 treatments were adjusted for the total area, ie crop + catchment area, to account for the opportunity cost of not planting the catchment area (Rodríguez <u>et al.</u> 1993). Partial budgets developed for each crop, season, location and trial (Rodríguez <u>et al.</u> 1993) were used to evaluate the benefits and costs (in constant rupees of 1986) associated with each water-harvesting treatment. The costs of different operations, such as land preparation, maintenance, tillage, planting, harvesting, etc. were divided by the price of grain to compute imputed quantities for each operation expressed in terms of kilograms of grain. These imputed quantities and the cost per operation were used to compute the second term in equation (1), and the grain and straw yields, and their prices per unit of weight, were used to compute the first term in equation (1).

The number of years necessary to capture the trend in intertemporal TFPs for a particular treatment was estimated with the following relationships:

(2) $N = [(3.46\ Z_{\alpha/2}\ S_y) \ /\ (\delta\ b)]^{2/3}$

(3) TFP = a + b years

where N is the number of years required to estimate the trend in TFP within a specified error limit of δ (expressed as a proportion of the trend being estimated) with a chosen probability of coverage ($1-\alpha$). The values of δ and α are arbitrary. $Z_{\alpha/2}$ is the upper probability point of the standard normal distribution. The intercept a and the trend b are estimated fitting equation (3), S_y is the estimate of standard error of the dependent variable (TFP) in equation (3). Equation (2), with restrictions in $Z_{\alpha/2}$ and δ ($1-\alpha=0.997$ and $\delta=1$[1]), was used by Monteith (1990) to evaluate productivity trends and was also used by Whitaker (1991) to determine trends in TFP.

5.4.4 Results and discussion

Sustainability. Net benefits and intertemporal TFPs for wheat in the 1986-1992 period under different water-harvesting treatments are shown in Table 5.4.1. Averages of net benefits of all seasons were calculated as well as the coefficients of variation (CV). Under the 1:1 treatment wheat had 23% higher net benefits than the traditional practice; but the 2:1 treatment showed inferior performance (31% lower net benefits), due to waterlogging effects in the first, fourth and fifth seasons (Rodríguez et al. 1993).

Because TFP is calculated between pairs of consecutive seasons, only five figures arise from six seasons' data. The TFPs for the 1987/88 season over the 1986/87 season were the lowest for all treatments, ranging from 0.08 under traditional practice to 0.14 in the 2:1 treatment. These figures imply that the productivity in 1987/88 was only 8 to 14% of the productivity in the 1986/87 season, using the same input bundle as for the 1986/87 season[1]. In contrast, the TFPs for the 1987/88 season over the 1988/89 season ranged from 3 in the 2:1 treatment to 4.5 under traditional practice. This implies that productivity from traditional practice during 1988/89 was four and a half times larger than productivity during 1987/88, using the same input bundle as for 1987/88.

Fluctuations in TFP depended on variations in the cost and revenue shares of contiguous seasons. These variations were related to the quantity and distribution of rainfall which determined crop

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1. This implies that b is estimated with a 100% error above and below its value when the coefficient of variation of the original series of measurements is assumed to be 33%.

1. This excludes the most important uncontrolled input, rainfall.

performance. Based on the frequency of times when the intertemporal TFP was the highest among treatments, the traditional practice seems more sustainable than the alternative treatments. In contrast, based on the number of times when TFP was larger than one, the 2:1 water-harvesting appears more sustainable than the others. However, because the time series analyzed is too short, no conclusions should be made with regard to the long-term sustainability of the system.

Net benefits and intertemporal TFP values of barley in the 1989-1992 period are shown in Table 5.4.2. Only in the 1988/89 season did the net benefits of the 1:1 and 2:1 treatments show an improvement over traditional practice, even though they were all

Table 5.4.1 Net benefits (Rs/ha), in constant rupees of 1986*, intertemporal total factor productivity and rainfall (mm) of wheat trials for the years 1986-1992 in highland Balochistan

		Season						All seasons	
	Treatment	86/87	87/88	88/89	89/90	90/91	91/92	Avg[1]	CV[1]
Net benefit	Trad. pract.	1397	-438	-65	563	385	-5	306	191
	1:1	1510	-232	41	542	393	-3	375	151
	2:1	981	-173	71	272	22	91	210	175
Total factor product.	Trad. pract.		0.08	4.53	2.31	0.60	0.81		
	1:1		0.11	3.23	2.22	0.64	0.72		
	2:1		0.14	3.00	1.76	0.43	1.44		
Rainfall		282	99	211	224	240	280	223	28

* Rs 17.1=1 USD; 1) Avg=average; CV=coefficient of variation (%)

Table 5.4.2 Net benefits (Rs/ha), in constant rupees of 1986*, intertemporal total factor productivity and rainfall (mm) of barley trials for the years 1988-1992 in highland Balochistan

		Season				All seasons	
	Treatment	88/89	89/90	90/91	91/92	Avg[1]	CV[1]
Net benefit	Trad. pract.	-192	600	507	289	301	102
	1:1	-60	581	187	155	216	107
	2:1	-35	536	-8	248	185	124
Total factor product.	Trad. pract.		2.36	0.77	0.69		
	1:1		1.53	0.74	0.86		
	2:1		2.28	0.33	1.44		
Rainfall		211	224	240	280	238	26

* Rs 17.1=1 USD; 1) Avg=average; CV=coefficient of variation (%)

negative (due to waterlogging, Rodríguez et al. 1993). The 2:1 treatment gave negative net benefits again in the 1989/90 and 1990/91 seasons. Only in 1988/89 and 1991/92 was the 2:1 treatment superior to the 1:1 treatment, and on average, over the four years, the 1:1 and 2:1 treatments generated 31 to 38% lower net benefits than traditional practice. The CV of the net benefits of the 2:1 treatment was about 20% above that of the other treatments.

The highest TFP figures for barley occurred between the 1988/89 and the 1989/90 seasons for all treatments. In the subsequent seasons, TFPs declined from 62% in the 2:1 treatment to 48% in the 1:1 treatment. Similarly to wheat, contrasting statements can be made based on the number of times when the intertemporal TFP was the highest among treatments or when TFP was greater than one; but the limited size of the data set precludes any firm conclusions being made on the long-term sustainability of the system.

The estimated number of years required to capture the TFP trends under different levels of α(0.10, 0.05 and 0.01) and different water-harvesting treatments are shown in Table 5.4.3. The TFP trends for wheat under the traditional practice and 1:1 treatments were negative (ie unsustainable), and that for the 2:1 treatment was positive (ie sustainable). However, none of these trends was significantly different from zero. For wheat under traditional practice and 1:1 treatments, 13 to 22 years are required to capture the TFP trends, and under the 2:1 treatment more than 180 years. The slopes of the barley trends under all treatments were negative (ie unsustainable) and none of them was significantly different from zero. In contrast, it appears that only 3 to 9 years data are required to capture the barley TFP trends.

Table 5.4.3 Number of years necessary to determine the trend in intertemporal TFPs for wheat and barley under different water-harvesting treatments in highland Balochistan using equations (2)[1] and (3)[2]

							N		
							α		
Species	Treatment	S_y	b	a	r^2	df	0.1	0.05	0.01
Wheat	Trad. pract.	2.032	−0.247	2.03	0.05	3	13	15	19
	1:1	1.476	−0.137	1.48	0.03	3	16	17	22
	2:1	1.318	0.003	1.32	0.00	3	184	207	263
Barley	Trad. pract.	0.616	−0.835	4.61	0.79	1	3	3	4
	1:1	0.372	−0.335	2.38	0.62	1	3	4	5
	2:1	1.249	−0.420	3.03	0.18	1	7	7	9

1. $N=[(3.46\ Z_{\alpha/2}\ S_y)/(\delta\ b)]^{2/3}$, and $\delta=1$

2. TFP=a+b years

Great caution is needed in the interpretation of these results. The equations for wheat and barley had very few degrees of freedom, and longer series of measurements are really needed to estimate TFP trends reliably. At this stage it is premature to assess the economic sustainability of cereal crops grown under the different water-harvesting treatments. The negative trends in Table 5.4.3 could be related to soil nutrient decline because no fertilizer was applied during these experiments. Farmers usually have sheep and goats grazing the stubble, and some nutrients are recycled. Resource flow measurements could be relevant to explain the TFP trends, but they are not available for this study.

Economic viability. Interspatial TFPs for both wheat and barley are shown in Table 5.4.4. In this instance, the subscripts of equation 1 represent water-harvesting treatments, and $\ln T_{vu}$ is an expression of: (a) the 1:1 treatment over traditional practice, (b) the 2:1 treatment over the 1:1 treatment, and (c) the 2:1 treatment over traditional practice. In wheat, the 1:1 treatment was consistently more productive than the traditional practice. The 2:1 treatment was more productive than the 1:1 treatment in 50% of the seasons and the opposite happened in the other 50% of the seasons. The treatment 2:1 was more productive than the traditional practice only in the 89/90 and 90/91 seasons. Thus, in terms of wheat productivity, 1:1 > traditional practice > 2:1.

Table 5.4.4 Interspatial (inter water-harvesting treatment) total factor productivity indices of cereals grown under different treatments of water-harvesting in highland Balochistan

Season	Wheat			Barley		
	1:1/T[1]	2:1/1:1	2:1/T[1]	1:1/T[1]	2:1/1:1	2:1/T[1]
86/87	1.26	0.92	0.86	—	—	—
87/88	1.75	1.20	0.48	—	—	—
88/89	1.23	1.11	0.73	1.26	1.06	0.75
89/90	1.18	0.83	1.02	0.84	1.50	0.79
90/91	1.24	0.57	1.42	0.76	0.72	1.82
91/92	1.10	1.14	0.80	0.95	1.22	0.86
AVG[2]	1.30	0.97	0.89	0.95	1.12	1.06
CV[2]	18	24	36	20	25	42

1. T=traditional practice
2. Avg=average; CV=coefficient of variation (%)

In barley, the 1:1 treatment was more productive than the 2:1 treatment in one out of four seasons. The 2:1 treatment was more productive than the 1:1 treatment three out of four seasons. The 2:1 treatment was only more productive than the traditional practice in one out of four seasons. Thus, in terms of barley productivity, traditional > 2:1 > 1:1. The results for wheat support previous findings of Rodríguez et al. (1993), based on averages of net benefits and their coefficients of variation, that wheat under the 1:1 treatment increased net benefits and had lower variation than the traditional practice or the 2:1 treatment. Net benefits and TFP figures for barley suggest that the traditional practice was a better option than the water-harvesting treatments.

Interspatial TFPs for alternative crops compared for the same season and water-harvesting treatment (subscripts u and v in equation 1 were for barley and wheat, respectively) are shown in Table 5.4.5. While the average net benefits of wheat and barley under the traditional practice and the 2:1 treatment were about the same (Tables 5.4.1 and 5.4.2), the interspatial TFP values in Table 5.4.5 show that barley was more productive than wheat three seasons out of four when grown under traditional practice. This is because wheat production utilized a more costly bundle of inputs (higher seed costs) than barley. Under the 1:1 treatment wheat yielded more than barley, which offset the higher seed costs. Thus, barley appears a more suitable crop for the very dry conditions of highland Balochistan under traditional agriculture, but wheat may be more productive under 1:1 water-harvesting conditions. Even though barley was more productive than wheat under the 2:1 treatment, barley cannot be recommended, because TFP values in Table 5.4.4 suggest that 2:1 water-harvesting is not a better option for barley than 1:1 or traditional practice. Factors such as food security and the lack of market for barley, which may explain farmers' actual production preferences, were not included in our analysis.

Table 5.4.5 Interspatial (intercrop) total factor productivity indices of barley compared to wheat grown under different treatments of water-harvesting in highland Balochistan

Season	Trad. pract.	1:1	2:1
88/89	0.95	0.98	0.94
89/90	1.04	0.74	1.38
90/91	1.31	0.82	1.04
91/92	1.17	1.02	1.10
AVG[1]	1.12	0.89	1.12
CV[1]	12	13	15

1 Avg=average; CV=coefficient of variation (%)

5.4.5 Conclusions

It is still premature to assess the economic sustainability of growing cereal crops under water-harvesting. Six seasons for wheat and four seasons for barley are not long enough to estimate the trends of intertemporal TFP indices. It was estimated that 13 to 22 years of measurements would be necessary to determine the trend in TFP and the sustainability of wheat under traditional practice and the 1:1 treatment; and more than 180 years for the 2:1 treatment. For barley, the corresponding figures come out at only three to nine years, but caution is recommended in view of the extremely short time series available for analysis.

Results of interspatial TFP, comparing water-harvesting treatments within a crop, showed that wheat under the 1:1 treatment was more productive, or more viable, than under traditional practice or the 2:1 treatment. In contrast, for barley, traditional practice was more productive, or viable, than the water-harvesting treatments. Interspatial TFP results, comparing crops within a given water-harvesting treatment, showed that barley was more productive than wheat under traditional practice and that wheat was more productive than barley under 1:1 water-harvesting.

The practical advice for the national program's researchers is that it would be desirable to continue water-harvesting trials to improve the assessment of sustainability. Discontinuation of the 2:1 treatment for wheat might be advisable in light of the superiority of the 1:1 treatment. Barley trials using the traditional practice should be continued to demonstrate the greater viability of barley over wheat under the extremely harsh conditions of highland Balochistan.

Acknowledgments

Efforts of agronomists and economists at the Arid Zone Research Institute and ICARDA (MART/AZR Project), Quetta, Pakistan have made it possible to evaluate seven years of field work. Stimulating discussions on the uses of TFP with Simeon Ehui and Murari Singh are deeply appreciated. M. Afzal, I. Ali, U. Mustafa, E. Bailey, M. Jones, T. Nordblom, R. Tutwiler, and E. Thomson provided helpful suggestions to this endeavor. [*Abelardo Rodríguez*]

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5.5 Impact of Modern Farm Technology on the Yield and Net Returns from Wheat in Upper Egypt

5.5.1 Introduction

Egyptian agriculture is in a transitional period. The two decades of the 1960's and 1970's were characterized by a heavy government intervention. Government policies included the control of output prices and land rent, input subsidies and area allotments. Farmers were required to deliver a quota of their production of the major food commodities like wheat, maize, and faba beans to the department of supply at fixed prices lower than the market prices. Farmers were also obligated to plant a certain proportion of their farm area to major crops like cotton, sugar cane, rice and wheat. Those policies affected output and input marketing and distribution and credit services. Farmers decisions during that period were heavily influenced by those policies.

In the late 1980s, as part of an economic reform program, agricultural liberalization policies were initiated. In the new policy environment output markets were liberalized and quota deliveries were eliminated. In addition, floor prices were introduced, subsidies on inputs were reduced and crop area allotments were eliminated for most crops. These policies are still being gradually implemented and their full impact on agriculture is not yet known. The new policies will, however, present new opportunities and constraints to farmers which will affect their choices in resource allocation and technology adoption. Research and extension activities have also been intensified. For the last few years productivity has increased for most of the major cereal crops, including maize, rice, and wheat (Gomaa 1993).

The objective of this study was to evaluate the adoption of modern wheat production technologies and their impact on the profitability of wheat enterprises in Upper Egypt.

5.5.2 Trends in wheat area, production and yield

Indices for Egypt's major wheat producing regions for the 1980-1992 period show a negative growth in area before 1984 (Figure 5.5.1). However, wheat production shifted dramatically upwards after 1986. The area increased from about 507,000 ha in 1986 to about 878,000 ha in 1992, and total production increased sharply from 1.87m tons in 1986 to 4.3m tons in 1992. The production of wheat, stagnant in the period 1980-84, grew at rates of 13 and 11 percent in the periods of 1984-88 and 1988-92, respectively (Table 5.5.1). The increase in wheat area and production was a result of increased profitability due to higher prices and improved farm technology. As mentioned earlier, output prices were liberalized in 1986 and thereafter increased dramatically. In addition, the adoption of modern agricultural technologies increased productivity and profitability.

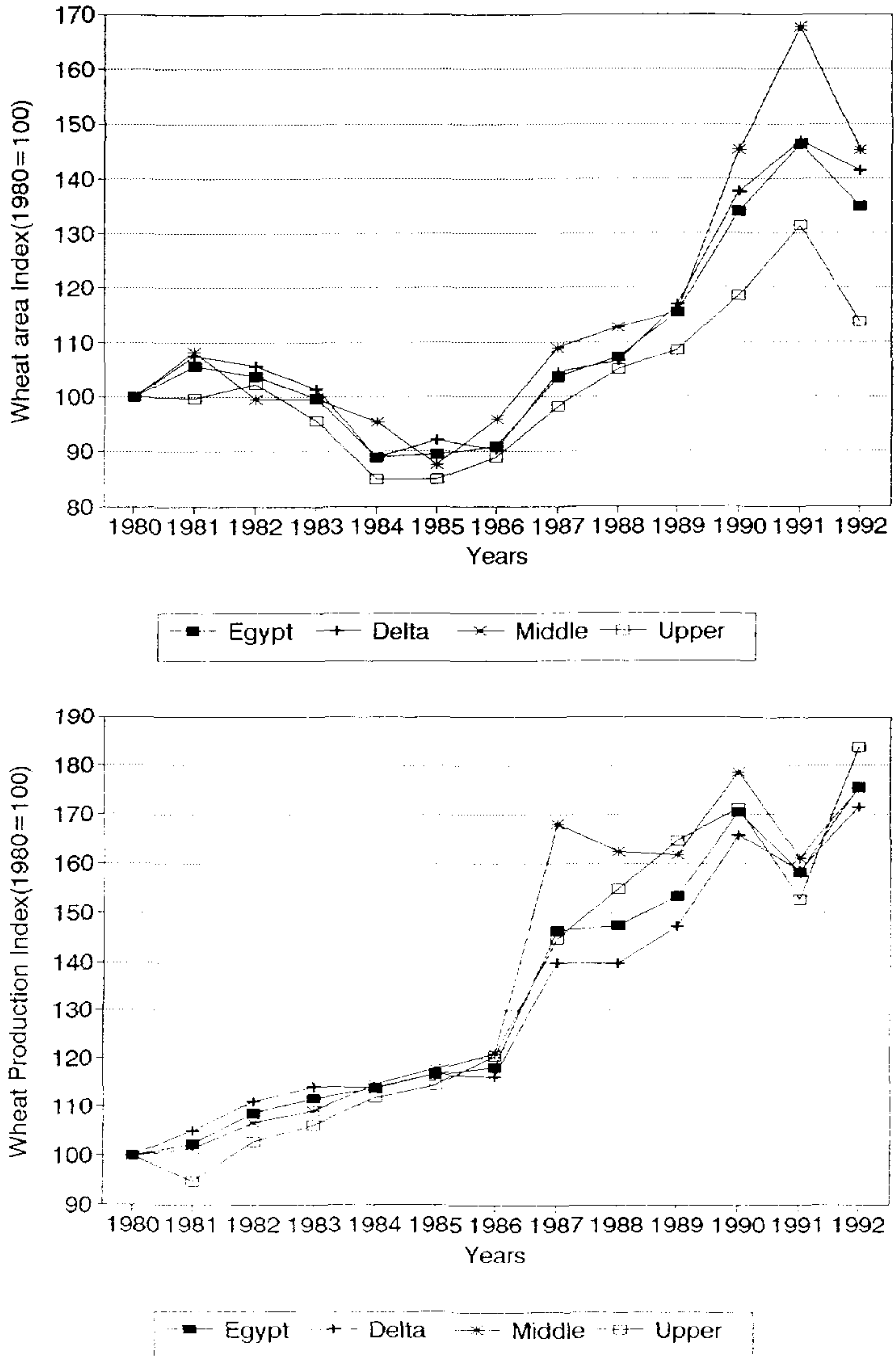

Figure 5.5.1 Wheat area and production indices in Egypt, by major producing region, 1981-1992

Table 5.5.1 Average growth rates in wheat area, production, and yield in Egypt in the main producing regions, 1980-92.

Period	Average growth rates			
	Egypt	Delta	Middle	Upper
		Area percent		
1980-84	-2.9	-3.0	-1.8	-3.7
1984-88	5.2	4.9	5.6	5.7
1988-92	7.0	8.0	8.8	3.5
1980-92	3.0	3.1	3.8	2.0
		Production percent		
1980-84	0.5	0.5	1.6	-0.3
1984-88	12.7	10.8	16.1	14.6
1988-92	10.8	12.8	10.2	6.2
1980-92	8.0	7.6	9.3	7.7
		Yield percent		
1980-84	3.5	3.5	3.4	3.4
1984-88	7.5	5.9	10.5	8.9
1988-92	3.8	4.8	1.4	2.7
1980-92	5.0	4.5	5.5	5.6

Source: growth rates are regression estimates using data from the Ministry of Agriculture, Egypt

The average yields of wheat in Egypt were 3.5, 4.3, and 5.4 tons/ha in the 1980-84, 1984-88, 1988-92 periods, respectively. Values for Upper Egypt were lower than those of the Delta in all three periods (Figure 5.5.2). The mean national growth rate of yield during 1980-92 is estimated at 5.0% annum, with values of 3.5% in the period 1980-84, 7.5% in 1984-88, and 3.8% in 1988-92. Lower yield growth rates are generally expected at higher yield levels as the yield curve approaches a plateau.

The combination of greater yield levels and higher output prices resulted in a greater profitability for wheat growing, making it more competitive with other crops and economically more feasible in marginal situations such as reclaimed land and rainfed areas. The increased wheat area, however, arises both from a reduction in area of other crops like berseem, sugar cane and vegetables and from increased cultivation on the reclaimed land and rainfed areas. Sustainable high yields on these marginal soils may require greater research effort in the future.

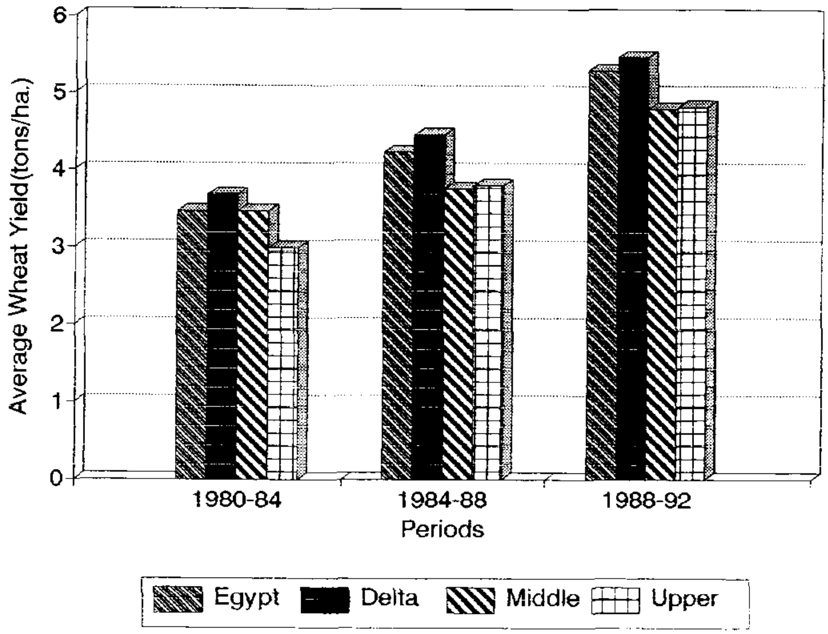

Figure 5.5.2 Average wheat yields in the main producing regions of Egypt, 1980-1992

5.5.3 <u>The study area</u>

The two provinces of Sohag and Qena in Upper Egypt were selected for this study because wheat yields there are below the national average, and research and extension efforts have recently been directed to increase farmers' adoption of improved wheat technology.

5.5.4 <u>Methodology</u>

Three districts were first selected from each province, and two villages from each district, according to their production importance as indicated by cultivated wheat area. For each village, fifteen farmers were randomly drawn from the list of wheat growers in the 1992/93 winter season, to give a total sample of 90 wheat growers in each province.

A questionnaire was prepared and pretested. Trained enumerators and supervisors administered the farmers' interviews. Data on farmers' practices, on farmers' awareness and evaluation of technologies, and on costs of production were collected. Adoption levels of different components of the improved wheat production package were estimated. The results of on-farm trials were used to estimate the yields attainable under different management levels and technological options.

A complete wheat enterprise budget was used to estimate the effect of the adoption of improved technologies on the profitability of wheat production in upper Egypt. Different output and input price levels were used to estimate the impact of the recent agricultural policy changes on profitability and on technology adoption.

5.5.5 Technology generation and transfer

Wheat area in Upper Egypt accounts for about 24% of the total wheat area of Egypt. Wheat is the most important winter crop, and hence, an important source of farm income in the study area. Yields, however, are lower than the national average. This is attributed to natural environmental factors like higher temperatures during grain filling, and management factors such as lower seed rate, lower fertilizer rate, and use of old varieties. Farmers' adoption of the modern technology was retarded by inadequate access to extension information.

The wheat research program in Egypt recently increased its effort in adaptive research through verification trials and demonstration fields. The Nile Valley Regional Program (NVRP), a cooperative research program between ICARDA and the National Research Systems in Egypt, Ethiopia and Sudan, provides support in generating and testing improved technologies for the cool season cereals and food legumes. Its research activities are mainly adaptive in nature, with the main objectives being to disseminate improved agricultural technologies by increasing farmers' access to them and to enhance farmer-researcher interaction through on-farm trials and field demonstrations. Hence, large numbers of trials and demonstrations are conducted every season on farmers' fields, to evaluate improved technologies under farmers' conditions and educate farmers on the benefits of these technologies. The technical package for wheat popularized in the study area by the NVRP includes: (1) planting modern high-yielding varieties such as Giza160, Giza163, Giza164, Sakha69, Sohag1, and Sohag2; (2) planting in the first half of November with a seed rate of 158-178 kg/ha; (3) proper seed bed preparation to ensure good crop establishment; (4) fertilization with 180 kg N/ha and 35.7 kg P_2O_5/ha; (5) pest and weed control; and (6) five to six irrigations at 2-3 week intervals (Ali et al. 1993).

Farmers' adoption of the modern wheat production technology resulted in a yield growth rate of 3% per annum over the last four years (1988-1992). In Sohag and Qena, the demonstration fields where the full package had been applied produced significantly higher yields than the farmers' fields. Adoption of these technologies increases farmers' income. Table 5.5.2 shows the wheat yields attained by the farmers participating in the NVRP's demonstration fields and comparable non-participant farmers' yields.

The data summarize the results of many demonstrations conducted at different locations in Sohag and Qena provinces over four years. The average yield from the demonstration fields was 6.33 t/ha, whereas that from the non-demonstration fields was 4.28 t/ha.

Table 5.5.2 Wheat grain yields of demonstration and non-demonstration farmers' fields in Sohag and Qena provinces, Egypt, 1989-93.

Year	Demonstration farmers		Non-demonstration farmers	
	Sohag	Qena	Sohag	Qena
	t/ha			
1989	6.13	4.74	3.87	3.70
1990	7.36	8.60	5.21	5.28
1991	5.68	4.72	3.40	3.58
1992	6.12	6.39	4.04	4.54
1993	6.93	6.60	4.45	4.71

Source: Ali et al. 1993

5.5.6 Selected survey results

Importance of wheat. According to the survey data, most farmers in Upper Egypt (83%) ranked wheat as their most important winter crop. Comparatively, faba beans, tomatoes, and Egyptian clover (berseem) were ranked as their most important winter crop by only 6%, 7%, and 3% of the sample, respectively. Wheat is grown for subsistence and for cash. Although wheat is a profitable commodity, small farmers in Upper Egypt grow it mainly for family consumption. About 69% of the farmers interviewed set aside more than 50% of their total wheat production for home use. Securing an adequate staple food supply to avoid uncertain market prices is one of the goals of a small family farm.

Adoption of Improved Technologies. Preliminary results of the survey data indicate that there have been high adoption rates of some technologies like variety (64%), planting date (73%) and irrigation interval (77%), but low adoption rates for others such as crop establishment practices (12%), seed rate (12%), nitrogen fertilizers (7%) and timing of first irrigation (37%) (Table 5.5.3).

Farmers' awareness of the recommended technologies is high, but they consider the recommendations in respect of the least adopted technologies, planting method, seed rate, and nitrogen fertilizer application, to be inadequate. Future farmer participation in the agronomic and economic evaluation of these technologies is, therefore, imperative. One constraint on adoption is the lack of sufficient extension information.

Table 5.5.3 Adoption rates of improved technologies in Sohag and Qena provinces of Upper Egypt, 1992/93

Technology	Adoption rates[1] (%) farmers		
	Sohag	Qena	All
Variety:			
Giza 164	58	71	64
Sohag 142	8	-	4
Giza 155	26	28	27
Others	8	1	5
Planting Date:			
Before 1st November	7	-	3
1-15 November	64	80	73
After 15 November	30	20	24
Seed Rate: (2)			
Recommended	12	11	12
Lower rate	68	43	58
Higher rate	20	36	30
Planting Method:			
Wet	94	82	88
Dry	6	18	12
Nitrogen Fertilizer:			
175-185 kg N/ha	7	8	7
less than 175 kg N/ha	49	53	51
more than 185 kg N/ha	44	39	42
Irrigation Interval: (3)			
less than 21 days	67	87	77
more than 21 days	33	13	23
First Irrigation:			
less than 21 days	20	53	37
more than 21 days	80	47	63

(1) Adoption rates are estimated from survey data, 1992/3 season.
(2) Sohag is recommended for a higher seed rate (190 kg/ha) than Qena (155 kg/ha), which is why relatively more farmers in Sohag were categorized as users of lower seed rate than Qena farmers.
(3) Two to three weeks irrigation intervals are recommended for wheat in Upper Egypt.

Impact on productivity. The average wheat yield in the study area was 4.86 t/ha. Figure 5.5.3 shows the distribution of yield in the sample. Most farmers (67%) reported a yield range of 3.8 to 5.8 t/ha, with an average of 4.76 t/ha; relatively few farmers reported

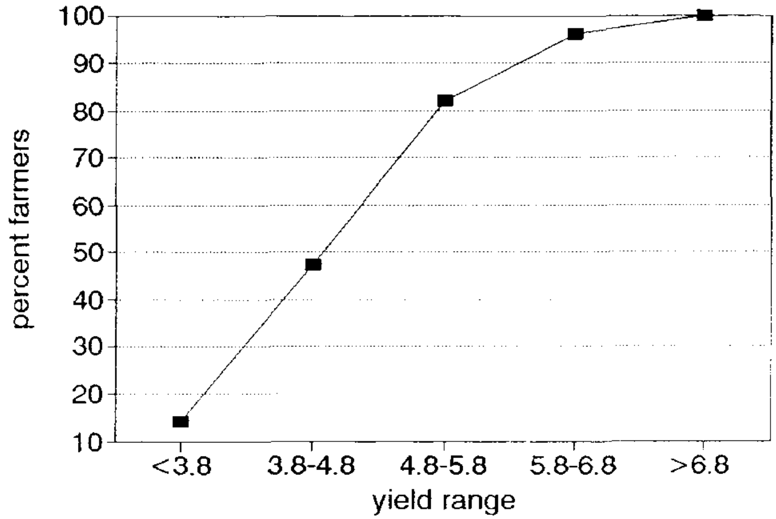

Figure 5.5.3 Yield range and distribution in a sample of farmers in Upper Egypt

yield levels higher than 5.8 tons/ha (18%) or lower than 3.8 t/ha (14%). The overall variability of wheat yields was due to the different levels of technology and management practice adopted.

In spite of the increase in yield so far achieved, a significant yield gap still exists between the farmer-managed demonstration fields where a full package of wheat production technologies is applied and farmers' fields where a lower level of technology persists.This yield gap is attributed to the use of old varieties (Giza 155, Beladi and Indian), poor crop establishment, lower seed and fertilizer rates, inadequate irrigation regimes and delayed planting (Ali et al. 1993). Figure 5.5.4 depicts potential wheat yields for three possible technical levels, each comprising a set of feasible bundles of inputs and outputs. The input rates and yields for each option were estimated from the results of the on-farm trials, the demonstration fields and the survey data.

For the first level it was assumed that a farmer uses a relatively old wheat variety (Giza 155), applies seed and fertilizer at rates lower than those recommended, and uses longer than recommended irrigation intervals, hence fewer irrigations. This lower level of technology and management represents the conditions prevailing in Upper Egypt in the past. The wheat yield for the study area in 1988/89 was estimated as 3.8 ton/ha for the non-demonstration farmers' fields. Only 14 percent of the surveyed farmers now fall in this yield level category.

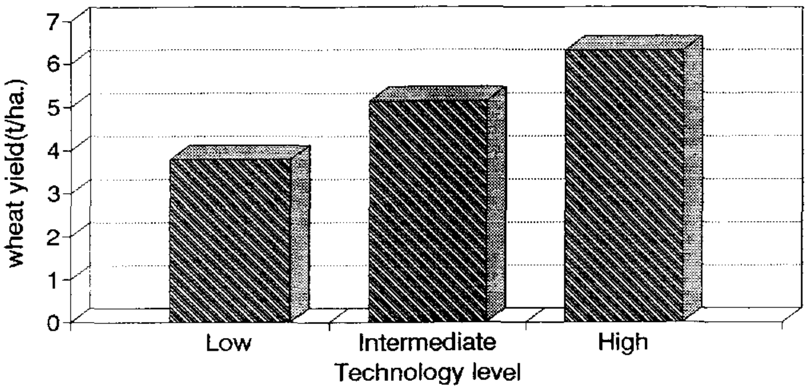

Figure 5.5.4 Potential wheat yield levels for different technology and management options in Upper Egypt

For the second level it was assumed that the farmer uses the modern high-yielding wheat varieties (MVs) and the recommended planting date but has not adopted the recommendations on seed rate, fertilizer rate and irrigation regime. This scenario is realistic, because survey results indicated that most farmers use the MVs and plant at the recommended date, while adoption levels of recommendations on seed and fertilizer rates and irrigation regime were relatively lower. The average wheat yield under intermediate technology and management in the study area was estimated as 5.13 t/ha. This level represents 35% of the farmers surveyed, with yields ranging from 4.8 to 5.8 t/ha.

For the third level it was assumed that MVs were used and all recommended input levels and management practices were applied. This high-level technology and management scenario represents farmers who adopt the full package of recommendations. The average yield over four years of the demonstration fields in the study area was estimated as 6.33 tons/ha. This is considered a conservative estimate of the yield achieved under the high technology option in Upper Egypt.

Price levels. The new agricultural policy significantly affected wheat prices. In 1986, area allotments and quota delivery were eliminated and a floor price introduced. As a result wheat prices increased dramatically (Figure 5.5.5). The market price increased from about 172 LE/ton in 1985 to about 526 LE/ton in 1992, then declined in 1993 to 500 LE/ton.

Agricultural policy also affected input prices. Chemical fertilizers, pesticides and seeds are the major inputs purchased for wheat production. Table 5.5.4 shows the prices of wheat grain, straw, seed and commonly used fertilizers and pesticides for 1985, 1988 and 1993. These years and prices, used in the economic

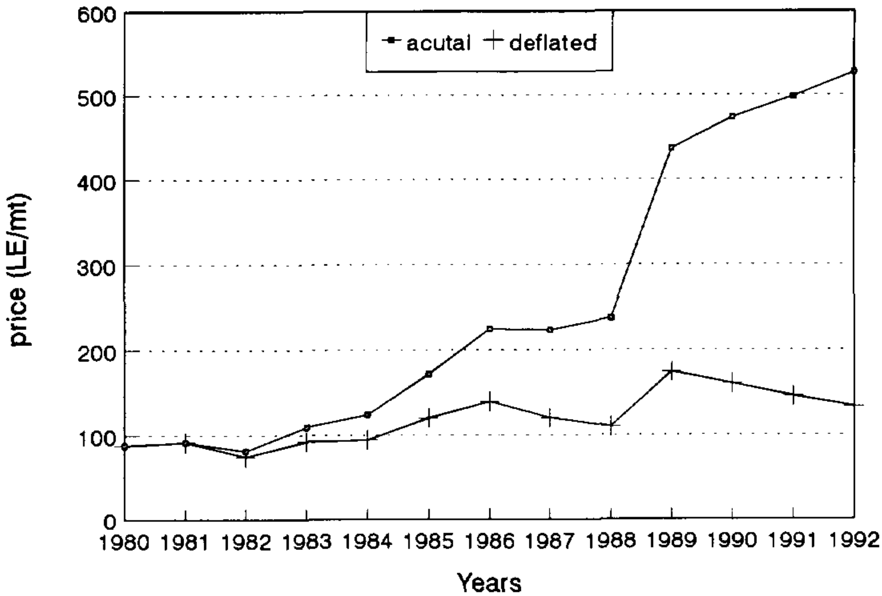

Figure 5.5.5 Actual and deflated wheat prices in Egypt, 1980-92

analysis, were selected to represent the successive policy changes that have occurred. It should be noted that the policy change on wheat price started in 1986 while the major changes on input subsidies started in 1989. Subsequently, input prices shifted upwards and increased production costs.

Table 5.5.4 Market price of wheat grain, straw, seed and main chemical inputs

Years	Units	1985	1988	1993
		------- LE/Unit		---------
Grain	tonne	167.0	436.7	500.0
Straw	tonne	108.0	104.0	161.3
Seed	tonne	292.0	600.0	806.7
Urea (46.5%)	tonne	131.0	266.0	515.0
Ammonium Nitrate	tonne	91.3	141.0	430.0
Super Phosphate (15%)	tonne	30.3	71.0	188.0
Malathion	litre	9.9	9.9	9.9

Source: Ministry of Agriculture and Principal Bank for Development & Credit, Egypt

Impact on profitability. The profitability of wheat production under the three technology levels described above were analyzed using the price levels of 1985, 1988 and 1993. The total costs, gross and net returns from each option were estimated using enterprise budgets (Table 5.5.5; Figure 5.5.6). The net returns were the total revenue less the total operating costs and the cost of borrowed capital. They represent the returns to land, family provided capital, management and risk.

Table 5.5.5 Total costs and gross returns from wheat in Upper Egypt under three technical options and three price levels.

Technology option	Total costs			Gross returns		
	1985	1989	1993	1985	1989	1993
	LE/ha					
Low technology	743	930	1212	1199	2185	2391
Intermediate technology	874	1102	1448	1619	2950	3227
High technology	987	1252	1660	1998	3640	3982

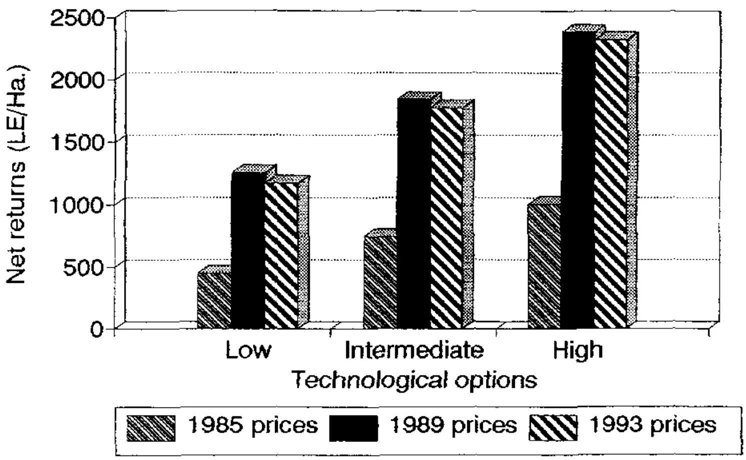

Figure 5.5.6 Net returns from wheat in Upper Egypt under three technology options and three price levels

The analysis indicated that the profitability of wheat increased substantially when producers adopted the improved technology. Estimated net returns for low, intermediate, and high technology were, respectively, 456, 745, and 1011 LE/ha when 1985 prices were assumed. The wheat price increase due to the policy change had a dramatic impact. When the 1989 prices were assumed, the net farm returns increased to 1255, 1848 and 2388 LE/ha, respectively. The higher the technology option the farmer adopted, the greater was the increase in his net returns per hectare from the price increase. This result shows that higher wheat prices will induce farmers to adopt the improved technologies.

When the 1993 prices were assumed, the net farm returns per hectare declined under all technology options. This was because wheat prices increased only slightly over 1989 values, whereas input costs, following the reduction in subsidies, increased significantly. The reduction in net returns was greater (76 LE/ha) under the low technology option than under the intermediate (70 LE/ha) and high technology (66 LE/ha) options, because the lower technology option had a higher average cost of production per unit output relative to the other options. This result shows that farmers can minimize the negative impact of the reduced input subsidies and at the same time increase their net returns by adopting the improved technology.

Impact on farm income. The average annual total (gross) farm income from wheat in Upper Egypt was estimated as LE 78.8m, LE 176.4m, and LE 464.8m, respectively, for the periods 1980-84, 1984-88, 1988-92. These three periods were differentiated by the policy environment prevailing and the productivity growth in each period. Total farm income grew at rates of 11.1, 26.4, and 16.3%, and farm income per hectare increased significantly, being estimated as LE 557.4, LE 1301.9, and LE 2747.0 for the three periods, respectively. This increase in farm income in Upper Egypt will, through a multiplier effect, affect other sectors directly or indirectly dependent on agriculture and will augment the national income.

5.5.7 Conclusion

Wheat production in Egypt has recently increased following increases in the area planted and the productivity per unit area. The increase in area was the result of increased profitability. Preliminary results of a farm survey in Upper Egypt show that farmers' adoption of some technologies, like improved variety, date of planting, and irrigation regime, has been high. That of other technologies, seed rate, nitrogen fertilizer, and crop establishment practices, has been relatively low. Farmers' awareness of the recommended technologies is high, but lack of adequate extension information is a major reason for retarded adoption. Farmers' participation in their agronomic and economic evaluation is, therefore, essential.

Analysis of profitability indicated that higher technology options increase farmers' net returns substantially. The increase in wheat price had a dramatic impact on farmers' net returns, and the higher the technology level the greater the increase in net returns per hectare. The removal of input subsidies, when not fully offset by an increase in output prices, had a negative impact on farm income. The analysis indicated that the increase in the cost of inputs, following the reduction of subsidies, reduced farmers' income, but the higher the technology level adopted the lower the reduction. The average annual farm income from wheat in Upper Egypt was estimated as LE 78.8m, LE 176.4m, and LE 464.8m, respectively, for 1980-84, 1984-88, 1988-92. This dramatic rise was a result of higher prices and of productivity growth resulting from improved technology, which induced farmers to cultivate a greater area with wheat. [*Aden Aw-Hassan (Rockefeller Post-Doctorate Fellow), M. Mansour and E. Ghanem (ARC, Egypt) and M.B. Solh (ICARDA, Egypt)*]

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5.6 Triticale Production and Utilization in Tunisia: Constraints and Prospects

Tunisia started promoting triticale production in the early 1980s to reduce maize imports for poultry feeding. Although the area of triticale increased rapidly (16,500 ha in 1991), its utilization remained very limited until 1990, leading to a sharp build-up in expensive government stocks. As a result, policy makers started to seriously question whether or not to continue promoting triticale production.

The main objectives of this study were: (1) to identify the major constraints to adoption and diffusion of triticale cultivation, (2) to examine the factors underlying recent trends in triticale production and utilization and (3) to suggest recommendations for policy and future research.

A survey of 52 triticale growers was conducted in 1992 covering the favorable and semi-arid zones. Survey farmers consistently praised triticale's resistance to diseases and lodging and its tolerance to drought. Triticale outyielded barley by an average of 22% and, because of its higher producer price, its gross revenues were substantially higher (55%) than those of barley. Triticale's yield advantage over wheat was modest in normal years (5-7%) and was largely offset by wheat's higher prices. During dry years, however, triticale's yield advantage was more apparent, and it outyielded durum wheat by 40% and bread wheat by 10%, with gross revenues 14% higher than those of durum or bread wheat. According to survey farmers, the key constraint to triticale production was the uncertainty about the State's future support. This uncertainty largely explains the recent decline in total triticale area (13,200 ha in 1993) and could lead to a substantial drop in future production unless the government clearly re-confirms its policy of guaranteed purchases of triticale.

The main reason for limited tritical utilization before 1990 was found to be the cheaper consumer prices of competing feed ingredients (maize and barley). However, starting in 1991, subsidies on barley and maize were gradually removed resulting in a triticale consumer price lower than those of maize and barley. This resulted in a sudden and dramatic increase in triticale utilization which, by 1992, had exceeded production by more than 80% leading to the complete elimination of excess stocks and to the rationing of triticale sales. However, as long as triticale remains cheaper than barley, most triticale utilization will continue to be for ruminant feeding rather than for poultry. Thus, in order to encourage the allocation of the limited triticale supplies to their most economically efficient use (ie in poultry feeding), feed prices should be modified in such a way as to keep triticale consumer prices lower than maize but higher than barley. *[Maurice Saade, from a collaborative study with INRAT, Office des Céréales and DGPA, Tunisia]*

5.7 Constraints to the Adoption of New Barley Varieties in Morocco

Research efforts for the genetic improvement of barley in Morocco have resulted in the release of 19 varieties, 13 of them since 1984. However, the adoption of these varieties remains very limited: total quantities of certified barley seed sold to farmers in 1991/92 was less than 2% of total barley seed used in Morocco. This is in sharp contrast with 37% in the case of bread wheat seed and 17% for durum wheat.

The goal of this study was to identify the main reasons for the limited adoption of the new barley varieties in Morocco. The study attempted to clarify three basic questions: (1) Are the new varieties adapted to farmers' production and utilization constraints? (2) Do farmers have access to the seed of the new varieties? and (3) Are farmers aware of the existence and potential of the new varieties?

The main research approach consisted of a survey of 173 barley farmers in seven districts (*Centres de Travaux*, or *CT*) covering three agroclimatic zones: favorable, semi-arid and arid. Two categories of farmers were surveyed: (1) a random sample of 113 barley farmers, and (2) sixty farmers who have already tested some of the new varieties within the on-farm trial program regularly conducted by DPV.

Preliminary results indicate that the adoption of improved barley varieties is more widespread than expected (24% of barley area in the survey zone). However, adoption is essentially limited to the semi-arid zone and to two relatively old varieties (Arig 8 and ACSAD 60). These varieties are appreciated for their high grain yields and for their excellent quality for human consumption. However, low straw yield and poor grain quality for animal feeding could offset the benefits from higher grain yield and reduce the economic incentive for wide adoption of the new varieties, particularly the 2-row types.

Farmers' limited access to certified barley seeds is likely to become the key constraint to the adoption of new varieties in the future. This is because SONACOS plans to concentrate on producing certified wheat seeds, which is a more profitable and less risky enterprise than barley seed production. Current prices for certified barley seeds are relatively high, which will encourage farmers to rely more on their own seed to meet their needs, particularly following a good season when barley market prices were low.

Farmers appear to be well informed of the potential (and of the disadvantages) of the two available improved barley varieties, particularly in the semi-arid zone which has been the target of most efforts to promote new varieties. Future transfer of technology activities (and breeding efforts) ought to focus more on the arid zones, where more than half of barley areas are located. [***Maurice Saade, from a collaborative study with INRA and DPV, Morocco***]

6. TRAINING AND AGROTECHNOLOGY TRANSFER

FRMP's training activities are directed primarily towards improving the national programs research capabilities in specific aspects of FSR and components of resource management. Wherever possible, FRMP utilizes its on-going research program as working demonstration.

Training activities conducted at headquarters and in-country in 1993 may be summarized as follows:

6.1 Headquarters Training Courses

6.1.1 Short-term group training

Supplemental irrigation management: This regional course was attended by nine participants from Algeria, Lebanon, Libya, Morocco, Syria, Tunisia, and Yemen. It was conducted during the period 9-20 May 1993.

6.1.2 Individual non-degree training

Participant	Country	Subject	Duration
Ali Kneifes	Syria	Data entry	3 weeks
Hassan Hebbo	Syria	Data entry	3 weeks
Ali Zeghida	Algeria	Data entry and analysis	2 weeks
Muhammad Islam	Pakistan	Neutron probe usage	3 weeks
Zahid Ali Qureshi	Pakistan	Neutron probe usage	3 weeks
Attieh Michel Nemeh	Syria	Mineral-N determination and evaluation	1 week
Bassema Jayroudi (Ms)	Syria	Mineral-N determination and evaluation	1 week
Farouk Jeroudi	Syria	Soil and plant analysis	1 week
Hala Darwish (Ms)	Syria	Soil and plant analysis	1 week
Maher Hammouda	Syria	Supplemental irrigation	16 months
Srour Saman Hazim	Syria	Agronomy field experiments	6 weeks

6.1.3 Individual degree training

Name	Country	Degree	University	Topic
Zuheir Masri	Syria	PhD	Dokuchaev/ Russia	Soil physical status of rotations

6.2 Non-headquarters Training Courses

Winter chickpea technology transfer: This was a sub-regional course conducted jointly by LP and FRMP in cooperation with DASR, Syria. It was held in Kamishly, Syria, during the period 23-26 May 1993, and attended by 23 participants from Jordan, Lebanon and Syria.

Water harvesting concepts and techniques for arid and semi-arid areas: This was a regional course conducted in collaboration with UNDP. It was held in Tunis, Tunisia, during the period 1-11 November 1993, and attended by eight participants from Algeria, Iraq, Jordan, Libya, Syria and Tunisia.

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Mustafa Pala[1]	Wheat based systems agronomist
Richard Tutwiler	Anthropologist
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Ahmed Mazid	Agricultural economist
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Elianor Nasseh[2]	Research Technician I
Ali Haj Dibo	Research Technician I
Ghazi Yassin	Research Technician I
Jihad Abdullah	Assistant Research Technician
Abdul Baset Khatib[4]	Assistant Research Technician
Hayel el Shaker	Assistant Research Technician
Mohamed Elewi Karram[2]	Assistant Research Technician
Marica Boyagi	Senior Secretary
Zuka Istanbouli	Secretary II

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1. On Sabbatical leave at WSU, USA (from August 1993)
2. Left the Program in 1993
3. Joined the Program in 1993
4. Transferred to Motor Pool

المركز الدولي للبحوث الزراعية في المناطق الجافة

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