AFFR-11

FARM RESOURCE MANAGEMENT PROGRAM

Annual Report for 1994

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 16 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 covers the whole rainfed agricultural environment of WANA: the climate, the natural resources of soil, water and natural vegetation; the farming systems; the social, economic and policy contexts in which those systems function; and all their interactions, particularly as they affect productivity and the conservation of the resource base. Increasingly, this agenda is expanding to take in resource management aspects of irrigated agriculture. As noted last year, water is becoming an ever more potent issue in agriculture worldwide and, not least, in WANA. Moreover, during 1994, FRMP's scientists became more deeply involved in the new Resource Management component of ICARDA's Nile Valley Regional Program in Egypt, and resource management in Egypt consists largely of variations on the theme of the management of irrigation water.

The maintenance of Program coherence across this very broad field is an act of faith, supported by a holistic philosophy, which seeks: to view each problem, each research task, in its technical, economic and social context; and, as far as possible, to conduct activities, within Program and with partners in other ICARDA Programs and National Programs, with a multidisciplinary, farming system or resource management system perspective. These various research activities, subject to the constraints of human resources, continued through 1994 to be conceptualized within three broad 'projects':

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

and these form the basis of our reporting here.

Some reorganization of 'projects' is anticipated in 1995, to align with the structure envisaged in ICARDA's Medium Term Plan. FRMP activities will then fall mainly into five Projects: 1. Agroecological Characterization; 2.

Resource Conservation and Management; 13. Agronomic Management of Farming Systems; 19. Socio-economics of Natural Resource Management; and 20. Production Systems, Adoption and Impact; with some interest also in 21. Policy and Public Management.

However, is not anticipated that these changes will impose any sudden shift in the overall program of work, rather a rational evolution to accomodate new priorities. All research activities have an inherent time scale, that varies considerably with the nature of the activity. Within FRMP, long time scales are inherent in a group of agronomic activities that centre on a well-established set of rotation trials. Originally set up to identify optimal sequences of crops and management treatments, these trials (and their considerable data sets) now provide opportunities for the exploration of long-term trends in productivity and the *effects of choice of crop and management practice on the* sustainability of production. Last year's report carried a 'special focus' chapter on the topical subject of water. This year, we shift the special focus (Chapter 2) to our rotation trials and our widening perspective of their research utility.

1.2 Staff News

Budgetary constraints continued to have their impact in 1994, most particularly with the departure in April of Dr Peter Smith, who for two years had frequently stimulated, and sometimes bewildered, us with his mix of energy, ideas and lateral thinking. Another serious loss, though in this case a planned departure, was that of Dr Hazel Harris in November. For nearly ten years, her broad knowledge, experience and practical good sense was one of the firm rocks upon which technical research in FRMP was founded. She will be greatly missed in the Program, in ICARDA generally, and in the Region. The good news is she will return from Australia from time to time as a consultant.

Dr Aktar Beg, who had been with us as a visiting scientist for more than two years, also left in 1994; but we were pleased to see him return at the end of the year as a consultant to complete and write up his intensive study of oilseed crops. We plan to get this work continued on a project basis at the earliest opportunity.

Dr Aden Aw-Hassan completed his two-year Rockefeller fellowship, in Cairo, at the end of 1994. The stimulus he provided to socio-economic work in the Nile Valley Regional Program, and especially to adoption and impact studies of new production technology in Egypt and Sudan, were greatly appreciated; and we have high hopes he will soon rejoin us at base in FRMP as the new DRMP coordinator. Meanwhile, FRMP representation in Cairo has been maintained, indeed expanded, by the recruitment of two postdoctoral NPOs to strengthen ICARDA's input into the new Resource Management component of the Nile Valley Program work in Egypt: Dr Mohamed Abdel Moneim in soil management, and Dr Hamdy El-Houssainy Khalifa in water management. Both these scientists have already provided a major input into the preparatory studies and planning workshop for these new activities.

Dr Mustapha Pala returned in August from his sabbatical at Washington State University, full of enthusiasm and new skills in crop modelling. We trust the extra duties he has incurred on the departure of Dr Harris will not deter him from pursuing this new line of work, which is currently seriously under-represented in ICARDA's work program. In this context, it must be noted regretfully that our recruitment exercise during 1994 for a new agroclimatologist was unsuccessful. Two excellent candidates were interviewed but not appointed. As of early 1995, we are re-advertising this post and also that of soil conservation/land management specialist, which had been frozen for two years.

Given the ongoing shortage of permanent professional staff, we have been particularly grateful for the part-time contributions of professional colleagues from Aleppo University, Dr Michel Wakil in groundwater quality studies and Dr Abbas Hazzouri in water harvesting studies. Dr Wakil's findings, summarized in last year's and this year's report, have drawn our attention to the risks of salinization even in the context of supplemental irrigation. We have also been pleased to welcome two PhD students from Germany, Ms Susanne Pecher (from Hohenheim University) who is studying barley marketing with Dr Rodriguez; and, early in 1995, Ms Annette Oberle (from Karlsruhe University) to work with Dr Oweis on techniques of remote sensing for the identication of sites with water-harvesting potential.

More good news is that Ahmed Mazid and Sonia Garabed each successfully completed PhD studies early in 1995, respectively at Nottingham and Reading Universities (UK), after long years of study pursued in parallel with normal duties within the Program. FRMP is proud of both of them.

It is also a pleasure to record that there were no further losses from the Program support staff in 1994. The cheerful and conscientious way in which those staff have maintained all ongoing FRMP activities (and some new ones) is most gratefully acknowledged. Sadly however, since this is written in mid-1995, one tragic event in 1995 must be recorded. Early in the year we recruited Joanna Haider, previously an employee in the Legume Program, as a technical consultant to work with Dr Tutwiler on the Mohassa project for one year. Her death a few weeks later in an horrific road accident while on duty stunned and saddened everyone. A highly capable young lady, with a very positive, happy personality, Joanna had been known, appreciated and loved all over ICARDA. She is greatly missed. Our deepest sympathy goes to her family in Lebanon.

1.3 The Weather in 1994

The 1993/94 cropping season in West Asia and North Africa (WANA) was marked by a heat wave in April and May in the eastern Mediterranean region, which adversely affected crop yields. In Turkey, the autumn of 1993 was the driest in 35 years, but favorable precipitation during winter saved yields from falling below average. Iran and, to a lesser extent, Iraq and Afghanistan enjoyed above-average precipitation and favorable rowing conditions, leading to another bumper crop in Iran. In western Pakistan, the season was one of the driest on record and crop failure was widespread.

In North Africa, Morocco enjoyed high rainfall during autumn and winter, ending a two-year-long drought and leading to an above-average crop in spite of lower than average rainfall at the end of the season. Algeria faced successive dry periods during the growing season that was warmer than usual, resulting in below-average to average yields. In Tunisia and Libya, planting was delayed by a dry autumn, and crops were stressed by inadequate rainfall and high temperatures during spring. Yields were below average.

In Ethiopia, the main summer rains were generally adequate, although somewhat late. Yields were good except in some parts of the country. The rainy season in Eritrea and Yemen started late and ended early, reducing crop yields to less than average.

Table 1.1. Monthly precipitation (mm) for the 1993/94 season

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Jindiress													
1993/94 season	0.0	8.2	76.2	27.6	143.8	175.4	49.8	15.6	36.9	0.0	0.0	0.0	533.5
Long term average (34s.)	1.5	29.6	56.1	89.8	85.8	76.1	61.9	40.7	20.6	4.5	0.0	1.4	468.0
% of long term average	0	28	136	31	168	230	80	38	179	0	-	0	114
Tel Hadya													
1993/94 season	0.0	13.1	45.7	18.9	112.6	139.8	14.6	13.0	15.6	0.0	0.0	0.0	373.3
Long term average (16s.)	0.4	25.4	47.0	52.7	64.1	56.8	40.2	24.0	16.3	2.7	0.0	0.6	330.2
% of long term average	0	52	97	36	176	246	36	54	96	0	-	0	113
Breda													
1993/94 season	0.0	3.2	27.8	14.6	88.0	126.2	9.8	15.2	6.4	0.0	0.0	0.0	291.2
Long term average (36s.)	1.5	16.1	31.8	51.2	49.2	41.0	33.8	29.5	16.2	1.5	0.2	0.0	272.0
% of long term average	0	20	87	29	179	308	29	52	40	0	0	-	107
Boueidar													
1993/94 season	0.0	14.0	52.2	9.4	60.7	74.1	12.2	11.6	11.4	0.0	0.0	0.0	245.6
Long term average (21s.)	0.1	18.4	25.1	35.8	42.9	37.2	26.9	16.3	10.0	1.0	0.1	0.0	213.8
% of long term average	-	76	208	26	141	199	45	71	114	0	0	-	115
Ghrerife													
1993/94 season	0.0	4.0	33.5	18.6	60.0	89.3	20.0	8.6	11.8	0.0	0.0	0.0	246.4
Long term average (9s.)	0.4	28.2	28.1	37.2	48.2	46.4	32.7	10.0	17.9	2.8	0.0	0.0	251.9
% of long term average	0	14	119	50	126	192	61	86	66	0	-	-	98
Terbol													
1993/94 season	0.0	15.6	79.8	34.6	159.0	103.0	59.8	20.2	5.6	0.0	0.0	0.0	477.6
Long term average (13s.)	0.0	22.4	68.8	93.3	128.0	117.4	96.1	24.3	18.4	2.9	0.3	0.0	571.9
% of long term average	-	70	116	37	124	88	62	83	30	0.0	0.0	-	84

Table 1.2. Monthly air temperature (°C) for the 1993/94 season

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Jindiress												
Mean max.	33.4	31.9	16.8	13.5	12.1	12.2	17.1	25.0	29.0	32.1	32.8	35.5
Mean min.	18.4	15.4	4.7	6.3	4.4	2.6	5.1	9.7	12.7	16.9	21.2	21.1
Average	26.0	23.7	10.7	10.0	8.3	7.5	11.1	17.4	20.8	24.5	27.0	28.3
Abs. max.	40.0	36.8	24.5	18.0	17.0	17.2	21.3	31.7	37.5	35.2	36.5	42.5
Abs. min.	11.8	10.2	-3.0	-1.6	-0.6	-4.0	-0.1	3.0	7.0	11.5	16.5	18.3
Tel Hadya												
Mean max.	34.8	30.7	16.1	14.1	13.3	13.8	18.9	26.9	31.6	34.7	35.6	37.6
Mean min.	16.0	12.8	4.1	4.9	3.7	2.8	4.0	8.3	11.8	17.7	22.7	21.1
Average	25.4	21.8	10.1	9.5	8.5	8.3	11.5	17.6	21.7	26.2	29.2	29.4
Abs. max.	39.8	33.4	24.5	18.1	16.5	18.8	24.3	34.6	39.6	38.2	39.5	43.9
Abs. min.	9.3	8.7	-4.6	0.2	-1.5	-2.6	-1.6	1.1	5.1	11.8	16.8	18.0
Breda												
Mean max.	33.5	29.4	14.4	10.4	10.3	10.9	15.6	23.8	29.2	34.1	35.2	36.8
Mean min.	14.8	12.8	3.0	2.7	1.5	2.0	3.1	7.3	11.4	16.9	20.3	18.9
Average	24.2	21.1	8.7	6.8	5.9	6.5	9.4	15.6	20.3	25.8	27.8	27.9
Abs. max.	38.0	32.8	23.1	14.9	13.8	15.7	21.6	33.0	37.4	38.0	39.0	44.0
Abs. min.	10.0	8.1	-7.0	-5.0	-3.8	-3.8	-0.1	1.8	4.8	11.7	16.9	16.4
Boueidar												
Mean max.	31.7	29.2	13.7	10.3	10.4	10.6	15.5	24.3	28.8	33.0	34.2	35.9
Mean min.	11.3	11.1	1.6	2.6	1.6	1.3	3.3	6.5	10.7	14.2	16.6	16.9
Average	21.4	20.1	7.7	6.5	6.0	5.9	9.4	15.4	19.7	23.6	25.4	26.4
Abs. max.	37.0	31.9	23.2	15.0	14.9	16.3	21.0	34.2	37.0	38.1	37.4	42.0
Abs. min.	6.3	6.3	-6.8	-3.2	-4.9	-5.0	-2.1	0.0	3.8	9.8	14.9	14.8
Ghrerife												
Mean max.	33.0	29.9	15.3	12.3	12.2	12.0	17.8	26.1	30.6	34.2	34.9	36.9
Mean min.	17.3	15.1	4.6	5.4	4.7	3.6	6.6	12.1	15.7	18.5	20.7	21.1
Average	25.2	22.6	9.9	8.9	8.5	8.1	12.2	19.1	23.2	26.4	27.9	29.1
Abs. max.	38.1	32.9	24.8	17.0	16.0	17.8	23.3	36.0	38.5	38.5	38.5	44.9
Abs. min.	7.0	10.2	-3.5	-3.0	-2.0	-2.7	1.0	6.0	9.1	14.8	19.0	18.8
Terbol												
Mean max.	33.9	29.1	17.8	15.5	12.8	11.8	16.8	24.7	28.2	31.1	31.7	33.9
Mean min.	9.7	8.8	2.0	-0.5	0.6	1.1	2.0	4.8	7.0	8.4	10.0	11.0
Average	21.5	18.6	9.8	7.5	6.5	6.5	9.2	14.9	17.6	19.8	20.9	22.5
Abs. max.	38.9	32.0	26.1	20.0	18.0	19.0	23.5	32.5	36.5	35.0	35.0	40.0
Abs. min.	5.0	4.9	-4.5	-5.5	-5.0	-4.0	-2.5	-2.0	0.0	5.0	6.0	9.0

Table 1.3. Frost events during the 1993/94 season

	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Jindiress								
No. of frost days	6	1	1	9	1			18
Abs. min. (°C)	-3.0	-1.6	-0.6	-4.0	-0.1	-	-	-4.0
Tel Hadya								
No. of frost days	6	-	4	9	1	-	-	20
Abs. min. (°C)	-4.6	-	-1.5	-2.6	-1.6	-	-	-4.6
Breda								
No. of frost days	6	9	12	8	2	-	-	37
Abs. min. (°C)	-7.0	-5.0	-3.8	-3.8	-0.1	-	-	-7.0
Boueidar								
No. of frost days	10	7	11	12	7	1	-	48
Abs. min. (°C)	-6.8	-3.2	-4.9	-5.0	-2.1	0.0	-	-6.8
Ghrerife								
No. of frost days	5	3	2	6	-	-	-	16
Abs. min. (°C)	-3.5	-3.0	-2.0	-2.7	-	-	-	-3.5
Terbol								
No. of frost days	9	20	12	12	9	4	1	67
Abs. min. (°C)	-4.5	-5.5	-5.0	-4.0	-2.5	-2.0	0.0	-5.5

Table 1.4. Frost events at 5 cm above the ground during the 1993/94 season

Abs. min (°C)	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Tel Hadya								
Frost days	6	1	5	11	3	1	-	27
Abs. min (°C)	-5.6	-0.6	-2.4	-5.6	-2.9	0	-	-5.6

2. SPECIAL FOCUS: ROTATION TRIALS

Introduction

Though too often loosely used as a buzzword, the concept of sustainability has over the last five years given new emphasis to a much neglected dimension of agricultural research, that of time. The dominant quest year by year to increase annual production is now increasingly subject to the question, 'but what are the consequences, what are the long-term trends?'

Numerous definitions of sustainability have been coined, to match the concerns of different interest groups. In the agricultural context, the most widely perceived sustainability goal is the indefinite prolongation of agricultural output at present levels and, preferably, also of a rising trend in that output to match rising demand. However, as resource scientists and economists point out, such goals are dependent upon the maintenance (and, where possible, the enhancement) of the resources upon which production is based - both the externally procured inputs like chemical fertilizers and, particularly, the local natural resources of soil, water and vegetation. Sustainable output depends on the optimization of production per unit of input and the avoidance of overdependence on such inputs. It also depends on the adoption of production systems that build up rather than run down the natural resource base. From now on, agricultural research is concerned with both sides of the coin, the maintenance and enhancement of production and also the maintenance and enhancement of production potential. This demands research with a strong time perspective.

Fortunately, over the last 15 years, ICARDA scientists have set up a considerable number of long-term trials. Many of those that remain have now been running for ten years or longer. The primary purpose of each of them was (and remains) to compare the productivity, biological and economic, of different rotational systems of crops and management treatments. We may call this 'system optimization', noting, however, that given the large annual variation in rainfall and therefore in crop yields, several cycles of cropping may be needed to distinguish significant differences.

A secondary but closely related purpose of many of the trials is to monitor differences in various soil, soil-water and pest variables. Such information may serve to explain yield differences between production systems and point to ways in which crop sequences and management operations may be chosen to increase efficiencies in water and nutrient utilization and to control weed and pest populations. In this respect, long-term trials act as 'laboratories', in which particular problems or mechanisms may be studied in an ongoing field environment, for which the cropping and input/output history is well known.

All these activities - system optimization and 'laboratory' research - are directed essentially at the improvement of production practices. They will only incidently throw up information on issues determining long-term sustainability. For that, it is necessary to examine trends over time. These may be trends either in the quality of the resource base - specifically, is the productive potential of the soil increasing or decreasing? - or in the yields of the crops. For soil trends, the parameter most commonly used (for non-irrigated soils) is organic matter content. Unfortunately, for most of our early-established trials there are no initial baseline data, and trends can only be interpolated, from current treatment differences.

Long-term trends in crop yields are difficult to identify in annually variable rainfed environments. Whatever the fertilizer rate or tillage practice or antecedent crop might be, the strongest determinant of yield is rainfall; and large inter-annual fluctuations in weather result in large inter-annual fluctuations in production, which obscure any trend. To detect trends in such data, it is necessary to find biometric and statistical techniques that reduce the 'background noise' of seasonal variation.

Over the last year, a biometric procedure has been developed at ICARDA to quantify trends in data sequences from long-term trials (see 2.1). Although some refinements for increased precision are still needed, this procedure promises to identify differences in absolute and relative yield sustainability among different sequences of crops, inputs and crop management treatments, using relatively short data sets.

Applied to seven years of data from a trial continuously cropped to barley under different fertilizer regimes, the procedure indicated - somewhat surprisingly - a generally rising yield trend, greater, more reliable and more fertilizer-related for straw than for grain. This pattern, in fact, matches agronomic experience; cereal straw yields usually follow rainfall total and fertilizer rate quite strongly and tend to be less affected by random seasonal factors (eg late drought, pest attack) than are grain yields.

However, a seven-year sequence of data is very short. Longer sequences, by providing more degrees of freedom for the analysis across years, would permit a more sophisticated approach. The present procedure allows for annual variability simply as a quadratic function of total growth-season rainfall. With longer data sequences, it would be possible to include other parameters of the seasonal growth environment. Further, while the current approach estimates only a linear yield trend for the seven-year data set, over longer periods a curvilinear trend is biologically inevitable, and adjustments will have to be made to allow for this.

Other long-term trials at ICARDA have sequences of data from up to 15 years rotational cropping. Most have more complex data sets than that from the continuous barley trial, but this is not expected to give insuperable problems. Such analyses will get increasing emphasis over the next few years as the statistical procedure is made more versatile. Meantime, interest in system optimization and in understanding specific processes and mechanisms within systems is undiminished. Subsequent sections in this chapter report on particular aspects of these concerns.

Thus, in 2.2, we look again at the situation in barley rotations and the question of replacing fallow (or, more frequently, continuous barley) with productive, well-adapted forage legumes. Results presented here: (i) demonstrate the effect of legume harvest stage (green grazing or mature crop) on subsequent barley yields and overall rotation productivity; and (ii) compare the performance of narbon vetch with common vetch and common lathyrus (chickling) within rotations with barley.

The next two sections (2.3 and 2.4) look at wheat-based rotations and the effects on productivity of specific management interventions, tillage, sowing date and stubble burning. In the first, the monitoring of crop water use confirmed expected differences between wheat and lentil but also showed up interactions between crop water use and tillage system. Under conventional tillage, storage of unused water in the soil after each lentil crop increased the supply to the following wheat crop (in amounts varying with the volume and distribution of the lentil-season rainfall); but results obtained under zero tillage (direct drilling) suggest that this water-conserving effect of lentils is largely negated by such a practice. In addition, it has been noticed that the zero-tillage system increase the problems of weed and rodent control.

In the second of these trials, effects of burning the wheat stubble have tended to be small and slow to emerge. Nevertheless, over 7 years, burning increased the mean lentil yield by 13% over the unburnt control; and weed biomass was reduced in both wheat and lentil crops. These advantages have, however, to be weighed against the loss of potential livestock feed.

Production data from the large two-course wheat-based rotation trial at Tel Hadya have been summarized in several previous Annual Reports from FRMP. This year we report findings from two 'laboratory' type studies conducted within this trial, on treatment differences in soil structural properties (2.5) and on nematode populations in chickpeas (2.6) and medic pasture (2.7).

In contrast to chemical fertility, the physical condition of the soil is widely ignored. Yet, slow physical changes, particularly in such properties as soil structure, may come to have major effects on productivity. As a step in the right direction, topsoil samples from two wheat rotations were compared to provide information on treatment effects on soil aggregation (a parameter of soil structure, relating to the extent soil particles of sand, silt and clay cohere into stable crumbs). All the indices used gave essentially the same result: aggregate stability was generally greater in the wheat-medic than the wheat-fallow rotation. This is attributed to a better soil organic matter status, presumed to have arisen from the return to the soil of medic roots, leaves and the faeces and urine of the sheep grazing the medic. Somewhat surprisingly, aggregate stability was also improved relative to an ungrazed treatment by heavy grazing of the wheat stubble; and nitrogen fertilization of the wheat crop also had a positive effect on stability.

Nematodes also tend to be forgotten - until somebody goes to look for them; and then they are found nearly everywhere, and it becomes difficult to judge their importance. Different crop species have different susceptibilities, and different sequences of crops and crop management treatments may build up different degrees of infestation in the soil, with important carry-over effects from one crop to the next. Such effects may partly explain the yield difference of a particular crop grown in different rotations. The chief finding of the present study on chickpeas was that damage to economic yield was related to water availability, and this in turn had an important bearing on the success of the winter-sowing of this crop. In medic pastures, the degree of nematode infestation was shown to differ very greatly between the various Medicago species present. However, one of the three dominant species in the sward was also one of those more heavily infested by nematodes - with little apparent effect on its productivity.

2.1 Statistical Estimation of Time-trends in Continuous Cropping

2.1.1 Introduction

An assessment of time-trends of yields under various cropping systems practised at Rothamsted experimental station, U.K. has been addressed in Dyke (1988), Jenkinson *et al.* (1994), and of those used at Iowa Agricultural experimental station by Fuller and Cady (1965). One common feature of long-term trials from a statistical point of view is that the responses measured periodically over a period of time on the same plots are likely to be correlated. Such measurements might be annual, as in a monoculture system, eg continuous barley cropping, or biennial as in a two course rotation system, eg barley alternating with a legume or a fallow year, and so on. Methods of analysis for situations in which repeated observations on each experimental units are made have been discussed by Rowell and Walters (1976), Diggle (1988), Cullis and McGilchrist (1990), Schaalje *et al.* (1991). Björnsson (1978) analyses a series of long-term grassland experiments using autocorrelated errors over time.

In the 1986/87 season, two similar long-term barley trials were initiated at Tel Hadya and Breda, each involving two contrasting cropping systems: continuous annual barley (B-B rotation), and barley alternating with bare fallow (B-F rotation). The purpose was to test the hypothesis that yield decline under continuous barley cropping can be averted by appropriate fertilizer use. Within the B-B rotation, nine fertilizer treatments consisting of factorial combinations of 3 rates of nitrogen (0, 60, 120 kg N/ha) and 3 rates of phosphorus (0, 45, 90 kg P_2O_5/ha) were applied each year at the appropriate times. To maintain the B-F rotation, plots representing both halves of the rotation, barley and fallow, were on the ground each year, but only two fertilized treatments were employed ($N:P_2O_5$ = 0:0 and 120:90 kg/ha), the fertilizer being applied biennially to the barley crop. There were six replicates under complete randomization at each site.

This report presents a statistical technique to estimate time-trends for the above experimental situations, after accounting for the effect of rainfall, and the number of years required to detect a statistically significant time-trend. This approach is then illustrated using grain and straw yields from the Breda trial.

2.1.2 <u>Estimation of time-trends</u>

2.1.2.1 <u>Continuous cropping (B-B rotation)</u>

Let y_t (t=1, 2, ..., n) be the observations over n annual time points on the same plot under a given annual fertilizer treatment, and let R_t be the total rainfall during that season. Jenkinson *et al.* (1994) modelled the effects of sunshine hours and CO_2 concentration, in addition to rainfall, for estimating time-trends in herbage yields in a hay experiment conducted at Rothamsted Experimental Station (RES), UK. We shall, however, consider, modelling only the rainfall effect in the time-trend estimation. Scatter plots of yields and rainfall indicated variable patterns; in some plots the relationship was linear, in others it was quadratic. However, our computer program is able to select the better of the two models for time-trend estimation (better in the sense of higher percentage of variance accounted for). We shall present estimates when the plot errors are assumed (i) to be uncorrelated (this case is appropriate when the series is short and even a high autocorrelation value could be detected insignificant) and (ii) to follow first-order autocorrelation structure. The model presented here can be generalized to incorporate a general auto-regressive integrated moving-average structure, but we satisfy ourselves with the first order autocorrelated structure, since we have only seven years data, while the effects of 3 degrees of freedom due to a quadratic polynomial in rainfall and time-trend are to be estimated.

A. <u>When plot errors are assumed uncorrelated</u>

Considering the linear effect of the rainfall, the model for yield is

$$y_t = a + bR_t + ct + \epsilon_t \, (t = 1, 2, \ldots, n) \qquad \textbf{(1)}$$

where coefficient b is the response to rainfall, c is the time-trend and a is a constant (intercept). The errors ϵ_t assumed normally distributed with mean zero, variance σ_ϵ^2 and are independent (or uncorrelated). Our main interest lies in the estimation of parameter c, which measures a constant increase or decrease in response per year. Applying the ordinary least-square method (Rao 1973) on model (1), we get the following estimate $\hat{c}$

where $\bar{y}$, $\bar{R}$, $\bar{t}$, means of y s, R s and t s over n time points, are given by

$$\hat{c}=\frac{\sum_{t=1}^{n}(R_t-\bar{R})^2\sum_{t=1}^{n}(t-\bar{t})(y_t-\bar{y})-\sum_{t=1}^{n}(t-\bar{t})(R_t-\bar{R})\sum_{t=1}^{n}(R_t-\bar{R})(y_t-\bar{y})}{\sum_{t=1}^{n}(R_t-\bar{R})^2\sum_{t=1}^{n}(t-\bar{t})^2-(\sum_{t=1}^{n}(t-\bar{t})(R_t-\bar{R}))^2} \quad (2)$$

$$\bar{y}=\sum_{t=1}^{n}y_t/n,\quad \bar{R}=\sum_{t=1}^{n}R_t/n,\quad \bar{t}=\sum_{t=1}^{n}t/n=(n+1)/2,$$

respectively.

Variance of $\hat{c}$ is

$$var(\hat{c})=\sigma_\epsilon^2/(\sum_{t=1}^{n}(t-\bar{t})^2(1-\rho^2)) \quad (3)$$

where ρ = correlation between t and R_t .

An estimate of variance of $\hat{c}$ can be obtained by substituting residual mean square ($\hat{\sigma}_\epsilon^2$) for σ_ϵ^2 in (3).

Noting an alternative expression

$$\sum_{t=1}^{n}(t-\bar{t})^2=n(n^2-1)/12,$$

expression for var($\hat{c}$) simplifies to

$$var(\hat{c})=12\sigma_\epsilon^2/\{n(n^2-1)(1-\rho^2)\} \quad (4)$$

Model (1) can be generalized to contain more than one variable, such as R_t and R_t^2, or along with them other environmental variables such as sunshine hours and carbon dioxide concentration. Let there be p such variables with values

$X_{1t}, X_{2t}, \ldots, X_{pt}$ at time t .

The model for y_t would then be

$$y_t = a + b_1 X_{1t} + b_2 X_{2t} + \ldots + b_p X_{pt} + ct + \epsilon_t \quad (5)$$

$$t = 1, \ldots, n \;; \quad \epsilon_t \sim N(o, \sigma_\epsilon^2).$$

Ordinary least-square estimate of c can be obtained by using any of the general statistical packages. The expression for variance of $\hat{c}$ simplifies to

$$\mathrm{var}(\hat{c}) = \{ \underset{\sim}{t}' \underset{\sim}{t} - \underset{\sim}{t}' \underset{\sim}{x} (\underset{\sim}{x}' \underset{\sim}{x})^{-1} \underset{\sim}{x}' \underset{\sim}{t} \}^{-1} \sigma_\epsilon^2$$

$$= \sigma_\epsilon^2 / \left(\sum_{t=1}^{n} (t - \bar{t})^2 (1 - \rho_m^2) \right) \quad (6)$$

where $\underset{\sim}{t} = (1-\bar{t}, 2-\bar{t}, \ldots, n-\bar{t})'_{n\times 1}$, $\bar{t} = (n+1)/2$

$$\underset{\sim}{x} = (x_{it})_{p\times n} \quad x_{it} = X_{it} - \bar{X}_{i.}$$

$$\bar{X}_i = \sum_{t=1}^{n} X_{it} / n$$

ρ_m^2 is coefficient of determination of t in terms of linear regression on $X_1, \ldots, X_p$. The expressions $\underset{\sim}{t}'$, $\underset{\sim}{x}'$ are the transposes of column vector $\underset{\sim}{t}$ and matrix $\underset{\sim}{x}$ respectively. Using the expression for $\sum_{t=1}^{n} (t - \bar{t})^2$ in terms of n,

$$\mathrm{var}(\hat{c}) = 12\sigma_\epsilon^2 / (n(n^2-1)(1-\rho_m^2)) \quad (7)$$

B. <u>When plot errors are assumed to follow first-order autocorrelation</u>

Linear model (1) with autocorrelated errors can be modelled as
where ϵ_t follows first-order autocorrelation process:

$$y_t = a + bR_t + ct + \epsilon_t \qquad \textbf{(8)}$$

$$\epsilon_t = \phi \; \epsilon_{t-1} + \eta_t$$

where η_t is an independent innovation having normal distribution with mean zero and variance σ^2_η. Note that variance of ϵ_t can also be expressed as (see Johnson 1972).

$$\text{var}(\epsilon_t) = \sigma^2_\epsilon = \sigma^2_\eta \; / \; (1-\phi^2).$$

Estimates of the parameters in (8) can be obtained using the ESTIMATE directive of GENSTAT 5 after setting TSM and using regressors R_t and t. In order to express variance of $\hat{c}$, we can transform (8) as

$$y_t - \phi y_{t-1} = a(1-\phi) + b(R_t - \phi R_{t-1}) + c(t - \phi(t-1)) + \eta_t$$

or,

$$y^*_t = a^* + bR^*_t + ct^* + \eta_t \qquad \textbf{(9)}$$

where transformed variables

$$y^*_t = y_t - \phi y_{t-1} \; , \quad R^*_t = R_t - \phi R_{t-1}$$

$$t^* = t - \phi(t-1) = t(1-\phi) + \phi$$

and $\quad a^* = a(1-\phi)$ for $t = 2, 3, \ldots, n$.

Model (9) appears like model (1), if ϕ is known. In this case using (3) the variance of $\hat{c}$ would be

$$var(\hat{c}) = \sigma^2_\eta / \left(\sum_{t=2}^{n} (t^* - \bar{t}^*)^2 (1-\rho^{*2})\right)$$

where ρ^* is correlation between t^* and R^*_t. With some algebraic simplification, we can show

$$(i) \qquad \sum_{t=2}^{n} (t^{*}-\bar{t}^{*})^2=(1-\phi)^2 \sum_{t=2}^{n} (t-\bar{t})^2$$

$$=n(n-1)(n-2)(1-\phi)^2/12$$

since, $\bar{t} = (n+2)/2$.

$$(ii) \qquad \rho^{*2}=(\rho-\phi\rho_1)/(1+\phi^2-2\phi\ \phi_R)^{1/2}$$

where ρ_1 is correlation between t and R_{t-1}, the rainfall in the preceding year and ϕ_R is correlation between R_t and R_{t-1}.

[Proof: $cov(t^*, R_t^*) = cov\ ((1-\phi)t+\phi\ ,\ R_t - \phi R_{t-1}\ )$
$= (1-\phi)\ cov\ (t,R_t - \phi R_{t-1})$
$= (1-\phi)\ (cov\ (t,R_t) - \phi\ cov\ (t,R_{t-1}))$
$= (1-\phi)(\rho\ \sigma_t\ \sigma_{R_t} - \phi\ \rho\ \sigma_t\ \sigma_{R_t})$
$= (1-\phi)(\rho - \phi\ \rho_1)\ \sigma_t\ \sigma_{R_t}$

where σ_t and σ_{R_t} are standard deviation of t and R_t. The variance of R_t and R_{t-1} could be assumed approximately equal in a reasonably moderately long series. ρ_1 is correlation between t and R_{t-1}.

$var(t^*) = (1-\phi)^2\ \sigma_t^2$
$var(R_t^*) = var(R_t - \phi\ R_{t-1}) = (1 + \phi^2 - 2\phi\ \phi_R)\ \sigma_{Rt}^2$
where ϕ_R is correlation between R_t and R_{t-1}. Hence the proof.]
Thus,

$$var(\hat{c})=12\phi_\eta^2/(n(n-1)(n-2)(1-\phi)^2(1-\rho^{*2})) \qquad \textbf{(10)}$$

A generalization of model (8) to include several variables, made similar to (5), would be

$$y_t = a + b_1 X_{1t} + b_2 X_{2t} + \ldots + b_{pX_{pt}} + ct + \epsilon_t$$

where,

$$\epsilon_t = \phi \epsilon_{t-1} = \eta_t ; \eta_t \sim N(o, \sigma_\eta^2) \qquad \textbf{(11)}$$

Using a transformation similar to (9) with first order differences, we can write (11) as

$$y_t^* = a^* + \sum_{i=1}^{p} b_i X_{it}^* + ct^* + \eta_t$$

where

$$y_t^* = y_t - \phi y_{t-1}, \quad X_{it}^* = X_{it} - \phi X_{it-1}$$

$$t = 2, 3, \ldots, n.$$

Following the estimation approach as for model (5) we can write variance of estimate $\hat{c}$ of c as

$$var(\hat{c}) = 12\sigma_\eta^2 / \{n(n-1)(n-2)(1-\phi)^2(1-\rho_m^{*2})\}$$

where ρ_m^{*2} is the coefficient of determination of t^* in terms of linear regression on X_{1t}^*, X_{2t}^*, ..., X_{pt}^*.

The variances of $\hat{c}$ can be estimated by substituting estimates of σ_η^2, ϕ and ρ_m^{*2} .

2.1.2.2 <u>Barley/fallow system (B-F rotation)</u>

Each replicate of each treatment in the B-F rotation comprises two plots, with each year one under barley, the other plot under fallow:

	Year			
	1	2	3	4 . . . n
Plot 1	B	F	B	F . . . .
Plot 2	F	B	F	B . . . .
Yield	y_1	y_2	y_3	y_4 . . . .

B = barley   F = fallow

It may be noted that y_1, y_2, y_3 ... arise over time but from two plots. Thus y_1, y_3, y_5 ... may be autocorrelated and y_2, y_4, y_6 ... may be autocorrelated while the sequence (y_1, y_3, y_5, ...) is independent of (y_2, y_4, ...). If the series is short, as in our case of n=7 years, we get only 4 measurements on one plot and 3 on the other. Considering that the response is to be modelled in terms of linear and quadratic polynomial of rainfall beside the time variable, it would be appropriate to consider y_1, y_2, y_3 ... y_n to be uncorrelated. However we must recognize the different effect or levels of the two plots. Thus, the y_t would be modelled, in case of say linear in rainfall, as

$$y_t = a_i + bR_t + ct + \epsilon_t$$

where i = 1 for t=1, 3, 5,... and i = 2 for t=2, 4, 6,... Its generalization to more than one regressor is straightforward. The parameters can be estimated in similar fashion to those of models (1) and (5).

2.1.3 Estimation of time required for detecting a significant time-trend

We shall consider only the cases with multiple regressors. (The case of single regressor such as linear in rainfall R_t would be its special case).

2.1.3.1 Plot errors assumed to be uncorrelated

Recalling the expression (7) for variance of $\hat{c}$, and substituting for the estimates of σ_ϵ^2 and ρ_m^2, say $\hat{\sigma}_\epsilon^2$ and $\hat{\rho}_m^2$ respectively, an approximate test of significance of c is given below.

c is significantly different from zero at 100α% level of significance if

$$|\hat{c}/(est\ var(\hat{c}))^{1/2}| > t_{\upsilon\ \alpha/2} \qquad (12)$$

where υ is degrees of freedom (df) for estimating σ_ϵ^2.

Inequality (12) in terms of estimates yields

$$\hat{c}^2 n(n^2-1)(1-\hat{\rho}_m^2)/(12\hat{\sigma}_\epsilon^2) > t^2_{v,\alpha/2}$$

or,

$$n(n^2-1) \geq 12\hat{\sigma}_\epsilon^2 t^2_{v,\alpha/2}/(\hat{c}(1-\hat{p}_m^2)) \qquad \textbf{(13)}$$

$= q_1$, say.

Equation (13) can be solved iteratively for n, the number of years (or time) required to detect a significant c. An approximate solution of (13) would be obtained by considering $n(n^2-1) \approx n^3$ (at an error of $100/n^2$% ie error is less than 1% for n>10) which gives

$$n_o = q_1^{1/3} \qquad \textbf{(14)}$$

as a solution for n. However, an exact solution of (13) can be obtained by using Newton-Raphson iteration considering n_0 as the initial value of n. The n at i-th iteration is

$$n_{(i)} = n_{(i-1)} - (n_{(i-1)}(n^2_{(i-1)} - 1) - q_1)/(3n^2_{(i-1)} - 1)$$

where i=1, 2, ..., $n_{(0)} = n_0$. The iteration process is stopped as soon as desired convergence in successive values of n is achieved.

2.1.3.2 Plot errors assumed to follow first-order autocorrelation

Considering expression (10) for variance of $\hat{c}$ and the approach in (3.1), c would be detected significant at 100α% level of significance, if

$$|\hat{c}/(est\ var(\hat{c}))^{1/2}| > t_{v',\alpha/2} \qquad \textbf{(15)}$$

where υ' is df in estimating σ^2_η.
Inequality (15) can be written in terms of n as

$$n(n-1)(n-2) \geq 12 t_{\upsilon',\alpha/2} \hat{\sigma}^2_\eta / (\hat{c}^2(1-\hat{\phi})^2(1-\hat{\rho}^{*2}_m)) \quad \textbf{(16)}$$

$= q_2$, say

An approximate explicit solution of (16) is

$$n = n_0 = q_2^{1/3}$$

using n^3 as an approximation for n(n-1)(n-2). Error in such approximation is $(n-1)(n-2)/n^2-1$ or equivalently $100(-3/n + 2/n^2)$%. However, an exact solution of (16) is obtainable from Newton-Raphson iterative method, where one can start with n_0 as an initial value of n, and computes n at i-th iteration, using

$$n_{(i)} = n_{(i-1)} - \frac{n_{(i-1)}(n_{(i-1)}-1)(n_{(i-2)}-2)-q_2}{3n^2_{(i-1)}-6n_{(i-1)}+2}$$

where i = 1, 2, ... $n_{(0)} = n_0$ until the convergence in values of n is attained.

It may be noted that the number of years required to detect a significant c is inversely proportional to the square of c, ie the smaller the true time-trend, the more time required to detect it. Also, n increases with σ^2_η or σ^2_ϵ, indicating that if the variability unexplained by models (1) or (5) is high, the time taken would be longer. Further, the autocorrelation ϕ and coefficient of determination or multiple correlation (ρ_m or ρ^*_m) also affect the time required to detect a significant c.

2.1.4 An application of the methodology

It is anticipated that the statistical methodology outlined above could be used to appraise time-trends in most, if not all, of ICARDA's long-term trials. Several of these trials now have continuous data sets from ten years cropping or longer. Our present purpose, however, is simply to demonstrate the potential of the methodology, utilizing just seven years grain and straw yield data (1986-1993) from the Breda long-term barley trial. As noted earlier, this trial comprises nine treatment combinations of N (0, 60, 120 kg N/ha) and P (0, 45, 90 Kg P_2O_5/ha) in B-B and two in B-F plots (N : P_2O_5 = 0:0 kg/ha and 120 : 90 kg/ha), each replicated six times.

The estimates of time-trends (c) and of the number of years (n) required to detect a significant time-trend are presented for each B-B and B-F treatment (in Tables 2.1.1, 2.1.2 and 2.1.3). Two approaches were compared.

Approach 1: The models were fitted to the yield means of each fertility treatment, thereby eliminating any individual plot effects and assuming plot errors to be uncorrelated from one year to the next. Two alternatives of each model were worked out, one assuming a linear relationship of yield with rainfall (Model 1), the other assuming a quadratic relationship (Model 2).

Approach 2: Models were fitted on individual plot values, assuming that plot errors follow a first-order autocorrelation structure over years; but in this case only estimates from the optimum model, whether linear or quadratic in rainfall, are presented. In order to evaluate the effects of fertilizer on time-trends and the number of years to detect significance, we partitioned the variation on 8 df arising from the 9 N-P fertilizer combinations in the B-B rotation into that due to nitrogen (N) on 2 df, phosphorus (P) on 2 df and their interaction (NxP) on 4 df (Table 2.1.4). The due partitioning was done using weighted regression of these estimates (with weights equal to the inverse of the square of their standard errors) for Approach 1 while unweighted ANOVA was employed under Approach 2.

Estimates of c-values and n-values obtained from Approach 1 and Approach 2 are given in Tables 2.1.1, 2.1.2 and 2.1.3. We may note that within Approach 1, model 2 (quadratic) tended to give c-values of greater (positive) magnitude and with a greater frequency of statistical

Table 2.1.1. Estimates of time-trends (c-values; kg/ha/yr) in the fertility treatments in B-B rotations at Breda, based on regressions of yield on time, linear (Model 1) or quadratic in rainfall (Model 2), with plot errors assumed independent (Approach 1)

	P:	Grain 0	Grain 45	Grain 90	Grain Mean	Straw 0	Straw 45	Straw 90	Straw Mean
	N								
Model 1	0	-35	22	-1	-5	48	79	72	66
	60	19	-18	27	9	79	**142**	**247**	156
	120	41	-0	-2	13	107	**144**	**195**	149
	Mean	8	1	8	6	78	122	171	124
Model 2	0	9	20	0	10	100	85	82	89
	60	**92**	32	86	70	**167**	**214**	**304**	228
	120	**110**	30	43	61	**191**	**207**	**308**	235
	Mean	73	27	43	47	153	169	231	184

Bold-faced figures indicate statistically significant (ie different from zero) at 1% level and underlined figures at 5%. Significance of means not worked out.

Table 2.1.2. Estimates of the number of years (n) to detect significant time trends in the fertility treatments in B-B rotations at Breda

	P:	Grain 0	Grain 45	Grain 90	Grain Mean(log)		Straw 0	Straw 45	Straw 90	Straw Mean
	N									
Model 1	0	18	22	153	39		17	11	12	13
	60	31	29	24	28		14	9	6	9
	120	18	440	135	103		12	9	9	10
	Mean(log)	22	65	79	48	Mean	14	10	9	11
Model 2	0	44	25	880	99		11	11	12	11
	60	10	20	11	13		8	7	6	7
	120	9	23	18	15		8	8	7	7
	Mean(log)	16	22	56	27	Mean	9	8	8	8

Mean(log) values are back transformations of means of log-transformed values. The n-values for straw were nearly homogeneous, so no transformations were necessary.

Table 2.1.3. Estimates of time-trends (c-values) and number of years (n-values) to detect a significant time-trend in the fertility treatments in B-B rotation at Breda, based on regressions of yield on time, linear or quadratic in rainfall for each individual plot assuming first-order autocorrelation in plot-errors (Approach 2)

	Time-trend (kg/ha/year)							
	Grain				Straw			
N\P	0	45	90	Mean	0	45	90	Mean
0	**22**	49	**28**	33	**105**	**98**	90	**97**
60	**94**	58	**87**	**80**	**166**	**189**	**294**	**216**
120	**108**	26	38	**57**	**187**	**219**	**293**	**233**
SE		±37.7		±21.8		±37.5		±21.7
Mean	**75**	**44**	**51**	**57**	**153**	**168**	**225**	**182**
SE		±21.8				±21.7		
	Number of years (n-values)[+]							
0	17	11	12	13	20	10	10	12
60	13	19	25	18	21	15	10	15
120	13	36	40	26	14	12	11	12
Mean	14	20	23	18	18	12	10	13

Boldfaced figures indicate statistical significance at 5% level.
Plot-wise data on n-value were analyzed using log-transformation. The means and their SEs under log-transformation were obtained but not presented here.
[+] Back transformations on means of log-transformed values.

Table 2.1.4. Probabilities of null effects for comparing fertilizers on time-trends (c) and number of years (n) required to detect significant time-trends

		Approach 1				Approach 2			
		c-values				c-values		n-values	
		Model 1		Model 2					
	df	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
+ N	2	0.837	0.080	0.132	0.021	0.326	<.001	0.023	0.521
+ P	2	0.980	0.165	0.401	0.260	0.592	0.054	0.115	0.017
+ NxP	4	0.467	0.496	0.553	0.437	0.647	0.342	0.088	0.706

significance than model 1 (linear), and corresponding n-values tended to be lower. At the same time, Approach 2 produced c-values very similar in magnitude to those obtained from model 2 in Approach 1 but with a greater frequency of statistical significance. Thus working simply from treatment means, and ignoring the possibility of autocorrelation at the plot level, did not greatly affect the numerical values of trends identified; however, as might be expected, utilizing the larger data set provided by the individual plot values improved statistical sensitivity. Perhaps for the same reason, n-values from Approach 2 were less erratic than those from Approach 1; but, curiously, in respect of the straw data they were rather greater in the magnitude.

Generally, across both approaches, c-values for barley straw tended to be larger and more frequently statistically significant than those for grain. Moreover, as Table 4 confirms, the positive responses of the straw c-values to the use of increasing rates of P-fertilizer and to the first increment of N-fertilizer (60 kg N/ha) were also statistically significant. For grain, c-values showed some increase from the first increament of N-fertilizer, but this was not statistically significant.

Altogether, these findings imply that, over seven years, continuous barley showed a generally rising yield trend, which was, however, greater and more reliable for straw than for grain. In the case of straw only, that rising trend was significantly enhanced by the annual application of N and P fertilizers.

This greater clarity in the pattern of the straw values matches agronomic experience of cereal crops; straw yields follow rainfall and fertilizer rate quite strongly and tend to be less affected by ill-defined seasonal factors than are grain yields. So, in seeking time-trends in cereal production, we may expect straw to provide the earlier indicator. Further, since harvest index is a strongly conservative attribute in any particular cereal variety (notwithstanding large annual variations), we may reasonably expect the trend identified for the straw to be followed ultimately by the grain.

2.1.5 Discussion

The purpose of the present paper was to explore an approach for the identification of yield time-trends, not to present a definitive methodology or definitive agronomic conclusions. Those will come later. For the moment it is evident that information on time-trends can be elicited even from a rather brief and unpromising data set; and we may reasonably expect to obtain clearer, more significant information when and where time series of greater length are available. However, a number of points have arisen during the present exploration that bear on the development and application of the methodology and merit mention here.

Autocorrelations: Approach 2 models the data allowing autocorrelations to be plot specific, but in a series of only seven years their estimation is very imprecise as only 2 df are available for residuals. In a short series, one might satisfy even with a common autocorrelation by obtaining a pooled estimate of autocorrelation from all plots or at least one under each fertilizer treatment.

Robust estimates of number of years to detect significant time-trends: The relatively larger mean values of n under Approach 2 most probably arise from the huge variation in individual plot values, contributed by one or two values (or possibly outliers) within each fertility treatment. A proper treatment of such values, such as robust methods for estimation of means in the presence of outliers, is expected to provide the results comparable to those found with Approach 1.

Choice of the experimental and sampling designs: Precise estimation of time-trends requires very good control of experimental errors through the implementation of a suitable field design. This generally involves the choice of an effective blocking system leading to homogeneous plots within each block. The design of the present experiment was not ideal for the analysis attempted here. It was initially intended to accommodate six combinations of two additional factors (such as weed and disease control measures), but they were never implemented. The resulting layout became a completely randomized design with six replications. It would have been of advantage to present purposes if an appropriate blocking technique had been used to control the experimental errors. However, relative success here despite that limitation demonstrates the robust potential of the method. In general, the application of experimental treatments and crop-husbandry practices, and the sampling and measurement of responses should be consistent across years to reflect cumulative effects or time-trends only, and the effect of any interrupting factor added at a point of time should be taken into account. Any long-term effect of such a factor could be explored by an application of intervention analysis.

Allowing for annual variability: Total seasonal rainfall has been used as a single value to represent the source of annual yield variability, but how sound is it as a measure of the biological potential of the year (or the environment)? Although the linear and quadratic components of rainfall account for a large portion of the total variability in yields over years, there are obviously other environmental parameters such as temperature, humidity, sunshine hours that would also contribute. Data are often available for such parameters but are difficult to utilize. There are two difficulties, at least. Unlike total rainfall, there is no obvious way to summarize the information for the other parameters in single values; and some of the parameters are meaningless except in the context of the others - such as plentiful sunshine hours are useless if rainfall is low. Secondly, each parameter, even if encapsulated in one value, requires an extra degree of freedom. This makes it essential to identify just those one or two most influential additional variables for inclusion in the model. Alternatively, one may seek a non-physical parameter that summarizes, again in a single value, as many as possible of the features of the growth environment influencing crop performance. An obvious example here is date of planting.

Variables such as rainfall and temperature may describe the environment physically but even a reasonably complex function of them may not provide an adequate biological measure of the environment experienced by the crop. An alternative used in crop improvement programs is to evaluate genotype x environment (GxE) interaction by examining the behavior of genotypic response over environments (site-year combinations). Mean yield of all genotypes in a particular environment is assumed to integrate all the components of that environment and hence is considered as a reasonable biological measure for it, provided the set of genotypes is reasonably representative of the crop species (Yates and Cochran 1936, Finlay and Wilkinson 1963, Eberhart and Russell 1966). The same approach would be worth exploring in long-term trials, in this case using the mean across treatments as an index of the growth environment. Thus, in the present trial, the mean of nine fertilizer regimes (or perhaps, better, the mean of routine production fields at the station) could be used to provide a meaningful estimate of the biological effect of the year.

Other components of time-trend. In both of the above approaches, we have considered the time-trend arising only from the linear component of time, besides the other non-time variables. It is quite possible that in a relatively longer series the cumulative time-trend might be more adequately expressed as a quadratic function of time. The model (1) could then be written as

$$y_t = a + b R_t + c t + d t^2 + \epsilon_t \quad (t = 1, 2, \ldots, n)$$

The estimation procedure would be straightforward, although error df would be further reduced, and the case of autocorrelated errors could also be modelled.

2.1.6 Conclusion

An exploration of approaches to the identification of time-trends in the yield data from a long-term barley trial has demonstrated that such trends can apparently be detected even in a sub-optimal data set of seven years duration when due allowance is made for annual variation due to rainfall. It is anticipated that it will be possible to analyse time series of yield data from most other time series in a similar way and that agronomic interpretation of such analyses will give useful insight into the production sustainability of different cropping systems. *[Murari Singh, CBSU, and Mike Jones, with acknowledgements to Mr. Nerses Chapanian and Mr. Fadel Rida for their technical input in data management*

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2.2 Effect of Type and Harvest Time of Forage Legumes on Yields in Barley-Forage Legume Rotations

2.2.1 Introduction

The need for greater crop diversification in the drier barley-growing areas has long been recognized. Initially, the aim was to replace fallow in what were predominantly barley-fallow sequences; but, over time, as farmers' systems have intensified, this aim has evolved into a search for acceptable crops to break what has become in many places an almost continuous annual barley sequence. Work has concentrated largely on forage legumes, with the rationale that legumes, and particularly forage legumes, will contribute feed and nitrogen into what remain relatively low-input systems in which animal production is the major enterprise.

Common vetch (*Vicia sativa*), lathyrus (*Lathyrus sativus*) and narbon vetch (*Vicia narbonensis*) are all species indigenous to this dry winter-rainfall zone, and the first two, at least, were utilized in the past to provide forage for draught animals. Now, most farmers' priority is to produce as much barley as possible, for sale and feed, and the inclusion of legumes appears to be viewed as unnecessary and detrimental to this purpose. One research issue, of many, is which legume is potentially the most attractive to farmers; another is how best might that legume be utilized - as green grazing, as hay, as seed and straw? - within ongoing barley-livestock production systems, to maximize benefits and minimize any loss of barley production.

This report summarizes findings from two related investigations: (i) a series of simple two-year trials, examining the effect of mode, or time, of vetch harvest on subsequent barley performance; and (ii) two ongoing long-term trials that compare three types of rotation, barley-forage legume, barley-fallow and barley-barley.

2.2.2 Vetch utilization trials

In each trial, three methods of harvesting - simulated green grazing (GG), hay cutting (H) at early pod-formation stage, and removal at maturity (M) - were imposed on a uniform field of unfertilized common vetch (*Vicia sativa*) as a simple randomized plot design in six replicates; and the resulting effects were measured in the yields of barley grown in the following season. A total of eight such two-year trials were grown over eight seasons, 1986-1994, (one trial at Ghrerife, seven at Breda).

Highest yields of barley grain were in all cases obtained after green-grazed vetch, and in four trials out of eight differences between harvest-time treatments were significant (Table 2.2.1). Grain yields following the hay treatment tended to be greater than or similar to those following mature harvest. Means over eight trials for grain, straw and other harvest parameters in Table 2.2.2 show a consistent trend: GG > H > M. Mean grain yields for GG and H treatments exceeded those from the M treatment by 39 % and 17 %, respectively; and corresponding figures for straw were 26 % and 10%.

Table 2.2.1. Yield of barley grain (t/ha) following different modes/times of harvest of a preceding crop of *Vicia sativa*

Trial	Years	Rainfall, mm Yr 1	Yr 2	Vetch harvest mode Graze	Hay	Mature	Level of signif.	SE/ mean
1. Breda	86-88	245	399	1.55	1.43	1.26	ns	0.074
2. Breda	87-89	399	180	1.29	1.15	0.53	***	0.048
3. Gh'rfe	87-89	431	201	0.92	0.49	0.19	**	0.096
4. Breda	88-90	180	177	0.92	0.82	0.83	*	0.027
5. Breda	89-91	177	209	0.90	0.78	0.81	ns	0.036
6. Breda	90-92	209	231	0.68	0.65	0.52	ns	0.070
7. Breda	91-93	231	251	2.07	1.66	1.70	**	0.067
8. Breda	92-94	251	292	1.03	0.90	0.89	ns	0.112

a) Each yield value is the mean of six plots, unfertilized except in 1989-91 and 1990-92, when three plots were unfertilized and three received 60 kg P2O5/ha in the seedbed.
b) Rainfall total, October to April inclusive.

Table 2.2.2. Eight-trial means of harvest parameters of barley following different modes/times of harvest of a preceding crop of *Vicia sativa*

	Vetch harvest mode Graze	May	Mature
Grain, t/ha	1.17	0.99	0.84
Straw, t/ha	1.86	1.62	1.47
Total dry matter, t/ha	3.03	2.61	2.32
Harvest index	38.7	37.8	36.3
1000-grain weight, g	32.8	31.9	31.2

The initial hypothesis behind these trials was that different harvest times of vetch would leave different amounts of water stored in the soil profile and thereby influence the productivity of the succeeding crop. However, appreciable treatment differences in barley yields (significant for the straw component) were recorded in Trial 1, even though the barley growing season was most unusually wet; and it was suggested that vetch cutting times might also influence nitrogen availability to the barley crop (Jones 1989).

Unfortunately, it was not possible to monitor barley water use in subsequent trials. However, greatest treatment differences were observed in Trials 2 and 3 (both 1987-89), when a very dry barley-growing season followed a very wet vetch season - which is strongly suggestive of an appreciable stored-water effect. Subsequently, least barley-yield differences between treatments occurred in trials (nos. 4, 5 and 6) in which both growing seasons were very dry (Table 2.2.1).

2.2.3 Barley-forage legume rotation trials at Tel Hadya and Breda

2.2.3.1 Introduction

The so-called 'new' rotation trials at Tel Hadya and Breda were initiated in the 1982/83 season. Each trial comprises three replicates of both phases of an incomplete factorial combination of six two-year rotations of barley with fallow, with barley, or with a legume forage. Results up to the end of the 1988/89 were summarized in a recent publication (Jones and Singh 1995); a number of treatment modifications were detailed in Jones (1992); and more results were presented in Jones (1993). The data summarized in the present report derive from:

- three years, 1991-94
- five rotations
    - A. Barley-lathyrus (*Lathyrus sativus*)
    - B. Barley-narbon vetch (*Vicia narbonensis*)
    - C. Barley-common vetch (*Vicia sativa*)
    - D. Barley-common vetch (*Vicia sativa*)
    - E. Barley-fallow

- two fertilizer regimes

  III. 20N and $60P_2O_5$ to the barley phase only

  VI. Zero fertilizer control.

In rotations A, B and C, the forage legume is harvested at maturity for grain and straw. In rotation D, the vetch is cut to simulate 'zero grazing' at the pre-flowering green stage. There is no regrowth. (The full scheme of treatments can be seen in Table 3.5.1 in Jones 1992).

The data are presented below in three sections:

- to examine the effect of mode of vetch harvest on subsequent barley productivity and total rotational output (rotations C & D);
- to compare rotation B, with narbon vetch (first introduced in the 1990/91 season), with rotations A and C (lathyrus and common vetch, grown since 1982/83) and rotation E (fallow), again in respect of barley productivity and total rotational output;
- to compare rotations C, D and E in respect of water use by the barley crop, at Breda only.

Barley yield data for all five rotations in each of the three years under study are presented in Table 2.2.3. These data form the basis of barley yield summaries in subsequent sections.

2.2.3.2 Effect of mode of vetch harvest

Barley yields: Yields of grain and straw were 10-15% higher when barley was grown after vetch harvested as green grazing rather than grown to maturity (Table 2.2.4). At Tel Hadya, but not appreciably at Breda, total N content of the barley was enhanced more than the dry-matter increase by the preceding green grazing, implying perhaps that the immature harvest of the legume left more nitrogen to the succeeding crop.

Legume dry matter yield was approximately halved by harvesting at the green stage, but the reduction in total nitrogen offtake was smaller, 34% at Tel Hadya, 28% at Breda (Table 2.2.5). This is because the N content (%) of the harvested material is generally higher at the green stage: 2.83 v. 2.19 at Tel Hadya, and 3.06 v. 2.17 at Breda.

Table 2.2.3. Effect of preceding crop on barley yields in barley-forage legume rotation, Tel Hadya and Breda, 1991-94

Preceding crop	Tel Hadya				Breda			
	91/2	92/3	93/4	Mean	91/2	92/3	93/4	Mean
Rain, mm	*326*	*240*	*358*		*231*	*251*	*292*	
				Grain, t/ha				
	*	ns	ns		ns	***	***	
Lathyrus	2.46	2.81	1.74	2.34	1.05	1.16	1.43	1.21
Vetch	2.49	2.56	1.98	2.34	1.08	1.11	1.46	1.22
Narbon V	2.40	2.35	1.86	2.20	1.14	0.98	1.42	1.18
Green V	3.11	2.81	2.02	2.65	1.22	1.34	1.68	1.41
Fallow	3.04	3.36	1.97	2.79	1.28	1.71	1.72	1.57
SE ±	0.191	0.189	0.133		0.065	0.057	0.041	
				Straw, t/ha				
	*	ns	ns		ns	ns	**	
Lathyrus	3.09	3.79	3.21	3.36	2.34	3.64	2.69	2.89
Vetch	3.08	3.70	3.28	3.35	2.30	3.55	2.74	2.86
Narbon V	2.83	3.18	3.22	3.08	2.36	3.43	2.83	2.87
Green V	3.76	3.83	3.67	3.75	2.47	3.86	3.10	3.14
Fallow	3.74	4.12	3.20	3.69	2.36	3.83	2.93	3.04
SE ±	0.183	0.243	0.197		0.047	0.104	0.049	
				TDM, t/ha				
	*	ns	ns		ns	**	***	
Lathyrus	5.55	6.60	4.95	5.70	3.39	4.80	4.11	4.10
Vetch	5.56	6.26	5.25	5.69	3.38	4.66	4.20	4.08
Narbon V	5.23	5.53	5.07	5.28	3.50	4.41	4.25	4.05
Green V	6.87	6.64	5.69	6.40	3.69	5.19	4.77	4.55
Fallow	6.78	7.47	5.17	6.47	3.64	5.54	4.65	4.61
SE ±	0.321	0.424	0.316		0.086	0.139	0.082	
				Total N, kg/ha				
	***	ns	ns	ns	*	ns		
Lathyrus	57.3	82.2	46.4	62.0	42.7	53.2	45.9	47.3
Vetch	54.7	78.7	49.3	60.9	40.2	52.7	47.3	46.7
Narbon V	51.0	63.1	46.0	53.4	41.6	46.0	51.1	46.2
Green V	79.5	89.2	56.6	75.1	46.8	56.3	56.8	53.3
Fallow	61.1	88.1	41.7	63.6	45.8	58.2	53.5	52.5
SE ±	3.08	5.31	4.34		2.22	1.97	2.39	

Values are means across two fertilizer regimes, with and without NP applied to the barley phase.

Legumes are: lathyrus, *Lathyrus sativus*; vetch, *Vicia sativa*; narbon vetch, *Vicia narbonensis*; green vetch, *Vicia sativa*, harvested by simulated zero grazing at the green stage.

Rain amounts indicated are totals for October-April, inclusive.

Table 2.2.4. Effect of vetch harvest mode on harvest parameters of subsequent barley crop, three-year means, Tel Hadya and Breda, 1991-94

	Vetch harvest	Mean yields, t/ha Grain	Straw	TDM	Total N, kg/ha
Tel Hadya	Mature	2.34	3.35	5.69	60.9
	Green	2.65	3.75	6.40	75.1
	Difference	0.31	0.40	0.71	14.2
	%	13.2	11.9	12.5	23.3
Breda	Mature	1.22	2.86	4.08	46.7
	Green	1.41	3.14	4.55	53.3
	Difference	0.19	0.28	0.47	6.6
	%	15.6	9.8	11.5	14.1

Values are means across 2 fertilizer regimes, with and without NP applied to the barley phase.

Table 2.2.5. Effect of harvest mode on vetch harvest parameters, three-year means, Tel Hadya and Breda, 1991-94

Harvest mode	Tel Hadya TDM t/ha	Tel Hadya Total N kg/ha	Breda TDM t/ha	Breda Total N kg/ha
Mature	2.20	48.2	2.19	47.6
Green	1.12	31.7	1.12	34.3
Difference	1.08	16.5	1.07	13.3

Values are means across 2 fertilizer regimes, with and without NP applied to the barley phase.

Rotational productivity: Total two-crop rotational output (on a 50:50 area basis) was, on five occasions out of six, lower in the green-harvest rotation, but the margin overall was not large, as the three-year means in Table 2.2.6 show: 4.8% at Tel Hadya and 9.6% at Breda. Corresponding values for total rotational output of nitrogen were 2.2% and 7.2%, respectively. Particularly under Tel Hadya conditions, total production of biomass and protein is only marginally reduced if the vetch in a vetch-barley rotation is grazed green instead of being allowed to grow to maturity.

Table 2.2.6. Effect of harvest mode of vetch on total output of TDM and N in a vetch-barley rotation, three-year means, Tel Hadya and Breda, 1991-94

	Tel Hadya		Breda	
	Mature	Green	Mature	Green
TDM, t/ha	3.95	3.76	3.14	2.84
% from barley	72.1	85.1	65.1	80.2
% from legume	27.9	14.9	34.9	19.8
Total N, kg/ha	54.6	53.4	47.2	43.8
% from barley	55.8	70.3	49.5	60.8
% from legume	44.2	29.7	50.5	39.2

Values are means across 2 fertilizer regimes, with and without NP applied to the barley phase.

2.2.3.3 Relative value of narbon vetch

Barley yields: As can be seen in Table 2.2.3, yields of barley following mature-harvested lathyrus (*Lathyrus sativus*, LS) and common vetch (*Vicia sativa*, VS) were closely similar in all three years at both sites, in respect of grain, straw, total dry matter and total N content. Values for barley following narbon vetch (*Vicia narbonensis*, VN) were nearly always lower (though rarely significantly) at Tel Hadya. In some contrast, at Breda, yields were broadly comparable with those from LS and VS rotations, even non-significantly higher, except in 1992/93.

Barley in all three of these rotations tended to be slightly less productive than barley grown in rotation with fallow. Nevertheless, as Table 2.2.7 shows, the three-year mean loss in barley production resulting from replacing fallow with a forage legume grown to maturity was only 11-18% (in terms of total dry matter) and 2-16% (total N), with little difference between the two environments, Tel Hadya and Breda. For the vetch crop grazed green, corresponding values are 1% (TDM) and, for total N, gains of 18% (Tel Hadya) and 1.5% (Breda) (calculated from Table 2.2.3).

Table 2.2.7. Harvest parameters (total dry matter and total N) for barley in rotation with three mature-harvested forage legumes, as percentages of corresponding values for barley grown in rotation with fallow

	Preceding legume crop		
	LS	VS	VN
Tel Hadya:			
Total dry matter	88.1	87.9	81.6
Total crop N	97.5	95.8	84.0
Breda:			
Total dry matter	88.9	88.5	87.9
Total crop N	90.0	89.0	88.0

Values are based on three-year means across two fertilizer regimes, with and without NP applied to the barley phase.

Mature legume yields: Despite the lower rainfall, all three legumes tended to be more productive at Breda than at Tel Hadya (Table 2.2.8). For total dry matter, differences were inconsistent between years and species, and the mean advantage to Breda was small (5.7%); but for grain, differences were consistently large (mean, 36.8%), reflecting a generally higher harvest index at Breda than Tel Hadya (means, 39.6% and 30.6%, respectively). The reason for this is not known.

Differences between lathyrus and common vetch (LS and VS) were small and inconsistent, but narbon vetch (VN) tended to be more productive, especially of straw. Over three years at both sites, mean VN grain production was 18% higher than that of the mean of the other two species. Corresponding values for straw and total dry matter were 35% and 29%, respectively. Differences in crop total N were less consistent. At Tel Hadya, mean total N values were very similar for all three legumes; but at Breda, VN was superior, by a mean of 12.5 kg N/ha/annum (or about 25%).

Rotational productivity: Mean three-year mean values of total rotational dry matter production and N output show relatively small differences between the different forage legumes (Table 2.2.9). However, it may be noted that:

Table 2.2.8. Mature legume yields in barley-forage legume rotation, Tel Hadya and Breda, 1991-94

	Tel Hadya				Breda			
Crop	91/2	92/3	93/4	Mean	91/2	92/3	93/4	Mean
				Grain, t/ha				
Lathyrus	0.73	0.62	0.63	0.66	0.79	1.21	0.85	0.95
Vetch (VS)	0.55	0.92	0.58	0.68	0.66	0.92	0.87	0.82
Narbon V	0.72	0.87	0.66	0.75	0.86	1.19	1.23	1.09
				Straw, t/ha				
Lathyrus	1.07	1.17	1.80	1.35	1.00	1.51	1.08	1.20
Vetch (VS)	1.14	1.32	2.08	1.51	0.97	1.80	1.36	1.38
Narbon V	1.80	1.56	2.26	1.87	1.51	2.05	1.81	1.79
				TDM, t/ha				
Lathyrus	1.80	1.79	2.43	2.01	1.79	2.72	1.92	2.14
Vetch (VS)	1.69	2.24	2.66	2.20	1.63	2.72	2.23	2.19
Narbon V	2.52	2.43	2.92	2.62	2.38	3.25	3.04	2.89
				Total N, kg/ha				
Lathyrus	44.0	40.9	63.3	49.4	41.4	66.3	53.8	53.8
Vetch (VS)	36.0	51.1	57.4	48.2	36.1	55.1	51.5	47.6
Narbon V	47.2	49.7	52.5	49.8	51.6	66.4	71.6	63.2

Values are means across two fertilizer regimes, with and without NP applied to the barley phase.

Table 2.2.9. Total output of total dry matter and nitrogen in three barley-mature legume rotations, three-year means, Tel Hadya and Breda, 1991-94

	LS	VS	VN	F	LS	VS	VN	F
				TDM, t/ha				
Barley	5.70	5.69	5.28	6.47	4.10	4.08	4.05	4.61
Legume	2.01	2.20	2.62	0.00	2.14	2.19	2.89	0.00
Mean	3.86	3.95	3.95	3.24	3.12	3.14	3.47	2.31
As %	119	122	122	100	135	136	151	100
				Total N, kg/ha				
Barley	62.0	60.9	53.4	63.6	47.3	46.7	46.2	52.5
Legume	49.4	48.2	49.8	0.0	53.8	47.6	63.2	0.0
Mean	55.7	54.6	51.6	31.8	50.6	47.2	54.7	26.3
As %	175	172	162	100	193	180	208	100

Values are means across two fertilizer regimes, with and without NP applied to the barley phase.

- Legumes produced a smaller proportion of the total biomass at Tel Hadya (21.5% for LS and VS, 33.2% for VN) than at Breda (34.6% for LS and VS, 41.8% for VN); and there were similar trends in the total N data (respective values being 43.7% and 48.3% at Tel Hadya, and 51.9% and 57.8% at Breda).
- Rotations with narbon vetch, as the preceding figures illustrate, yielded a greater proportion of their biomass and nitrogen in the legume phase than did rotations with lathyrus and common vetch.

Comparisons with the barley-fallow rotation (in which half the land area is unproductive each year) show a large advantage in favour of the legume rotations. Mean increases over fallow rotation values were:
- at Tel Hadya, 19-22% for TDM and 62-75% for N;
- at Breda, 35-51% for TDM and 80-108% for N.

Comparisons between Tables 2.2.6 and 2.2.9 show rotations of barley with 'green-grazed' vetch to be less productive of dry matter and nitrogen than rotations involving mature-harvested legumes but, nevertheless, more productive in both respects than barley-fallow rotation.

2.2.3.4 <u>Barley water use at Breda</u>

Part of the effect of different modes of legume harvest on barley yield has been attributed to a soil stored-water effect. To follow up on this, crop water use has been monitored by neutron probe in selected treatments of the Breda trial. Three-year means of water use (evapotranspiration) by barley in rotation with common vetch (mature), common vetch (green grazed) and fallow are given in Table 2.2.10. They show that barley following 'green grazing' was, on average, able to utilize 11 mm more water than barley following mature-harvested vetch. Respective annual values (not shown in table) were 8, 7 and 18 mm, which were in turn 3, 11 and 1 mm less than the water utilized by barley following the bare fallow. It has been reported previously that the Breda soil stores very little water from a winter fallow over the summer for the next crop (Harris

1989); on the present evidence, nearly 70% of any such benefit may be available following green-grazed vetch. In all cases, the amounts involved are undoubtedly small; but it should be remembered that any soil-stored water that survives the long hot summer is deep in the profile and therefore fully utilized by the barley crop, for transpiration. It is therefore worth perhaps two or three times as much as the same volume of water arriving at the soil surface as rainwater, much of which is lost directly to evaporation.

Table 2.2.10. Seasonal evapotranspiration (mm) of barley crops grown at Breda following vetch, mature or harvested green, and fallow; three-year means, 1991-94

	Preceding crop			
	Vetch mature	Vetch, green-grazed	Fallow	Mean
		*		***
No fertilizer	263	273	272	269
NP to barley	271	283	294	283
SE, ±		2.4		1.4
		***		
Mean	267	278	283	
SE, ±		1.7		

Annual means (across preceeding crops and fertilizer regimes) and [corresponding rainfall amounts, October-April], mm: 1991/92 - 255 [231]; 1992/3 - 272 [251]; 1993/4 - 301 [292].

2.2.4 Conclusions

Harvesting vetch by zero grazing at the green stage, relative to harvesting at maturity, increased grain and straw yields of subsequent barley crops - by means, respectively, of 39% and 26% in eight independent 2-year trials at Breda and Ghrerife, and by 10-15% over three years in long-term rotation trials at Breda and Tel Hadya. Mean barley yields, after green grazing, in these long-term trials were equal to those from barley grown in rotation with bare fallow. This result is consistent with crop evapotranspiration data from

Breda that suggest that green harvesting of vetch conserves a small amount of soil water for the following crop, equivalent, on average, to nearly 70% of the conservation by bare fallow. Such water savings would almost certainly be larger, on an absolute basis, at Tel Hadya.

However, growing vetch to maturity approximately doubles the production of legume biomass and contributes to a rotational productivity (barley + legume biomass and nitrogen offtake) slightly greater than that of the green-harvest rotation. However, the differences here are small (all less than 10%), and clearly in a real-farm situation there would be no reason to avoid the green-grazing option, if that best fitted the needs of the feed calendar. Indeed, it could be that, in many situations, high-value green grazing for milk production or lamb fattening, followed by barley yields equivalent to those usually achieved by prior fallowing, could be the most profitable option.

Vicia narbonensis has sometimes been seen as the species with the potential to provide the breakthrough in the transfer and acceptance of forage legumes by dry-area barley farmers. Common vetch and lathyrus are rarely visually impressive crops under low rainfall conditions, and farmers' reluctance to grow them is not difficult to understand; but narbon vetch often manages to look more robust and vigorous. This impression is partly supported by the present findings. Yields of narbon grain and, particularly, straw were appreciably higher than those of the other two species. However, this advantage was not matched, at least at Tel Hadya, by correspondingly higher values of total N, while associated barley yields (total dry matter and N) were relatively depressed.

In terms of rotational productivity, narbon-barley was best at Breda, by a margin of about 10%, but at Tel Hadya all three legume rotations were effectively equal. There is no strong basis here for a breakthrough at farm level, particularly since narbon vetch is unpalatable at the green stage and therefore less versatile in its utilization. Nevertheless, two further points are worth noting. First, all three forage legumes were relatively more successful in the drier Breda environment - that is, they contributed a greater proportion of the rotational biomass and N output than at Tel Hadya. Secondly, it was only in this drier environment that the narbon-based rotation outproduced the others; and Breda more closely typifies the target environment of these studies. What this result means, whether it is found over wider range of time and environments, and how it might be exploited, undoubtedly requires further research. ***[Mike Jones, with major technical inputs from Nerses Chapanian and Zuhair Arous]***

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2.3 The Response of Wheat and Lentil to Tillage and Time of Sowing in a Two-Course Rotation

2.3.1 Introduction

Maintenance of the soil structure is the basic requirement for any tillage package aimed at maintaining the productivity of the soil. Conventional or clean tillage has a long tradition in rainfed cropping areas of the world, but conservation tillage, which requires that stubble residues remain on or near the soil surface, is becoming more widely used. The no-tillage system is a powerful point of entry to solve the problems of soil erosion, soil fertility and soil with low water holding capacity (Lal 1976 1983). Crop yields from no-till agriculture are usually as high or higher than yields from crops produced by conventional tillage (Campbell *et al.* 1984). However, the no-till system may create new challenges to be coped with, such as weed and pest infestations.

To examine these issues in the WANA environment, we compared conventional tillage for different times of planting with no-till planting. In the first phase of the work the focus was mainly on weed population changes. In the second phase, we have looked into the effect of different times of conventional tillage and no-till planting on changes in soil structure and the productivity of the systems in wheat-lentil rotation.

2.3.2 Materials and methods

The two course rotation, lentil-wheat, was begun at Tel Hadya in the 1978/79 season on a soil classified as a vertic (calcic) luvisol, with a pH of 8-8.5, organic matter 0.9-1 percent, and EC (electrical conductivity) 0.62-1.48 mmhos/cm. The soil depth ranged between 80 cm to greater than 2.0 m. The objective was to study the effect of five main tillage systems, five weed control methods, and fertilization on crop yield and the weed community. The tillage systems used were:

1. Conventional tillage (the most common farmers' practice) with three dates (Early,Mid,Late)
   a) Disking, harrowing and sowing before the first rain of the season (CTE).
   b) Disking before rain, harrowing and sowing after rain (CTM).
   c) Disking, harrowing and sowing after the first rain of the season (CTL).
2. Zero tillage with two dates (Early and Mid)
   a) Direct drill at same time as CTE.
   b) Direct drill at same time as CTM.

Five different weed control methods were imposed on each tillage system:

1. Weedy control
2. One hand weeding
3. Two hand weedings
4. Broadleaf herbicide
5. Broadspectrum herbicide

Two fertilizer treatments, with and without, were superimposed on each weed control method.

In the 1982/83 season, soil moisture measurements were initiated in selected treatments: the early date of conventional and zero tillage, with weedy and weed-free as sub-treatments, and fertilized versus unfertilized as sub-sub treatments.

In the 1985/86 season changes were made to the trial design, because:

- Sufficient results had been obtained in the weed studies.
- Grain yields in the unfertilized plots were declining.
- Changes in soil structure due to tillage had been observed.
- It was necessary to grow both crops annually.

The adjustments included:

a) Planting both crops in the rotation every year to facilitate a better interpretation of the data.

b) Adding phosphate to the unfertilized plots to rebuild the fertility.

c) Adding access tubes to monitor moisture in all tillage treatments.

d) Controlling weeds through integrated weed control.

e) Introducing direct drill equipment (30 cm row spacing) as replacement for the local drill (at 17.5 cm row spacing) which had been used as a 'direct drill' in the first phase of the trial.

2.3.3 Effect of tillage systems, weed control, and fertilization on grain yield, 1978-1984

The main objective was to look at the effects on the system as a whole of tillage, fertilizer and weed control treatments, irrespective of the crop grown. However, interpretation of the data was made difficult by the single-phase nature of the rotation, with only one crop, lentil or wheat, grown each year. This does not allow annual trends to be seen, which was the reason for the change in 1985 to having both phases represented each year. Results may be summarized:

- Disc plowing and harrowing in the conventional tillage treatments increased grain yields significantly over those from no-tillage (Table 2.3.1). Low yields from the no-tillage treatments were attributed mainly to the poor seed placement achieved by the Amazon planter, which was not very suitable for seeding into uncultivated land. Differences in grain yield between dates of seeding varied from one season to another due to the uneven rainfall distribution within each cropping season.
- All weed control methods significantly increased grain yield relative to the weedy control (Table 2.3.2). Both hand weeding once (farmers' practice) and applying a combination of broad-leaf herbicide and a grass killer were effective in increasing grain yield, with the chemicals more effective in wheat and less effective in lentil. However, labor cost or unavailability are the main factors in hand weeding, so that whenever proper herbicides are available farmers are aware of their beneficial effects.
- Adding phosphorus fertilizer to wheat and lentil, and nitrogen to wheat, significantly increased grain yields (not presented), except in 1983 when rainfall was low and poorly distributed. Altogether, mean yields in non-fertilized plots were only 77% (wheat) and 64% (lentil) of those in fertilized plots.

Table 2.3.1. Effect of tillage system on the grain yield (kg/ha) of wheat and lentil, Tel Hadya, 1979-1984

Tillage system*	1979 Wheat	1980 Lentil	1981 Wheat	1982 Lentil	1983 Wheat	1984 Lentil
CTE	1.97	0.49	1.48	0.58	0.43	1.04
CTM	2.40	0.40	1.70	0.54	0.65	0.73
CTL	1.74	0.11	1.75	0.55	0.47	0.81
ZTE	1.24	0.41	0.57	0.55	0.16	0.45
ZTM	0.85	0.24	0.69	0.25	0.62	0.69
e.s.e[1] (±)	0.11	0.04	0.07	0.08	0.05	0.05
	**	**	**	NS	**	
Rainfall (mm)	425.9	372.1	337.6	324.4	230.3	372.6

1. standard error of the mean within seasons.
* For details, see text

Table 2.3.2. Effect of weed control methods on grain yield (kg/ha) of wheat and lentil, Tel Hadya, 1979-1984

Season	1979 Wheat	1980 Lentil	1981 Wheat	1982 Lentil	1983 Wheat	1984 Lentil
Unweeded control	1.02	0.23	0.57	0.21	0.18	0.39
1 weeding	1.65	0.42	0.20	0.61	0.43	0.58
2 weedings	2.39	0.43	1.86	0.72	0.57	0.62
Broadleaf h'cide	1.60	0.33	1.01	0.46	0.44	0.46
Broadspectrum herbicide	1.55	0.24	1.55	0.48	0.70	0.62
e.s.e[1](±)	0.08 **	0.02 **	0.05 **	0.03 **	0.02 **	0.03 **

1. standard error of mean within same season.

2.3.4 Effect of tillage systems and sowing dates on biomass and yields of wheat and lentil, 1986-1993

Sowing dates are always partly determined by the weather. However, over seven seasons, early sowing was consistently achieved in early to mid October, intermediate sowing less consistently in mid to late November, and late sowing in December or early January (Table 2.3.3).

In five of the seven seasons, biomass production of lentil was greatest from the early-sown crops, and, within those seasons, was mostly, but not always significantly, greater from the zero tillage treatment (ZTE) than the conventional tillage (CTE) (Table 2.3.4). Wheat biomass showed a somewhat opposite trend. The intermediate sowing date gave greater biomass than early sowing in five of the seven seasons; and, within those seasons, biomass from conventional tillage (CTM) was very close to that from zero tillage (ZTM) (Table 2.3.5). Within conventional tillage treatments both crops yielded least from the late sowing (CTL), although differences did not always show statistical significance. Grain yield trends were similar to those of the biomass.

Table 2.3.3. Dates of sowing and counts of emerged plants

Tillage	87/88	88/89	89/90	90/91	91/92	92/93[1]	93/94
			Sowing date for wheat and lentil				
CTE	16/10	6/10	8/10	14/10	15/10	13/10	11/10
CTM	20/11	12/11	28/11	13/12	13/11	27/12	25/11
CTL	22/12	27/11	27/12	14/1	17/12	13/1	13/12
ZTE	16/10	6/10	8/10	11/10	14/10	12/10	10/10
ZTM	20/11	12/11	3/12	12/12	12/11	29/12	22/11
			Dates of counting emerged lentil				
CTE	24/11	1/11	6/12	24/2	14/11	7/2	28/11
CTM	10/12	7/12	10/1	24/2	24/12	1/3	21/12
CTL	5/2	14/12	5/2	24/2	18/2	21/2	9/1
ZTE	24/11	1/11	5/12	11/2	5/11	5/1	22/11
ZTM	10/12	7/12	10/1	11/2	22/12	1/3	18/12
			Dates of counting emerged wheat				
CTE	18/11	31/10	6/12	18/2	21/11	7/2	22/11
CTM	10/12	1/12	27/12	8/22	3/12	16/2	21/12
CTC	4/2	13/12	28/1	21/2	23/1	22/2	9/1
ZTE	18/11	31/10	5/12	5/2	4/11	5/1	22/11
ZTM	10/12	1/12	27/12	5/2	22/12	16/2	16/12
Rainfall (mm)[2]	504	234	233	327	353	290	373

Seasons: 87/88 to 93/94.

1. Because of poor emergence of lentil crop with CTM, plant count was done later than CTL. Also ZTE gave better emergence than CTE, so counting was done 1 month earlier for both crops. 2. Total rainfall between October and June.

Analysis of the total data set has to allow for the fact that each crop grows on a different set of plots in alternate seasons, and the contribution of the individual plots to the variance needs to be considered. Ideally, the analysis should treat the data as two separate series cycling on the same plots. In reality, in the Tel Hadya environment where yields vary greatly from season to season because of the variability of the rainfall, this requires a long run of data. Our data, for only seven (biomass) or eight (seed) years, ie three and a half and four cycles of the rotation, are insufficient for this form of anlaysis. As a compromise, the data have been subjected to a variance components analysis, using the REML facility of GENSTAT, treating 'year' as a random variable, and replicate and tillage treatments as fixed. This means that all variance arising from seasonal weather and plot differences is ascribed to the random variable.

Table 2.3.4. Lentil biomass and grain production (t/ha) in response to tillage and sowing date treatments in eight seasons in a two course rotation trial at Tel Hadya

Season	Tillage and sowing date					e.s.e[1] (±)
	CTE	CTM	CTL	ZTE	ZTM	
			Biomass yield			
1986/87	-	-	-	-	-	-
1987/88	6.10	5.43	4.34	4.53	4.76	0.252
1988/89	3.31	2.23	2.13	3.75	1.63	0.117
1989/90	1.72	1.12	0.98	1.96	1.28	0.097
1990/91	1.69	1.46	1.50	2.17	3.02	0.098
1991/92	4.23	3.63	1.88	4.83	3.82	0.260
1992/93	3.82	1.87	1.80	4.15	2.25	0.116
1993/94	4.66	4.02	2.89	5.37	5.82	0.218
Means	3.65	2.82	2.22	3.82	3.23	
			Grain yield			
1986/87	1.51	1.42	1.02	1.01	1.43	0.092
1987/88	1.78	1.55	1.28	1.67	1.63	0.087
1988/89	0.66	0.41	0.49	0.82	0.50	0.024
1989/90	0.39	0.24	0.05	0.43	0.30	0.025
1990/91	0.40	0.38	0.30	0.70	0.76	0.044
1991/92	1.00	1.14	0.49	1.22	1.29	0.068
1992/93	1.13	0.54	0.48	1.31	0.85	0.043
1993/94	1.22	1.22	0.82	1.20	1.70	0.129
Means	0.94	0.78	0.56	1.05	1.00	

1. Standard error of the means within same season.

Table 2.3.5. Wheat biomass and grain production (t/ha) in response to tillage and sowing date treatments in eight seasons in a two course rotation trial at Tel Hadya

Season	Tillage and sowing date					e.s.e[1] (±)
	CTE	CTM	CTL	ZTE	ZTM	
			Biomass yield			
1986/87	-	-	-	-	-	-
1987/88	7.18	8.10	7.83	4.70	7.78	0.630
1988/89	3.43	5.11	3.87	2.90	4.60	0.300
1989/90	1.95	1.88	1.59	1.76	2.14	0.320
1990/91	2.18	2.42	2.80	2.77	3.93	0.180
1991/92	5.21	5.25	4.76	4.98	5.26	0.210
1992/93	7.13	5.96	6.16	6.24	5.53	0.400
1993/94	6.75	7.50	7.31	6.17	7.39	0.300
Means	4.83	5.17	4.90	4.22	5.23	

			Grain yield			
1986/87	1.72	1.75	1.52	1.33	1.46	0.059
1987/88	2.47	2.96	2.56	1.98	2.90	0.163
1988/89	1.12	1.42	0.68	0.77	0.98	0.068
1989/90	0.45	0.35	0.32	0.49	0.63	0.041
1990/91	0.48	0.59	0.60	0.62	0.88	0.031
1991/92	1.91	1.89	1.57	1.72	1.67	0.088
1992/93	2.08	1.66	1.58	1.57	1.71	0.089
1993/94	2.07	2.36	2.44	1.88	2.24	0.046
Means	1.51	1.60	1.39	1.29	1.57	

1. Standard error of the means within same season.

Variance of biomass and grain yields of both crops was mostly explained by the differences due to 'year', largely differences in rainfall amount and distribution (Table 2.3.6). 'Year' explained about 75, 83, 84 and 91% of lentil biomass and grain, and wheat biomass and grain, production, respectively. The second most important component was the year x tillage interaction.

Table 2.3.6. Variance components (%) of lentil and wheat biomass and grain yield

Effective random term	d.f.	Lentil biomass	Lentil grain	Wheat biomass	Wheat grain
Year	6	75.4	82.7	83.8	91.3
Rep x Year	12	0.8	0.6	1.4	0.0
Rep x Tillage	8	0.8	0.8	0.5	0.0
Year x Tillage	24	19.5	10.6	6.9	5.5
Rep x Year x Tillage	48	3.5	5.3	7.4	3.2

2.3.5 Effect of tillage systems and sowing dates on crop water use, 1986-1993

The above pattern of yields was in many ways reflected in the pattern of water use (Table 2.3.7). This was particularly the case under conventional tillage. In all seasons, wheat used more water than was received as rainfall, while lentil used less water. Storage of water in the soil after each lentil crop increased the supply to the following wheat crop, though in amounts varying according to the volume and distribution of the lentil-season rainfall. This effect was much less clear under zero tillage. With lentils, and also the middle planting of wheat, yield per unit of water use appeared appreciably higher than under conventional tillage - the lentils gave more yield from the same water use, while wheat gave a similar yield from a lower water use. The figures show that wheat under zero tillage used less water (averages of 15 and 22 mm) than did wheat crops under conventional tillage. Actual use was, on average, quite close to the mean rainfall (about 300 mm), suggesting that zero tillage largely negates the water-conserving effect of the lentil crop. Similar results have been reported earlier (Harris and Pala 1988).

Table 2.3.7. Water use of mature lentil and wheat crop as affected by tillage and sowing dates

	Tillage and sowing date					Rainfall[2]
Season	CTE	CTM	CTL	ZTE	ZTM	(mm)
		Lentil water use (mm)				
1986/87	300	295	276	301	290	313
1987/88	405	374	364	396	366	444
1988/89	229	207	212	194	188	234
1989/90	181	174	173	183	179	204
1990/91	223	220	223	220	230	253
1991/92	260	240	216	278	240	299
1992/93	264	227	230	256	232	287
1993/94	290	288	254	304	313	346
Mean	269	253	244	267	255	298
e.s.e[1](±)	24	22	20	25	23	26
		Wheat water use (mm)				
1986/87	342	363	392	331	330	317
1987/88	455	464	448	426	439	444
1988/89	286	333	285	257	266	249
1989/90	208	204	203	199	203	209
1990/91	250	249	250	247	250	261
1991/92	317	319	315	310	310	306
1992/93	301	311	298	293	290	287
1993/94	366	383	387	347	357	358
Mean	316	328	322	301	306	304
e.s.e[1](±)	27	28	29	25	26	26

1. standard error of mean across the seasons.
2. from start of season to harvest.

2.3.6 Conclusions

- Results demonstrate the possibility of achieving zero-till yields equal to those from conventional tillage. However, the benefit of reducing the tillage costs needs to be compared with the increasing costs of rodent and weed control.
- Continued use of the same tillage systems over a long period
  a) has created differences in the soil structure (which need to be quantitatively measured);
  b) resulted in differences in the weed flora from one tillage to another.
- Sowing date effects on wheat yields appear to derive in large part from seasonal rainfall distribution; but lentil yields show a fairly consistent advantage for early planting. ***[S. Dozom, M. Pala and H. Harris]***

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2.4 Effect of Stubble Burning and Seedbed Preparation Systems on Crop Yield and Weeds in Wheat-Lentil Rotation

2.4.1 Introduction

Though a relatively low quality feed, wheat straw often plays an important role in supporting livestock, either by direct grazing after harvest or by baling for the winter use. About 60% of wheat dry matter is straw, which may well remain on the ground if farmers do not find it possible or profitable to graze or bale it. Under these conditions, field burning may become the main method of disposal to permit easy soil preparation for the following crop. This became the case in 1987/88 season in northwest Syria when the number of stubble fields burned by farmers appeared to increase markedly compared with previous years (Tutwiler *et al.* 1990). In favorable regions of Turkey also stubble burning has become a serious option to farmers to facilitate better field preparation; and similar cases are found in other parts of the world irrespective of development level (Staniforth 1982).

Burning is often thought to destroy weed seeds. However, it is not clear that direct economies can be made in herbicide use as a result of burning, although it may be that herbicides are more effective on the reduced weed populations that result from burning (Staniforth 1982).

Crop establishment is one of the most important steps in crop production. Some tillage is normally used to prepare the seedbed. However, tillage operations are costly and can form 30 to 50% of the costs of planting (Harris and Pala 1988). Alternatively, burning is believed to leave the soil in a friable condition suitable for direct drilling.

To examine these issues, a long-term trial was started at Tel Hadya in the 1987/88 season. Its objectives were to assess the effects of straw and stubble burning and different seedbed preparation systems on crop yield, soil chemical and physical stability, and weed infestation level in a two-course wheat-lentil rotation. This report summarizes results from the first seven years.

2.4.2 Materials and methods

The trial was initiated, with 2-phase entry, in 1987/88. Each phase comprised 24 combinations of two stubble burning, six seedbed preparation systems and two weed control (control and herbicide use) treatments in a split plot design with two treatment factors in three replications. The mainplot comparison were between stubble burning and control, and subplot comparisons between the following seedbed preparations:

1. Disc plowing before the first rain (PBR)
2. Disc plowing after the first rain (PAR)
3. Ducksfoot cultivation after the first rain (DAR)
4. Ducksfoot cultivation after the first rain plus single pass planter (DAR+SPP)
5. Single pass planter following the first rain without previous tillage (SPP)
6. Broadcast over the ridges following the first rain without previous tillage (BAR).

Except in treatments 4 and 5, where a single pass planter was used, all plots were seeded by broadcasting over ridges (farmers' practice, called ayar and rdad locally), and half of the plots were kept weedy as subplots. Details of the single pass planter and of sowing by broadcasting over ridges were given by Harris and Pala (1988). Fertilizers were applied as 50 kg P_2O_5/ha (wheat and lentil), 20 kg N/ha at sowing (lentil) and 50 kg N/ha, half at sowing half at mid-tillering (wheat). All sowings followed the first rain falling after mid-November. A mixture of bromoxynil and diclofop-methyl for wheat was sprayed once at 2-3 leaf stage (0.5 + 1.0 kg/ha), and a mixture of cyanazine and pronamide for lentil was sprayed pre-emergence at the rate of 0.5 + 0.5 kg ai/ha. Cultivars used were Cham 1 (wheat) and Jaleb 1 (lentil).

Base-line date for soil aggregate stability and chemical analysis were taken at the start of the trial and are planned to be repeated in the tenth year.

2.4.3 Results and discussion

2.4.3.1 Effect of seedbed preparation

Lentils: Field differences between the four broadcast sowing treatments (PBR, PAR, DAR and BAR) were very small. Neither the form nor time of cultivation prior to sowing showed any consistent improvement over the directly broadcast control (BAR) and mean yields over seven years differed only by 2-3% (Table 2.4.1).

Table 2.4.1. Effect of seedbed preparation on lentil grain yield (kg/ha) during 1987-1994 growing seasons

Seedbed	87/88	88/89	89/90	90/91	91/92	92/93	93/94	Means
PBR	1297	509	327	348	701	756	856	685
PAR	1206	533	333	441	617	725	926	683
DAR	1246	544	247	484	519	810	894	678
DAR+SPP	1086	527	335	491	734	883	870	704
SPP	1052	554	347	606	778	707	755	686
BAR	1147	508	259	466	583	797	922	669
s.e.d[1]	78	52	32	36	59	63	105	-
	*	NS	**	**	**	NS	NS	
Rainfall	503.6	234.1	233.3	293.5	352.5	290.1	373.3	

1. Standard error of difference in each season.

The single pass planter, used either without previous seedbed preparation (SPP) or after ducksfoot cultivation (DAR+SPP), gave slight increases in grain yield over control (BAR) except in the very wet 1987/88 season. The advantage of SPP is that is provides a more uniform seed depth of 5-7 cm than broadcast sowing which can result in a seed depth varying from 2-3 cm to as much as 15-17 cm (Harris and Pala 1988).

Plowing before rain (PBR) and plowing after rain (PAR) were equally effective in controlling weeds, reducing weed biomass compared with direct ayar and rdad (BAR) (Table 2.4.3). Ducksfoot cultivation was less effective in controlling weeds than plowing, and the highest weed infestation was usually recorded where the single pass planter (SPP) was used.

Wheat: Signficiant differences were observed only in 3 out of 7 years (Table 2.4.2). The three seedbed preparation methods (PBT, PAR and DAR) increased grain yields by an average of 4 to 8% relative to direct broadcasting (BAR). Using the single pass planter, alone or after ducksfoot cultivation, gave about the same mean grain yield as BAR.

As with lentils, weeds in wheat were best controlled by plowing (PBR, PAR); ducksfoot cultivation was less effective; while highest weed infestations were recorded where the single pass planter was used directly or after ducksfoot (Table 2.4.4).

Table 2.4.2. Effect of seedbed preparation on wheat grain yield (kg/ha) during 1987-1994 growing seasons

Seedbed	87/88	88/89	89/90	90/91	91/92	92/93	93/94	Means
PBR	3540	686	337	608	1736	1760	2703	1624
PAR	3781	570	363	634	1744	1844	2706	1663
DAR	3622	597	244	668	1846	1961	2832	1681
DAR+SPP	3855	449	322	643	1701	1676	2254	1557
SPP	3827	477	400	618	1558	1501	2239	1517
BAR	3312	652	291	635	1635	1739	2637	1557
SE	173	50	53	39	91	155	166	-
	*	**	NS	NS	NS	NS	**	

Table 2.4.3. Effect of seedbed preparation on weed biomass (kg/ha) in lentil crop during 1987-1994 growing seasons

Seedbed	87/88	88/89	89/90	90/91	91/92	92/93	93/94	Mean
PBR	340	95	161	225	179	282	257	220
PAR	348	112	289	165	222	206	395	248
DAR	488	179	445	229	234	168	419	309
DAR+SPP	687	89	477	394	354	257	660	417
SPP	773	98	448	296	242	194	491	363
BAR	594	175	391	297	304	280	352	342
SE	84	29	50	43	41	63	96	
	**	**	**	**	*	NS	**	

Table 2.4.4. Effect of seedbed preparation on weed biomass (kg/ha) in wheat crop during 1987-1994 growing seasons

Seedbed	87/88	88/89	89/90	90/91	91/92	92/93	93/94	Mean
PBR	258	55	66	148	209	177	549	209
PAR	377	72	90	126	190	156	565	225
DAR	374	167	163	271	353	321	586	319
DAR+SPP	581	143	218	406	515	358	971	456
SPP	711	158	223	311	478	262	1432	511
BAR	579	95	262	230	430	219	563	340
SE	116	27	44	66	75	50	311	
	**	**	**	**	**	**	*	

2.4.3.2 Effect of stubble burning

Lentil: Burning wheat stubble increased subsequent lentil grain yield significantly in four seasons out of seven (Table 2.4.5), but effects on weeds was small and inconsistent (Table 2.4.6). Stubble burning has been reported to lead to better yields if field burning makes possible the timely sowing of crops that would otherwise be delayed (Staniforth 1982), which was not the case in our trial because all the treatments were sown at the same time. The difference may possibly be explained in terms of additional plant nutrients, in particular nitrogen, which may be released in a flush of mineralization following a partial sterilization of the surface soil by burning. Thus, stubble burning increased protein percentage in lentil grain significantly from 26.6% to 27.1% (not shown in Tables). How this may relate to the fixation of nitrogen by the lentil crop is not clear, and further research on the effect of straw and stubble burning on N-fixation by the following legumes is needed.

Wheat: The effect of stubble burning on wheat yield was variable in the early years, but a more more consistent positive trend began to show up in the last 3 years of the trial (Table 2.4.5). Any effect on weeds was small (Table 2.4.6). This was to be expected, since the burning is done once every two years, after wheat and before lentil.

Table 2.4.5. Effect of stubble burning on crop grain yields (kg/ha), 1987-1994

Stubble burning	87/88	88/89	89/90	90/91	91/92	92/93	93/94
				Lentil			
Control	1110	487	299	419	663	682	832
Burned	1235	571	317	527	648	877	909
SE	45	30	19	21	34	36	61
	**	**	NS	**	NS	**	NS
				Wheat			
Control	3909	527	379	616	1516	1656	2175
Burned	3404	617	273	652	1891	1838	2949
SE	100	29	30	22	52	90	96
	**	**	**	NS	**	*	**

Table 2.4.6. Effect of stubble burning on weed biomass (kg/ha) in lentil and wheat crops, 1987-1994

Stubble burning	87/88	88/89	89/90	90/91	91/92	92/93	93/94
				Lentil			
Control	546	117	383	320	251	237	537
Burned	531	132	353	216	260	225	321
SE	48	17	29	25	29	36	56
	NS	NS	NS	**	NS	NS	**
				Wheat			
Control	442	116	195	232	420	296	844
Burned	518	114	145	265	306	201	711
SE	67	16	25	38	43	29	179
	NS	NS	NS	NS	*	**	NS

Allen (1981) reported that the general experimental evidence is against the view that the addition of straw improves soil conditions and leads to increased yields, so that the disposal of straw by burning is necessary if baling or grazing of straw is not possible. However, in the ICARDA region, livestock is such an integral part of most farming systems that burning can hardly be justified. Any yield increase from burning should be considered against the loss in livestock utilization.

2.4.3.3 Effect of weed control

Lentil: Weed control is an important factor in the achievement of acceptable lentil yields, as this crop is a poor competitor with weeds. Spraying a mixture of cyanazine and pronamide increased grain yields significantly in four seasons out of seven (Table 2.4.7), with a significant reduction in weed biomass in five seasons out of seven (Table 2.4.8). These results are in agreement with previous studies on weed control in lentils (Basler 1981; Pala and Mazid 1992). However, there was no interaction between weed control and seedbed preparation, because even direct drilling with the single pass planter (SPP) effectively provided a cultivation during sowing sufficient to kill any early emerged weeds.

Table 2.4.7. Effect of weed control on crop grain yields (kg/ha), 1987-1994

Weed control	87/88	88/89	89/90	90/91	91/92	92/93	93/94
				Lentil			
Sprayed	1153	595	351	556	740	801	1046
Weedy	1192	549	264	390	571	757	695
SE	45	30	19	21	34	36	61
	NS	NS	**	**	**	NS	**
				Wheat			
Sprayed	3630	531	370	653	1719	1984	2728
Weedy	3683	527	282	616	1688	150	2396
SE	100	29	30	22	52	90	96
	NS	NS	**	NS	NS	**	**

Table 2.4.8. Effect of weed control on weed biomass (kg/ha) in lentil and wheat crops, 1987-1994

Weed control	87/88	88/89	89/90	90/91	91/92	92/93	93/94
				Lentil			
Sprayed	495	116	240	171	178	132	243
Weedy	582	133	497	364	334	330	615
SE	48	17	29	25	29	36	56
	NS	NS	**	**	**	**	**
				Wheat			
Sprayed	237	51	25	159	211	68	260
Weedy	733	179	315	338	514	430	1295
SE	76	16	25	38	43	29	179
	**	**	**	**	**	**	**

Wheat: Herbicide effects on wheat yield were less pronounced than on lentil, because wheat is more competitive. Spraying a mixture of bromoxynil and diclofop-methyl increased grain yield significantly in three seasons out of seven (Table 2.4.7) and controlled weeds significantly in all seasons (Table 2.4.8). Similar results have been reported for on-farm studies in northwest Syria (Kukula and Dakermanji 1985; Bin Shuaib 1987).

2.4.4 Preliminary Conclusions

- Seedbed preparation with minimum tillage seems promising compared with conventional deep disking which carries the risk of degrading soil structure.
- Chemical weed control was once more proved effective in increasing yield and decreasing the weed biomass particularly in lentil, but it did not interact with seedbed preparation or stubble burning.
- Straw and stubble burning gave significant yield increases in some years, but livestock integration in the farming systems of the region should reduce the need for burning. *[M. Pala and S. Dozom]*

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2.5 Impact of a Long-term Rotation on Soil Aggregation and its Implications for Cropping

2.5.1 Introduction

A frequently disregarded determinant of the productivity of arable land is the physical structure of the soil. An important parameter of soil structure is aggregation (the degree of coherence of the constituent soil particles of sand, silt and clay into stable crumbs or peds). When a soil, particularly a clay soil, has a large proportion of its material in the form of stable aggregates, resistance to rainfall impact, surface capping and erosion is greater, water infiltration and permeability are enhanced, and the environment for crop root growth is generally more favourable. However, aggregation is not a permanent property but varies according to how the soil is managed. Inappropriate management over time tends to degrade soil aggregation, with potentially serious effects on productive capacity. Long-term rotation trials provide an excellent venue for examining the effects of different sequences of crops and crop management interventions on soil physical conditions.

One of the principal long-term rotation trials at ICARDA is the two-course rotation in Field C-16. The rationale for this trial, along with yield and soil moisture data for the early years of its existence, were described by Harris (1990). The limited data on soil N were described by Matar and Harris (1991), while detailed soil N and organic matter data and crop N uptake were described by Ryan *et al.* (1992) and by Harris *et al.* (1993). However, despite the likely impact of rotations on soil physical properties, few if any data had previously been collected before the present study was started in 1992.

Preliminary results presented here provide several indices of aggregation in soils taken from the wheat/fallow and wheat/medic rotations under a range of N and stubble grazing treatments.

2.5.2 Materials and methods

Soil: The soil at the site of the two-course rotation trial is a clayey, montmorillonitic, thermic, Calcixerollic Xerochrept. The surface soil, Ap or plough layer from 0-15 cm, sampled for laboratory analysis is red (2.5 YR 4/6) when dry and dark red (2.5 YR 3/6) when moist, clay, moderate, fine-to-medium granular, hard dry, friable moist, sticky, plastic, calcareous with a very small amount of gravel up to 2 cm in diameter. The moisture content by weight at 33 Kpa is 35.8% and at 1500 Kpa it is 23.1%. In most of the area the soil is 1 to 2 m deep, but there are areas where the depth is variable with some patches of less than 0.5 m. Detailed chemical, physical, and morphological description of the soil profile at this site are found in Ryan *et al.* (1995).

Inputs: This trial was established in 1986 on land that had been under cereal-based rotations since 1977. The main treatments are:

1. Seven cropping sequences, wheat/fallow (W/F), wheat/medic (W/M), wheat/wheat (W/W), wheat/summer crop (W/Sc), wheat/chickpea (W/Ch), wheat/lentil (W/L), and wheat/vetch (W/V), chosen to represent the range of cropping sequence options open to farmers in the environment represented by ICARDA. Each rotation is replicated three times, and both phases of the rotation are included each year. (However, only the W/F and W/M rotations were used for soil physical determinations).
2. Four levels of nitrogen (0,30,60, and 90 kg N/ka), applied to subplots in the wheat phase, for the dual purpose of assessing the long-term pattern of N responses and evaluating the capability of the associated legume to supply N to the system.
3. Three wheat stubble management treatments, heavy grazing, moderate grazing, and stubble retention, to assess the effects of grazing on the soil resource base, and, in particular, how stocking rate influences the physical and chemical properties of the soil.

Soil sampling: Sub-samples (0-15 cm) were taken with a small shovel prior to planting (November 1992) and were air-dried. Half of each set of five sub-samples was bulked to obtain a composite sample and passed through a 2-mm sieve and thoroughly mixed. The treatment samples came from three replications, two phases (both wheat and the alternate crop, medic or fallow), two rotations (W/F, W/M), two levels of N (0,90 kg N/ha), and two levels of grazing (heavy, zero grazing). The other half of the samples were left for dry-sieving and some physical analyses.

2.5.3 Laboratory assessment of aggregation

Several indices of aggregate stability were obtained using tests based on those reported by Rengasamy *et al.* (1984) and Tisdale and Oades (1980) or modifications of them.

Dispersion Test: This test may be regarded as generally useful for showing up major differences between experimental treatments (rotation, fertilization, and stubble retention).

Method: A 40 g sample of 2 mm air-dried sieved aggregates was weighed into standard glass cylinders, and 200 ml deionized water slowly added down the side of the cylinder to avoid disturbance. The mixture was left overnight and then hand-shaken 20 times at a speed of about 10 rev/min using mid-way or half-circle motion.

The dispersed clay was sampled by pipetting 10 ml of suspension from a depth of 5 cm after 4 hours and measured spectrophotometrically. The coefficient of dispersion was calculated as dispersed clay divided by granular clay content and expressed as g/100 g soil.

Wet-Sieving: Samples of 1-2 mm air-dried aggregates were wetted and subject to disruption by wet-sieving. The percentage retention of wet-sieved aggregates on a 0.5 mm sieve after the sample has been submerged in deionized water for 30 minutes gives an 'index of stability'.

Aggregate Swelling or Aggregate Particle Density: Swelling is one way in which the reaction between clay and water is shown. This test uses a simple pycnometer technique to measure the increase in volume displacement on wetting for those aggregates stable to wetting. Such aggregates may act as building blocks in the formation of large aggregates.

Aggregate Bulk Density: Soil density is a function of soil porosity and the tendency of soil aggregates to slake.

Aggregate bulk densities of fractions of 4-5, 2-4, and 1-2 mm aggregates were measured using a kerosene saturation and displacement technique and calculated as weight/volume.

Polysaccharides as an Index of Aggregate Stability: 5g subsamples of 2 mm dry-sieved aggregates of representative samples were first treated with water and then with 3N sulfuric acid, incubated overnight and centrifuged. The soil polysaccharides and their derivatives were determined spectrophotometrically using the phenol-sulfuric acid reaction.

2.5.4 Results and discussion

Dispersion test: Indices of clay dispersion showed strong treatment effects (Figures 2.5.1 and 2.5.2). Resistance to dispersion, implying more stable surface-soil aggregates, was apparently encouraged by medic relative to fallow, by increasing rates of fertilizer N applied to the wheat, and by heavy grazing of wheat stubble. The latter effect is possibly attributable to the return of the soil of animal dung and urine.

Wet sieving: The stability index (of wet-sieved aggregates) measures the extent to which the cohesive forces between primary soil particles can withstand applied disruptive forces. In line with the results from the dispersion test, values of this index indicated greater aggregate stability from medic (relative to fallow) from N fertilizer use and from heavy grazing (Figure 2.5.3).

Aggregate swelling: Following wetting of stable aggregates, lower aggregate densities (greater swelling) were recorded for soils taken from the medic rotation, and from high nitrogen and grazed stubble treatments (Figure 2.5.4). This pattern was consistent across aggregate size fractions, but in general smaller aggregates had higher densities. Some interactions were observed. Thus, for the 4-5 mm aggregate fraction, grazing and nitrogen effects on density were apparently more pronounced in soil from the medic rotation than from the fallow (Figure 2.5.5).

Aggregate Bulk Density: Differences here again followed a similar pattern (Figure 2.5.6). Irrespective of aggregate size, bulk density was considerably lower in medic and high

N treatments. However, the effect of grazing was not positive or consistent. With the larger particles (4-5 mm) and the smaller ones (1-2 mm) there was no effect, while grazing had a negative effect on the median fraction.

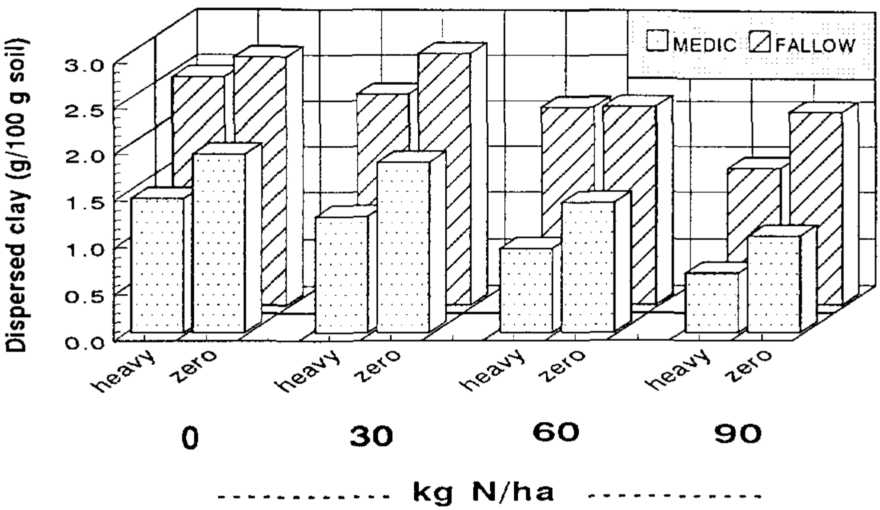

Figure 2.5.1. Coefficient of clay dispersion in medic and fallow plots in rotation with wheat, as affected by zero and heavy grazing of wheat stubble and four rates of N fertilizer to the wheat

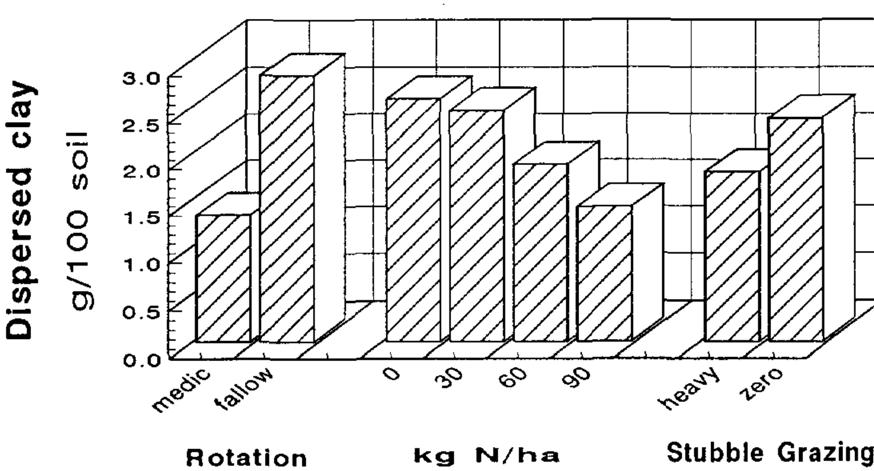

Figure 2.5.2. Overall effect of rotation, nitrogen and stubble grazing on the coefficient of dispersion

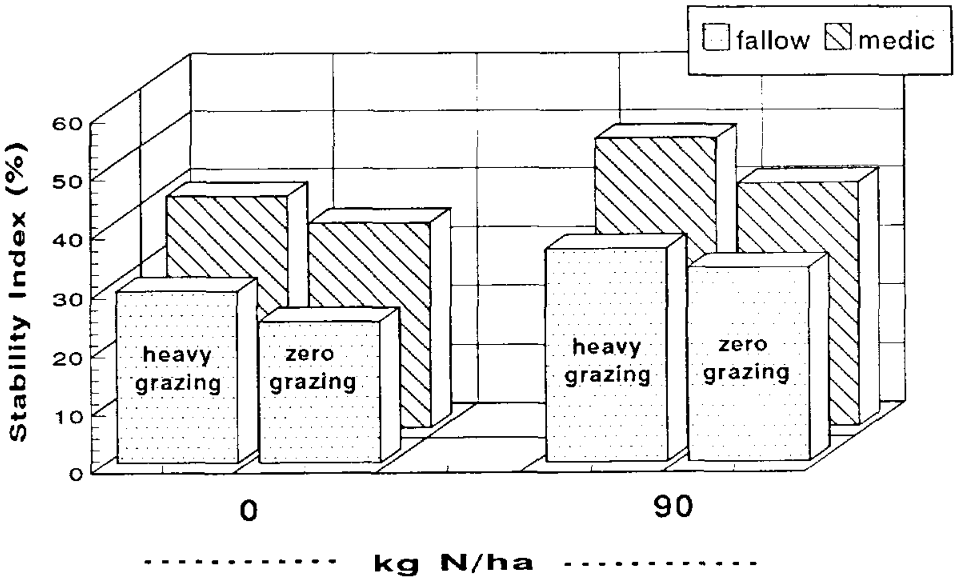

Figure 2.5.3. Stability of wet-sieved soil aggregates under medic and fallow rotation with two levels of stubble grazing and either 0 or 90 kg N/ha

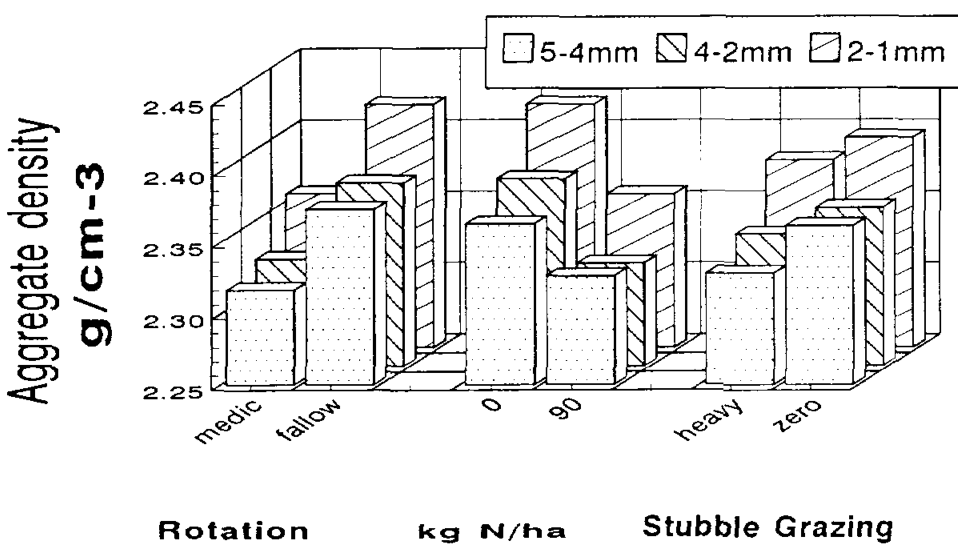

Figure 2.5.4. Overall effects of rotation, nitrogen and stubble grazing on aggregate density

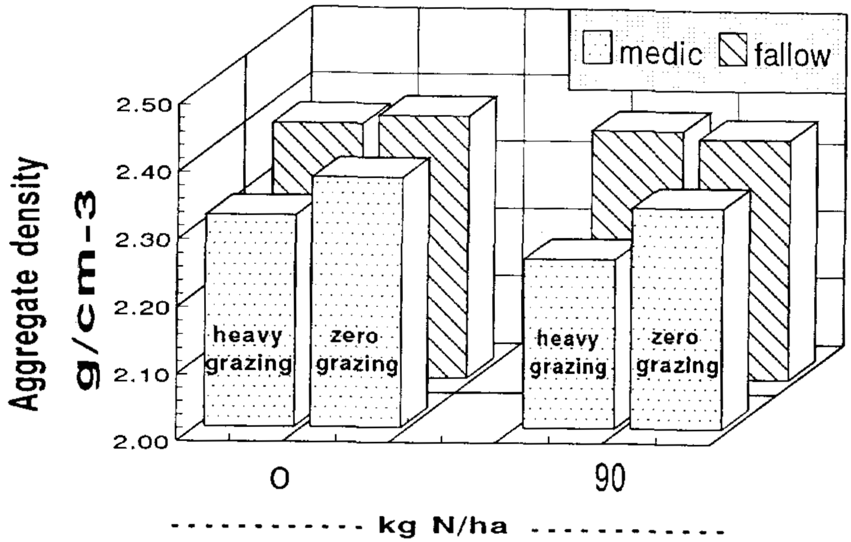

Figure 2.5.5. The effect of medic and fallow rotation with two levels of grazing and with 09 and 90 kg N/ha on soil swelling (for 4-5 mm aggregates)

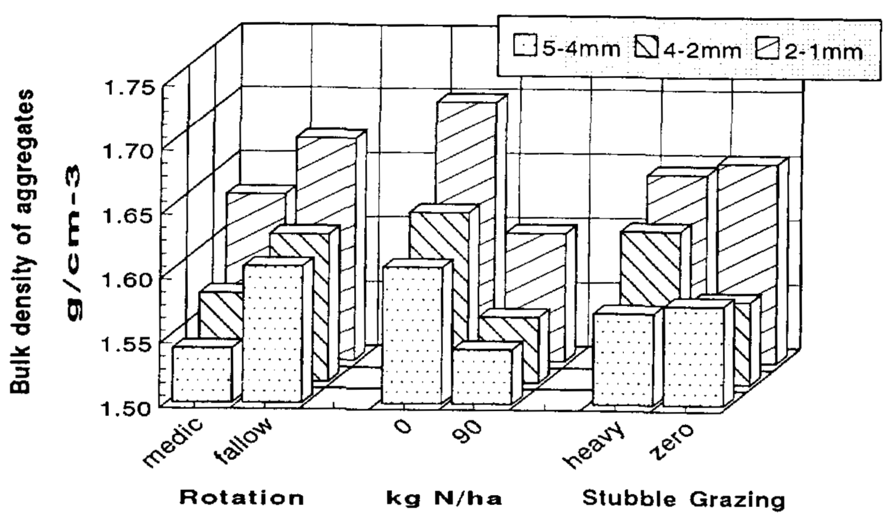

Figure 2.5.6. Overall effect of rotation, nitrogen and stubble grazing on bulk density of different soil aggregates fractions

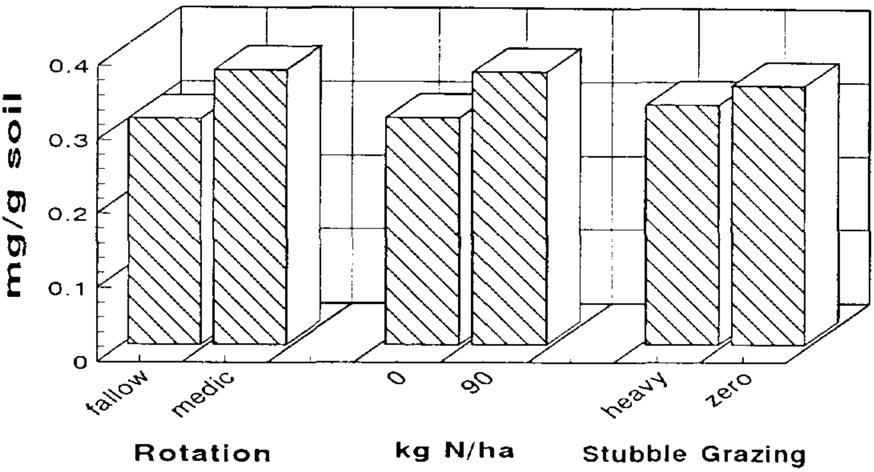

Figure 2.5.7. Polysaccharide extracted by water from soil under medic and fallow rotation with zero and heavy grazing and with 0 or 90 kg N/ha

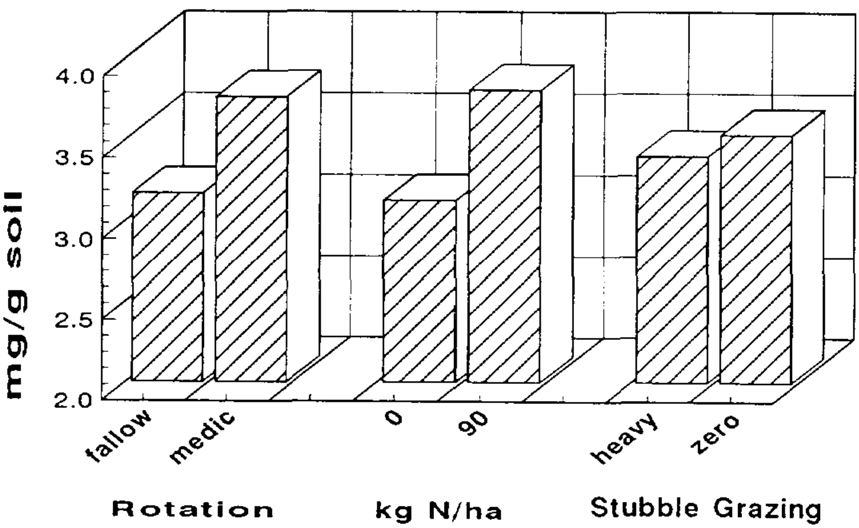

Figure 2.5.8. Polysaccharide extracted by H_2SO_4 from soil under medic and fallow rotation, with zero and heavy grazing and with 0 or 90 kg N/ha

<u>Polysaccharides</u>: The average content of soil polysaccharide extracted by sulfuric acid (Figure 2.5.7) and water (Figure 2.5.8) again exhibited a similar pattern. The

amount of polysaccharides was greater in the medic rotation and the 90 kg N treatment. This is explained by the microbially-produced soil polysaccharides that are capable of stabilizing soil aggregate against dispersion in water under the medic rotation and 90 N treatment, where there is more organic carbon and N.

Stubble grazing differences in polysaccharides were small, and the somewhat higher values under zero grazing were not consistent with the other indices in this regard.

2.5.5 Conclusion

Good soil structure depends on the presence of stable aggregates. Such aggregates influence infiltration, soil water retention, and transmission of water and air within the soil. Though essentially empirical in nature, the various methods used to assess the preparation of soil aggregates give a good measure of treatment effects on soil structure.

All the indices obtained show essentially the same treatment effects. Aggregate stability was generally greater in the rotation of wheat with medic. Aggregates from the wheat-fallow rotation were more likely to swell and disperse in the presence of water; and the amount of clay dispersed by shaking soil aggregates in water was approximately twice as great in samples from wheat-fallow as in samples from the wheat-medic rotation. Somewhat surprisingly, aggregate stability was apparently improved by heavy grazing of the wheat stubble relative to the ungrazed treatment; and nitrogen fertilization of the wheat crop also had a positive effect on stability.

The positive effect of nitrogen is attributed to greater growth of wheat roots and thereby a greater contribution of organic residues to the soil. More generally, the better physical condition of the soil under the wheat-medic rotation is attributed to a better organic matter status that is presumed to have arisen from the return to the soil of medic roots, leaves, and the faeces and urine of the sheep grazing the medic. The mean organic matter content of the wheat-medic plough layer is 1.44% compared with 1.22% under wheat-fallow. In fact, these figures alone are only indicative, not conclusive. Soil organic matter is a very complex material, and different components of it contribute differently to soil properties. Aggregate stability has often been found to be associated with the soil polysaccharide component. It is therefore significant in the present case that the relative amounts of polysaccharide extracted from these soils (Figure 2.5.8) quite closely mirror the pattern of the aggregate stability.

These results, though they derive from only two out of seven rotation treatments in a single trial, provide an important insight into the effects of different soil and crop management practices on soil physical conditions. The impact on crop performance of any physical deterioration of the soil is usually more insidious and more difficult to detect than that of declining chemical fertility; but it is also much more difficult to correct once the damage is appreciable. We have here a timely warning that sustainable production depends on the maintenance of soil physical as well as soil chemical and biological health. ***[Zuhair Masri and John Ryan]***

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2.6 Nematodes in Two- and Three-course Crop Rotations Involving Wheat and Chickpea

Since the introduction of winter sowing of chickpea (*Cicer arietinum* L.), made possible by improved cold and Ascochyta blight tolerance, there has been an increase in the incidence of nematode (mainly root-lesion nematodes, *Pratylenchus* spp.) infestation in the crop. The problem is not worse in winter than in spring plantings, but symptoms of infestation, yellowing and stunting of plants, appear earlier in the crop cycle when winter planting is practised. Damage in spring planted crops may be more severe, but is less likely to be detected as the symptoms tend to be attributed to water stress. Infestations in winter sowings have become apparent in the long-term trials on Tel Hadya (FRMP 1990, 1991, 1993) where chickpea is included in a two-course rotation with durum wheat and a three-course rotation with bread wheat and water melon.

It was deemed desirable to quantify the effect of the infestation on yield in order to judge its significance. For four years, therefore, a nematicide (aldicarb or carbofuran) was applied at 10 kg a.i./ha to strips of wheat and chickpea crops within the trials by broadcasting a granular form immediately after planting. Yield comparisons were made of treated and untreated strips by taking 5 x 1 m row samples from each. Wheat showed no response to the treatment and the data therefore are not reported, but there were significant effects on chickpea seed yields (Table 2.6.1).

Table 2.6.1. Chickpea grain yields in long-term rotation trials in response to application of a nematicide

Treatment	Season 1989-90	1990-91	1991-92	1992-93
	---------------- kg/ha			----------------
2-Course Rotation				
Minus	370	1050	1975[1]	1230
Plus	415	705	1515	1100
s.e.m.	9.9	50.4	41.4	22.4
3-Course Rotation				
Minus	195	430	680	1190[1]
Plus	235	345	805	1395
s.e.m.	4.4	10.2	21.5	31.3
	--- Value of Yield Difference, SYL/ha[2] ----			
2-Course Rotation	+855	-6555	-8740	-2470
3-Course Rotation	+760	-1615	+2375	+3895

1. Cultivar changed from Ghab 1 to Ghab 3.
2. Syrian Lira. 1994 prices used to estimate values.

In all cases there was an effect of nematicide on seed yield, but there was little consistency in the direction of the response. In the first season yields were severely limited by drought, only approximately 220 mm of rain being received. Rainfall was better in the second year (*ca.* 290 mm), but a hail storm just prior to harvest caused damage estimated at about 20 percent. The reported yields for the two-course rotation have been adjusted for this loss from estimates of the proportion of pods that were stripped from the plants, but the variability of the yield estimates was greater than usual. Rainfall in the other seasons was approximately 350 mm in 1991-92, and a well-distributed 290 mm in 1992-93.

In the two-course rotation the seed yield response to the nematicide was negative in 3 of the 4 years, and although positive in the first year the yield levels were so low and the difference so small that it had no practical significance. The negative response in the other years arose from an interaction of water use and the nematicide treatment. Plants in the treated strips were more vigorous than untreated plants during vegetative growth and by flowering had achieved a greater yield potential. However, as a consequence of this better growth they used more water during vegetative growth and suffered greater water stress during pod filling. They matured a few days earlier than untreated plants and the increased potential was not realised. It seems likely that a similar, but less extreme, effect accounted for the failure of wheat to respond to treatment.

In contrast, in the three-course rotation the response was positive in the last two years when moisture stress was less severe. Again, vegetative growth was enhanced by the nematicide treatment. The difference between the trials in the direction of the response possibly arose because the infestation appears to be more severe in the three-course trial, and the yield of the untreated areas thus is probably more severely reduced.

However, this visual observation is not supported by two years' data on root damage and nematode numbers in chickpea roots (Table 2.6.2), which indicate no marked differences between the trials. In addition to the root-lesion nematode, the root knot nematode, *Meloidoygne artiella*, was noted to be present in 15 and 8 percent of plots in the two- and three-course rotations respectively. The cyst nematode, *Heterodera ciceri*, was present only in one or two samples in each trial.

The three-course rotation includes tillage methods as a main treatment. In the first year, nematode numbers and root damage (as indicated by the score for degree of infestation) were greater in a zero-till treatment than where either deep discing, or chisel or sweep cultivation were used as the primary tillage. A similar trend in the second year was not significant. Chickpea yields, however, were not affected, so either greater numbers of nematodes did not further affect the crop, or, more likely, their effect was counterbalanced by other factors influencing the yield.

Table 2.6.2. The degree of nematode infestation, and nematode numbers in chickpea and wheat crops without and with nematicide application in long-term rotation trials

Season	Trial	Treatment	Chickpea	Chickpea	Wheat
			Infest.[1]	No.[2]	No.[2]
1989-90[3]	2CRO[5]	Minus	7.6	1350	
		Plus	4.7	55	
		s.e.m.	0.36	110	
	3CRO[6]	Minus	6.3	1197	
		Plus	2.3	14	
		s.e.m.	0.40	139	
1990-91[4]	2CRO	Minus	-	1124	819
		Plus	-	258	128
		s.e.m.	-	116	89
	3CRO	Minus	-	1810	261
		Plus	-	306	101
		s.e.m.	-	162	34.8

1. Degree of infestation (0-9 score); 2. Number of *Pratylenchus thornei* per g roots; 3. Sampled April 1990; 4. Sampled after harvest 1991; 5. Two-Course Rotation of Wheat-Chickpea; 6. Three-Course Rotation of Wheat-Chickpea-Water Melon.

In the two-course rotation, two auxiliary treatments applied to the wheat phase, nitrogen application rates and intensity of grazing of stubble, had no effect on either the response to the nematicide or nematode numbers. Similarly, in the three-course rotation it made no difference whether the stubble of the preceding wheat crop was grazed or burned.

The lack, in our data, of sharper differences in nematode populations between the trials and among treatments within the trials is most likely to be due to the timing of the sampling. Continuous cropping with host species, wheat and chickpea, in the two-course rotation would be expected to lead to a greater population than where a host is present only two years in three as in the three-course rotation. We have found that *P. thornei* populations in the soil vary, depending on the situation, at the time crops are planted, but build to a fairly constant ceiling after several generations have been completed by about the podding stage of plant development. In general, a clear relationship exists between the soil population at planting and crop yields, but, unfortunately, we do not have samples at planting from these trials. We now know that by sampling, as we did, only late in the crop season we have reduced our capacity to detect factors contributing to differences. This does not, however, negate the overall finding that damage is related to water availability.

The alternative to winter sowing of chickpea is to defer planting until mid-March (spring planting) and to have the crop grow largely on water stored in the soil profile during the winter. This is the traditional method for avoidance of *Ascochyta* blight, which can decimate susceptible varieties. The apparent severity of the nematode problem with winter planting led us to reconsider spring planting, and this option was introduced into the three-course rotation trial. Yields determined by harvesting 20% of the area (subplots for sowing date are 0.375 ha) with a plot combine are shown in Table 2.6.3. The differences reached statistical significance in years two and four, when planting resulted in somewhat more yield.

Table 2.6.3. Seed yields of winter and spring planted chickpea in a three-course rotation trial

Sowing Time	Season 1989-90	1990-91	1991-92	1992-93
	kg/ha			
Winter	200	485	700	1135[1]
Spring	260	285	895	940
s.e.m.	12.5	8.5	37.1	24.7

1. Cultivar changed from Ghab 1 to Ghab 3.

These results must be viewed in the overall context of chickpea production in west Asia. The rainfall at Tel Hadya (mean 330 mm) is marginal for chickpea production which mostly takes place, in northern Syria at least, in areas with more than 400 mm average rainfall. With more rain, more water is stored in the soil during the winter rainy season to maintain the growth of crops after rain ceases, generally in late March or April. The impact of nematode damage in winter sown crops would be expected to be proportionally greater in those conditions, as terminal drought would be less severe and potential yield gains from the greater biomass resulting from winter planting should be better able to be expressed. Reduced biomass production by unthrifty nematode-infested crops would reduce their yield potential and could quite substantially reduce returns on the crop. A critical evaluation of the cost of infestation would need to be done in the wetter areas to confirm this.

However, to some extent the situation at Tel Hadya is undoubtedly influenced by the experimental conditions. Farmers do not use a fixed sequence of crops on the same piece of land, as is necessary for the interpretation of data in experiments. Rather, in areas where three-course rotations are practised, they tend to use a cereal-legume-summer crop sequence - where the legume may be either chickpea or lentil, and the summer crop one of several options including water melon. Thus, mainly because lentil is only sparsely susceptible to the root-lesion nematode, it is not likely that farmers would experience the problem to the same degree as it occurs in our experimental conditions. Nonetheless, the situation deserves to be monitored.

Finally, it must be clearly stated that the use of a nematicide is an experimental tool only, and under no circumstances could it be considered as a viable option for control of nematodes in field crops. The cost would be prohibitive. ***H.C. Harris, R. Makboul, M. Labibidi (FRMP); M.C. Saxena, S. Hajjar (LP); M. Di Vito, N. Greco (C.R.N., Bari, Italy)***

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2.7 <u>Nematodes in pastures of mixed *Medicago* spp.</u>

As part of the studies on nematodes in long-term rotation trials, pastures comprising mixtures of annual *Medicago* spp. (medic) were sampled in the summer of 1991. The land had been under a wheat-medic rotation since the 1983-84 season, the pastures sampled being established in the autumn of 1984. When sampled they had thus just completed the fourth cycle of the rotation.

Two auxiliary treatments are superimposed in the wheat phase of the rotation, namely four rates of nitrogen fertiliser and three intensities of grazing of the wheat stubble, in a split strip design. Each sub-plot was sampled, giving (with 3 replications) a total of 36 samples.

At establishment, 12 species of medic were sown, and all have persisted (Cocks 1992). However, the swards are dominated by 3 species, *M. rigidula* and *M. noeana* which were present in most of the samples, and *M. rotata* which occurred in 50 percent. Four other species were represented in the samples, *viz.*, *M. turbinata*, *M. constricta*, *M. aculeata* and *M. blanchiana*, but the last three occurred only once each (Table 2.7.1).

Table 2.7.1. Observations on the occurrence of nematode infestation in annual *Medicago* spp. in mixed pastures

Species	Occurrences in samples[1]	Infestation with *P. thornei* (%)	Number[2] of *P. thornei* /g roots
M. noeana	31	23	256
M. rigidula	35	51	331
M. rotata	17	6	5000
M. turbinata	7	29	384
M. constricta	1	100	1428
M. aculeata	1	100	11667
M. blanchiana	1	0	0

1. Total number of samples was 36.; 2. Mean for infested samples.

Half of the *M. rigidula*, and about a quarter of the *M. noeana* and *M. turbinata* were infested with root-lesion nematodes (*Pratylenchus thornei*) although the numbers per gram of root were not large. Twenty percent of the *M. rigidula* carried *Meloidogyne artiellia*, the root knot nematode, as did two samples of *M. noeana*. Nematodes were recorded in only 1 of 17 samples of *M. rotata*, but then the infestation was heavy. This leads us to speculate that this specimen may have been wrongly classified as *M. rotata*. *M. constricta* and *M. aculeata* were both infested when they were present, the latter very heavily.

It is difficult to assess the practical significance of this information. It would appear that *M. rotata* is probably resistant to the nematode species present in the environment, while *M. noeana* is somewhat susceptible, and *M. rigidula* considerably more so. Yet, judged by its representation in mixed swards, *M. rigidula* is apparently very competitive, and it would thus appear that this level of infestation does not disadvantage it.

The pastures are quite productive and over a wide range of seasonal conditions have supported an average of almost 2000 sheep grazing days per year in the past six years. In addition, there has been a substantial buildup of soil nitrogen, indicating that symbiotic dinitrogen fixation is active (FRMP 1993; Harris *et al*. 1994). Measurements of the soil water balance under the pastures also indicates the presence of an extensive root system which is able to exploit water stored in the soil to a depth of at least 180 cm (FRMP 1990). It would thus appear that, so far as the functioning of the medic is concerned, there are no clear deleterious effects of the nematodes at these relatively low levels of infestation.

Wheat following medic is less productive than wheat after other legumes such as lentil or vetch, but that can be shown to be largely due to the efficiency of medic in extracting soil water. It could be, though, that there is some effect of a carry-over nematode population on the performance of the wheat, the roots of which do show nematode lesions. The best way to address this would be to look at nematode populations at the time of planting. ***H.C. Harris, R. Makboul, M. Lababidi (FRMP); M.C. Saxena, S. Hajjar, M. Bellar (LP); M. Di Vito, N. Greco (C.R.N., Bari, Italy).***

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3. AGROECOLOGICAL CHARACTERIZATION

Introduction

The broad objective of agroecological characterization is to describe agricultural production environments and their natural resources, with the purpose of informing and guiding other research, development and, ultimately, production activities. It involves: the collection, computerization and integration of natural resource data bases; the generalization and application of the information in those data bases through models and linkage to other (eg crop growth) models; and, hence, the output of purpose-designed model packages and of specific information, eg on crop yield potentials or parameters of risk of pest attack or drought or frost loss, for identified sites or, spatially referenced, for geographically defined areas.

This is a demanding task, with potentially large payoffs, which, regrettably, has always been under-resourced in ICARDA. There have thus been severe limitations on data acquisition, on the dissemination of techniques, and on their extension and application outside the narrower field of agroclimatology. The two reports that follow exemplify what, nevertheless, has been achieved and provide strong reasons for strengthening input into these activities.

The first (3.1) shows how a reliable crop model linked to a 'weather generator' model that integrates the geographically referenced weather history of a target area can, from up-to-date weather information at any point in the current growing season, go on to predict the final harvest in the target area on a probabalistic basis. Thus descriptive material - patterns of past weather behaviour and of crop yield response to weather - are used, in predictive mode, to translate an evolving data base describing the current seasonal situation into a real-time forecast of production. This could, if required, be applied to a whole country, providing government planners with a reliable early-warning system of production shortfalls and surpluses on a regional or district basis.

The second (3.2) seeks to apply the spatio-historical weather perspective encapsulated in the 'weather generator' to the quantification of the parasitization risk of faba bean crops by orobanche (broomrape). Combining simple models of the phenological development both of faba bean and orobanche, the work shows how a small difference in the environmental requirements of host crop and parasite may be exploited, by choice of location and planting date, to minimize the risk of early infestation and subsequent crop failure. The results are mapped for an area of northwest Syria for which detailed weather records are available, but the same approach could be used anywhere with a sufficient data base of meteorological records. Moreover, similar approaches could be followed in respect of other pests which have a weather-related incidence or phenology. Very often the basic biological observation data, from which simple behavioural models might be built, is already on record. The potential to develop and refine such approaches in the general cause of integrated pest management appears to be considerable.

3.1 Stochastic Crop Yield Forecasting: Forecasting with Weather Generator and Crop Models

3.1.1 Introduction

Several times in the past, the use of aggregated models -- crop simulation models, stochastic climate models, and econometric models -- for the quantitative characterization of agricultural environments has been described in ICARDA annual reports. Examples were the combinations of a weather generator with a wheat simulation model (Göbel 1991, ICARDA 1993 and in press; also Pala elsewhere in this report) or with production functions for barley (Göbel 1990). This paper describes the usage of such models for crop yield forecasting and the *ex-ante* evaluation of alternative crop management options and discusses the possibility of using a similar approach for crop production forecasting.

3.1.2 Crop yield forecasting and crop production forecasting

In a general way, yield forecasting may be defined as providing information which increases the precision of the estimate of expected crop yield under defined cultural practices beyond the general yield potential of the site. Conceptually, yield forecasting is site-specific, valid for a certain point in space. In stochastic yield forecasting, the forecast yield is a function of:

- site characteristics, describing the general, for time horizons of several years, practically time-invariant qualities of the site, ie climate and soil profile,
- crop characteristics, the genotypic make-up of the crop variety,
- the specific weather conditions of the current cropping season, ie the site weather up to the moment the forecast is made plus, if available, the weather forecast for the following days; additionally, if available, the current soil moisture and nutrient status,
- past and anticipated future crop management during the current season,
- the knowledge of the interactions between climate and weather and between weather, soil, and crop built into the aggregate of models used in the process; because of the incomplete knowledge of crop-environment interactions and because some of the factors, like biotic competition, are ignored by the models, the specific status of the currently growing crop, as well as the current soil moisture and nutrient status, are helpful for calibration purposes.

Crop production forecasting adds a spatial dimension to yield forecasting. It can be regarded as the integration of forecast, site-specific yields across all sites planted with a certain crop. It is a much more demanding task than yield forecasting, requiring the same data as is required for yield forecasting, but on a spatial basis, either continuous or for a representative sample of points, plus information on the current season's land use, ie information about which crop and variety are growing where.

3.1.3 Method and models

Stochastic yield forecasting uses a weather generator, a crop model, which may be a simulation model or an empirical model, and some statistical tool to analyze the results. An economics module can be used to provide an economic interpretation of the results. The current study employs the Spatial Weather Generator (SWG; Göbel 1990, 1991) linked to the wheat simulation model SIMTAG (Stapper 1993) and a custom-written module for the statistical and economic analysis of the output.

In this setup, the weather generator creates examples of weather series forming a synthetic sample of growing seasons -- or parts thereof -- which is in all relevant properties representative of the climate at the site of the simulation. The crop model simulates the appropriate corresponding sample of crop yields, which in turn provides the basis for the calculation of economic returns.

All model outputs are amenable to statistical analysis, making it possible to characterize the site environment and the effects of its variability in time on crop production, not only through means but also through descriptors of dispersion, shape, and other properties of the frequency distributions. To evaluate the merits and disadvantages of competing land or crop management options, one is thus not restricted to the comparison of averages or of typical outcomes but is able to compare the resulting frequency distributions through appropriate techniques, such as stochastic dominance analysis.

It has to be emphasized, however, that the weather series produced by the weather generator are random instances, representative of the climate of a certain location, not actual forecasts of weather conditions to be expected at any time in the future. Similarly, the crop yields generated by a combination of weather generator and crop model are from a random series, representative of yields expected as the result of a certain crop management under the climatic and environmental conditions characterizing the simulated location.

If the weather generator is used to generate series of entire growing seasons, both the sequence of the generated yields and the starting conditions for the generation and simulation in the climate-crop-system are random, each season chaining to the end of the previous season's random weather series. The yield values so obtained provide a frequency distribution of the yield to be expected at the given location with random initial conditions; ie they reflect the general yield potential of the site for a certain crop and management.

Things are different if the initial conditions are fixed and the generation/simulation is repeated a number of times, each time reinitialized to the same starting conditions. Then a "memory effect" of the stochastic generation process becomes apparent. This is a consequence of the statistical models employed by the weather generator to model the sequence of wet and dry days -- in the present case this is a second order Markov-chain with two states, wet and dry -- and to handle air temperature and global radiation, which are conditioned according to whether a day is wet or dry, and for which the serial correlations between consecutive days are maintained. This "memory effect" is most noticeable over short periods of a couple of day. It then decreases gradually but is still apparent in generated sequences of several weeks' length. Its expression is enhanced by a coupled crop model, since some of the climate effects on the crop are irreversible. The result is a less dispersed distribution of output variables, particularly by yield variables, which are biased towards the most likely yield given the current preconditions and anticipated future management. By harvest day, the distribution will have converged on a single value close to the observed yield, the remaining difference being due to the error term of the crop simulation model.

The differences between the yield distributions generated in this way, reflecting season-specific differences in initial growth conditions, can thus be used for forecasting purposes, as can the difference between yield distributions of crops grown under the same initial growth conditions, but with varying anticipated crop management.

The mode of operation of the aggregated models is shown in Figure 3.1.1. One year or cropping season is represented by the thick horizontal arrow. On it, from left to right, several relevant dates are marked by vertical lines: the start of the season, marking at the same time the beginning of the soil moisture balance well ahead of planting time; the planting date; the date labelled "Today" on which the forecast is being made; and the harvest period. From the start of the season until the day the forecast is made, the simulation of the crop model is driven by actual weather data measured at the site. The agreement between the simulation and the conditions in the field can be verified and corrected, if observations of the crop stage and condition

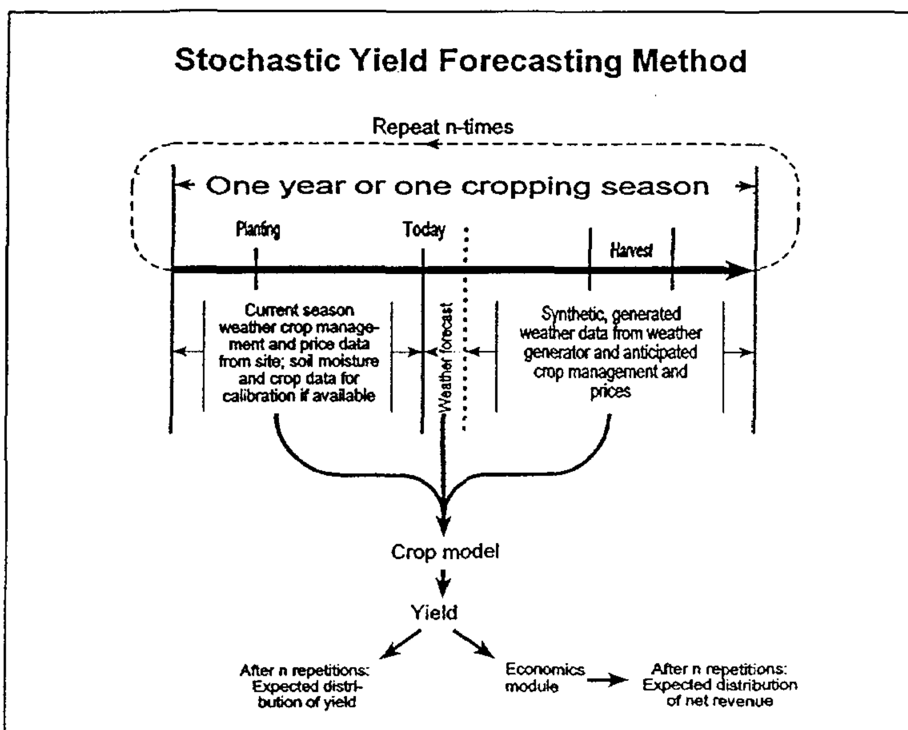

Figure 3.1.1. The principle of stochastic yield forecasting (for explanation see text)

and soil moisture and nutrients are available. From the day the forecast is made until the end of the season, the crop model is driven by synthetic, generated, yet site-specific weather data from the weather generator. For approximately the first five days, the weather forecast of the local meteorological service can be used instead of synthetic weather, if one of adequate precision is available.

The combination of weather generator and crop model go on to produce a harvest date for the season and a yield value. An attached economics module converts the yield into net returns using actual price data for inputs during the first part of the simulation, anticipated future prices for the second part. Then the system loops back and starts another simulation, again based on measured current season weather data up to the day on which the forecast is made, thereafter switching to weather forecast, if available, and then to synthetic, generated weather. After repeating the loop a number of times, the results obtained are frequency distributions of expected yield and net returns.

The entire multi-year cycle may then be repeated for alternative crop management options, leading to different predicted frequency distributions of yield and net returns. The expected outcomes of the alternative options can then be compared statistically. It would be similarly possible to compare alternative future price scenarios and their effect on income.

For the computation of the coefficients for the weather generator, on which the generation of synthetic weather data for the second part of the season is based, a long series of climatic data (20 to 30 years or more) for the site is needed. Alternatively, as in the case of this study, a spatial weather generator is used, which permits the spatial, topography-guided interpolation of the required generator coefficients from those computed for the nearest surrounding weather stations. It is more difficult to manage without the current season's site weather data (for the specific site). If it is not available, it may be possible to interpolate temperature data from the nearest weather stations and obtain precipitation estimates from remote sensing, from weather radar or, for convective types of precipitation, from Meteosat or NOAA satellite imagery.

3.1.4 An Example: forecast of durum wheat yield at Tel Hadya

The stochastic yield forecasting technique was tested against data for two treatments in a supplemental irrigation experiment in the 1992/93 season. The experiment is described by Oweis *et al.* (1994) and again elsewhere in this report.[1] The treatments selected were those using the durum wheat variety Cham-1 planted on 10 November, rainfed and with full profile recharge, in each case with the nitrogen level closest to the optimum (0 kg N/ha for the rainfed treatment, 120 kg N/ha for the full recharge). The genetic coefficients for Cham-1 for use with SIMTAG had been determined before by Harris (pers. comm.) and they were refined using data from this experiment. The selection of the N-levels was guided by the limitations of SIMTAG, which incorporates no nutrient submodels and assumes always an optimal supply of nutrients. The yield figures simulated by SIMTAG apply directly to experiment data from small plots (the average of four replicates of 15 m^2 each in this case); for large plots it would have been necessary to apply an empirical factor to decrease the predictions of the model.

Although current weather data for Tel Hadya are available from ICARDA's weather station, a representative climatic series for the site is not available yet, since weather observations started only after the installation of the experiment station in 1978. The weather generator coefficients for the site were therefore interpolated with the help of the Spatial Weather Generator from data of 18 government meteorological stations within a radius of 70 km, using 26 years of observations. The soil at the site is a calcixerollic xerochrept (Ryan *et al.* in press). Soil profile descriptions containing all data required by the SIMTAG wheat model have been prepared by Stapper (*loc. cit.*) and Harris (pers. comm.).

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1. I would like to thank T. Oweis for supplying data on crop management, phenology, and grain yield, as well as A. Mazid and A. Rodríguez for additional information on prices of inputs and outputs and costs for farm operations.

For the period from planting on 10 November 1992 to maturity, which occurred approximately on 21 May 1993 for the rainfed treatment and on 1 June for the treatment with full profile recharge, stochastic yield forecasts were made at two-weekly intervals, as well as for the dates when irrigations were applied. For each forecast, one thousand growing seasons were simulated, each time using current data from Tel Hadya weather station up to the day for which the forecast was being prepared and synthetic data from the Spatial Weather Generator for the remainder of the season. Weather forecasts were not used.

Figure 3.1.2 shows the expected yield distributions for the rainfed treatment obtained in fourteen forecasts between planting and maturity. Initially, the shape of the

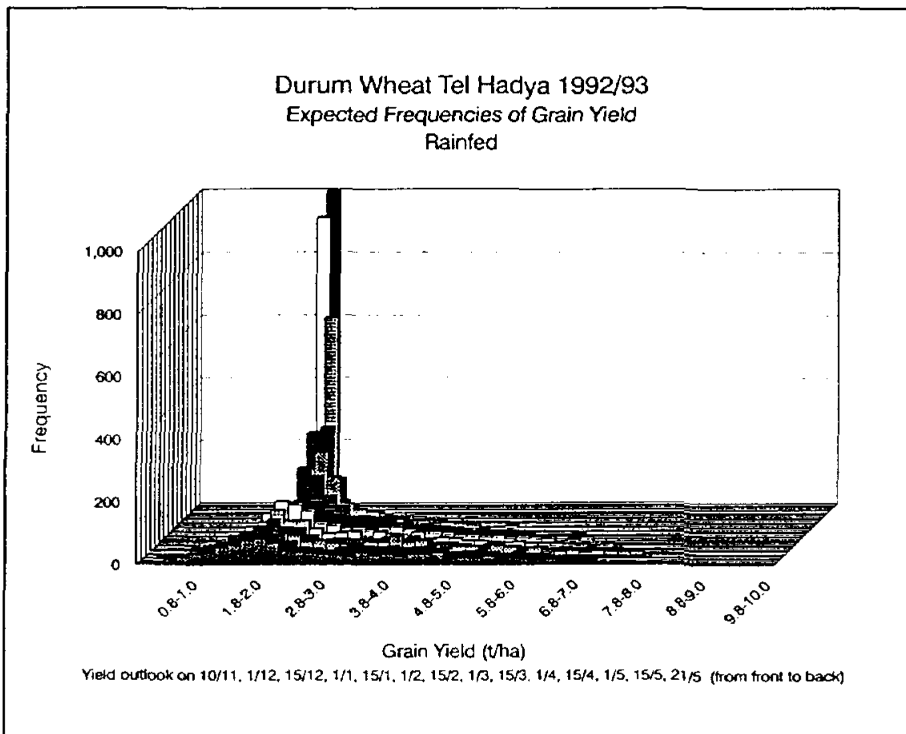

Figure 3.1.2. Histograms of expected grain yield of rainfed durum wheat for fourteen forecast dates between 10/11 (planting) and 21/5 (maturity)

distributions is very flat, reflecting the high variability and considerable uncertainty about future weather in the semi-arid environment. They do, however, become gradually less dispersed, as more and more of the stochastic weather is replaced by actually observed weather, unchanged between simulations, and as the possibilities of the crop to react to cumulative effects of weather become more limited with the progress of phenological development. During March, the situation shows a marked change. The distributions become less dispersed, indicating the increasing unlikelihood that a weather event would dramatically influence the yield from this stage onwards. The slope on the lower-yield side is much steeper during March and April than on the side of the higher yields, which shows that by then eventual yield could hardly be any more negatively affected by unfavourable weather, although there still was some chance that favourable weather would improve yields. Weather during May had no further influence on grain yield. Already three weeks before maturity, the forecast converged around 2.1 t/ha. In the end, simulations using real weather through until maturity, also gave 2.10 t/ha, compared with 2.19 t/ha which was the actual observed average yield of the four replicates.

The same data are presented in a different form in Figure 3.1.3, with yield on the y-axis and date on the x-axis, and curves linking yields expected to be reached with the same probabilities. In this form of presentation, it is easy to follow the development of the median and other percentiles of expected yield as they converge towards the actual yield at harvest. From planting until mid-December, all the percentiles showed an upward trend, reflecting to favourable weather during the establishment phase of the crop. During the second half of December, the crop was under moisture stress, which resulted in a downward correction of expected yield. It is interesting to note that the median of the expected yield distribution was already, from the beginning of March onwards without interruption, very close to the final value. It is also very clear that subsequent weather was extremely unlikely to affect yield in any way, positively or negatively, after mid-April.

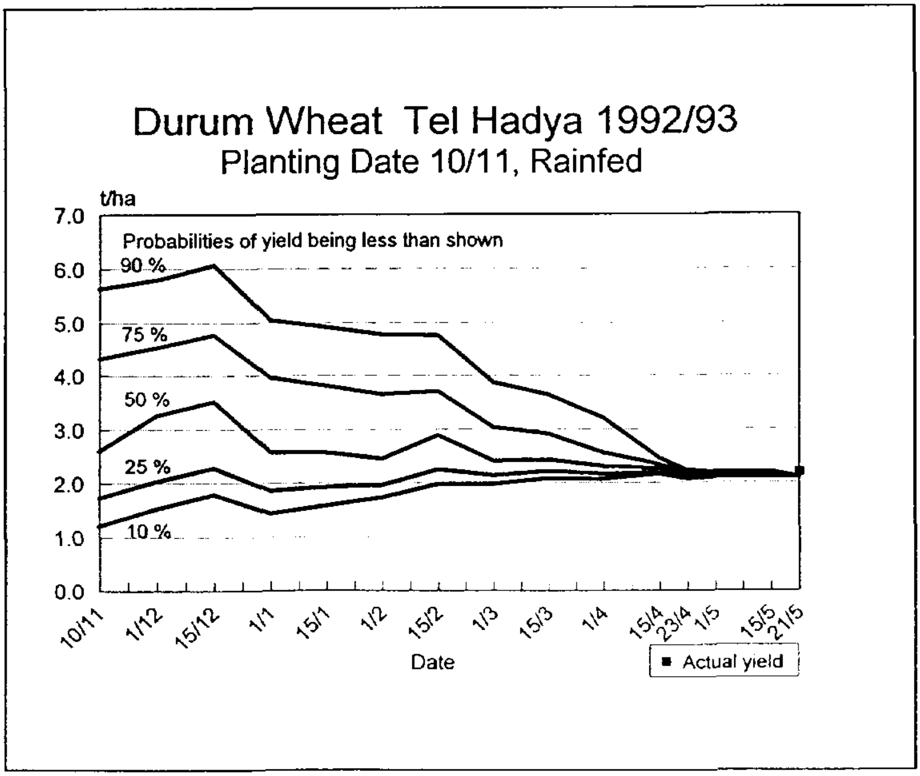

Figure 3.1.3. Yield levels of rainfed durum wheat expected with selected probabilities according to forecasts made on the indicated dates from planting to maturity. The actually observed yield was 2.19 t/ha.

The way in which supplemental irrigation changes the yield outlook is very conspicuous in Figures 3.1.4 and 3.1.5. Up to 15 March, the yield histograms and percentage points are identical to those shown in Figures 3.1.2 and 3.1.3 for the rainfed crop. The irrigation with 130 mm on 1 April caused a dramatic shift of the distribution towards higher values, almost tripling expected yields. Another irrigation of 145 mm on 15 April produced another significant shift towards higher yields. With full knowledge of weather until maturity, the simulation produced a grain yield of 8.68 t/ha compared to an actual yield of 7.70 t/ha. The overprediction of about 12% lies within the typical error margin of predictions with crop simulation models but could also be due to slight disease or pest infestation.

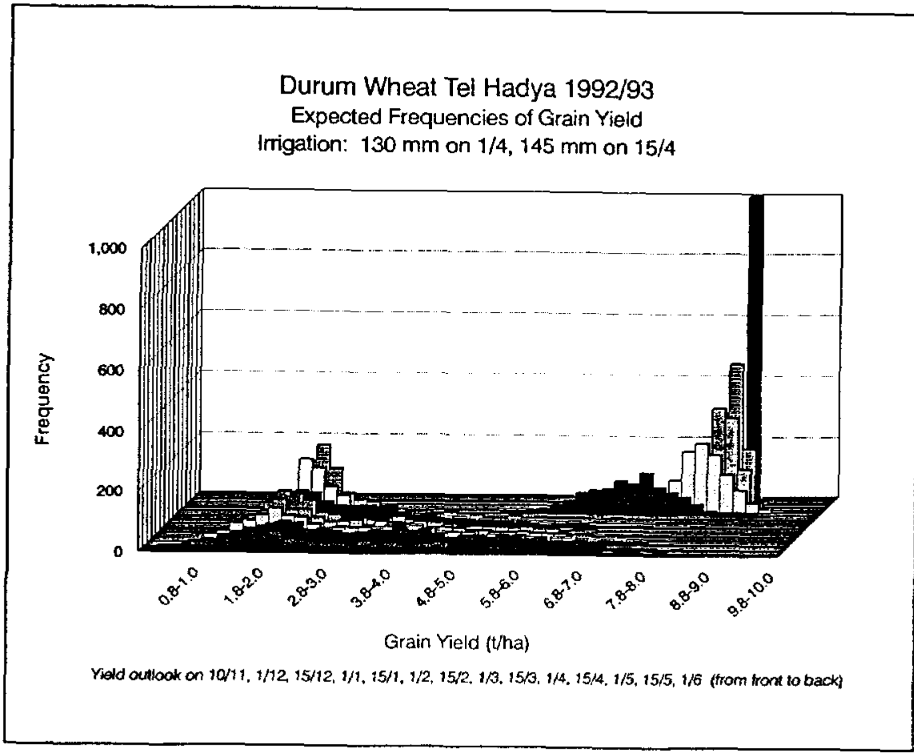

Figure 3.1.4. Histograms of expected grain yield of twice irrigated durum wheat for fourteen forecast dates between 10/11 (planting) and 1/6 (maturity)

For 1 and 15 April, the days that the crop was irrigated, Figure 3.1.5 permits the direct comparison of the expected yield distributions with and without irrigations on those days. The fact that the shifts caused by the irrigations are so dramatic -- the 10% percentile of expected yield with irrigation is higher than the 90% percentile without irrigation -- demonstrates clearly that it is the moisture deficit which is the limiting factor and that the genetic yield potential of the cultivar cannot be exploited under rainfed conditions at this site.

That the irrigations on 1 and 15 April could be expected to be highly profitable in economic terms is illustrated by Figure 3.1.6. The diagram on the left compares the cumulative distribution of expected net returns

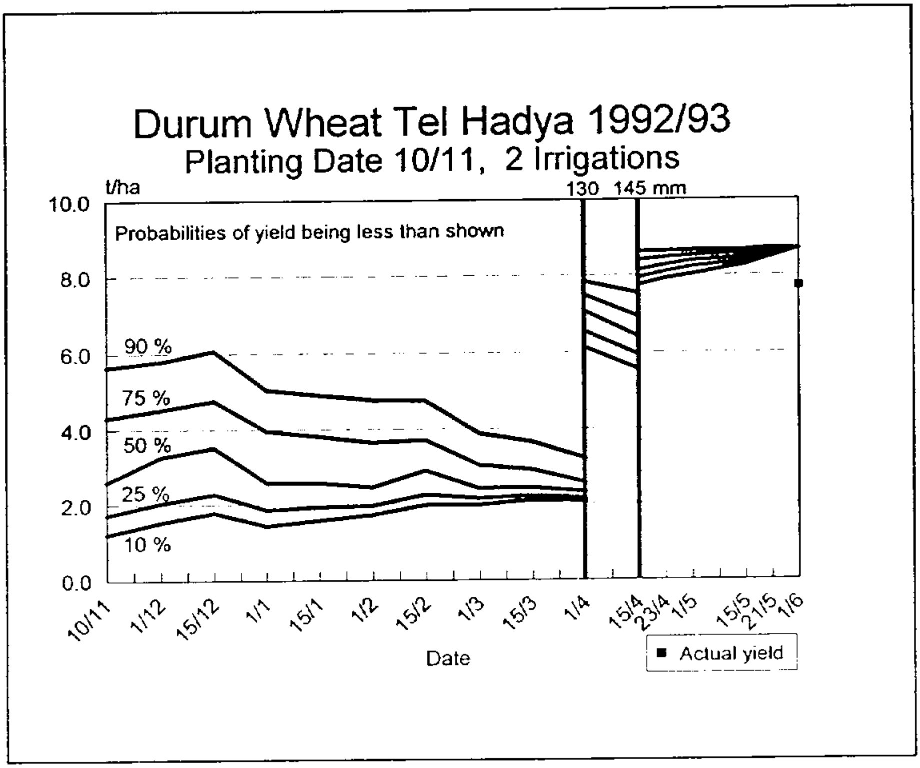

Figure 3.1.5. Yield levels of twice irrigated durum wheat expected with selected probabilities according to forecasts made on the indicated dates from planting to maturity. The actually observed yield was 7.70 t/ha

of the rainfed treatment on 1 April to that of the irrigated treatment. The difference of the medians is more than 40,000 Syrian Pounds (SYL) per hectare, which means that the net returns could approximately be tripled by the first irrigation. The second irrigation on 15 April -- centre diagram -- could still be expected to be profitable, even though at approximately 15,000 SYL/ha, the margin to a single irrigation was not as conspicuous as that between a single irrigation and the rainfed treatment. But beyond increasing the expected net returns, the second irrigation also had a stabilizing effect on the yield, evidence of which is the flatter slope of the curve.

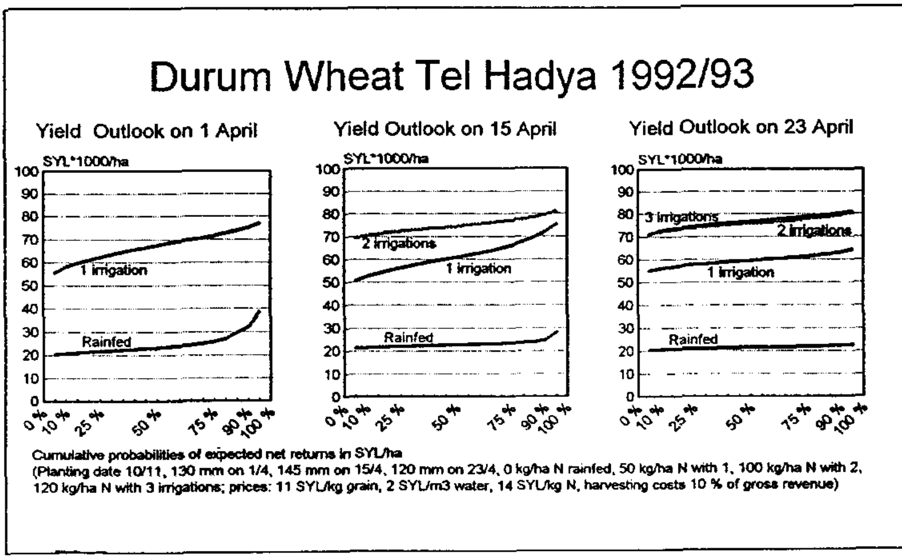

Figure 3.1.6. Cumulative probability distributions of expected net returns from durum wheat grain yield, rainfed and with one, two, and three irrigations on 1, 15, and 23 April

A third irrigation of 120 mm on 23 April would, however, hardly have been economic, even though the soil profile was depleted of moisture and the crop was still green. This can be seen in the right-hand diagram. The curve for the treatment with three irrigations virtually lies on top of the one for two irrigations. On closer inspection, one would find that the two curves cut each other at the 7% level. This means that the third irrigation would not noticeably increase the net returns, and in 7% of years one would actually expect to lose money. There would, though, still be an increase in grain yield from the third irrigation, but it would just be big enough to cover the additional marginal costs and would not pay anything towards the additional labor involved nor towards the amortization of the capital cost.

Since it is possible to generate results and curves as shown in Figure 3.1.6 in real time, before the decision to irrigate or not is made, the method could serve as a tool in the decision-making process in farm management. By using models other than SIMTAG, which are able to simulate the effect of varying levels of nutrient supply on crop growth and yield, one could answer similar questions in relation to fertilizer applications, eg nitrogen top-dressing. In combination with disease models, the likely profitability of fungicide applications could be predicted. The same applies to insecticide applications if pest models are available.

3.1.5 Prospects for improvement and for adapting the method for production forecasting

The aim is to provide a forecast which is as accurate as possible, ie to exclude as many as possible of the potential, but unrealized, possibilities of development of weather and yield formation throughout the season, as soon as possible. The forecast yield distribution should show as little dispersion as possible, with the median yield pointing towards the eventually achieved yield as early in the season as possible.

On the weather generator side, this means that the longer lasting the "memory effect" is, which is built into the model, the better, since this limits for a longer timespan the possible directions into which the generated weather can develop, causing less dispersed distributions of expected weather events and crop responses to them. In other words, this means that the forecast yield distribution is likely to be more narrowly focussed if the weather generator can be enhanced to simulate persistencies of weather going beyond a couple of days in a more realistic way. An obvious way of doing this would be to classify the synoptic weather situations for each day and use calculated transition probabilities between the different classes to model the persistencies and changes of weather from one type to another. Such a weather generator has recently been developed for sites in Germany, based on the classification of weather situations employed by the German Weather Service (Schubert 1994). Since the classification of weather situations employed is specific for central and western Europe, the approach cannot be transferred directly to other regions of the world. A general approach should not be based on a predefined classification scheme but should create the classification itself as part of the process of estimating the weather generator coefficients.

On the crop model side, the prediction of yield will be the more accurate, the more that the interactions of the crop with its physical and biological environment can be modeled with reasonable accuracy. Many currently available crop models are quite well able to model phenological development, dry matter accumulation and partitioning, and the effects of moisture stress. However, typical weaknesses include the handling of cold or heat stress, the dynamics of nutrients and the effects of nutrient stress (except for the nitrogen submodels attached to some of the models), the effects of competition between crop plants and with weeds, and the effects of diseases, parasites, and pests (although a number of separate disease and pest models do exist). Improvement or inclusion of the handling of any of these effects on yield would obviously improve the yield forecast. For forecasts stretching beyond a couple of days, the effects of diseases, parasites, pests, and weeds would have to be modeled in a probabilistic or stochastic manner, similar to the weather generator approach, since the intensity of their influence on yield depends not only on the environmental conditions during the period of interaction with the host plant, but also on whether the pathogen, pest, or weed exists at the site and is able to infect, attack, or compete with the crop in the first place.

Whether the method can be used for production forecasting depends on whether the necessary input data can be made available in real time. No major problems are posed by the time-invariant site characteristics of climate and soil. The real time weather data could be obtained from the network of synoptic weather stations or from agrometeorological stations. But for precipitation there would be a need for data either from satellite imagery (NOAA, Meteosat) if, as in the tropics, the precipitation were of the convective type; or for frontal precipitation, only weather radar seems to offer reasonably accurate spatial estimates. This is one of the reasons why more and more countries in the temperate and subtropical zones are setting up national or provincial weather radar networks. The necessary land-use and crop information -- on which areas which crops are growing, which varieties were planted, which is the typical management used, which stages have the crops reached, and what state are they in -- requires the support of an efficient extension service well aware of what farmers are doing and how the crops look and able to take representative samples for model calibration all across the region. Corroborating data can be obtained from satellites (Landsat, Spot, ERS).

These are demanding, but not forbidding, data requirements. As with yield forecasting, the advantage would be to obtain a frequency distribution of expected crop production in the region, rather than a single estimated figure. In a country where an efficient extension service is already collecting the necessary information and doing the sampling for national production forecasting by a different method, it should be tested to see if production forecasting based on stochastic yield forecasting would give planners a more accurate and detailed picture of the future. ***[W. Göbel with A. El Ouali, Maroc Météo, and A. Ambri, INRA-Maroc]***

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3.2 Mapping *Orobanche Crenata* Risk to Faba Bean Cultivation in Northern Syria

3.2.1 Introduction

Orobanche crenata Forsk., crenate broomrape, is a holoparasitic flowering plant that attacks a wide variety of hosts, among them a number of economically important legume crops including faba bean, chickpea, and lentil. With the exception of the cold highlands, *Orobanche crenata* is spread throughout the Mediterranean region. The damage caused to agriculture is substantial; a faba bean crop severely infested by the parasitic weed may be completely wiped out and produce no yield at all. The damage is greater in humid areas and in irrigated agriculture than in rainfed agriculture in semi-arid areas. The seeds of *Orobanche crenata* remain viable for up to ten years in the soil. It is therefore not easy to eliminate the parasite by changing the sequence and combination of crops in the rotation. *Orobanche crenata* can only be eradicated from a field by growing non-susceptible crops for many seasons in sequence or through solarization of the soil (Linke 1992). Without eradication of the weed, it is possible to reduce the infestation and damage caused through the use of less susceptible cultivars or through late planting (van Hezewijk *et al.* 1987, Mesa-García and García-Torres 1986).

That it is possible to reduce *Orobanche crenata* damage to faba bean in some years through late planting is an indication that the environmental requirements of parasite and host plant are not identical. Analysis of experiments undertaken at Tel Hadya over several growing seasons by two of the authors and other researchers[1] shows that *Orobanche crenata's* attack on faba bean is favoured by warm temperatures and by high soil moisture levels during the early stages of the parasite's life cycle. As the present report tries to show, this knowledge can be used to estimate the frequency across growing seasons that a faba bean crop will suffer severe yield loss at a given site. The quantitative risk is essentially a function of climate (temperature and rainfall) and can therefore be mapped and used to delineate areas where the parasite poses an actual or potential hazard to faba bean cultivation. It is not able to provide a quantitative assessment of faba bean yield loss.

3.2.2 Faba bean phenology and *Orobanche crenata* development

The phenological development of faba bean (*Vicia faba* L.) is determined by temperature and daylength. The FAGS simulation model (Stützel 1990), originally developed for German faba bean cultivars, is able to predict faba bean flowering for Tel Hadya, with an error of plus/minus two days, as a function of date of emergence and mean air temperature. For the present study, therefore, the approach developed by Stützel was used. Cultivar-dependent genetic coefficients were estimated for the cultivar ILB 1814 (Syrian Local Large).

The FAGS model uses two equations with cultivar-specific coefficients, one for days with a mean air

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1. The authors are indebted to M.C. Saxena for his invaluable assistance in examining original experiment records and permission to use the data.

temperature below or equal to the optimum temperature for flowering and one for the days with a higher temperature It uses these equations to compute a daily phenological increment towards flowering as a function of the interaction between daylength and daily mean air temperature, assuming a base temperature of 0°C. The daily values are accumulated, and flowering is assumed to begin, when the cumulative value of the increments towards flowering is equal to one. Pod setting commences 200 degree days after the start of flowering, rapid seed filling 350 degree days later, again taking 0°C as base temperature. From then on, all shoot dry matter, newly assimilated or retranslocated, is partitioned into the pods.

For the period from planting to emergence, not covered by the FAGS model, the following approximations are made on the basis of data from various experiments and observations in the Syrian environment:

- From germination to emergence, it takes a temperature sum of approximately 240 degree days, using mean soil temperature at 10 cm depth and a base temperature of 3°C; if the crop is irrigated at planting, the same temperature sum is valid for the period from planting to emergence;
- Under rainfed conditions, it is assumed that germination of a planted crop will occur 20 mm if rain falls over one or two days, but that the crop fails if it does not rain at least another 10 mm during the following ten days (1 mm of this requirement being waived for every 1.5 mm of rain in excess of the 20 mm during the two days before germination). If an irrigation of 30 mm or more is given at planting, no delays of germination and emergence are expected.

Orobanche crenata germinates only after detection of stimulating agents emitted by the host plant. The parasite then grows against the gradient of the stimulating agent and attaches itself to a secondary root of the host, where it develops a haustorium to tap assimilates and water. Over the point of attachment, *Orobanche* forms a tubercle, from which crown roots and a bud develop. Out of the bud grows a shoot which emerges and flowers. Where crown roots come into contact with other host roots, secondary haustoria and tubercles form. If enough assimilates are available, ie if not too many primary attachments to the same host plant have taken place, secondary shoots develop from these secondary tubercles (Pieterse 1979). Each shoot produces up to 500,000 seeds.

The time which elapses between the planting of the crop and the attachment of *Orobanche* to the host plant depends on a whole range of factors:

- The soil temperature; the warmer the soil, the faster the parasite can grow. The base temperature for *Orobanche crenata* from germination to bud formation is higher than that for vegetative growth of *Vicia faba*. According to literature, it is around 5°C (Sauerborn 1989, van Hezewijk *et al*. 1991); although with the experimental data used in this analysis, the best fit was achieved with 3.5°C;
- The soil moisture content; a wetter soil facilitates the growth both of faba bean roots and the germinated parasite. In addition, agents stimulating parasite germination emitted by the host plant spread faster. On top of that comes the indirect effect of increased root length density of the *Vicia faba* in a moist soil, which reduces the average distance between host plant root and parasite seed;
- The seed bank of *Orobanche crenata;* at low to medium infestation rates the average duration from planting to parasite attachment is relatively delayed by the longer average distance between host plant root and parasite seed. With high infestation rates (more than approximately 200 seeds per kg of soil in the top 15 cm), no delay is apparent;
- Genotypic differences between different *Vicia faba* cultivars, expressed as differences in root length density at a given soil moisture content, in the amounts of parasite germination stimulating agents emitted by the roots, as well as by the possible presence or absence of parasite germination inhibiting agents.

Once attachment has taken place, *Orobanche crenata* acts like an additional sink for *Vicia faba* assimilates. It does not interfere with the photosynthetic capabilities of the host; the additional sink may even have a stimulating effect.

***Vicia faba* phenology (ILB 1814):**

RTF = -0.000556 + 0.000122 AT * DLG
(mean air temperature ≤ 12.3 °C)
RTF = 0.0596 - 0.00001 AT * DLG
(mean air temperature > 12.3 °C)
Flowering of first internode occurs when cumulative RTF since emergence is equal to one.
(RTF: rate towards flowering, AT: mean air temperature, DLG: day length)

***Orobanche crenata* development:**

DTB = 617.3 - 44.02 ST - 2.9562 P + 0.27179 ST * P
(Base temperature: 3.5 °C; r^2 = 0.79)
DSH = 51.083 - 1.7447 ST + 0.96283 P - 0.08834 ST * P
(Base temperature: 5.0 °C; r^2 = 0.87)
(DTB: days from faba bean germination until tubercle observation, DSH: days from tubercle observation until shoot emergence, ST: mean soil temperature during the period at 10 cm depth, P: total of precipitation and irrigation during the period)

The strength of the sink created by parasite shoots is comparable to that of *Vicia faba* pods at the rapid grain filling phase. As soon as *Orobanche* starts growing a shoot, all assimilates are directed towards the parasite, unless faba bean is already at the stage of rapid grain filling of a pod. Then this pod will continue to develop and produce seeds, but subsequent pods will not develop further (Mosaddegh-Manschadi *et al.* in press).

The available data from Syria on the phenology of *Orobanche crenata*, in publications (van Hezewijk *et al.* 1987, Sauerborn 1991, Mosaddegh-Manschadi *et al.* in press) and from unpublished experimental records, often contain information on only a very limited number of development stages. To work with these data, which are from six growing seasons at one site (Tel Hadya), it was therefore necessary to use a very simple model of *Orobanche* development. Only two development stages are taken into account: tubercle and shoot emergence. Since the information sources often do not provide more precise definition of what has been observed, tubercle stage is taken to mean any stage in the development of the parasite between development of a visible tubercle after attachment and the formation of the bud. Using observations made on the local large-seeded Syrian *Vicia faba* landrace in plots with high *Orobanche crenata* infestation rate, the days elapsed between planting of faba bean and the tubercle stage, were regressed against the period mean soil temperature at 10 cm depth, the period total of rainfall and irrigation, and the interaction between these two factors. A similar calculation was made for the period from tubercle stage to *Orobanche* shoot emergence.

The assumption is that, if *Orobanche* emerges before faba bean has entered the rapid grain-filling stage of the first pod, ie before 550 degree days after the beginning of flowering, total yield loss is a certainty. If bud formation, the end point of the tubercle stage as defined for this analysis, were reached by then, near total yield loss would also already be very likely, because *Orobanche* shoot growth follows immediately after bud formation, after which faba bean is not able to grow any new pods. Since sufficient information on the timing of bud formation is not available, it is assumed instead that significant yield loss is already likely if the simulated date of the tubercle stage precedes the beginning of flowering of faba bean. The underlying supposition here is that, having already reached the tubercle stage, *Orobanche* is likely to form buds and start growing shoots before faba bean is able to grow more than a small number of pods. Severe yield loss can be excluded, if the tubercle stage has not been reached at the time of start of rapid grain filling.

3.2.3 Integration of host plant phenology and parasite development with a Spatial Weather Generator

A weather generator is a stochastic model, based on a number of coefficients computed from weather station data, able to generate synthetic weather series of any length desired. The generated weather is random but shows all the characteristics of real weather at the site. It can be regarded as weather which, given the site climate captured in the weather generator coefficients, might happen at the site at any time in the future. Weather generators produce possible weather scenarios but not forecasts in the sense of weather forecasts. By generating many years of data, it is easy to evaluate the expected frequencies of particular weather events at the site in question.

While a weather generator is able to generate synthetic weather only for the site of the weather station from which the generator coefficients were computed, the spatial weather generator (Göbel 1990, 1991) is capable of generating weather for any point in the area covered by its generator coefficient maps. These are created through topography-guided spatial interpolation of the coefficients computed for each of the weather stations in the region. The spatial weather generator can therefore be used to create maps by running the program successively for each point of a grid of points across the target area.

By coupling the spatial weather generator with a weather-driven predictive model of any type, it is possible to analyze and map the expected frequencies of events predicted by that model. In this case, the spatial weather generator was coupled with the phenology submodule of the FAGS faba bean model and with the regression model of *Orobanche crenata* development described above. The *Orobanche* model requires soil temperature as input. The spatial weather generator, however, is capable only of generating daily series of precipitation, maximum and minimum air temperature, and global radiation. It was therefore necessary to add another module to convert air temperature measured inside the screen at 150 cm above the ground into an estimate of soil temperature at 10 cm depth.

Such a module has been published as part of the CERES simulation models for cereal crops (Jones and Kiniry 1986). Verification with actual weather data from Northern Syria was, however, very unsatisfactory. Instead, a regression model was developed based on seven to thirteen years of data from five of ICARDA's meteorological stations in Northern

Syria. The best fit was achieved using the average air temperatures of the current day, the previous day, one of the five days before that, and one of the fifteen days before the five-day period as independent variables. The regression was calculated separately for each calendar month. The correlation coefficients range from 61% to 86% for the different calendar months. Across individual years, the standard errors of the estimates vary between 0.8 and 2.1°C.

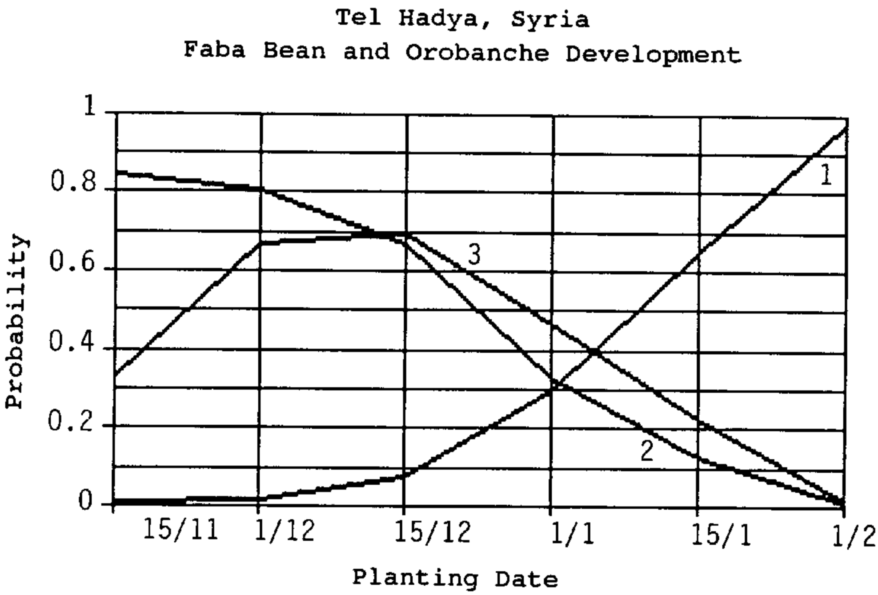
3.2.4 Results and discussion

Using the linked models, an attempt was made to address the following questions:

- Assuming a medium to high infestation of the soil with *Orobanche crenata* seeds, what is the likelihood that *Vicia faba* (ILB 1814) suffers severe yield loss if planted at a certain date?
- How effective is late planting as a counter-measure against *Orobanche crenata*?
- Are there areas in Northern Syria where *Orobanche crenata* cannot thrive because of a climate that is unsuitable for the parasite?

Using the spatial weather generator, one hundred growing seasons were simulated for the points of a grid spanning Northern Syria between 35°30' and 36°30' North and between 36°30' and 38°00' East. The size of the grid cells was 4' by 4', or about seven by six kilometers. To reduce the inter-seasonal variability due to late emergence of faba bean in years with a dry start of the season, an irrigation of 30 mm with planting was assumed, instead of simulating an entirely rainfed crop. This also conforms to local practice, as faba bean would not be planted into dry soil; either an initial irrigation would be given or planting would be postponed until the topsoil contains sufficient moisture for germination and emergence.

Figure 3.2.1 shows the effect of the planting date on the timing of *Orobanche* tubercle stage and shoot emergence in relation to faba bean phenology for Tel Hadya. The curve indicating the probability that faba bean reaches the rapid seed filling stage before *Orobanche* is in the tubercle stage,



Curve 1 is Prob. Tubercle after seed filling
Curve 2 is Prob. Tubercle before flowering
Curve 3 is Prob. shoot before seed filling

Figure 3.2.1. Simulated coincidences of critical development stages of faba bean with development stages of *Orobanche crenata* at Tel Hadya, Syria, for different planting dates

ie the probability that *Orobanche* will cause no or only moderate damage, rises from 1% for the planting date of 15 November, at first gradually, then more steeply to 30% for 1 January and 98% for 1 February as planting dates. Thus the probability that *Orobanche* will cause substantial or even total damage, decreases from 85% for planting on 15 November to 33% on 1 January and 1% on 1 February. Not quite so harmoniously, the curve showing the probability that *Orobanche* shoots emerge before faba bean has begun to fill grain rapidly, which entails the complete loss of the crop, first rises from a value of 33% for crops planted on 15 November to 70% for 15 December plantings, before it drops off to 2% for crops planted on 1 February.

These results corroborate the theory that late planting of faba bean reduces the risk of *Orobanche crenata* damage.

However, to reduce the risk to insignificant levels, at Tel Hadya, planting would have to be so late -- in the second half of January according to the simulations -- that faba bean yield would suffer. Not explained is the apparent decrease of risk of total yield loss for plantings before 15 December. This may be an artifact of the oversimplified model employed to simulate *Orobanche* shoot emergence and the small data base, with few data on early planted crops, on which it is built.

Figures 3.2.2 and 3.2.3 add a spatial dimension to some of these findings. For the two planting dates of 1 December and 1 January, they show the probabilities of *Vicia faba* escaping attack by *Orobanche crenata* with no or little harm, ie the probabilities of faba bean reaching rapid grain filling before *Orobanche* tubercles are visible. By comparing the two maps, it becomes apparent that late planting reduces the risk of *Orobanche*-inflicted damage everywhere with the exception of the wetter areas in the west and northwest.

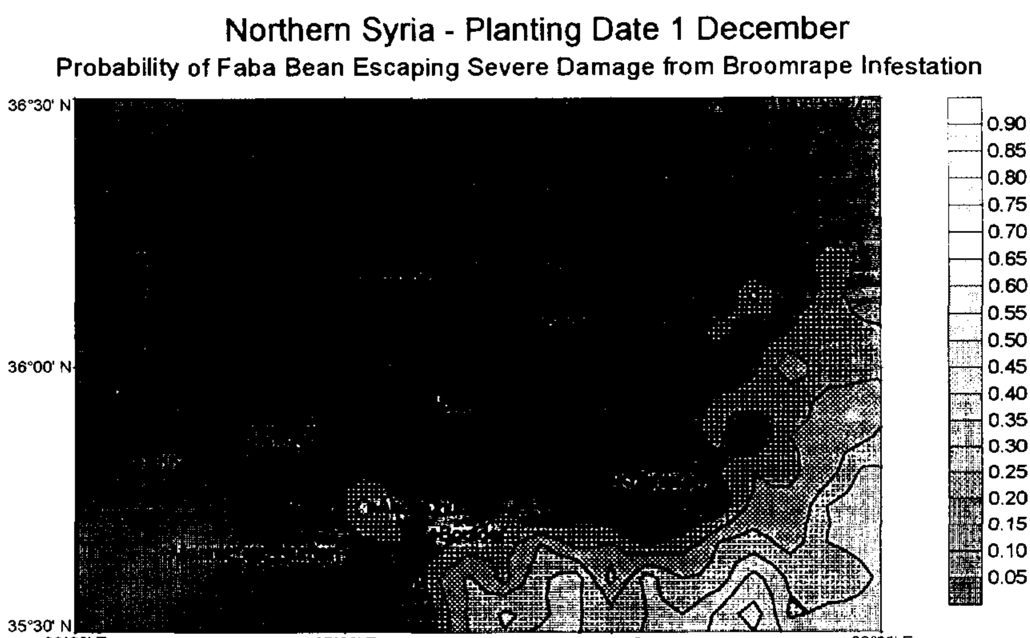


Figure 3.2.2. Northern Syria - Planting date 1 December

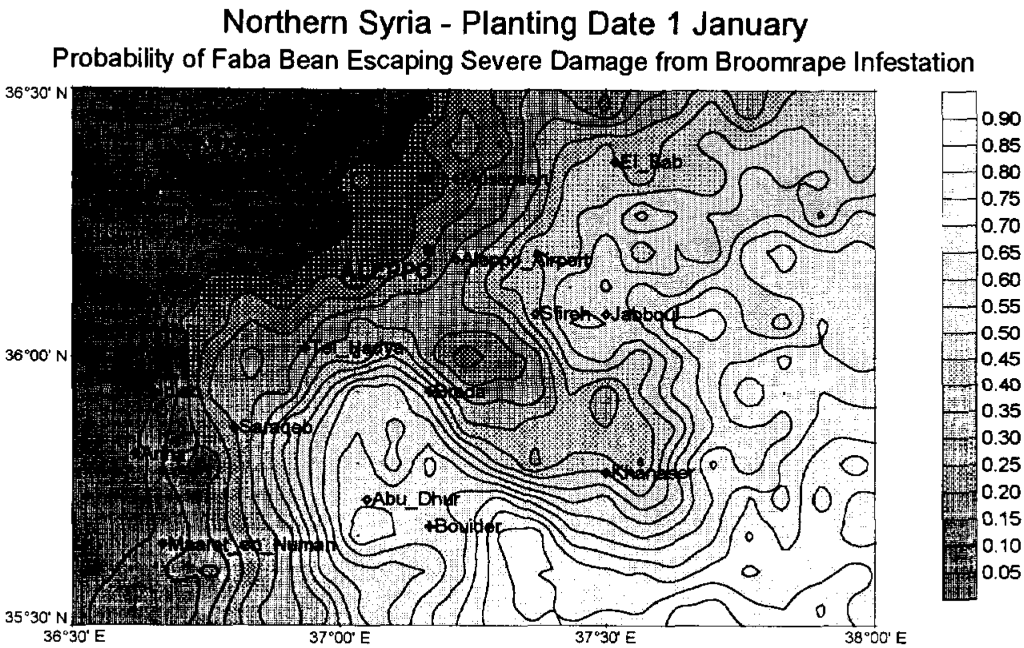


Figure 3.2.3. Northern Syria - Planting date 1 January

Here, the risk of yield loss remains very high and late planting is by itself not a sufficient measure in the fight against the parasite. The situation appears to be more favourable in the dry areas in the southeast. But this is only seemingly so, because the environments are too dry to grow rainfed faba bean. With the necessary irrigations, *Orobanche* would thrive there too. The greatest benefit from late planting is reaped in the intermediate areas around Saraqeb, Tel Hadya, Aleppo, and El Bab, where the probability that faba bean will escape the attack by *Orobanche* is raised from below ten percent to more than fifty percent by delaying planting by one month. It is apparent that the parasite is extremely well adapted to the ecology of its host plant. The environments where faba bean would be more likely to have a relative advantage over the parasite would seem to be cooler climates, eg highland climates not found in the area covered by the maps.

It is obvious that the very simple model demonstrated here has severe limitations. It is only a poor representation of the complex system of host-parasite interactions. To provide more reliable estimates of the risk of *Orobanche* infestation in faba bean, as well as for the quantification of the damage which might be caused, a simulation model of the host-parasite system is required. For this, it will first be necessary to integrate the effect of moisture stress on *Vicia faba* into the existing FAGS model. Concerning *Orobanche*, all the various factors affecting germination and attachment to the host need to be understood and quantified, and the phenology of the parasite needs to be modelled in considerably more detail than at present. A good appreciation exists already of the factors influencing the partitioning of dry matter between host plant and parasite (Mosaddegh-Manschadi *et al.* in press). Most important of all, the knowledge base on *Orobanche crenata* development needs to be expanded through detailed observations across a range of environments, from wet to dry and from warm to cold. ***[W. Göbel and S. Fehrenbach, FRMP, A. Mosaddegh-Manschadi, GP, and J. Sauerborn, University of Gießen]***

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4. MANAGEMENT OF SOIL, WATER AND NUTRIENTS

Introduction

Research activities reported under this title in previous FRMP reports have traditionally been of a broadly agronomic nature, concerned with the management of soil and crops and their associated inputs, fertilizer and water. This year, much of that work, on long-term trials, is presented earlier, under special focus; and work on wind erosion, reported here for the last three years, has come to a halt, temporarily (we hope), in the absence of a qualified scientist to conduct it. The dominant themes of the chapter this year are thus water and crop modelling.

The increasing urgency of water as an issue was highlighted last year. Since then, this urgency has fuelled a thrust by ICARDA, and particularly by FRMP, to develop a proposal for a major ecoregional project, 'Water in WANA'; and consultations with NARS colleagues identified water harvesting as the main area of interest for this initiative. As part of the development of that proposal, a brief review of water harvesting research, worldwide and within WANA, was put together. It is reproduced here (4.1), for the record. Four broad areas of concern are distinguished as potential action themes:

1. Social and system factors, past experience and current realities. (That is, the human dimension: indigenous knowledge and present needs.)
2. Methodologies for resource appraisal. (How to identify sites of good water-harvesting potential and the appropriate mode of exploitation.)
3. Optimization of water utilization. ('Systems agronomy', or how best to use the water for profitable, sustainable output.)
4. Effective dissemination, to land users with appropriate government backup.

Supplemental irrigation is the use of limited amounts of water to increase and stabilize the yields of essentially rainfed crops. Much of this water is drawn from groundwater.

One issue, with obvious 'sustainability' implications, is the probable imbalance, in many situations, between withdrawal and recharge. Another is water quality, which varies according to location but often deteriorates as the groundwater supply is drawn down. This aspect has recently been studied in the Aleppo basin (4.2). Here, as in other parts of Syria, the only water available to some farmers is appreciably saline, but this does not stop them using it. The study reports a relationship, developed from field observations, between wheat yields and water quality. An urgent need for research to formulate a strategy for the safe utilization of saline groundwater for supplemental irrigation is urged.

The final two sections of this chapter are both essentially concerned with the response of wheat to water. The first (4.3) draws on a detailed two-year data set from purpose-designed supplemental irrigation trials at Tel Hadya to develop multi-factor production functions, from which a range of illustrative yield surfaces are produced. These surfaces reveal important differences among the four bread-wheat varieties tested, both in general yield level and in responses to inputs of water and fertilizer nitrogen. Differences between the four durum-wheat varieties tested are fewer. Generally, yields and responses to inputs are shown to decrease markedly with increasing lateness of planting.

A very different approach is followed in the fourth section (4.4). Data from an earlier set of supplementally irrigated durum trials were used to calibrate the CropSyst crop simulation model, which was then employed to generate a spatially-referenced 30-year output of wheat yields for northwestern Syria, taking account of soil type and rainfall zone. Again, the routines used were able to show responses to inputs of water and nitrogen and, in this case, reference them to rainfall zone as well as planting time. A discerning reader may note a less dramatic response to lateness of planting in these simulations than was indicated in the studies in 4.3. In part, at least, this is due to the selection of different ranges of planting dates for the two exercises (mid-November to mid-January and Mid-October to late-December, respectively); but the eventual need to reconcile different outputs from different approaches is acknowledged.

4.1 Water Harvesting - A Review

4.1.1 Introduction

Human ingenuity has been applied to the capture of water to enhance agricultural production since the begining of history: from groundwater, by means of wells and noria (aflaj, foggara); from rivers, using dams and canals; and from ephemeral surface runoff, through a range of techniques collectively termed water harvesting. Precisely because this range of techniques is so wide -- involving natural and stimulated flows from catchments of widely differing areas and, in each case, modified to local circumstances and utilized variously for domestic purposes, watering livestock and the production of treees, field crops and forages -- a fully satisfactory definition of water harvesting is elusive. Critchley & Siegert (1991) simply call it "collection of runoff for its productive use". For Reij *et al.* (1988) it is an hydro-agronomic term covering a whole range of methods of collecting and concentrating various forms of runoff within systems having, according to Perrier (1988), four common elements in sequence: catchment → conveyance device → storage facility → cultivated field.

System size varies greatly, with catchment areas ranging from a few dozen square meters to many square kilometers. Different terminologies coexist. Critchley & Siegert (1991) drew a useful distinction between 'rainwater harvesting' and 'floodwater harvesting' and further divided rainwater harvesting into microcatchments and external (or long-slope) catchments. Many American workers have assumed that catchment surfaces should be artificially treated to promote runoff, while elsewhere natural land surfaces, with the minimum of preparation, predominate (Reij *et al.* 1988). Most harvesting systems utilize water only near where it falls, so that extensive conveyance systems and major reservoirs are exceptional. However, some storage medium is essential because of the intermittent and ephemeral nature of the runoff, but in many cases this is the field soil itself.

Water harvesting is a broad and rapidly expanding topic. Any attempt to summarize the state of the art worldwide is well beyond the scope of the present review. The purpose of this review is rather to outline the historical context and to highlight the main thrusts in current global research and development that seem relevant to the planning of research initiatives in water husbandry for the WANA region.

4.1.2 History

The literature records examples of ancient and indigenous water-harvesting systems from many parts of the world and from many eras. These include: prehistoric systems from south-eastern Spain (Chapman 1978); contour terracing in the central highlands of Mexico (UNEP 1983); floodwater farming in desert areas of Arizona and northern Mexico dating back at least 1000 years (Zaunder and Hutchinson 1988); and 'khadin' systems in Rajasthan, India, initiated probably in the 15th century (Kolarkar *et al.* 1983). Reij *et al.* (1988) give a brief review of systems found in sub-Saharan Africa, including rock bunds and stone terraces in what is now Burkino Fasso and basin systems in Mali; and Critchley *et al.* (1992) describe the 'caag' system in the Hiraan region of central Somalia.

However, the greatest wealth of ancient water-harvesting systems is probably in the Middle East. Reviewing archaeological evidence, Prinz (1994) notes indications of water-harvesting structures in Jordan, believed to have been constructed over 9000 years ago, and in southern Mesopotamia from 4,500 BC (Bruins *et al.* 1986). He continues: "internationally, the most widely known runoff-irrigation systems have been found in the semi-arid to arid Negev desert region of Israel (Evanari *et al.* 1971). Runoff agriculture in this region can be traced back as far as the 10th centrury BC when it was introduced by the Israelites of that period (Adato 1987). The Negev's most productive period, however, began with the arrival of the Nabateans late in the 3rd century BC. Runoff farming continued throughout Roman rule and reached its peak during the Byzantine era."

Nabatean systems have also been discovered in the Hejaz at Qurayya in what is now north-western Saudi Arabia (Bowersock 1994); and floodwater diversion systems, believed to be nearly 3000 years old, are still in operation today in Yemen (Brunner and Haefner 1986; Eger 1988) and the South Tihama area of Saudi Arabia (Wildehahn 1985). There is also a tradition of water harvesting in northern coastal areas of Egypt, including wadi terracing and the utilization of small basins that provide natural runon for barley cultivation (Moustafa and Hamdi 1988; El-Naggar *et al.* 1988). Archaeological excavations in Libya have revealed "structures in an area several hundred kilometers from the coast, ... where the mean annual precipitation is well below fifty millimeters. The farming system here lasted well over 400 years and sustained a large stationary population" by producing barley, wheat, olives, grapes, figs, sheep and cattle (Prinz 1994).

There is also a long history of water harvesting in the Maghreb. In Morocco, Kutsch (1983) described highly-developed 'water-concentrating' systems employed by mountain Berber communities in the Anti-Atlas southwest of Agadir, which appear to be of ancient origin: water from mountain slopes is led by stone channels to terraces and to natural basins to support crop and tree growth in areas with mean annual rainfall of 100-200 mm. Prinz (1994) refers to traditional rainwater storage ponds, mainly for watering animals, in Algeria; and many different traditional systems have been recorded in Tunisia (Ennabli 1993).

4.1.3 Water harvesting in the modern world

Clearly, numerous indigenous systems of water harvesting have arisen in different parts of the world, as human societies have sought to modify their environment to assist survival. It is equally clear that a large proportion of these systems have fallen into disuse, and many that remain appear to be threatened -- which is ironic given that interest within the agricultural research and development community in the capture and efficient utilization of marginal/ephemeral water sources has probably never been greater.

A sequence of reviews and manuals produced over the last 20 years provide a good inventory of water harvesting techniques, old and new, and also essential information for their implementation (Frasier 1974; UNEP 1983; Pacey & Cullis 1986; Reij *et al.* 1988; Critchley & Siegert 1991; FAO 1994; and Prinz 1994). From these and other sources, one may note situations where farmers' innovations, ancient and modern, have stimulated research, and others where research has been started to solve perceived problems at the farm level. A selected sample of national experiences is summarized here to illustrate the range of experiences and potentialities.

Australia: The practical art of water harvesting has been rediscovered many times in the course of human history. The expansion of large-scale agriculture across the world's driest continent was probably one of the more recent occasions. Burdass (1974) pointed to the long history of harvesting for livestock watering on farms in Western Australia, farmer-initiated but "actively encouraged by the Department of Agriculture for half a century". The technique concerned, 'roaded catchments', comprising a "series of parallel and compacted 'roads' with exaggerated camber that adjoin to make approximately V-shaped channels, which discharge into a collecting drain", evolved from field experience, and in time rules of thumb for construction and maintenance were developed (Hollick 1974; Frith 1974)). Research studies to develop methods for calculating maximum nonerosive gradients and computer modelling to find the best catchment shape followed later (Hollick 1974).

USA: Stock watering needs in dry rangeland areas was the starting point also for a major research program on water harvesting at the University of Arizona. Much of that work has been concerned with the treatment of catchment surfaces to enhance runoff. Early treatments included asphalt sprays, plastic sheeting, salt and water repellants (Myers 1967), and later paraffin wax (Fink *et al.* 1973) and asphalt-fibreglass mixtures (Myers & Frasier 1974). Main interest focussed on water collection efficiency, surface durability (versus frost and insolation) and cost. Asphalt-fibreglass remained efficient after 10 years, but concrete lost 50% of the rainwater through macropores and surface cracks (Fink *et al.* 1979).

Scope was later expanded to experiments on jojoba and fruit and pine trees, with a catchment treatment combining petroleum wax and water repellents achieving a runoff efficiency of 91% (Fink & Ehrler 1980). Fink (1982) achieved efficient water-resistant surfaces using as little as 0.25 kg/m2 of petroleum wax. One further finding, however, was that surface treatment has to be tailored to soil conditions. One comparison of six low-cost treatments showed that the nature of the soil influenced their effectiveness, although clear relationships to specific soil properties could not be established (Emmerich *et al.* 1986).

India: The practice of damming local streams with earthen bunds to collect rainwater runoff in 'tanks' for both irrigation and domestic purposes is a very old technique in southern India and Sri Lanka; and the broad-bed and furrow runoff collection system developed by ICRISAT (Barrow 1987) may be seen as an attempt to improve the efficiency of collection and irrigational utilization of such systems.

However, the main center of Indian work on water harvesting is at the Central Arid Zone Research Insitutue in Jodhpur, inspired by the centuries-old traditional systems of Rajasthan (Kolarkar *et al.* 1980; 1983). At three locations (mean annual rainfall, 160, 200 and 275 mm), monsoon rainfall running off rocky hills or stoney ridges is bunded on valley-bottom land, left to infiltrate, and subsequently used to grow dry season crops, wheat and gram. Ratios of catchment to command area are quoted as 11:1, 2.2:1 and 8:1, respectively for the three locations. These values seem low. The authors comment that at the driest location, Jaisalmer, where there are over 500 such 'khadin' systems with a total cultivated area of 12140 ha cultivated land, the minimum ratio for efficient agriculture is 15:1. Many of the old khadins are constructed to fill from a total precipitation of just 75-100 mm.

Other work at Jodhpur relates to microcatchments, for environments in which rainfall may vary annually from 200 to 700 mm. Comparisons have been made for catchment areas ranging from 0 to 144 m2, with different catchment:command area ratios, slopes and slope lengths, supplying water to ber trees, Zizyphus mauritiana (Sharma *et al.* 1982; 1986; Sharma 1986). Catchments (on loamy sands) were graded and rolled initially and thereafter left undisturbed except to remove weeds. After 3 years, no more weeds were found because a hard crust had formed; and, over 7 years, the threshhold rainfall required to initiate runoff halved to 2-3 mm, and runoff efficiency doubled from 22-36 to 52-56%.

Microcatchments have also been tested for crops: 2-3 m-width planted strips fed by adjacent catchments 1.5 to 4 m wide showed surprisingly little difference due to catchment slope (4, 6 and 8%), and surface treatment (bare compaction, added bentonite or 'tank silt') made little difference to runoff efficiency, which averaged around 55% (Jain & Singh 1980; Singh 1985).

Israel: The study of water harvesting in Israel was stimulated by the discovery and rehabilitation of systems dating from the Nabatean and Byzantine era; and over the past 30 years there have been strong research programs in the same semi-desert area in the southern Negev examining a wide range of water-harvesting systems (Ben-Asher 1988).

Before attempting a brief summary, two general points may be made. One is that, in contrast to much of the USA work, nearly all Israeli studies have been on water collection from natural surfaces (ie without applied chemicals). This takes advantage of the natural crusting properties and consequent low infiltration and high runoff rates of the local 'loess' soil.

The second point follows from the observation that runoff efficiency depends on catchment size: smaller catchments, on which water has a shorter flow path have lower 'conveyance losses' (ie lose less to infiltration), are more efficient. Ben-Asher (1988) graphs an empirical relationship:

$$\text{Runoff efficiency (\%)} = 12.3\ A^{-0.4}$$

(where A is catchment area in hectares) which implies a fall in efficiency from around 70% for catchments of a few square metres towards an asymptotic value around 3% for catchments of hundreds and thousands of hectares. This leads to the conclusion that the most efficient utilization of water should be from:

- microcatchments (with high runoff% but low total volume)
- large catchments (with low runoff% but large total volume).

In fact, most research attention seems to have been given to microcatchment water harvesting (MCWH), on the grounds that, with conveyance losses minimized, runoff can be obtained even from light showers; and, being small, microcatchments can be constructed on almost any slope, even flat surfaces. Catchments tested have most frequently been squares of 100 to 250 m^2 feeding a basin in one corner containing a single tree (almond or pistachio). The challenge, the subject of some fairly sophisticated modelling, has been to identify the ratio between catchment and basin surface areas that gives the best compromise between evaporative losses from the basin surface and deep percolation losses below the root zone, particularly in wet years (Boers *et al.* 1986a; 1986b).

Conclusions from such work imply that MCWH is not economically viable in very dry conditions, as at Side Boquer (mean annual rainfall over experiment period, 91 mm). A contributing problem arises is the skew of runoff probability densities towards low values in such situations (Ben-Asher and Warrick 1987). However, Oron *et al.* (1983) showed a significant improvement in basin infiltration (reducing surface evaporation) from the vertical insertion of a perforated 1-metre plastic pipe, 10-20 cm diameter; and greater efficiency has also been claimed for hexagonal microcatchments, in which the basin is centrally located (Oron & Enthoven 1987). The problem (for economic viability) is to support a reasonably high per-hectare density of trees. Opinion seems to favour pistachios over almonds, presumably on a unit value basis, and suggestions have also been made that grouping trees together may be beneficial. Under rather higher rainfalls, MCWH probably is economic. Boers *et al.*

(1986a) concluded that for 200 mm conditions, a 40-80 sq metre catchment might well serve one pistachio tree in a 40 sq metre basin, giving an adequate areal density of trees.

Other work in the Negev relates to what Ben-Asher (1988) terms small-catchment and large-catchment water harvesting, SCWH and LCWH. SCWH involves catchments of perhaps several thousand hectares running on to cropped terraces or fields or groves of fruit and firewood trees, of perhaps 0.5 to 2 ha. As with MCWH, water storage in SCWH systems is in the target soil. Examples of SCWH are limans, in which storm runoff is directed to flood groves of trees, and the rehabilitated Nabatean systems. Early research on 'runoff farming' inspired by these systems has been described by Evenari *et al.* (1968) and Cohen *et al.* (1968). A later paper in this series (Tadmor *et al.* 1970) reports promising results from water spreading on ecotypes of 30 range species.

LCWH systems involve the diversion of wadi floodwaters to sequences of terraced fields (a historic system) or into reservoirs, for early use as irrigation water. Presumably because of differing capital costs, Ben-Asher (1988) describes water from SCWH as 'low-cost', whereas that from LCWH (stored in reservoirs) as 'high-cost' and therefore to be used for intensive, high-profit agriculture. He concludes with some rather sombre comments on the status of water harvesting in Israel. He notes that modern agriculture is perceived to require reliable supplies of water, while harvested water is seen as unreliable; that the development of new water resources is concentrated mostly on the use of waste and saline water; and that water harvesting proposals are often opposed by environmentalists.

Elsewhere in the Mediterranean area greatest attention to water harvesting appears to have been in Tunisia and Jordan.

Work in **Tunisia** may be divided broadly into two types: the description and rehabilitation of indigenous systems, and the large-scale technical development program of the 'Departement de la Conservation des Eaux et du Sol'. This latter program is one of the few in the WANA region which attempts to integrate soil and water conservation activities with hydrological priorities (DCES 1993; Selmi 1994). As well as the construction of bunds and terraces for conservation, it includes the building of small dams on watercourses high in the catchment areas of major rivers. Purposes include flood control, the recharge of shallow groundwater used for irrigation, and the reduction of siltation of major dams supplying domestic and industrial needs. Among the spinoffs is the availability to hill farmers of water 'harvested' by the small dams for use in supplemental irrigation. One acknowledged weakness of this whole program, however, is its primary focus on engineering works, in the undoubtedly good cause of conserving soil and water supply but tending to neglect the socio-economic problems and different utilization options of land users.

Indigenous systems in Tunisia have recently been described in two monographs, Ennabli (1993) and Alaya *et al.* (1993). The first provides detailed descriptions of nearly thirty traditional systems for capturing and utilizing water in the dry areas of Tunisia. The wide range of water interception, concentration, conveyance and storage techniques reported (many still under utilization) illustrate the wealth of ingenuity in human adaptation to dry environments. The second publication focusses on 'tabias', the earthen bunds widely and variously used in Tunisia to intercept and redirect runoff water to crops and trees. Though primarily an implementation manual, this book is also richly descriptive of traditional practices.

The 'meskat' system, which utilizes tabias to support olive plantations, is said to cover 300,000 ha in central Tunisia (Prinz 1994). Essentially it comprises catchments of about 500 sq metres surrounded by tabia and spillways to control runoff flow into bunded plots of trees. Undoubtedly this is a successful system, still well maintained; but Reij *et al.* (1988) comment that it suffers heavily from increasing land pressure resulting in a decrease of the catchment areas leading to lower efficiency.

The 'jessour' system is based upon the cultivation of sediments built up behind large tabia (often stone-reinforced and with stone spillways) constructed in cascade down narrow mountain valleys in southern Tunisia. Akrimi at al (1993), from the Institut des Regions Arides (IRA) near Medinine, reported a multidisciplinary study (technical and scoio-economic) involving jessour cultivators in the Matmata mountains. Maintenance of the tabia and spillway structures is a major problem in some areas, due partly to a degree of out-migration, and it is Tunisian Government policy to assist jessour rehabilitation. However, proposals for further research by the same IRA team note the launching of major development schemes for soil conservation and rainwater harvesting but comment that participation of the local population has been weak due to the failure of the schemes to take account of local traditions and existing production systems.

There have also been development schemes in **Jordan**, earth dams to divert runoff for pasture improvement (Al-Labadi 1993) and bund building for soil and moisture conservation on steep land (Shatanawi 1993). Research was started by the University of Jordan, in 1987, to explore the development potential and particularly the water-harvesting potential of a 70 km^2 catchment under low rainfall (100-250 mm per annum) east of Amman (Taimeh 1988). Irrigation from wadi flows trapped by earthern dams and microplots supporting fruit trees are two techniques that have shown promise, socio-economic as well as technical (Tutwiler *et al.* 1995), although Oweis & Taimeh (1995) have emphasized the need for careful adjustment of system parameters for microplots to avoid low efficiency. Currently, data collected in this catchment are being used to develop a coupled prediction-optimization model for water harvesting, storage and utilization in similar dry areas of Jordan and elsewhere (Sarraf & Taimeh 1994).

Other ongoing regional activities include a relatively large development project (with included research component) in a steppe area in southern **Syria**, for the integrated management of soil, water and vegetation resources (Rashed 1993). The project uses water supplied by various harvesting techniques in conjunction with a limited groundwater supply to enhance production, particularly of forage crops and bushes.

In **Yemen**, a major research focus is the conservation of the ancient terrace system, parts of which have fallen into disrepair following socioeconomic changes. The issue here is not simply the conservation of soil and water by the terraces, but the control of water from the highest, and often degraded, pasture lands (and including water harvesting for human consumption) down to the protection of the intensively utilized banks of the main wadis and the flood irrigation systems downstream. A new multidisciplinary project, with a participatory approach, addresses the socioeconomic, institutional and policy issues that are involved (Muhred 1994)

The rainfed coastal areas of **Egypt** have received considerable research and development attention over recent decades. Initially, the main aim was to facilitate the sedentarization of the bedouin population, and projects were undertaken to rehabilitate degraded rangeland and increase runoff utilization, through wadi terracing (similar to Tunisian jessours) and the enhancement of indigenous runoff farming systems (Perrier 1986). More recently, the coastal areas have come to be seen as another small but potentially productive national agricultural resource, and emphasis has shifted towards more intensive development. However, the natural resource issues -- water quantity and quality, population growth, and environmental deterioration (Abdel-Kader *et al.* 1994) -- remain the same.

In **Pakistan**, the Water Resources Research Institute in Islamabad conducts major programs in soil and water conservation and management for dry lands in both lowlands (barani) and mountain areas. This currently includes research -- in close collaboration with farmers and development agencies -- on water harvesting through site-specific land-forming techniques, storage in low-cost earthern reservoirs, and utilization as supplemental irrigation (Dr M Shafiq, personal communication). Other work, in highland Balochistan, has looked at ways to improve the indigenous 'khuskaba' system, by which bunds are used to guide runoff water and promote infiltration (Rees *et al.* 1991). Rodriguez *et al.* (1995) found 1:1 treatments (catchment:production area ratio) in valley floor situations increased seven-year wheat yields over control values, higher ratios having a risk of waterlogging in wetter years. It was also noted that farmers practising the indigenous khuskaba system adjust the size of the catchment area according to the soil moisture at planting and rainfall expectations for the season.

4.1.4 Discussion

Water harvesting is an individual or community response to an environmental limitation. Given the different social and economic needs of diverse individuals and communities and the many different conjugations of meteorology and topography in their living environments, undoubtedly and necessarily their water-harvesting responses are always site specific. That is already evident from the preceding review.

Some authorities see site-specificity as a severe limitation on research, which usually seeks out general truths, and also on development, which in turn seeks to provide generalized solutions for a limited number of standard problems. Nevertheless, for water harvesting, there are important research issues common to superficially very different situations. It is essential to be clear what those issues are, how they are implicated in site-specific field activities, and how they may be tackled in a coherent research program.

One lesson learned from the publications reviewed above is that research often follows where the land-user leads, or (particularly in the case of water harvesting) where earlier users have led, and tries to make improvements. Improvement requires an understanding of the system or technology in question and its context (indigenous knowledge). For water harvesting, that takes in the local meteorology, hydrology, production systems and socio-economic circumstances. Further, if the system is currently operational and successful, it is necessary to ask what makes it so; or, if the system was previously successful but eventually abandoned, why that happened.

There is nothing new in this. This is the first stage in the farming systems research approach, diagnosis. Such an approach is essential to working successfully with indigenous agricultural practices, and that includes attempts to improve upon past and present water harvesting systems and to disseminate their use more widely. It further follows that farmers should be involved in all subsequent stages of the work, alongside the researchers, identifying, testing and eventually demonstrating successful new techniques. As Reij *et al.* (1988)," .. a lot of research has been done on specific techniques, such as microcatchments, which is, however, not matched by a similar attention to the implementation of these techniques under field conditions". Any new initiative expecting to achieve implementation must involve technology users from the outset.

So, one issue common to superficially different situations is the need, first, to appraise past and present water harvesting activities from a multi-disciplinary 'farming systems' perspective and, second, to go on in that mode with the participation of farmers and other resource users in the research process. In an initiative spanning a number of countries, one would anticipate such 'on-farm' activities at one or more field sites in each country. This is essential for progress at the local, site-specific level but essential also if associated studies on other common issues, more strategic or theoretical in nature, are to be kept rooted in grass-roots experience.

Two such common issues arise directly from the problem highlighted by Ben-Asher (1988), that water harvesting is widely perceived as an unreliable source. One is the quantification of reliability. This requires research to identify, adapt or develop methodologies, first for the appropriate analysis of rainfall data and then for an extension of that analysis to include site parameters that allow the calculation of probabilities of runoff amounts and frequencies. Time has not permitted adequate investigation of the technical literature on this subject but Yair & Lavee (1985) provides one appropriate entry point.

The other issue relating to reliability is the possible joint utilization of harvested water with water from other sources. This idea is already current in the WANA region. Mouhred (1994), with reference to water shortages for municipal and agricultural purposes in Yemen, commented "the concept of conjunctive use of surface and groundwater sources should be adopted"; and the proposal (now under execution) for integrated watershed development in the Syrian steppe specifically includes the aim "to evaluate the feasibility and advantages of conjunctive uses of ground and surface water resources for supplementation of fodder crops and shrubs" (Rashed 1993). The term 'conjunctive use' has been defined by Vincent & Dempsey (1991, quoted by Moyo 1994) as the combined and integrated management of surface and groundwater for optimal productive and allocative efficiency. It appears to be applied most commonly to situations where the use of deep groundwater is combined with that of canal water or shallow ground- or drainage-water, but extension of the concept to the buffering of intermittent flows of runoff water with supplies from other sources appears particularly appropriate to the WANA situation. At some locations, the use of urban waste water might be included.

The fourth issue also concerns hydrology. There is a small river in northern Syria (and probably many similar ones elsewhere in the region) which is perennial in its upper reaches but dry downstream in summer, due to abstractions for small-scale irrigation by riparian farmers. For such rivers, utilization is a zero-sum game: you can pump the water out only once. Upstream users deprive potential downstream users. The extent to which a similar situation may be caused by abstractions from the natural hydrologic process by water harvesting is a question rarely asked. There is a perception, perhaps justified, that water harvesting uses hydrologically insignificant amounts of water, and, in any case, in dry areas, most unutilized surface runoff is lost to evaporation in salt lakes and surface pans.

However, in other cases, there may be real losses in aquifer recharge and surface supplies downstream; and, as competition for water in dry areas intensifies, questions on such topics will need to be answered with hard facts. Any new water harvesting initiative needs access to hydrological expertise. Current plans are founded on the belief that most water harvesting in dry areas utilizes 'new' water that was previously wasted. But we require to establish methodologies by which this can be demonstrated and, more broadly, by which the utilization of all the renewable water can be optimized.

Balances need to be struck between aquifer abstraction and recharge and, in some instances, between water harvesting for direct application and for aquifer recharge. These matters are already urgent in countries like Oman, where "a number of recharge dams have been constructed, and others are planned, to intercept and regulate the infrequent surface water flows which would otherwise bypass farming areas" (Barnett & Smith 1994).

A fifth issue is the location and design of water harvesting systems. Within traditional systems, indigenous knowledge on the siting and form of harvesting structures and field layouts was the product of trial and error. Modern urgencies do not permit such an approach for new developments today. Rather, we must seek to marry any relevant indigenous knowledge to the evaluation of local data for such parameters as hydrology, soils, and vegetation. Those data are not always readily available. Particularly when the area is large, remote sensing systems can provide a partial solution (Prinz *et al.* 1994; Colwell & Carneggie 199?; Tauer & Humborg 1992). The data they provide, combined with digitized topographical maps and other relevant parameters, within a geographical information system, permit a complex of multiple data analysis and model-building to be carried out to assist the identification of potentially fruitful harvesting areas and possible modes of utilization. As Prinz *et al.* (1994) point out, such analyses should be confirmed at every stage by ground checks <u>and</u> related wherever possible to climatic, agricultural, sociological and economic factors.

Two final points should be made. First, water harvesting is not separable from conservation issues. Even within the agricultural perspective, soil and water conservation and water harvesting are often jointly referred to as 'SWC/WH' (EC 1991). This is logical: all are activities, concerned with managing basic natural resources to ensure efficient and sustainable utilization, which should be integrated in complementary ways into the same landscapes. To complete the picture, one should add the conservation of vegetation, to include both the sustainable utilization of productive rangeland and the protection of biodiversity.

The second point concerns the dissemination of viable water-harvesting techniques. The importance of employing a farming systems research approach has been stressed, but this needs to be complemented by the involvement, from the start of activities, of personnel from the extension services, from hydrological and conservation services and not least from agricultural planning departments.

4.1.5 Conclusions

Water harvesting is a widespread practice in dry areas around the world, and, as competition for water intensifies, incentives to apply the practice more widely seem certain to increase. There are dangers in this: choosing the right system and adapting it successfully to local conditions is rarely straightforward; an inevitable degree of unreliability in supply demands careful choice of target crops; imposed systems will not be maintained unless they command the full confidence of their users; using land as catchment often involves opportunity costs and may adversely affect current users; it may also have adverse environmental implications; and abstracting water high in the catchment may have hydrological consequences downstream.

Even a brief review of the literature shows there has been much water-harvesting research, but the focus has very often been on technical details. Studies of broader, more strategic issues, and particularly studies concerned with community involvement and problems of technology transfer and dissemination, have been comparatively few. This is perhaps even more true of the world scene generally than it is of WANA, where at least a small number of recently initiated projects aspire to be holistic and multidisciplinary in approach and, in some cases, integrate research and development goals.

Nevertheless, there are large gaps, of a methodological or strategic nature. Summarizing, and to some extent, combining issues, four broad areas of concern emerge:

1. With a few notable exceptions, indigenous systems (past and present) have not been well described, still less analysed to highlight the lessons they demonstrate.

Further, a feature common to fields like agronomy and crop improvement, applies also to water harvesting, that research tends to be technically dominated. The human dimension and the systems context -- which must ultimately determine whether improved technology is accepted or not -- are often neglected. New research must therefore encompass the theme of '**social and system factors, past experience and current realities**'.

2. Social factors apart, the technical success of water harvesting in any location depends on the existence of a real resource, and its size and reliability. Methodologies for site appraisals are needed, probably for different scales and at different levels of sophistication. They need to cover: (a) probabilities of runoff (frequency, volume, intensity) through the year and would be based on rainfall records and assessments of catchment size and surface characteristics; (b) utilization options, including size and surface characteristics of potential command areas and climate characteristics, other than rainfall, affecting plant growth; and (c) hydrological considerations, particularly downstream consequences. The research required might be termed '**development of resource appraisal methodologies**'.
3. In many respects, the utilization of water, once harvested, is dominated by site-specific factors. Prior appraisal of some of these factors (by methodologies referred to in (2) will likely have determined harvesting system and mode of utilization (trees, crops, forages etc). Subsequent fine-tuning of the detail of this utilization is a matter of locally-focussed agronomic research, with end-user participation. Nevertheless, there remain at this stage a number of broader issues, to which site-specific research may be expected to contribute useful experience. These include: (a) the conjunctive use of water from different sources; (b) the balanced integration of more and less intensive modes of utilization (vegetables, trees, field crops, forage shrubs); and (c) relationships between the 'irrigated

island' and the surrounding 'sea' of catchment and non-catchment areas (probably involving crop-animal linkages and sustainable rangeland management). The general research theme here might be called '**optimizing water utilization**'.

4. The dissemination of tested water harvesting and utilization systems also involves strongly location-specific circumstances and, as has already been mentioned, requires the early involvement of personnel from other organizations (governmental and otherwise, not least agricultural planners and extension officers). Such cooperation is frequently difficult to establish. Here again, it may be anticipated that distillations of local experience will contribute to a general pool of research knowhow on building successful water harvesting into the broader infrastructure of agricultural and rural development. This might be called '**effective dissemination strategies**'. *[Mike Jones and Theib Oweis]*

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4.2 Supplemental Irrigation in the Aleppo Basin of Syria Using Saline Groundwater

4.2.1 Introduction

In the last decade, the area under supplemental irrigation in all of the watershed areas of Syria has increased. This has been primarily due to new government policies, such as crop price increase and loans to farmers for well drilling and pump installation. In 1993 approximately one-half of all irrigated land was under supplemental irrigation (363,000 ha). Seventy-five percent of these supplemental irrigated areas use ground water. The recent expansion of irrigated regions has extended into areas reliant upon saline groundwater sources. Currently, in the Khabur and the Aleppo basins, 25% of supplemental irrigation utilizes saline groundwater.

Wheat yield response to the use of saline water in the silty clay to clay soils of the Khabur basin area has been reported previously (Wakil 1994). The present study aims to evaluate the yield response to saline supplemental irrigation of wheat and barley in the clay loam to loamy soils of the Aleppo basin.

4.2.2 Natural characteristics of the Aleppo basin

The Aleppo basin (21,000 km^2) is located in north-western Syria. It is bounded to the north by Turkey, to the west by the Orontes (Assi) basin, to the east by the Euphrates basin and to the south by the desert basin. The climate is Mediterranean, characterized by a rainy winter and a dry hot summer. The rainy season generally starts in October and ends in May (Figure 4.2.1). Mean annual rainfall decreases from 500 mm in the north to 200 mm in the south. Mean annual potential evapotranspiration is around 2100 mm.

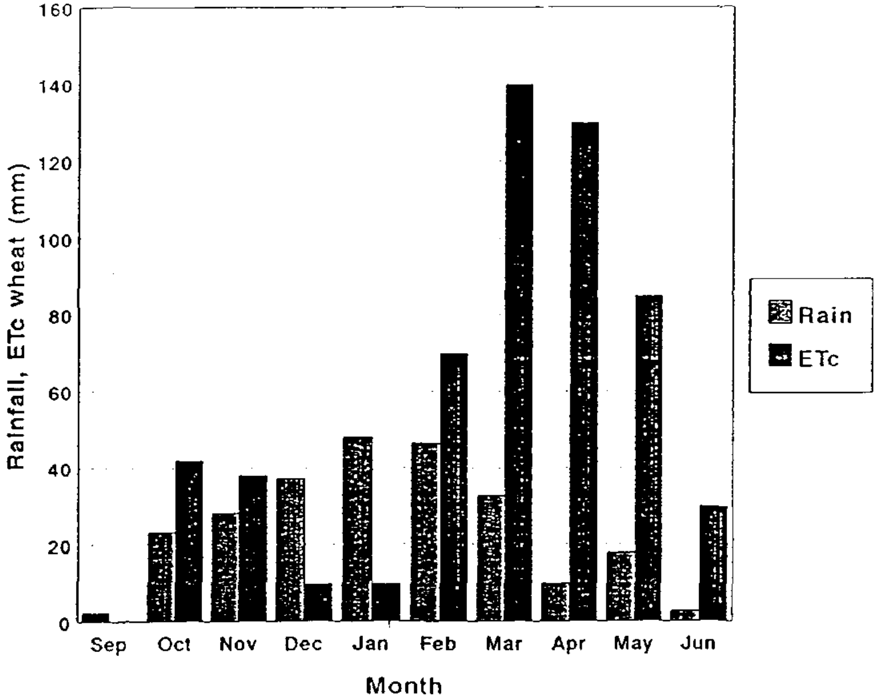

Figure 4.2.1. Monthly distribution of rainfall and wheat ETc (Oum-Gharraf st.)

The soils of the Aleppo basin are predominantly clay loam in the top 40 cm changing to loam and sandy clay loam with depth. The sand fraction generally increases with depth and may reach 50% at one metre. The soil structure is generally subangular blocky in the surface horizon and prismatic below. Soil aggregates contain many fine pores allowing for a rapid water infiltration (FSP 1981).

4.2.3 Water resources

The water resources of the Aleppo basin are estimated to be 800 million m^3/yr, of which the ground water constitutes 40%, contained within four major aquifers around Aleppo City. The safe yield of these aquifers varies from 50 to 90 million m^3/yr (MIR 1982). The southern half of this area is underlain by two superimposed aquifers. The deeper one (200 to 400 m deep), which constitutes the main hydrogeological system of the area, has poor quality water (see Ward and Smith 1984). The salinity increases southward up to 14 dS/m (Table 4.2.1). The water in the shallower aquifer (120 m deep) is of better quality (<1 dS/m), but this aquifer has a low well productivity of around 30 m^3/hr (GSFRS 1967).

Table 4.2.1. Ground water quality analysis from some locations in Aleppo basin

Location	pH	Ex dS/m	Boron ppm	Na meq/l	Ca+Mg meq/l	SAR
Tel-Toukan	7.6	1.6	0.33	7.8	10.1	3.47
Tawahinieh	7.1	4.0	0.74	20.0	26.6	5.49
Oum-Hota	7.4	6.4	1.99	38.8	43.5	8.33
Hamidieh	7.5	7.5	1.68	50.0	39.1	11.31
Khanasser	6.7	9.7	1.94	61.0	58.9	11.23
Kourbatieh (1)	7.2	12.5	2.65	74.0	78.3	11.82
Kourbatieh (2)	7.2	14.1	1.78	74.0	97.1	10.62

4.2.4 Cropping pattern

Supplemental irrigation in the Aleppo basin currently covers 35,800 ha, of which 28,800 ha uses a groundwater source (AAD

1994). Cropping patterns and cropping intensity are a function of well productivity and of water salinity. In the north-western portion, where well yield is high (up to 80 m^3ha) and water salinity is low, wheat is the main winter crop and cotton the summer crop. Cropping intensity reaches 120%, of which 90% is winter crops. In the south of the basin, where well yield is lower and the water more saline, cropping intensity is about 100%, of which 80% is winter crops, mainly wheat and/or barley.

In general, barley, which requires less water and is more salt-tolerant than wheat, is grown in areas where well yield is less than 30 m^3/hr and water salinity greater than 6 dS/m.

4.2.5 Irrigation practices

Ninety percent of the irrigated areas in the Aleppo basin is irrigated by the traditional surface furrow-basin method, and the rest by the sprinkler method. The amounts applied and their frequency and timing are governed by rainfall patterns and by local well yields. On average, wheat receives four to six irrigations of which the first immediately follows planting. Seeding into a dry bed is a common practice. The remaining irrigations are usually given between the beginning of April and the end of May or into June (Figure 4.2.1). Barley is irrigated three to four times, once after sowing and then between late March and early May.

4.2.6 Wheat yield

Yields of supplementally irrigated wheat vary from 1.0 to 5.5 t/ha. The higher yields are obtained in regions of low water salinity (less than 1.0 dS/m). Figure 4.2.2 illustrates the relationship between wheat relative yield (referenced to 5.5 t/ha) and irrigation water salinity for the southern parts of the Aleppo basin. The data were obtained from 28 farms using well water of salinity varying from 0.6 to 12.8 dS/m. The data show that, under the actual field conditions of the Aleppo basin, the relationship between wheat yield and irrigation water salinity is scattered. It has been

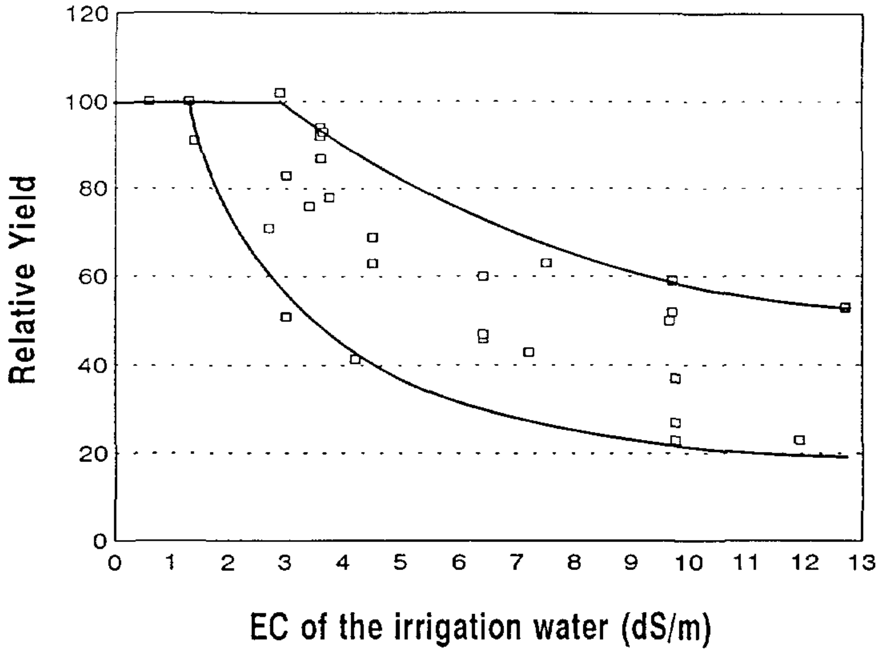

Figure 4.2.2. Relationship between irrigation water salinity and wheat relative yield in Aleppo basin

suggested elsewhere that such scatter can be caused by differences in agricultural inputs and by crop and irrigation management practices (Osterbaan *et al.* 1991).

The two envelope curves in Figure 4.2.2 define a threshold salinity value which varies from 1.5 to 3.0 dS/m. Above this range, wheat yield declines. For example, at a salinity of 8 dS/m relative yield averages 50%. The sharp decline in productivity experienced beyond the threshold value is due to the combined effects of various factors, which affect plant establishment, growth and yield. These factors may include: planting in an initially saline seedbed resulting from salt accumulation from previous seasons (Van Horn 1991); use of saline irrigation water particularly during critical growth stages such as germination, early seedling growth, and grain filling (Maas and Poss 1989); and the use of low leaching fractions (Prendergast 1993). The actual leaching fraction in the Aleppo basin varies between 0-0.2, depending on well productivity.

The present results show that wheat is more tolerant of saline irrigation water in the Aleppo basin than in the Khabur basin, where the maximum threshold value was found to be around 1.2 dS/m (Wakil 1994). This is primarly due to differences in soil physical characteristics between the two basins. Indeed, the prevailing climatic conditions in the two basins are almost the same. Soil properties, mainly texture and structure, may moderate crop response to salinity through their influence on the infiltration capacity and water holding capacity (Shalavet 1994). The rate of salt accumulation in the clay soil of Khabur basin is higher than in the loamy soil of Aleppo basin. Under the field conditions of arid regions, salt accumulation is reported to depend upon the soil clay content, increasing as the percentage of clay increases (Bhumbla 1976). In addition, the good internal drainage of soil profiles in the Aleppo basin enhances the natural leaching which can occur during the rainy season and reduces the salt accumulation in the soil.

4.2.7 Barley yield

The relationship between barley yield and the salinity of the irrigation water follows a similar trend to that of wheat (Table 4.2.2). Maximum yield is obtained when salinity is below 3 dS/m. Beyond this value, yield decreases as salinity increases. At 10 dS/m, relative yield averages 45%. Similar results were obtained by McKenzie *et al.* (1983).

4.2.8 Conclusion

Farmers' use of saline water for irrigation will continue to increase in various parts of Syria, because saline aquifers are the only water resources available in many agricultural areas. As a result, salt will progressively accumulate in soil profiles, leading to a decline in productive potential and, in the long term, to desertification.

Research is urgently needed to define a suitable strategy for the safe use of this saline water. Such work might include the study of the effects of some agricultural

Table 4.2.2. Barley yield as function of water salinity at different small farms in Aleppo basin

Farm	ECiw (dS/m)	Yield (t/ha)
Tel-Ahmad	2.7	5.4
Houllwieh	3.6	4.2
Oum-Gharraf (1)	3.8	4.0
Tel-Yemni	4.0	3.0
Oum-Garraf (2)	4.2	2.5
Hawaywee	7.2	1.5
Hamidieh	7.5	3.6
Bayaieh	8.2	2.5
Khanasser	9.7	2.4
Oum-Houteh	9.7	2.4

practices on soil salt accumulation and crop yield: eg rotation including purely rainfed crops and/or fallow to promote periodic natural leaching by rainfall; sequential use of non-saline and saline aquifer water over the growing season; mixing saline and non-saline water after plant establishment; different amounts and frequencies of supplemental irrigation; and soil tillage and fertilizer application treatments. ***[Michel Wakil, University of Aleppo, with technical assisstance from Hisham Salahieh and Sonia Garabet]***

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4.3 Response of Durum and Bread Wheat to Supplemental Irrigation and Management Practices

These two major experiments on supplemental irrigation (SI) of durum and bread wheat were started in the 1992/1993 season. Background and methodology, together with highlights from the results of the first season were presented in the FRMP report for 1993. The present report summarizes analyses of the results of the first two seasons.

4.3.1 Introduction

Supplemental irrigation (SI) is a major factor in the reent increase of wheat production in Syria. About 40% of the 'rainfed' area planted to wheat in 1994 was supplementally irrigated. Assuming that the average yield obtained with SI is at least twice that obtained without SI, this means that over two thirds of the rainfed wheat production in Syria now comes from supplementally irrigated crops.

There is no question that SI increases yield significantly. However, whether this practice is feasible, economically and socially, depends on many local factors related to the rates of each input and their interaction with the management and the weather. It is the selection and management of those inputs and input levels that determines feasibility or not. The most important of these inputs are the germplasm, the water, the nitrogen fertilizer, and the planting date.

Most wheat varieties available in Syria were developed either for drought resistance or for fully irrigated conditions. However, as water becomes less readily available and more costly, applying full crop water requirements in rainfed areas may no longer be practical. To develop the optimal SI strategy for these areas, the responses of different wheat varieties to the amount of water applied need to be determined. Further, although wheat response to nitrogen fertilizer is generally well documented, the interactions between nitrogen rate, variety and water rate have yet to be quantified for SI conditions. Finally, response to SI may differ with planting date, and this, too, needs to be quantified.

To make practical use of results from SI experiments, account must also be taken of the interactions of input factor effects with the highly variable weather conditions that prevail in rainfed areas. This can best be tackled by modelling. The development of such models requires accurate, detailed, and comprehensive field data. Accordingly, the two experiments reported here were designed to provide information on the effects of SI rates, nitrogen rates, and date of planting on the yields of four durum and four bread wheat varieties in a form that could be interpreted directly or, equally, be used for the building of crop simulation models.

4.3.2 Methodology

The two experiments were conducted in the B block at Tel Hadya station. The soils are clayey, deep and well drained, with a water-holding capacity of 45% by volume and a basic infiltration rate of 11 mm/hr.

The treatments included: three dates of planting (D1=early, mid November; D2=mid season, mid December; and D3=late, mid January): four rates of supplemental irrigation (W1=rainfed with no water application; W2=1/3 of W4; W3=2/3 of W4, and W4=100% of crop SI water requirements); four rates of nitrogen (N1, N2, N3 and N4=0, 50, 100 and 150 kg N/ha, respectively); and four bread wheat varieties for the first experiment (V1=Cham 4, V2=Gomam, V3=Cham 6, V4=Mexipak) and four durum wheat varieties for the second experiment (V1=Cham 1, V2=Lahn, V3=Cham 3, V4=Om Rabi 5).

A split-split-split plot design with three replicates was used. Dates of planting, varieties, water rates and N rates occupied the main plots, the sub plots, the sub-sub plots, and the sub-sub-sub plots, respectively.

A trickle irrigation system was designed and installed to provide a uniform soil moisture pattern within each SI treatment. This system is used as a research tool and would not be appropriate for cereal crops in farmers' fields (FRMP 1993). Water was applied to all treatments at the same time, that is, when the root zone of the W4 treatment had lost 50% of its available moisture. The amount of water then given to W4 were calculated to bring root-zone moisture back to field capacity. The other treatments receive fixed proportions (1/3 and 2/3) of that amount automatically. Soil moisture was measured weekly, before and after each water application, and after each rain, using neutron probes and access tubes inserted to 1.5 m depth.

The crop was planted in 17.5 cm rows at a seed rate of approximately 300 seeds/m^2. The nitrogen application was split, half at planting and half top-dressed at the early tillering stage. Plant samples were taken at various crop stages. Other measurements included: date of emergence, plant vigor, plant number, leaf area, dry matter, days to anthesis, tiller number at stage 65, number of grains per m^2, grain yield, total dry matter, 1000-grain weight, and days to maturity. Cold, insect and disease damage (if any) were also recorded.

4.3.3 Results

4.3.3.1 Bread wheat

Irrigation and rainfall: Table 4.3.1 shows the amounts and dates of supplemental irrigations applied during the two growing seasons 1992/1993 and 1993/1994. The amounts indicated are those for the W4 treatment; W3 and W2 treatments received 2/3 and 1/3 of those amounts. The rainfed treatment received only the rainfall, as shown.

The water applied in the final irrigation each year was not necessarily used totally by the crop before harvest. The actual amount utilized is calculated from soil moisture measurements before and after harvest, and the total SI use adjusted, for the purpose of calculation, to reflect the residual water in the soil.

Yield responses to management factors: The analysis of variance for the two years combined (Table 4.3.2) shows that each of the main factors except year had a significant effect on grain, total dry matter and straw yields. There were also quite a large number of significant interactions. Some of the more important of these for grain are summarized graphically. Grain response to water application was greater in 1992/93 than in 1993/94, when the crop was damaged by yellow rust (Figure 4.3.1a). Higher rainfed yield (3.2 t/ha) in 1993/94 than in 1992/93 (2.7 t/ha) may be explained by rainfall difference. Planting date was important. Mean yield response to water application was significantly and negatively affected by delaying the sowing date from November to January (Figure 4.3.1b).

The bread wheat varieties tested showed substantially different responses to water application (Figure 4.3.1c). Mexipak was the least responsive, with mean grain yield

Table 4.3.1 Amounts [W4 only] and dates of supplemental irrigations applied in the bread wheat experiment, Tel Hadya, 1992/93 and 1993/94

1992/93 (Total rainfall - 277 mm)			1993/94 (Total rainfall = 373 mm)		
Date of planting	Amount of irrig., mm	Date of irrig.	Date of planting	Amount of irrig. mm	Date of irrig.
D1=1/11	124	31/3/93	5/11/93	108	6/4/94
	162	22/3/93		154	20/4/94
	139	21/5/93			
	total=452			total=262	
D2=10/12	95	31/3/93	5/12/93	100	7/4/94
	86	14/4/93		76	19/4/94
	110	22/4/93		145	15/5/94
	120	22/5/93			
	total=411			total=321	
D3=16/1	57	31/3/93	12/1/94	65	5/4/94
	140	22/4/93		75	20/4/94
	100	2/5/63		125	16/6/94
	111	22/5/93			
	total=408			total=265	

increased from 2.5 (rainfed) to only 3.5 t/ha. Cham 4 and Cham 6 were the most responsive as well as the highest yielding under rainfed conditions. Gomam showed intermediate responses between Mexipak and Cham 4 and Cham 6.

Mean response of grain yield to nitrogen was strongly water dependent (Figure 4.3.1d). Under rainfed conditions, yield increased from 2.8 to 3.1 t/ha with an application of 50 kg N/ha but decreased back to 2.8 t/ha with 150 kg N/ha. With SI, responses to the first 50 kg N increment were large, but responses beyond 50 kg N/ha for W2 and beyond 100 kg N/ha for W3 and W4 were not significant.

Mean yield response to nitrogen was also affected by sowing date. Delayed sowing decreased overall grain yield as well as response to nitrogen application. November and December sowing increased grain yield relative to January sowing from about 3.5 to 4.9 t/ha with 100 kg N/ha (Figure 4.3.1e).

Varietal response differences to N application were similar to those to water application. Relative to control, mean yield (at the 100 kg N/ha rate) increased from 2.9 to

Table 4.3.2 Analysis of variance for bread wheat grain, total dry matter, and straw yields of the 1992/93 and 1993/1994 seasons combined

Source of variation	d.f.	Grain	D.M.	Straw
Year.Rep				
Yr	1	79.4	40.0	6.7
Residual	4	46.0	336.6	217.7
Yr.Rep.Date				
Date	2	250.4***	570.6***	567.9***
Yr.Date	2	7.3*	194.1***	126.2**
Residual	8	4.3	41.0	34.7
Yr.Rep.Date.Var.				
Var	3	350.0***	739.8***	79.2**
Yr.Var	3	44.4***	65.9	2.7
Date.Var	6	30.0*	120.5	36.0
Yr.Date.Var	6	14.2	49.8	17.2
Residual	36	72.2	492.9	217.5
Yr.Rep.Date.Var.Water				
Water	3	588.6***	31115.9***	1024.9***
Yr.Water	3	107.1***	799.6***	334.3***
Date.Water	6	17.9*	35.8	20.0
Var.Water	9	34.2**	76.9	14.6
Yr.Date.Water	6	29.6**	103.8	30.6
Yr.Var.Water	9	13.9	56.2	21.0
Date.Var.Water	18	34.3	156.7	51.6
Yr.Date.Var.Water	18	29.0	171.3	71.0
Residual	144	187.1	1255.1	581.2
Yr.Rep.Date.Var.Water.N				
N	3	220.9***	1888.4***	826.0***
Yr.N	3	5.0**	41.1***	19.3**
Date.N	6	35.6***	303.3***	131.9***
Var.N	9	15.9***	42.4*	9.1
Water.N	9	61.8***	204.4***	45.2***
Yr.Date.N	6	1.1	20.8	15.8
Yr.Var.N	9	3.4	9.1	7.8
Date.Var.N	18	7.4	22.1	11.5
Yr.Water.N	9	7.9**	45.6*	18.7
Date.Water.N	18	13.2**	58.4	23.1
Var.Water.N	27	10.4	58.7	24.8
Yr.Date.Var.N	18	5.1	33.0	16.1
Yr.Date.Water.N	18	5.1	39.9	20.6
Yr.Var.Water.N	27	4.7	39.9	24.2
Date.Var.water.N	54	11.6	89.7	57.0
Yr.Date.Var.Water.N	54	12.2	77.8	48.4
Residual	576	184.7	1383.9	749.4
Total	1151	2546.2	13781.0	5503.9

*** significant at P<0.001; ** significant at P<0.01
* significant at P<0.05

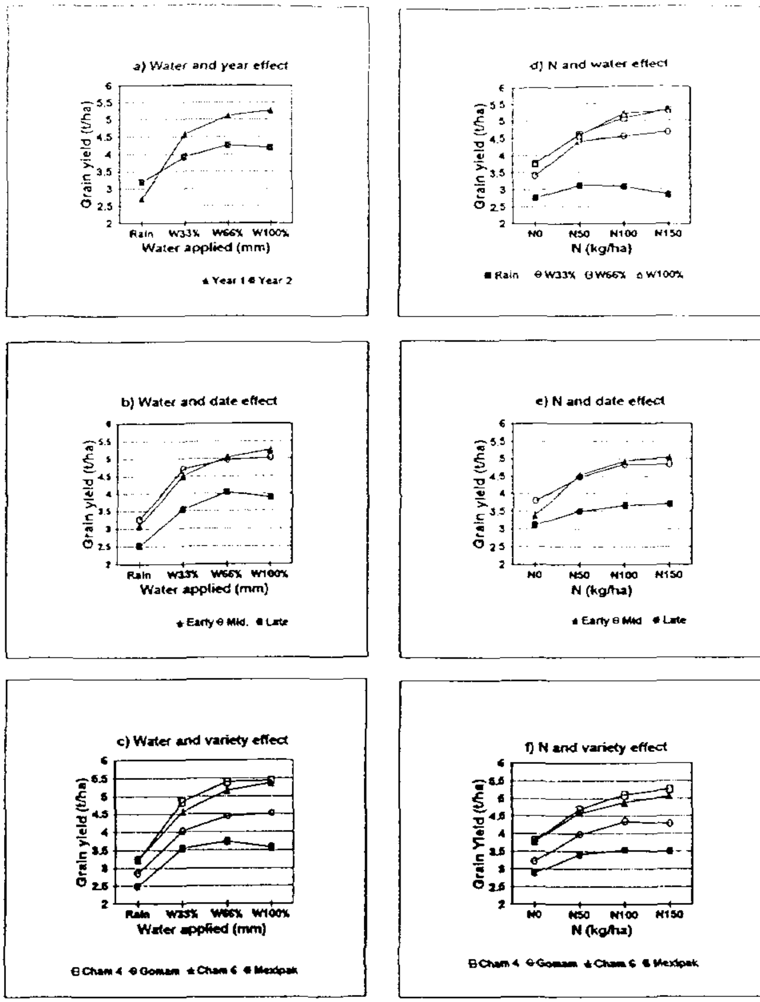


Figure 4.3.1. The effects of two factor interactions on bread wheat grain yield during 1992-94 seasons, Tel Hadya

3.5 t/ha for Mexipak, 3.2 to 4.3 t/ha for Gomam, 3.8 to 4.9 t/ha for Cham 6 and 3.8 to 5.1 t/ha for Cham 4 (Figure 4.3.1f). Lower yields in the second year were largely confined to Mexipak and Gomam. Mean values decreased from 3.7 to 3.0 t/ha for Mexipak, 4.5 to 3.4 t/ha for Gomam, 4.7 to 4.5 for Cham 6, and 4.8 to 4.7 for Cham 4. These differences correspond to yield reductions of 19, 24, 4 and 2%, respectively.

<u>Production functions</u>: The main factors and interactions significantly affecting yield components were used to develop production functions for grain, total dry matter, and straw yields, of the form:

$$Y=f_0+f_1(PR)+f_2(SI)+f_3(N)+f_4(D)+f_5(PR*SI)+f_6(PR*N)+f_7(PR*D)+f_8(SI*N)+f_9(SI*D)+f_{10}(N*D)+f_{11}(SI^2)+f_{12}(N^2)+f_{13}(D^2)+f_{14}(SI^2*N)+f_{15}(N^2*D)+f_{16}(N^2*PR)+f_{17}(D^2*PR)$$

where Y = yield in t/ha, f0 is the intercept, and f1 to f17 are the respective regression coefficients for each factor, as shown in Table 4.3.3. PR is precipitation in mm, SI is the net amount of supplemental irrigation in mm, N is the amount of applied nitrogen in kg/ha,and D is the delay in planting after the first of November in days. Percentage variance accounted for, for grain, total dry matter and straw yields, was 87.2, 86.1, and 84.3, respectively. Some examples of response surfaces generated from the model are illustrated in Figures 4.3.2 and 4.3.3.

Cham 4 and Cham 6 show very similar response surfaces in relation to water and N applications. Grain yield is increased from 2 to 4 t/ha by either 100 kg N/ha or 300 mm of supplemental irrigation separately. However, when both are applied together, the response is remarkable, with a further increase from 4 to 7 t/ha. At this level of inputs, a yield plateau is indicated. Further increases in N and SI will not, apparently, produce additional yield for these varieties.

The surface for Gomam follows a similar trend to that of Cham 4 and 6, but at a lower general yield level, while that of Mexipak was lower still. This was because of its sensitivity to yellow rust, which was a problem in the 1993/94 season. Increasing the rate of irrigation above 300 mm causes a greater decline in yield than that found in the other varieties. This result suggests that Mexipak in farmers' fields should give way to new improved varieties such as the Cham series.

Delay in planting is seen to cause a substantial yield reduction for all varieties when grown with 75 kg N/ha under

350 mm rainfall conditions (Figure 4.3.3). A 40-day delay after November 1 reduces grain yield from 6 to 3.5 t/ha in Cham 4 and 6, from 5 to 2.5 t/ha in Gomam and from 4 to 1 t/ha in Mexipak, showing the importance of timely sowing in wheat production. However, less supplemental water is required when planting is delayed, because higher water rates tend to decrease yield in late-planted crops.

Table 4.3.3 Estimates of regression coefficients for bread wheat production functions

Variable	Grain df=354	TDM df=362	Straw df=366
Intercept (Cham 4)	-0.119	3.75	0.649
Intercept (Gomam)	2.994	2.78	0.076
Intercept (Cham 6)	0.485	3.56	0.436
Intercept (Mexipak)	2.564	2.34	0.009
PR (Champ)	0.00895	0.01044	0.01093
PR (Gomam)	-0.00206	0.01044	0.01093
PR (Cham 6)	0.00688	0.01044	0.01093
PR (Mexipak)	-0.00091	0.01044	0.01093
SI (Champ)	0.03511	0.07372	0.04078
SI (Gomam)	0.03430	0.07372	0.04078
SI (Cham 6)	0.03512	0.07372	0.04078
SI (Mexipak)	0.03205	0.07372	0.04078
N (Champ)	-0.0032	-0.0058	0.0183
N (Gomam)	-0.0056	-0.0107	0.0183
N (Cham 6)	-0.0042	-0.0081	0.0183
N (Mexipak)	-0.0086	-0.0141	0.0183
D	-0.0175	-0.233	-0.202
PR.SI	-0.0000734	-0.0001583	-0.0000921
PR.N	0.0000762	0.0002086	0.0000597
PR.D	0.0001452	0.000889	0.000724
SI.N	0.0000681	0.0000667	0.0000334
SI.D	-0.0000424	0.0000	0.000
N.D	-0.0002315	-0.000682	-0.0004597
SI2	-0.000028	-0.0000478	0.000
N2	-0.0000003	-0.000009	-0.0001463
D2	0.000658	0.003776	0.003196
SI2.N	-0.10E-06	0.00000	0.000
N2.D	0.000001	0.0000028	0.0000019
N2.PR	-0.0000003	-0.0000007	0.000
D2.PR	-0.0000032	-0.0000145	-0.0000115

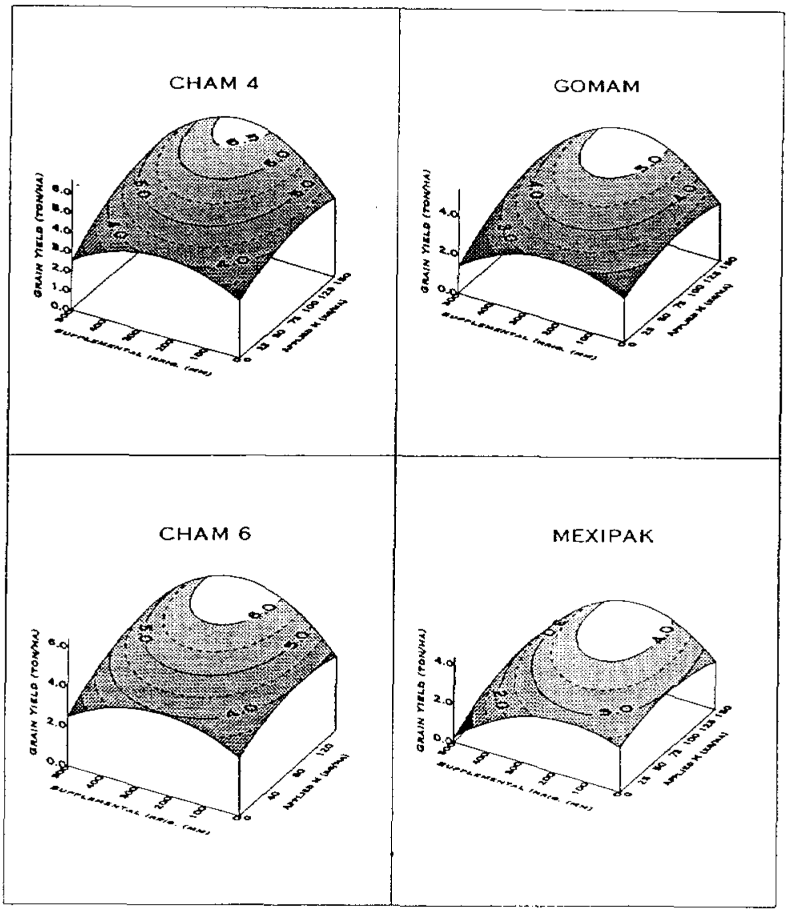


Figure 4.3.2. Response of bread wheat grain yield to supplemental irrigation and nitrogen, under 350 mm rainfall and with no delay in planting

4.3.3.2 Durum Wheat

Irrigation and rainfall: Table 4.3.4 shows the amounts and dates of supplemental irrigation applied during the two growing seasons 1992/1993 and 1993/1994 in the durum wheat

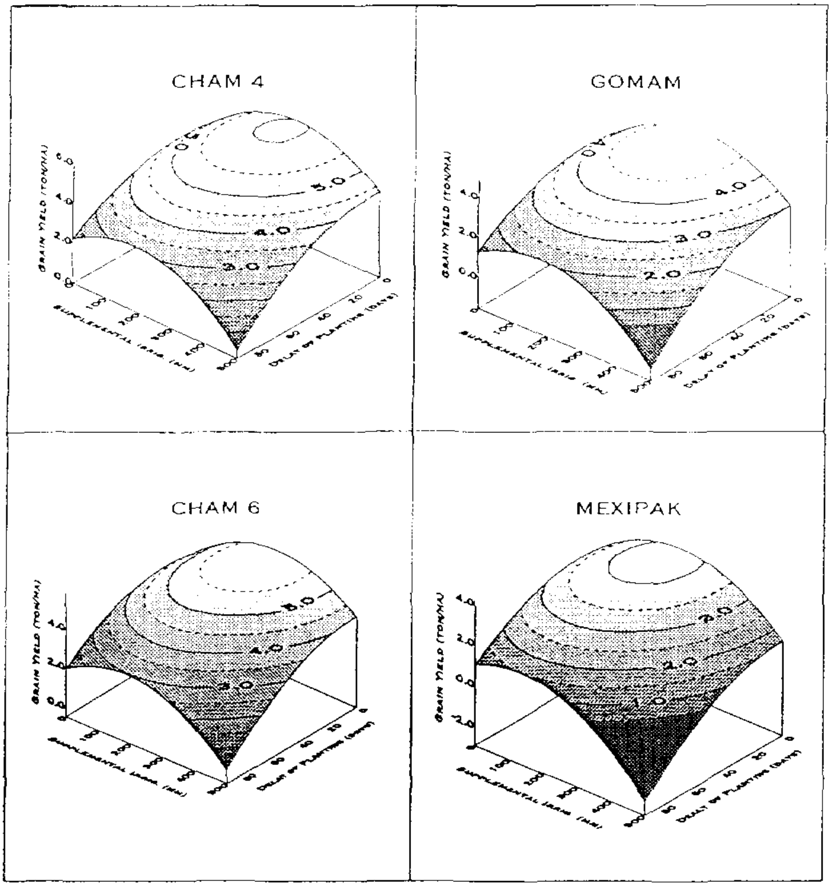


Figure 4.3.3. Response of bread wheat grain yield to supplemental irrigation and delay in planting with 75 kg/ha applied N and 350 mm rainfall

experiment. As in the case of bread wheat, the amounts indicated are for the W4 treatment only; and, again, the water applied in the last irrigation of the season was not necessarily used totally by the crop before harvest. The total amount of SI used in the subsequent calculation is adjusted to account for the residual portion left in the soil, as determined by soil moisture measurements.

Table 4.3.4 Amounts [W4 only] and dates of supplemental irrigations applied in the durum wheat experiment, Tel Hadya, 1992/93 and 1993/94

1992/93 (Total rainfall - 277 mm)			1993/94 (Total rainfall = 373 mm)		
Date of planting	Amount of irrig., mm	Date of irrig.	Date of planting	Amount of irrig. mm	Date of irrig.
D1=10/11	133	2/4/93	5/11/93	113	6/4/94
	146	15/4/93		85	21/4/94
	118	23/4/93		125	16/5/94
	151	21/5/93			
	total=548			total=323	
D2=21/12	95	1/4/93	5/12/93	106	7/4/94
	100	23/4/93		83	21/4/94
	100	4/5/93		164	15/5/94
	146	21/5/93			
	total=441			total=353	
D3=16/1	62	6/4/93	13/1/94	80	5/4/94
	84	23/4/93		89	22/4/94
	130	22/5/93		150	16/5/94
	total=276			total=319	

Yield responses to management factors: The analysis of variance for the two years combined is presented in Table 4.3.5. Results are similar to those for durum wheat, except the durum cultivars did not interact significantly with water or N applications. Cultivar differences are therefore omitted from Figure 4.3.4.

Mean response of grain yield to water application was greater in 1992/93 than in 1993/94, due to less favorable rainfall conditions in the earlier year - reflected in a yield of 2.2 t/ha from the rainfed treatment compared with 3.6 t/ha in 1993/94 (Figure 4.3.4a). A delay in sowing, even from November to December, reduced crop response to water (Figure 4.3.4b) and more generally to mean yield levels (Figure 4.3.4c), although the reasons for the observed difference between the two years results is not known.

Mean response of grain yield to nitrogen was strongly water dependent (Figure 4.3.4d). Under rainfed conditions, as with bread wheat, there was a small increase, from 2.7 to 3.0 t/ha, from 50 kg N/ha, but no further response. For the 33% water rate, mean yield increased from 3.5 to 4.5 t/ha

Table 4.3.5 Analysis of variance for durum wheat grain, total dry matter, and straw yields of 1992/93 and 1993/1994 seasons combined

Source of variation	d.f.	Grain	D.M.	Straw
Year.Rep				
Yr	1	15.6	485.4	327.1
Residual	4	17.6	101.1	52.3
Yr.Rep.Date				
date	2	55.8**	835.0***	459.2***
Yr.Date	2	63.3***	339.9**	110.1
Residual	8	3.8	26.9	11.3
Year.Rep.Date.Var				
Var	3	10.3***	36.4***	20.6***
Yr.Var	3	4.2**	7.7	1.2
Date.Var	6	1.1	6.7	3.6
Yr.Date.Var	6	2.2*	13.3*	6.0*
Residual	36	0.7	4.8	2.5
Yr.Rep.Date.Var.Water				
Water	3	401.2***	1866.7***	542.1***
Yr.Water	3	53.2***	325.5***	115.5***
Date.Water	6	5.4***	30.9***	10.6**
Var.Water	9	1.2	6.2	2.4
Yr.Date.Water	6	8.7**	49.9***	17.4***
Yr.Var.Water	9	1.7	11.6	4.8
Date.Var.Water	18	1.1	8.4	4.4
Yr.Date.Var.Water	18	1.1	7.7	3.7
Residual	144	1.1	6.8	3.1
Yr.Rep.Date.Var.Water.N				
N	3	105.5***	734.9***	290.8***
Yr.N	3	12.5***	91.1***	36.1***
Date.N	6	5.6***	58.1***	27.9***
Var.N	9	0.4	3.2	1.7
Water.N	9	9.9**	44.7***	12.8***
Yr.Date.N	6	2.8***	21.0***	8.7***
Yr.Var.N	9	0.2	0.9	0.5
Date.Var.N	18	0.3	2.5	1.4
Yr.Water.N	9	0.8**	3.1	1.1
Date.Water.N	18	0.9**	5.1***	1.9*
Var.Water.N	27	0.3	2.6	1.5
Yr.Date.Var.N	18	0.8***	3.5	1.4
Yr.Date.Water.N	18	0.4	3.6*	1.9*
Yr.Var.Water.N	27	0.2	2.0	1.0
Date.Var.water.N	54	0.3	1.8	0.9
yr.Date.Var.Water.N	54	0.4*	3.4**	1.6*
Residual	576	0.3	2.1	1.1
Total	1151			

*** significant at P< 0.001; ** significant at P< 0.01
* significant at P< 0.05

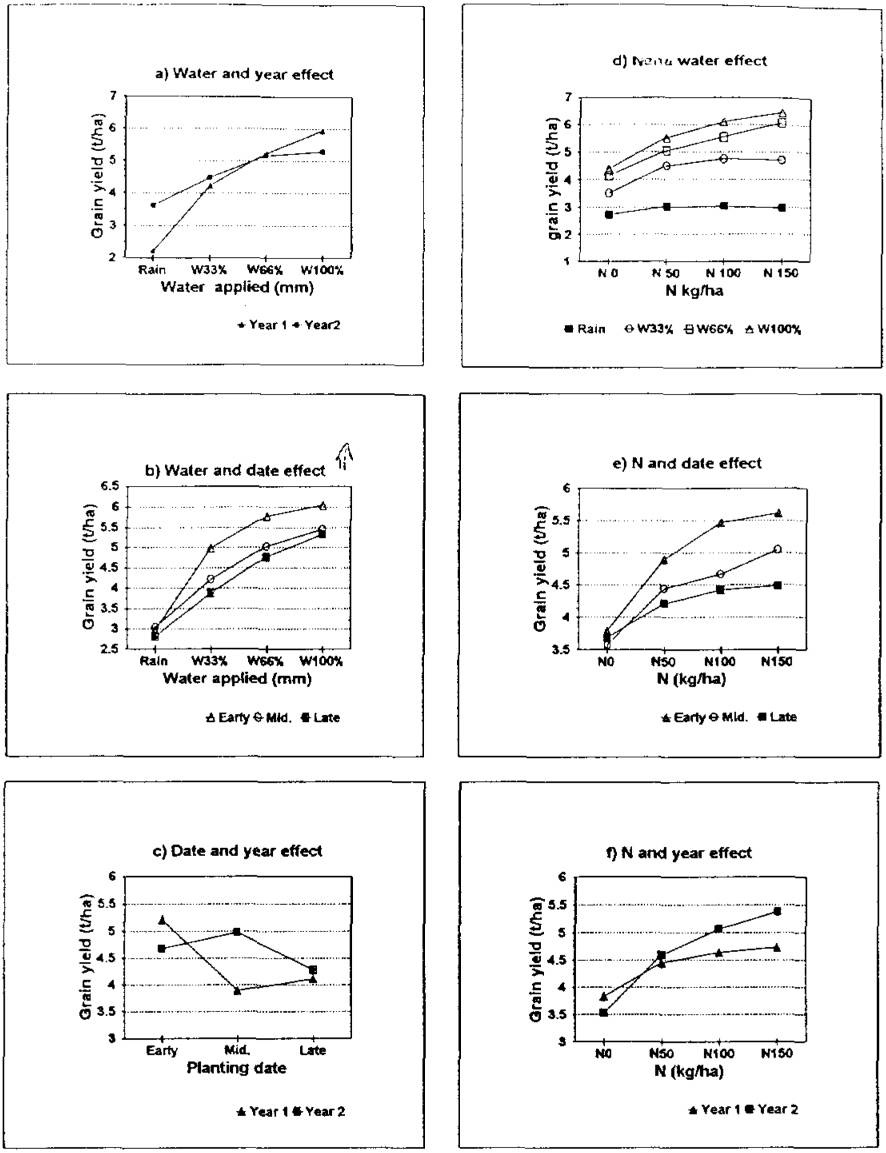


Figure 4.3.4. The effects of two factor interactions on durum wheat grain yield during 1992-94 seasons, Tel Hadya

with the first 50 kg N/ha increment but showed no significant increase above that from higher rates. However, for the 66% or 100% water rates, response to nitrogen continued to increase even above the 100 kg N/ha rate.

Response to nitrogen was also affected by sowing date Figure 4.3.4e). Mean grain yield increase, relative to control, from 100 kg N/ha for the early sowing increased grain yield from about 3.8 to 5.5 t/ha, but the corresponding increase for the December sowing was only from 3.6 to 4.7 t/ha, and for January sowing, from 3.7 to 4.4 t/ha. Mean response to N was greater in 1993/94 than in 1992/93, probably because growing conditions were more favorable (Figure 4.3.4f).

Cham 1, Cham 3 and Om Rabi 5 gave the same mean grain yields, 4.6 t/ha; that of the fourth variety, Lahn, was significantly lower, at 4.2 t/ha (data not shown in Figure). However, although this result suggests that improved varieties may not differ greatly from each other in mean productivity, they may still have different characteristics that suit them for specifically different environments.

Production Functions: A production function, similar to that for bread wheat, was developed for durum wheat, involving those factors shown to be significant by the analysis of variance (Table 4.3.5):

$$Y=f_0+f_1(PR)+f_2(SI)+f_3(N)+f_4(D)+f_5(PR*SI)+f_6(PR*N)+f_7(PR*D)+ f_8(SI*N)+f_9(SI*D)+f_{10}(N*D)+f_{11}(SI^2)+f_{12}(N^2)+f_{13}(D^2)+f_{14}(SI^2*N)+f_{15}(SI^2*D)+f_{16}(N^2*D)+f_{17}(D^2*PR)$$

where Y = yield in t/ha, f0 is the intercept, f1 to f17 are the respective regression coefficients for each factor, as shown in Table 4.3.6. These factors are described above in the corresponding for bread wheat. Percentage variance accounted for, for grain, total dry matter and straw yields was 88.2, 86.9, and 84.5, respectively. Some examples of response surfaces generated from the model are illustrated in Figures 4.3.5 and 4.3.6.

All the durum varieties produce very similar response surfaces for both sets of chosen conditions. With a November sowing and 350 mm rainfall (Figure 4.3.5), grain yield is increased from 3 to 4.0 t/ha by 100 kg N/ha under rainfed conditions but to 6.5 t/ha with the application of an extra

200 mm as supplemental irrigation. With 300 mm added yield reaches a plateau of 7.0 t/ha at 100 kg N/ha, thus providing a yield increase of only 0.5 t/ha from the additional 100 mm water. Compared with bread wheat, durum cultivars tend to reach the same yield level with less irrigation (compare Figures 4.3.2 and 4.3.5), showing higher water-use efficiency. Figure 4.3.6 shows how delayed planting causes a substantial yield reduction in all varieties, under the conditions of 75 kg N/ha and 350 mm rainfall.

Table 4.3.6 Estimates of regression coefficients for the durum wheat production functions

Variable	Grain df=360	TDM df=365	Straw df=366
Intercept (Cham 1)	0.139	0.82	-0.379
Intercept (Lahn)	0.654	0.36	-0.481
Intercept (Cham 3)	0.344	1.13	-0.101
Intercept (Omrabi 5)	1.948	0.46	-0.748
PR (Cham 1)	0.00770	0.01935	0.01472
PR (Lahn)	0.00499	0.01935	0.01472
PR (Cham 3)	0.00717	0.01935	0.01472
PR (Omrabi 5)	0.00214	0.01935	0.01472
SI 0.03323	0.07293	0.04018	
N -0.00739	-0.0131	-0.00568	
D -0.2264	-0.5749	-0.3179	
PR.SI	0.0000687	-0.0001587	-0.0000911
PR.N	0.0000779	0.0001924	0.0001146
PR.D	0.0006852	0.001661	0.000894
SI.N	0.0000676	0.0001496	0.000082
SI.D	0.0000361	0.0	0.0
N.D	-0.0001724	0.000559	-0.0003871
SI2	-0.0000156	-0.0000286	-0.0000121
N2	-0.0000882	-0.0002012	-0.000113
D2	0.003239	-0.0000286	0.004527
SI2.N	-0.80E-07	-0.19E-06	-0.11E-06
SI2.D	-0.20E-06	0.0	0.0
N2.D	0.0000007	0.000002	0.0000013
D2.PR	-0.0000098	0.0000238	-0.0000130

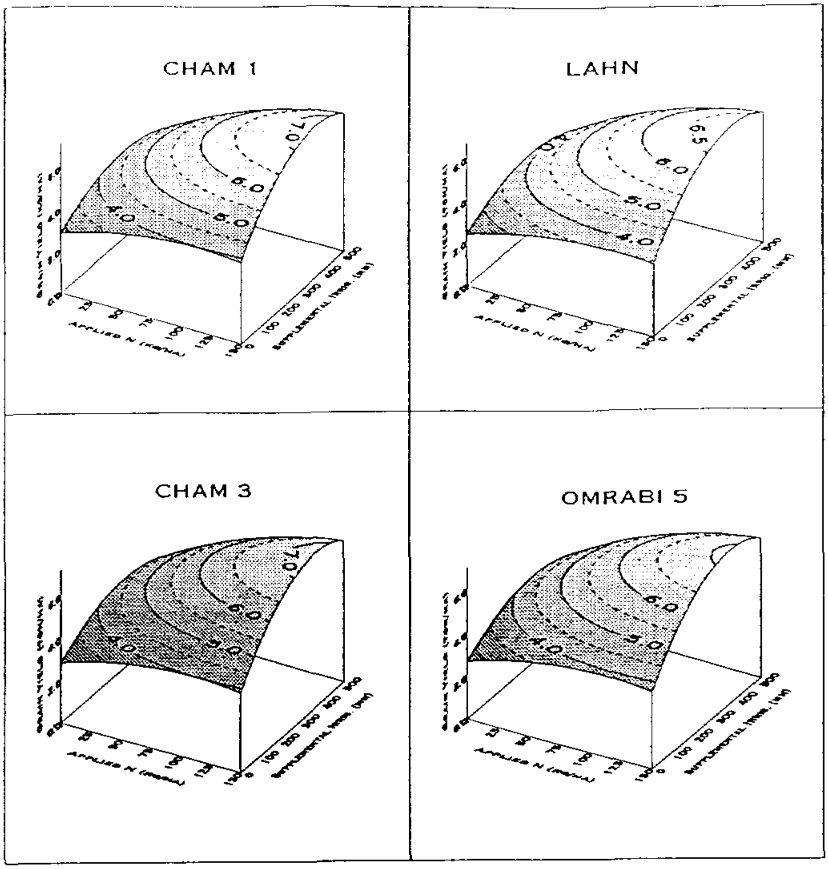


Figure 4.3.5. Response of durum wheat grain yield to supplemental irrigation and nitrogen with 350 mm rainfall and no delay in planting

4.3.4 <u>Conclusions</u>

All the main factors, except year, had a significant effect on the yield components of both crops, but subject to a number of interactions at different levels of significance. Water x year, water x nitrogen, water x date, and nitrogen x date were the most important ones common to both bread and durum wheat.

Sowing date had a marked effect: yields declined strongly with lateness of planting, irrespective of what

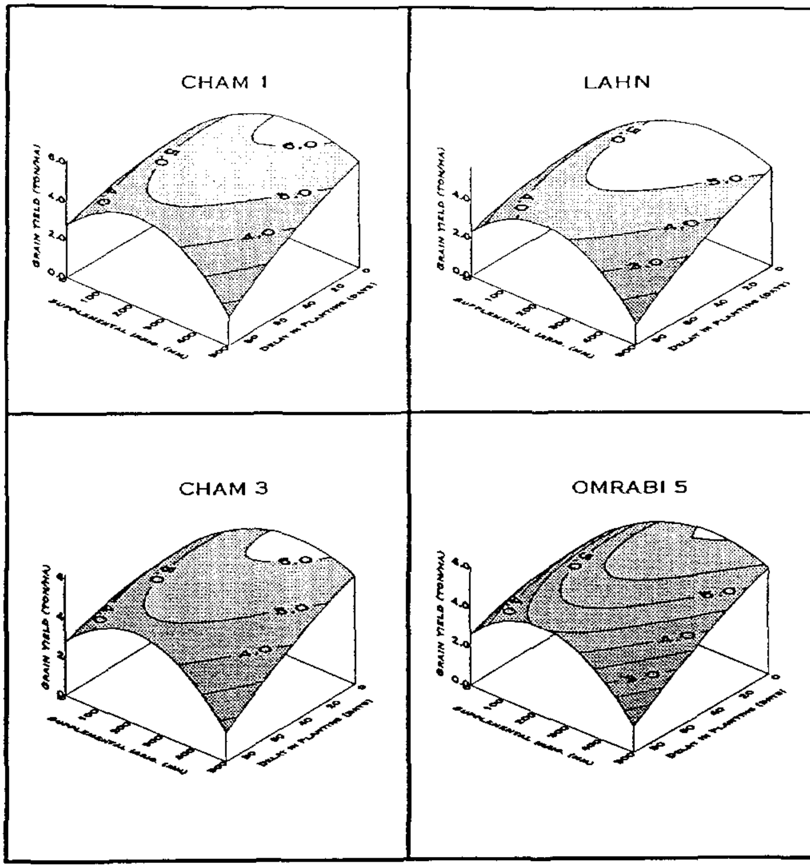


Figure 4.3.6. Response of durum wheat grain yield to supplemental irrigation and delay in planting date with 75 kg/ha N and 350 mm rainfall

other treatments were applied. It is clear that sowing should not be delayed beyond mid November if rainfall, supplemental irrigation and nitrogen are to be utilized efficiently. Response to both water and nitrogen decreased with lateness of sowing.

There were important varietal differences among the bread wheats, both in their general yield levels (even just their rainfed yield levels) and in their responses to water and nitrogen inputs. In fact, Cham 4 and Cham 6 were very similar to each other in all these respects, but Gomam was appreciably lower yielding and less responsive to inputs, and Mexipak was substantially worse. We may conclude that selection of variety is a key factor in the optimal use of supplemental irrigation and nitrogen on bread wheat.

Differences among durum wheat varieties were much smaller. Cham 1, Cham 3 and Om Rabi 5 all performed similarly, with Lahn generally around 0.5 t/ha lower. On this evidence, choice of variety would be less critical for durum than for bread wheat.

The regression models developed from the results are intended to give a better understanding of the interactions of the main treatment factors and allow some extrapolation for other conditions. In fact, a two-year data set is not a sufficient basis upon which to base form conclusions, even though it was useful that the two experimental seasons were quite different from each other both in the amount of seasonal rainfall and in mean temperatures. As more data becomes available in subsequent years, such response surfaces will become increasingly useful in guiding decisions over input utilization and management levels for wheat production under supplemental irrigation and for focussing further research needs. ***[T. Oweis, M. Pala, with support from J. Ryan, M. Nachit and G. Ortiz Ferrara]***

4.4 Calibration of the CropSyst Simulation Model and an Assessment of Durum Wheat Production Trends Across North-west Syria using Simulation/GIS Technology

4.4.1 Introduction

The rainfed farming systems of WANA have developed over centuries in areas of mean annual (winter) rainfall of 200-600 mm with considerable temporal and spatial variability. This deficient and unreliable rainfall is coupled with widespread nutrient deficiencies and often inadequate soil and crop management (Cooper et *al.* 1987).

Cereals are the principal crops grown, with wheat (*Triticum aestivum, T. Turgidum var. Durum*) covering about

50% and barley (*Hordeum vulgare*) 20% of the cropped land (Pala 1991). A cereal-fallow rotation with livestock grazing is the traditional system, but fallow efficiencies in storing water for the subsequent crop are low and variable (Harris *et al.* 1991). In any case, increased need for food and feed arising from population increase is causing the abandonment of fallowing in favour of continuous cropping (Acevedo *et al.* 1991). In Syria, wheat is grown from the wettest to the driest areas. In dry areas, where barley predominates, wheat is produced for subsistence, even at the edge of the steppe (Thomson *et al.* 1985). In wetter areas (over 325 mm), wheat is the dominant crop, in rotation with food legumes and summer crops such as water melon, sesame, cotton, and cucurbits.

Given the unreliability of the rainfall, increased and sustainable crop production requires more water-efficient, locally-adapted cultivars grown under appropriate management practices. Effective crop establishment is essential. To achieve this, it is important to have a properly tilled seed bed and to optimize the sowing date. However, under annual cropping, almost all extractable water is used each year, and further evaporation during the summer decreases soil water far below the wilting point. Sowing is therefore strongly dependent upon receiving sufficient early precipitation.

For dryland cropping in winter rainfall areas, achieving the optimum sowing date may have a substantial effect on water-use efficiency (WUE), and eventually on yield, by ensuring that the growth period is adjusted to the availability of the soil moisture. There are many indications that early crop establishment and early canopy development lead to higher wheat and barley yields (Bolton 1981; Cooper *et al.* 1983); and any lengthening of the effective growth period to achieve higher yields is possible only by earlier sowing (Keatinge *et al.* 1986; Photiades and Hadjichristodoulous 1984; French and Shultz 1984). However, early sowing is advantageous only if emergence also occurs early and if the crop can survive potential drought conditions at the seedling stage (Pala 1991). Currently, farmers in the Mediterranean region tend to sow wheat later than the optimum (usually mid November), for several reasons: unreliable initial rains (Dennet *et al.* 1984); the need to control weeds by pre-sowing tillage operations; and a risk of frost damage to early-sown crops.

There is thus a need to study the effect of sowing date on crop yield in relation to the long-term spatial and temporal variations in rainfall. Field experiments are the best tools to assess such an effect, but they are usually limited in their time span. For a reliable analysis of production variability, the minimum of a thirty year-data set is needed in most cases. Crop simulation models provide a possible alternative approach, provided there are data available for preliminary calibration; and geographic information systems (GIS) permit results from such models to be calculated and presented on a spatial basis, again provided there are sufficient data available to define the spatial environment.

The present study uses a suitable simulation model to identify the optimum sowing date under rainfed conditions for an improved durum wheat cultivar, Cham 1, across an area of northwest Syria. It goes on to determine the potential yield levels of this cultivar under conditions of sufficient water and nitrogen, assuming that, in many situations, supplemental irrigation is potentially available (Perrier and Salkini 1991). A third objective is to identify the nitrogen rate required for different soil and climatic zones under rainfed conditions to increase the efficiency of nitrogen use.

4.4.2 The CropSyst model

CropSyst is a multi-year, multi-crop daily time-step simulation model. It has been developed to serve as an analytical tool to study the effect of cropping system management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, grain yield, residue production and decomposition, and soil erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations and residue management.

The water budget in the model includes rainfall, irrigation, runoff, crop interception, water infiltration and redistribution in the soil profile, crop transpiration and evaporation. The nitrogen budget includes nitrogen application, nitrogen transport, nitrogen transformations, ammonium sorption and crop nitrogen uptake. Daily crop growth, expressed by biomass increase per unit area, is calculated on the basis of a minimum of four limiting factors, light, temperature, water and nitrogen. Details on the technical aspects and use of the CropSyst model are reported elsewhere (Stockle *et al.* 1994; Stockle and Nelson 1994).

To use the model, soil characteristics, initial conditions of available moisture, available N and organic matter, and daily weather data from the site(s) under study are inputted, along with appropriate crop parameters. The values used may either be those typical for the particular crop species, or they may be determined for the specific cultivar from experimental data or by calibration (as described below).

In the present case, the field data used for model validation were obtained from a line-source sprinkler experiment (Perrier and Salkini 1991) conducted at Tel Hadya during the 3 seasons, 1989-1992, using a strip block design with 3 replicates. Each year, Cham 1, an improved durum wheat cultivar, was grown under 3 rates of water (W0 = rainfed, W60, W100 = 60%, 100% of crop water requirement, respectively) and 2 rates of N fertilizer (0 and 100 kg N/ha) in a wheat-chickpea rotation. This gave a total of 18 combinations of 3 growing seasons, 3 water treatments and 2 nitrogen treatments. Two of these combinations, W100/N100 and W0/N0 in the 1991/1992 season (the best season of the experimental period), were used to calibrate the crop parameters (but were not used in the validation procedure described below). Calibration consisted of the adjustment of crop parameters, within their usual range of fluctuation, to produce a reasonable tracking throughout the season of the experimental data for green leaf area index (GAI), aboveground biomass, evapotranspiration (ET), and N uptake data.

Validation of the model for Tel Hadya soil conditions followed, using the remaining 16 treatment combinations, to compare values of GAI, aboveground biomass, cumulative ET and cumulative N uptake throughout the season. In addition, values of aboveground biomass, grain yield, cumulative ET, and cumulative crop N uptake at harvest were also available.

4.4.3 Model performance

To evaluate the ability of CropSyst to track the GAI, aboveground biomass, ET, and N uptake progression throughout each growing season, previously collected experimental data points were plotted against the daily simulated data for each treatment. An example is presented in Figure 4.4.1 for the 1990/91 season. Most simulation results were similar to this

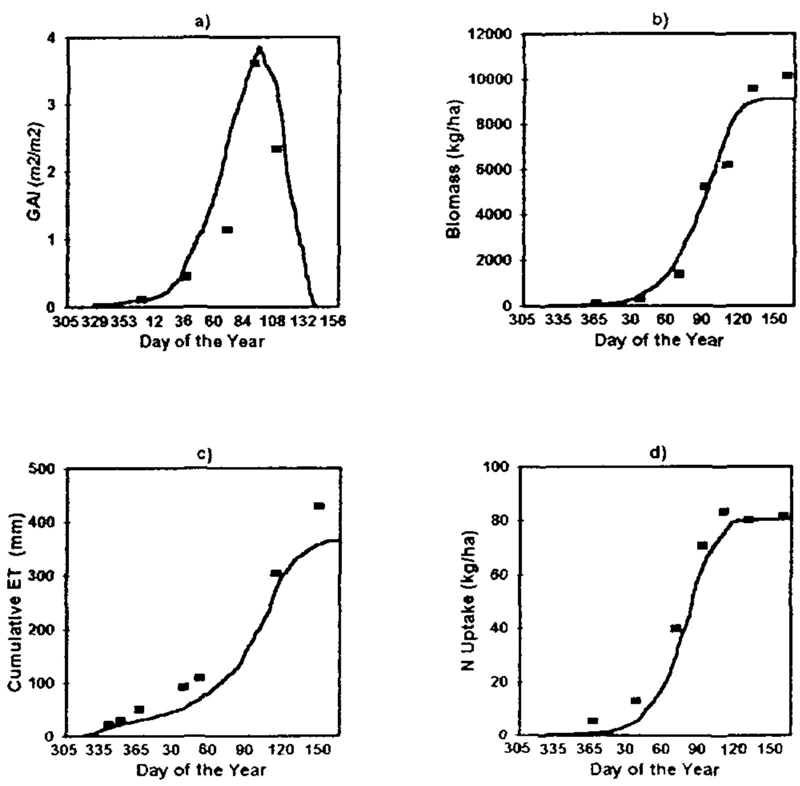


Figure 4.4.1. Distribution of the daily simulated data compared with the observed data obtained at different times during the 1990/91 growing season of Cham 1 durum cultivar, treatment W100/N0: (a) GAI, (b) above ground biomass, (c) cumulative ET, and (d) cumulative N uptake, where (▪) represents observed data points, and (—) represents simulated daily data.

example, with a few cases better or slightly worse. In general, the model tracked well the changes in GAI, biomass, ET and N uptake throughout the season. This is an important result, because it demonstrates the reliability of the model, when correctly calibrated, to predict harvest-time values, which is usually the information needed for the long-term analysis of management practices.

Observed and simulated values of aboveground biomass, grain yield, cumulative ET and cumulative N uptake at harvest are compared in Figure 4.4.2. Simulated outputs followed closely the 1:1 line when plotted against the experimental

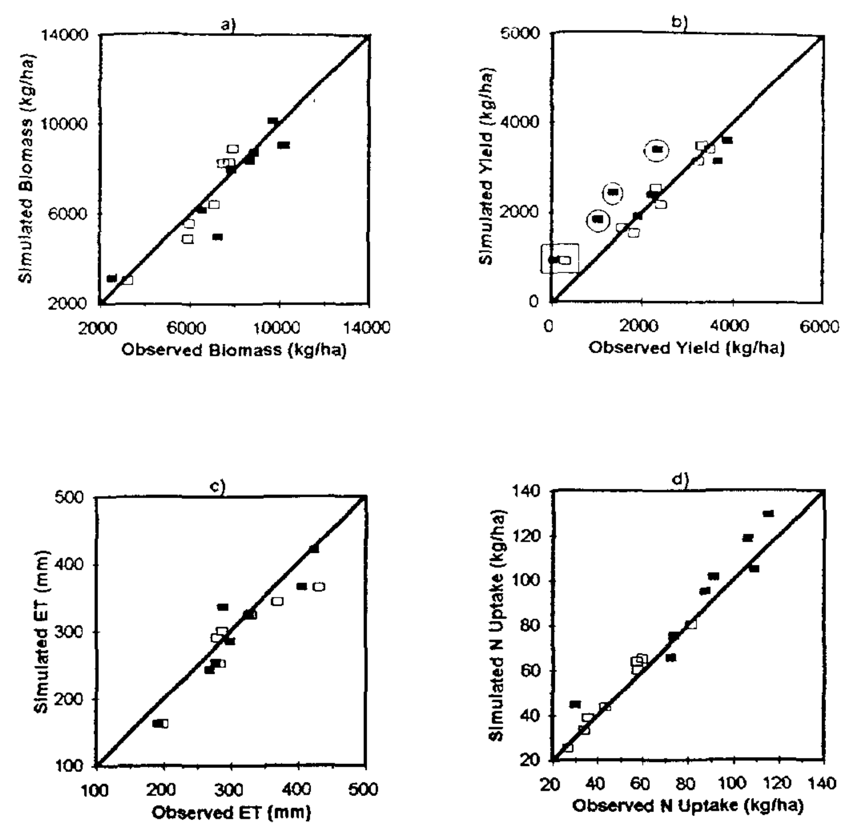


Figure 4.4.2. Simulated data plotted against observed data for Cham 1 wheat cultivar during the three seasons of the experiment; (a) above ground biomass, (b) grain yield, (c) cumulative ET, and (d) above ground crop N uptake

data. Statistical analysis of these data0 (Table 4.4.1) confirmed that CropSyst predicted the outputs reasonably well, showing a high index of agreement (d) and root mean square errors (RMSEs) corresponding to 9% (cumulative ET) to 25% (grain yield) of the observed mean values. The observed and simulated mean values of these for the 16 data points of each cultivar were very close (Table 4.4.1).

Table 4.4.1 Statistical summary comparing simulated vs. observed data for Cham 1

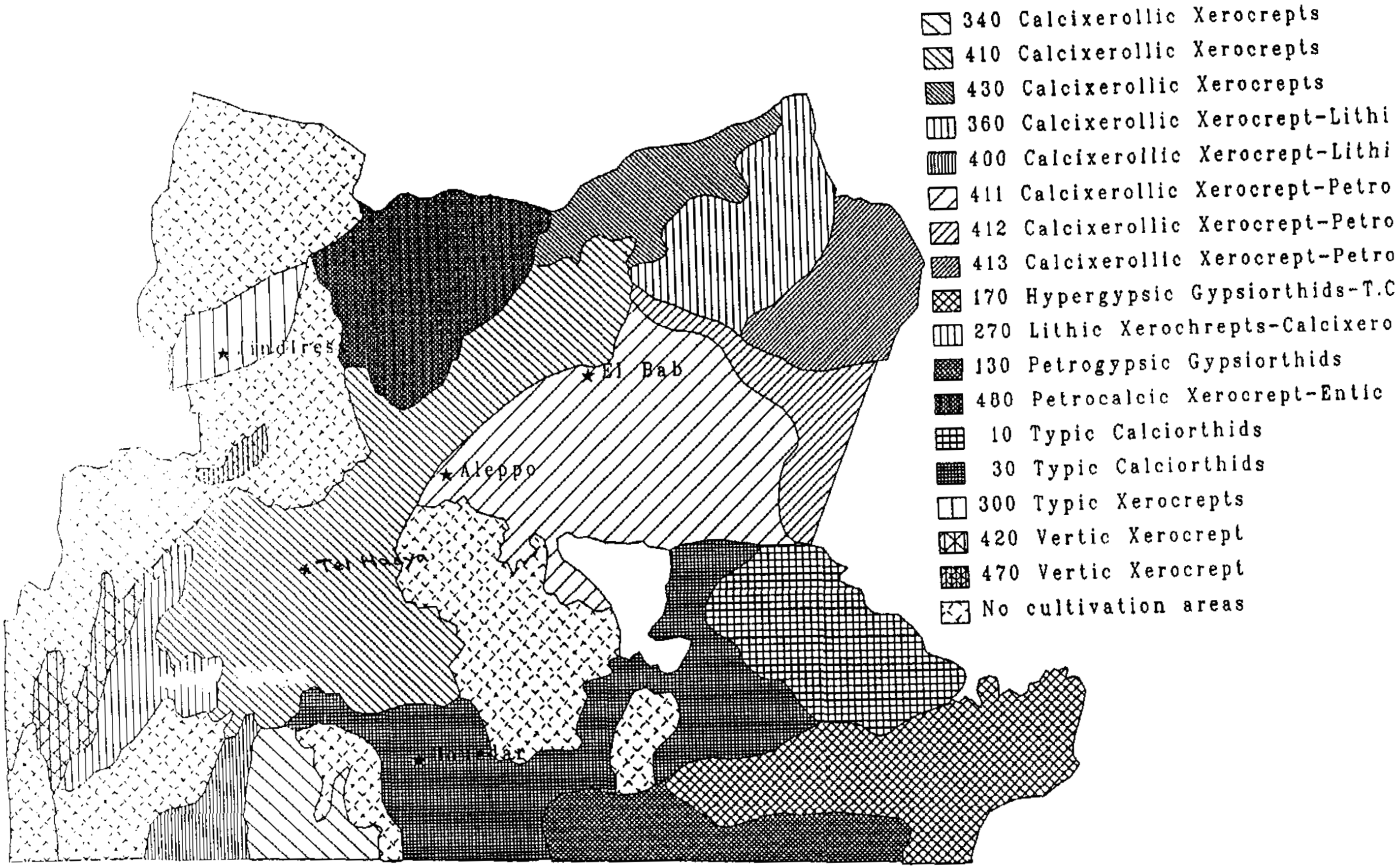
Data	n	Slope	Cons.	Adj R^2	Obs. Mean kg/ha	Sim. Mean kg/ha	RMSE kg/ha	RMSE /Obs. Mean	d (**)
Biomass	16	0.94	244	0.84	7310	7090	870	0.12	0.96
Grain	16	0.70	877	0.81	2180	2410	550	0.25	0.92
ET	16	0.93	7	0.85	311*	298*	29*	0.09	0.95
N uptake	16	10.5	1	0.96	67	72	8	0.11	0.98

* ET values are in mm
** Index of agreement (d0< as defined by Willmott (1982), where 0<d<1, with a value of 1 indicating perfect agreement between observed and predicted values

The reason for the overpredicted grain yield values marked with squares was the severe drought, on rainfed plots, associated with frost and strong hot winds in the 1989/90 season, which the model was unable to detect. The reason for the overestimated points marked with circles was the unusual negative response of grain yield to N fertilization observed during the 1990/91 season. In spite of these problems, the statistical analysis showed a reasonable agreement between observed and predicted grain yield data, with the index of agreement of 0.92 for Cham 1 (Table 4.4.1).

4.4.4 Characterization of the study area

Soils. Four major soil groups recognized on the FAO/UNESCO soil map of the world are found in north-west Syria (Map 4.4.1). These are all calcareous soils, formed from limestone residuum, but with very variable texture, depth, slope and stoniness. Organic matter contents are generally



Map 4.4.1. NW Syria - Soils

low, and structural stability is poor in some soils. Sabet and Harris (1986) reported surface capping by rainfall causing a serious constraint to production on calcic xerosols.

Agro-ecological zones. Syria has been divided into six 'agricultural stability' zones based on mean annual rainfall (Watson 1979). Five of these zones transect the study area. However, closer intervals of mean annual rainfall isohyets were used in the present simulation to maximize the visibility of differences across rainfall zones (Pala *et al.* 1992).

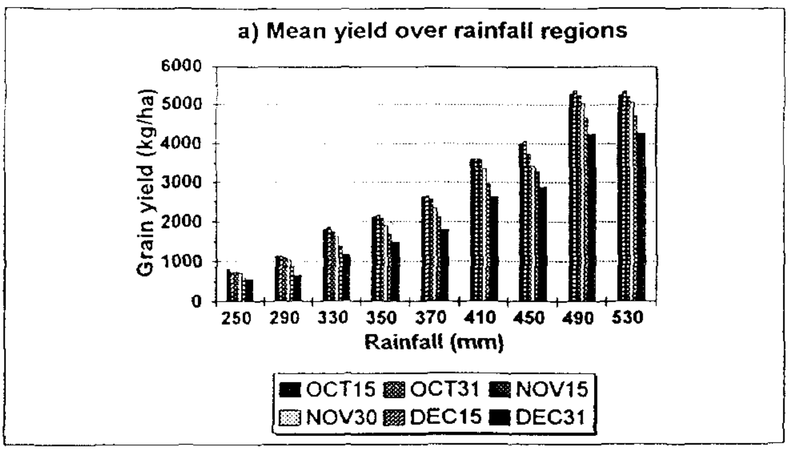
A total of 24 meteorological stations - 11 of them with daily rainfall, maximum and minimum temperatures data ranging from 12 to 29 years; 6 with daily rainfall data ranging from 13 to 28 years; and 7 with only monthly rainfall data ranging from 15 to 24 years - were used to generate weather data for pre-defined rainfall isohyets at 20 mm intervals (a total of 21 rainfall zones). Radiation data, available from ICARDA Tel Hadya station for 12 years only, were used as a standard for generating radiation values for all the other stations (Summer B parameter was 0.302818 and winter B parameter was 0.00575).

Production systems. The growing conditions for wheat, particularly the soil moisture profile at sowing time, will always depend in some degree on the nature of the preceding crop. Much of the dryland wheat in northwest Syria is grown in a two-year rotation with chickpea or lentil. However, as we have no simulation model available for legumes, it has been necessary in the present study to assume a continuous wheat sequence. In reality, we would expect continuous wheat to perform rather badly, due to a number of biotic factors not simulated by the model. However, chickpeas are very similar to wheat in the extent to which they dry out the soil profile; so, to a first approximation, we may assume that a wheat-wheat sequence (without biotic factors) simulates a chickpea-wheat sequence in respect of the soil moisture regime. The cultivar used for the simulation, Cham 1, is an improved durum wheat, already widely adopted by farmers in the study area (Pala and Rodriguez 1992). The simulated values presented below may therefore reasonably be thought to represent Cham 1 grown in rotation with chickpeas under the conditions widely found in northwest Syria.

4.4.5 Effect of sowing date on wheat production

The mean yield pattern from a 30-year simulation by the model/GIS combination for a mid-November sowing is given in Map 4.4.2. Half of the study area (about 40-60% of the total cropped land) yields only 0.5-1.5 t grain/ha. For sowing dates later than mid November, mean yields less than 1 t/ha cover about 25-50% of the area.

There is clear trend of increasing yield with increasing rainfall up to about 500 mm (Figure 4.4.3).



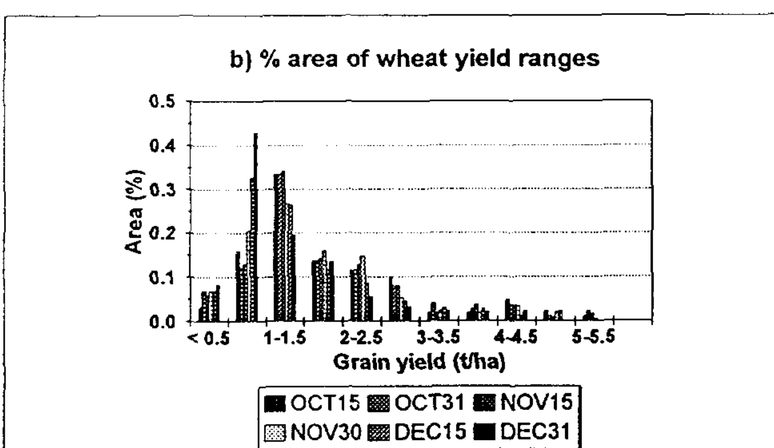
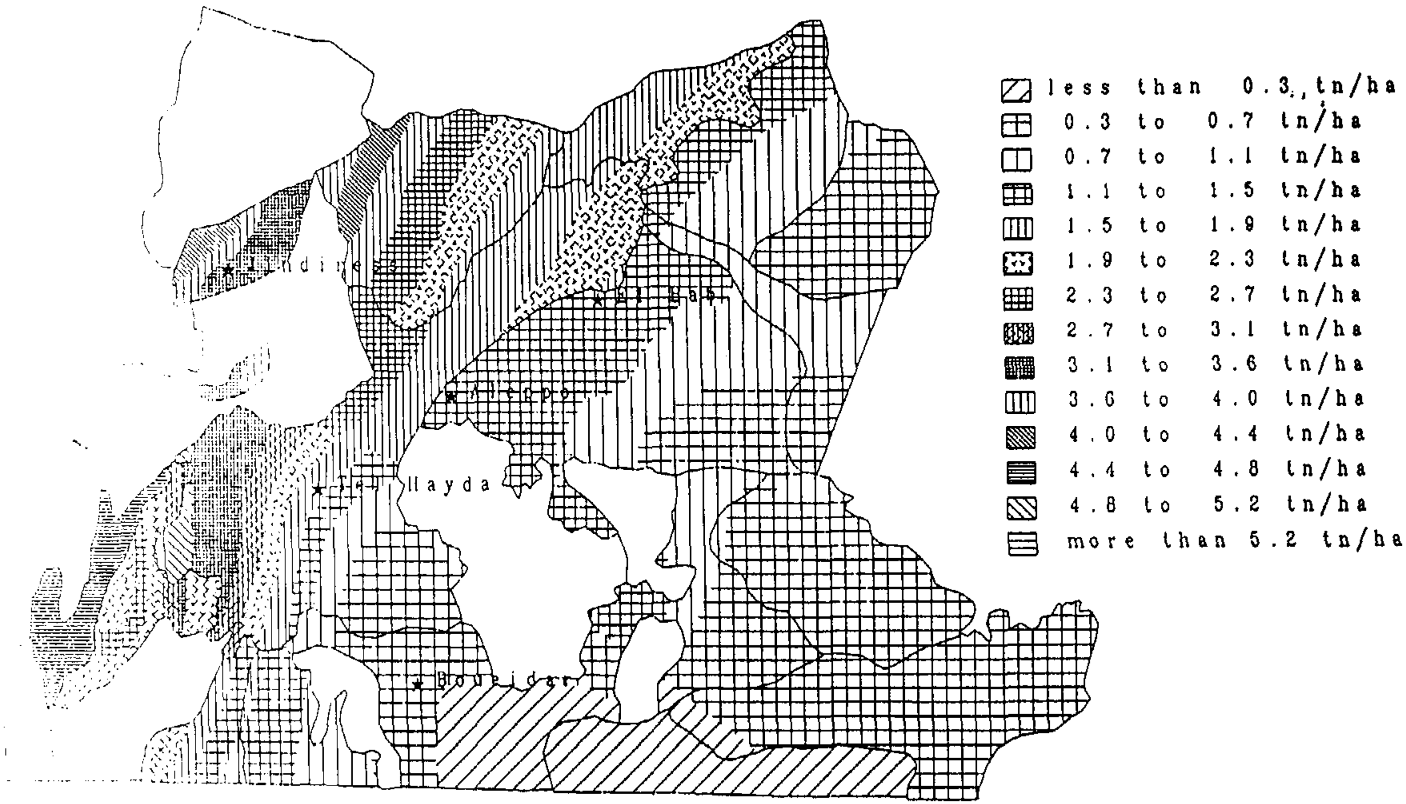


Figure 4.4.3. Mean predicted rainfed durum wheat yield with different sowing dates across rainfall regions and area percentages of different yield ranges in northwest Syria



Map 4.4.2. NW Syria - Durum wheat grain yield (t/ha), Nov 15 (planting)

In the higher rainfall areas, delays in sowing have a substantial negative effect on yield (5 t/ha from an early sowing declining to about 4 t/ha from a late December sowing); but this effect is less pronounced under drier conditions. In general, sowing wheat before mid November confers only a small yield advantage, but subsequent delays lead to decrease.

The distribution of yield probabilities from drier to wetter areas is given in Figure 4.4.4. For example, in the 250 mm rainfall zone, the probability of yield between 1 and 1.5 t/ha is just 20% and decreases substantially when sowing is delayed until late December. The extreme riskiness of sowing wheat in this zone is shown by the 40% probability at all sowing dates of obtaining zero yield. In fact, farmers in these areas to alleviate their overall risk by sowing most of their land to barley.

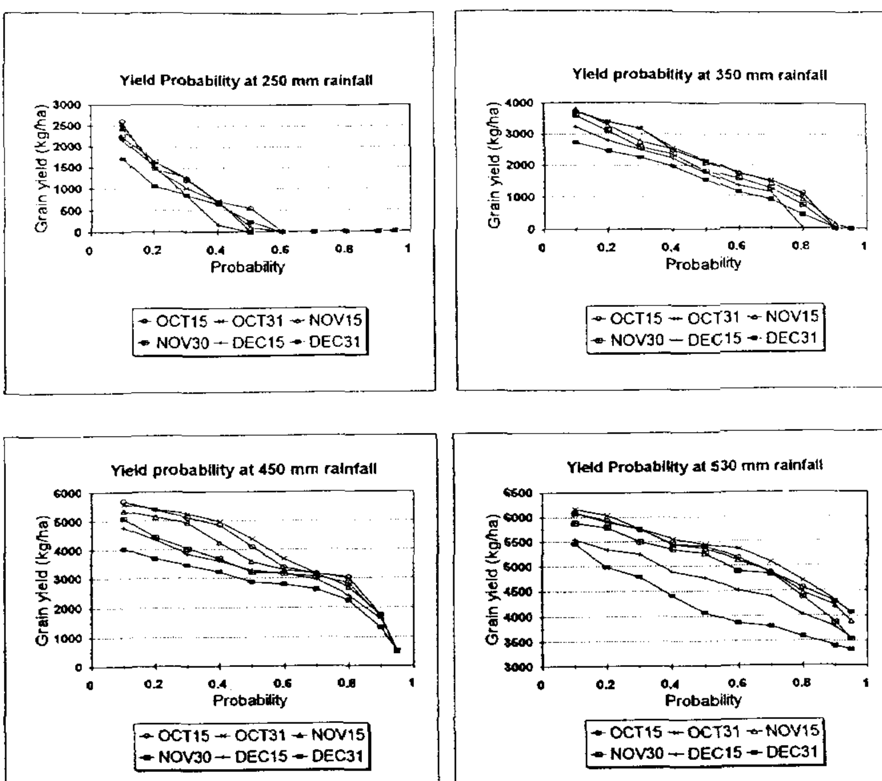


Figure 4.4.4. Yield probabilities with different sowing dates at different rainfall areas

In areas of more than 500 mm mean rainfall, sowing earlier than mid November is advantageous relative to later sowings and also free of risk. At the 20% probability level, yields would be about 5.8 t/ha for sowings up to late November, falling to around 5 t/ha when sowing is later than that. Corresponding figures for the 80% probability level are 4.4 t/ha and 3.5 t/ha.

4.4.6 Effect of supplemental irrigation and N application on wheat production

The effect of rainfall on wheat yield is small when values are simulated for conditions of supplemental irrigation applied at the 100% requirement rate (Figure 4.4.5a). This rate corresponds to a mean amount of 250-300 mm irrigation water for about 42% of the total cropped area, 300-400 mm for about 27%, 200-250 mm for 25% and less than 200 mm for the rest (6%) (Figure 4.4.5b). Thus, a greater part of the area needs more than 250 mm irrigation water to achieve the full potential yield. Figures 4.4.5c,d show how water requirement (100%) and the probability of any particular rate of water requirement decrease with increasing mean rainfall. A similar series of values could be calculated for supplemental irrigation rates less than the 100% requirement. Particularly where water is scarce, lower rates, say 50 or 60% of requirement, are recommended because they give greater returns per unit of water.

Calculated N requirements for wheat under the 100% requirement of supplemental irrigation are summarized in Figure 4.4.6. With rainfall effects minimized, the range of N requirement is narrowed and around 80% of the study area requires from 90 to 110 kg N/ha. These values are in agreement with those from earlier studies (Perrier and Salkini 1991; Pala *et al.* 1992).

4.4.7 Effect of N fertilizer application on wheat production under rainfed conditions

Mean rainfed yields increase linearly from little more than 0.5 t/ha in the 250 mm rainfall zone to than 5.0 t/ha at 490 mm and then level off (Figure 4.4.3). This is in good

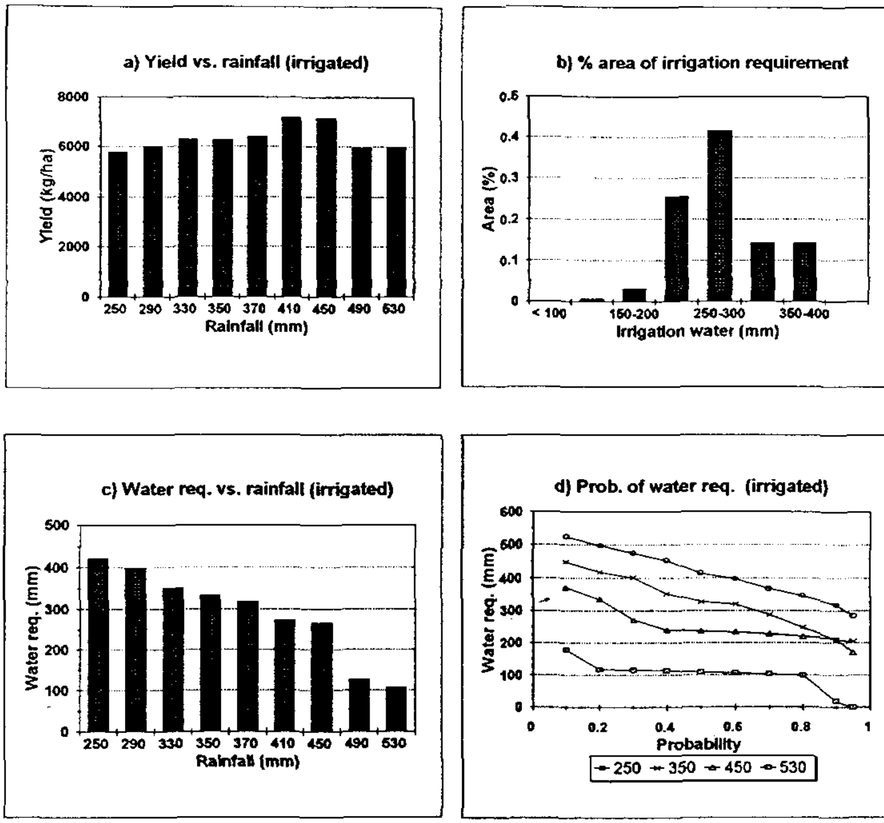


Figure 4.4.5. Mean durum wheat yield across rainfall regions, area percentage of ranges for 100% irrigation requirement and their probability distributions under irrigated conditions

agreement with an assessment of the effects of environmental factors on wheat response to N fertilizer (Pala *et al.* 1992). Wheat N requirement follows the yield trend and ranges from 25 kg N/ha at 250 mm to 110 kg N/ha at more than 500 mm area. Thus, for efficient utilization, about 65% of the study area needs 50-80 kg N/ha, and 17% needs 20-50 kg N/ha and 18% 80-120 kg N/ha (Figure 4.4.7). ***[Mustafa Pala, with acknowledgements to Hazel Harris, Haitham Halimah, Sabih Dehni and Samir Barbar for soil moisture and crop measurements; Wolfgang Gobel and Galia Martini for long-term weather data; Zuhair Masri for a soil map of northwest***

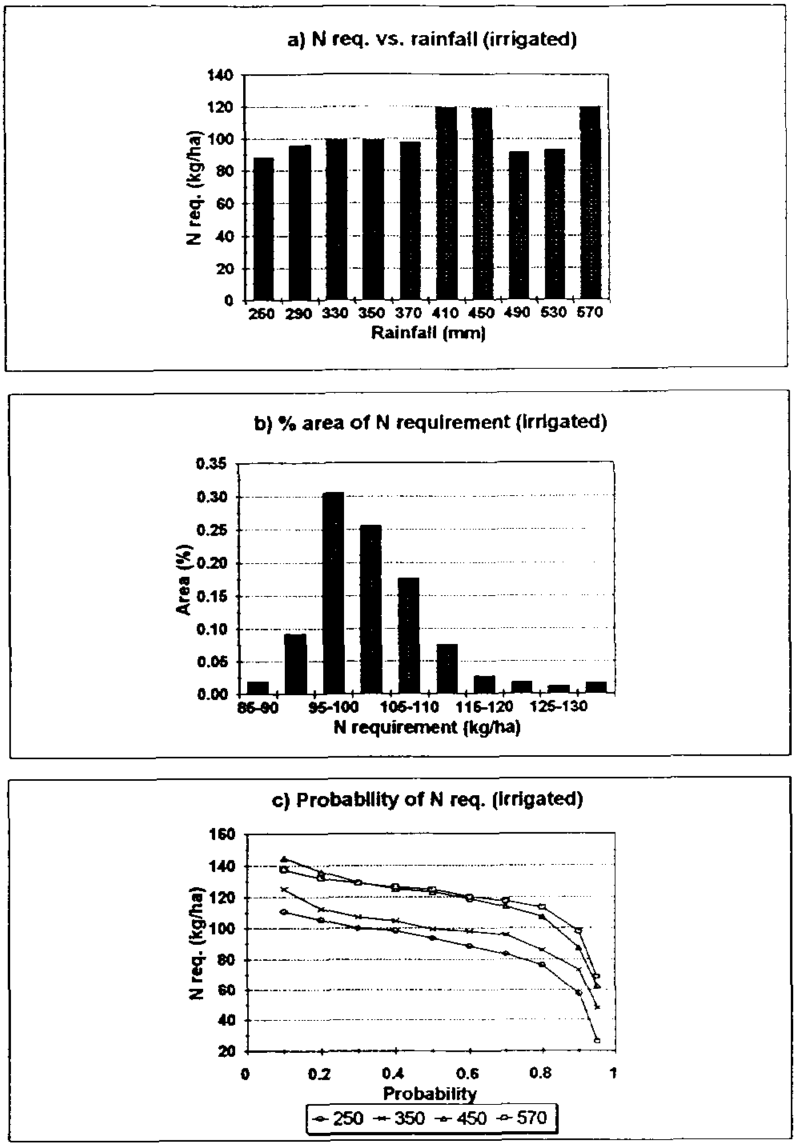


Figure 4.4.6. Nitrogen requirement of durum wheat under different rainfall areas, percentage of areas for ranges of N requirement and their probability distributions under irrigated conditions

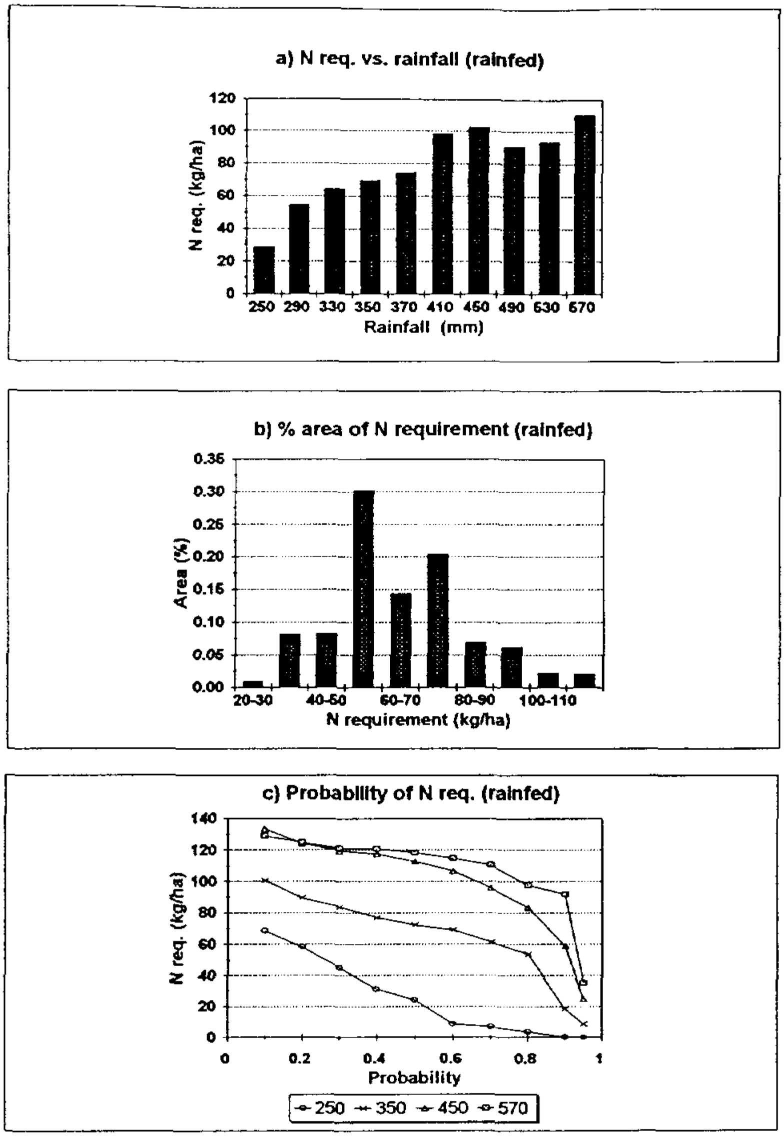


Figure 4.4.7. Nitrogen requirement of durum wheat under different rainfall areas, percentage of areas for ranges of N requirement and their probability distributions under rainfed conditions

Syria; and Claudio Stockle and the Department of Biological Systems Engineering of Washington State University for sharing the CropSyst model]

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5. ADOPTION AND IMPACT OF TECHNOLOGY

Introduction

'Adoption and impact' consumes the largest proportion of FRMP's talent and resources in the social sciences and is one of its most productive activities. Nonetheless, criticism surfaces at times from both inside and outside the Center that ICARDA neglects to measure and document the impact of its work around the region. The review presented in the first section of this chapter, on 'technology, adoption and impact studies' (5.1) is therefore appropriate and timely - to detail what has been done and, no less, to identify the present gaps and priorities for the future.

Over the last ten years, ICARDA and its NARS partners have undertaken and published 56 individual studies of technology evaluation, adoption and impact. However, coverage has been uneven. A major focus has been on wheat (22 studies) followed by barley (10). Activities for legumes, food, feed and pasture, have been far fewer; and only modest attention has been given to livestock and resource management issues. One of the highest priorities now is with lentils, a world mandate crop for ICARDA but so far the subject of only four studies.

Altogether, the distribution of adoption and impact work within WANA to date reflects two factors: demand and supply. Demand stems from national programs and donor agencies seeking to quantify the adoption of new technologies and their impact. Supply refers to the financial and human resources available to carry out the research. Syria has so far received most attention, and here the work has usually been either core funded and/or undertaken by graduate students. Elsewhere, studies are increasingly dependent on external funding and are undertaken by temporary ICARDA staff or by national scientists with technical backstopping from Aleppo. The Nile Valley Regional Project has recently initiated an important series of adoption and impact studies through its new socioeconomic research network. This points the way ahead: at both national and sub-regional level, the imperative is to build up and institutionalize local expertise in adoption and impact studies, with ICARDA's role one of training, backup and, not least, synthesis.

Two further sections of this chapter address specific adoption issues, both in Syria but with lessons of a wider significance. A report concerned with fertilizer use on rainfed barley (5.3) is the last installment in a sequence of work that has followed a very classical farming systems approach - survey of farmers and their problems; technical research on the farmers' field, researcher-managed and then farmer-managed; and then extension demonstrations - with an increasing involvement of national institutions as the sequence evolved. Now, finally, we have a study of the factors, technical and human, at the farm level, that have influenced adoption. There is a perspective here on farmer psychology that most technology transfer activities tend to ignore.

The second report, on the mechanical harvesting of lentils (5.4) is also part of a long story. Hand harvesting of lentils poses problems. It must be accomplished in a fairly narrow window of time before the pods shatter, making it costly to the producer, who must hire labour at a peak season. Such problems, because increasingly they discourage lentil cultivation, have led ICARDA scientists to look at ways to facilitate mechanical harvesting. The two essentials appear to be a taller, more erect cultivar and a flat, smooth field, over which a combine harvester (with minimal adjustment) can operate very close to the surface. An appropriately improved cultivar has been developed and released; but as the adoption study reported here has found, very little adoption either of the cultivar or of mechanical harvesting has occurred. The problem now is one of technology transfer, which appears so far not to have been well coordinated nor, perhaps, to have assessed the problem adequately from the farmer perspective. There is a package - cultivar, seedbed preparation and sowing method - but it requires cooperation between ICARDA and national institutions (extension, seed services and the General Organization for Agricultural Mechanization) to address it appropriately to the needs of the potential users.

The same concept, of understanding the farm-level situation before wheeling in technical solutions, lies behind the other research activities described in this chapter. A socio-economic survey of agricultural activities in the Muwaqqar catchment (70 km2, <200 mm rainfall) was undertaken to assess the potential to apply water-harvesting techniques, developed and tested locally by university scientists, to local farmers (**5.2**). One conclusion was that the capture and storage of wadi floods using earthern dams has obvious application for some types of enterprise, although issues like construction costs, water quality and utilization and distribution rights need further investigation - with local land-user participation. However, the main concern of the largest group of land users is to provide feed for livestock. For them, improved barley production has priority, and for this it may be more useful to seek ways to improve the traditional water-harvesting system that exploits local topography for run-on farming - again with farmer involvement.

Feed production and producer involvement are found also in two related studies conducted in Balochistan (**2.5** and **2.6**) and concerned with ways to enhance income generation for agro-pastoralists, based on a better appreciation of the small- ruminant market they supply. The problem is one of synchronizing improved production techniques, particularly feeding, within self-help and government schemes, in an economic and socially feasible way, to match the patterns of demand and price of the market. Difficulties include credit conditions too stringent for many would-be participants and the reality that many agropastroralists still sell primarily to raise cash, when needed, rather than to maximize their sale revenues.

5.1 Technology Evaluation, Adoption, and Impact Studies at ICARDA

5.1.1 Introduction

ICARDA undertakes four different types of impact assessment: (1) technology adoption and impact studies, (2) institutional impact and development studies, (3) regional and subregional sector studies, and (4) technology evaluation. The first two of these focus on what has been the impact of the Center (*ex post* assessment), whereas the second two address the issue of potential impact (*ex ante* assessment). The technology focus of impact assessment is on the sustainability and productivity of ICARDA's mandated crops and farming systems at the regional, national and farm levels, including the equity of benefit distribution. The institutional concerns are with the effectiveness of the Center's relationship with NARS and with the progress of technology transfer to our clients and beneficiaries.

A number of individual adoption and impact studies and technology evaluation studies are conducted each year by ICARDA staff in partnership with NARS scientists. These are an integral part of ICARDA's work in technology generation and transfer. Institutional impact and sector studies take place less frequently and are usually undertaken in response to specific special project and/or donor needs. Generally speaking, individual adoption and impact and technology evaluation studies are less expensive than institutional impact and sector studies. In part, this is because of higher costs of the external consultants employed for sector studies and the diverse nature of the institutional studies.

In response to increased emphasis by the CGIAR/TAC on IARC impact, we have made a short review of our progress in *ex-ante* evaluation of newly developed technologies and the *ex-post* assessment of their adoption and impact at the farm and national levels. This report highlights the results of that review. The general conclusion is that progress has been greatest in assessing the results of wheat research, followed by barley technologies. Progress has been less dramatic with legumes, including food, feed, and pasture legumes. Only modest attention has been given to livestock feeding practices.

Little work beyond diagnosis and evaluation was done prior to 1987 when a formal program on adoption and impact research was included in the Farm Resource Management Program. Since 1989, the number of annual studies has increased considerably, and the balance among *ex-ante* evaluation, adoption and impact has improved. This reflects both the maturation of the technology generation process and the diversification within the socio-economic staff at ICARDA. Of particular importance has been the reduction in number of *ex-ante* studies and the corresponding increase in *ex-post* impact analysis in the past three years. Prior to 1993, 60% of the studies were concerned with *ex-ante* evaluation of technology and only 4% looked at *ex-post* impact. In the last three years, only 29% of the studies have dealt with *ex-ante* assessment and the remainder have concentrated on *ex-post* adoption and impact.

5.1.2 Assembling the database

Within ICARDA's present research management structure, impact assessment is housed within MTP Project 20: Production Systems, Adoption and Impact. Four types of studies are associated with the general cycle of technology generation, adaptation, and transfer to farmers. In processual order, these are (1) diagnosis (or problem identification), (2) technology evaluation (or *ex-ante* assessment), (3) adoption (or farmer acceptance and use of new technologies), and (4) impact (*ex-post* evaluation of the benefits from adoption). In assembling the research database, all the permanent social science senior staff at ICARDA (three P-level scientists and three research associates) were consulted, and a list of all published research since 1985 was compiled. For the purposes of the review, diagnostic studies were excluded, although *ex-ante* assessments of potential adoption and impact of technologies being tested and adapted by ICARDA and its NARS partners have been included. To avoid duplication, in cases where the same study resulted in more than one publication, only one entry was used in the database.

Since 1985, ICARDA and its NARS partners have undertaken and published some 56 individual studies within the three categories of **technology evaluation, adoption** and **impact** (Table 5.1.1). Published results have appeared in a variety of forms, including articles in journals and proceedings, ICARDA annual program reports and special reports, and theses in universities. Articles presently in manuscript stage awaiting publication have been included.

Table 5.1.1. Technology evaluation, adoption and impact studies, ICARDA database, 1985-1995

Country	Crop	Technology	Year	Type	Location	Title
Syria	Forages	cultivar	1985	Evaluation	article	Testing the feasibility of annual forage legumes as grazing and conserved feed
Syria	Lentil	mech. harvesting	1985	Evaluation	report	Farm labor by age and sex in northwestern Syria: implications for two proposed technologies
Syria	Forages	cultivar	*1986*	*Evaluation*	*report*	*Feasibility of introducting annual forages in Northwest Syria*
Syria	Barley	fertilizer	1987	Evaluation	FRMP87	Fertilizer Use on Barley in North Syria. Yield Gap Analyses and potential impact
Jordan	Wheat	package	1988	Adoption	article	Adoption of Agricultural Technical Practices by Jordanian Cereal Farmers
Morocco	Chickpea	cultivar	1989	Adoption	FRMP89	Adoption Dynamics of Winter Sown Chickpea in Morocco
Syria	Lentil	package	1989	Adoption	FRMP89	Changes in Lentil Production Technology in Syria: A Comparative Study over Ten Years
Syria	Barley	package	1990	Evaluation	report	Barley Production Economics in SE Turkey and N Syria: A Comparative Study
Syria	Chickpea	cultivar	1990	Adoption	FRMP90	Adoption of Winter-Sown Chickpeas in Syria: 1989/90 Season
Jordan	Lentil	package	1990	Adoption	article	Adoption of improved lentil production package in Jordan
Syria	Wheat	supp irrigation	1990	Evaluation	FRMP90	Supplemental Irrigation Project: From Research to Extension
Syria	Wheat	package	1990	Adoption	thesis	A Study of the Adoption of Innovations by Syrian Farmers
Syria	Barley	fertilizer	1991	Evaluation	thesis	An Economic Analysis of Fertilizer Allocation and Improt Policies in Syria
Syria	Chickpea	cultivar	1991	Evaluation	FRMP91	Economic Analysis of Chickpea Production in Aleppo and Hassakeh Provinces of Syria
Syria	Wheat	fertilizer	1991	Evaluation	thesis	Optimizing input use in highly variable environments: nitrogen fertilizer use on rainfed wheat in northwest Syria
Syria	Wheat	package	1991	Evaluation	thesis	Economics of Wheat Production in Syria
Syria	Wheat	supp irrigation	1991	Evaluation	FRMP91	Impact Assessment of Supplemental Irrigation on Rainfed Wheat-based Farming Systems in Syria
Syria	Wheat	package	1991	Adoption	FRMP91	Impact of Modern Wheat Technology in Syria. Part One: the Adoption of New Technologies
Syria	Barley	fertilizer	1992	Evaluation	article	Incorporating risk in the economic analysis of agronomic trials: fertilizer use on barley in Syria
Sudan	Faba bean	package	1992	Impact	thesis	The economic impact of faba bean introduction in smallholdings: a case study of the Gezira Scheme in Sudan
Syria	Medics	cultivar	1992	Evaluation	PFLP92	The first economic analysis of medic pasture in WANA
Syria	Medics	cultivar	1992	Adoption	thesis	Introduction of ley-farming system into crop rotations by small farmers in southern Idleb region
Syria	Wheat	*supp irrigation*	*1992*	*Evaluation*	*thesis*	*Impact Assessment of Supplemental Irrigation on Rainfed Wheat-Based Farming Systems in Syria*
Pakistan	Wheat	water harvesting	1992	Evaluation	FRMP92	The Economics of Water Harvesting: analysis for wheat and barley in Balochistan
Lebanon	Wheat	package	1992	Adoption	FRMP92	Wheat Production Systems in Lebanon: a rapid appraisal
Syria	Barley	fertilizer	1993	Adoption	FRMP93	Preliminary results of a survey on the adoption of fertilizer use on rainfed barley
Tunisia	Chickpea	cultivar	1993	Evaluation	mss	Women and technological change in Tunisia: the case of new food legume technology
Syria	Livestock	cultivar	1993	Adoption	PFLP93	The utilization of fodder shrubs by agropastoralists in the northern Syrian steppe
Lebanon	Livestock	feeding	1993	Adoption	PFLP93	A rapid survey of small ruminant production in the Bekaa Valley of Lebanon

Syria	Medics	rotation	1993	Evaluation	article	Ley Farming in the Mediterranean from an Economic Point of View
Syria	Medics	rotation	1993	Evaluation	report	A Whole-farm Model for Economic Analysis of Medic Pasture in Two-Year Rotations with Wheat
Syria	Wheat	supp irrigation	1993	Evaluation	FRMP93	Optimizing supplemental irrigation for wheat production in Syria
Syria	Wheat	fertilizer	1993	Evaluation	FRMP93	Economics of nitrogen use in wheat-based two-course rotations at Tel hadya
Pakistan	Wheat	water harvesting	1993	Evaluation	FRMP93	Economic viability and sustainability of cereal production under water harvesting in highland Balochistan
Libya	Wheat	package	1993	Adoption	FRMP93	Cereal Production Systems in the Western Zone of Libya
Lebanon	Wheat	package	1993	Adoption	FRMP93	Wheat Production Systems in Lebanon: a diagnostic farm survey
Egypt	Wheat	package	1993	Impact	FRMP93	Impact of modern farm technology on the yield and net returns from wheat in Upper Egypt
Syria	Barley	fertilizer	1994	Evaluation	article	Impact of Fertilizer Pricing Policies on Barley-Livestock Production Systems in Northwestern Syria
Syria	Barley	fertilizer	1994	Adoption	thesis	Factors Influencing Adoption of New Agricultural Technology in Dry Areas of Syria
Morocco	Barley	cultivar	1994	Adoption	mss	Constraints to the Adoption of New Barley Varieties in Morocco
Syria	Chickpea	cultivar	1994	Adoption	article	The Great Chickpea Mystery: Introducing Winter Sowing in the Mediterranean Region
Morocco	Chickpea	cultivar	1994	Adoption	article	Approaches to overcoming constraints to winter chickpea adoption in Morocco, Syria, and Tunisia
Egypt	Faba bean	package	1994	Adoption	mss	Adoption of improved faba bean production package in Egypt
Pakistan	Livestock	feeding	1994	Adoption	article	Development of Sheep Fattening Schemes in Highland Balochistan
Syria	Medics	rotation	1994	Evaluation	article	From weed to wealth? Prospects for medic pastures in the Mediterranean farming system of north-west Syria
Tunisia	Wheat	cultivar	1994	Impact	mss	Adoption and Impact of High Yielding Wheat Varieties in Northern Tunisia
Egypt	Wheat	package	1994	Adoption	mss	Adoption of improved wheat production package in Middle Egypt
Syria	Barley	package	1995	Adoption	FRMP94	Impact of Mashreq Project on Adoption of Improved Barley Production Packages
Jordan	Barley	package	1995	Adoption	FRMP94	Impact of Mashreq Project on Adoption of Improved Barley Production Packages
Sudan	Faba bean	package	1995	Impact	mss	Adoption and Impact of modern faba bean technology in Sudan
Ethiopia	Faba bean	package	1995	Adoption	mss	Adoption of improved faba bean production package in the Fayyum
Syria	Lentil	mech. harvesting	1995	Evaluation	FRMP94	Adoption and Impact of lentil harvest mechanization in Syria
Syria	Wheat	package	1995	Impact	mss	Impact of improved durum wheat technology in Syria
Sudan	Wheat	package	1995	Impact	mss	Adoption and Impact of modern wheat technology in Sudan
Ethiopia	Wheat	package	1995	Adoption	mss	Adoption of improved wheat production package in Ethiopia
Egypt	Wheat	package	1995	Impact	mss	Impact of improved wheat production in Upper Egypt

notes:

evaluation refers to ex-ante study of technology performance for the purpose of assessing adoption and impact potential

adoption refers to an ex-post study to determine levels and frequencies of actual adoption of new technologies

impact refers to a study that utilizes adoption information and technology performance to estimate actual economic benefits of new technology

The distribution of studies according to type of publication are shown in Table 5.1.2, and the annual distribution of studies according to category of study, in Figure 5.1.1.

Table 5.1.2. Distribution of studies by type of publication

Publication	Type of Study			Total
	Evaluation	Adoption	Impact	
Program Annual Report	10	12	1	23
Article	5	5		10
Thesis	4	3	1	8
Separate report*	4			4
Manuscript	1	5	5	11
Total	**24**	**25**	**7**	**56**

* includes two Discussion Papers

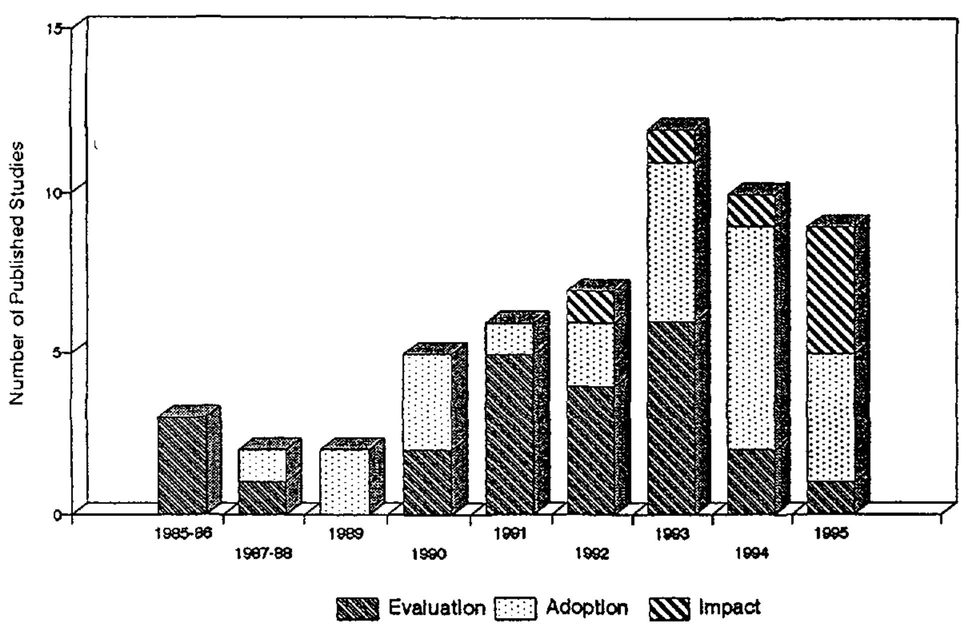

Figure 5.1.1. Technology evaluation, adoption and impact studies at ICARDA

5.1.3 Coverage by mandate commodity and technology

ICARDA has a very broad mandate of technology generation. In cooperation with NARS, the Germplasm Program produces improved cultivars of wheat, barley, chickpea, lentil, and annual forage legumes. There is still some residual work on faba bean germplasm and there is evaluation of medics. Together with FRMP and PFLP, the Germplasm Program and NARSs are also concerned with other components of improved production packages. One of the most important of these components within FRMP is fertilizer use. And within FRMP and PFLP, rotations receive considerable attention, particularly for the introduction of legumes within cereal-fallow rotations or cereal monoculture. As part of its work on improving annual pastures, PFLP is looking at the introduction of ley farming using medics and is developing methods of on-farm pasture seed production. FRMP and legume scientists have worked on the mechanical harvesting of annual legumes. FRMP, as part of its water management research, has been working on supplemental irrigation and water harvesting for cereal crops and forages, including fodder shrubs. ICARDA pays particular attention to the livestock component of WANA farming systems, and has looked into the use of fodder shrubs on rangeland and the feeding management of small ruminants.

The matrix of mandate commodities and technologies being developed for them is summarized in Table 5.1.3. Table 5.1.4 shows the distribution of studies across commodities. The figures reflect the maturity of the technology generation and transfer process of wheat and, to a lesser extent, faba bean relative to other commodities. Impact studies for most other commodities would still be premature, as the relevant technologies are still in the developmental and testing stages.

The distribution of studies across commodities by individual technologies is given in Figure 5.1.2. Again, the concentration on wheat is apparent, as is the relative diversification in the individual wheat technologies covered, including fertilizer, supplemental irrigation, and water harvesting. Most studies treat bread and durum wheat together, except in individual country situations where only

Table 5.1.3. Commodity x technology matrix at ICARDA

Commodities	Technologies
Wheat (bread & durum)	cultivars - fertilizer supplemental irrigation water harvesting rotation with legumes complete package*
Barley	cultivars - fertilizer rotation with legumes complete package
Chickpea	cultivars complete package
Lentil	cultivars mechanical harvesting complete package
Faba bean	cultivars complete package
Medics	cultivars rotation (ley farming) seed production grazing management
Forages	cultivars rotation with cereals
Livestock	feeding regimes fodder shrubs native pasture improvement

* In addition to inputs such as fertilizer, herbicides, and plant protection measures, a complete package usually includes such agronomic recommendations as seed rate, planting date, and seeding method. It may also include irrigation recommendations in some agro-ecologies such as the Nile Valley.

Table 5.1.4. Distribution of studies by commodities

Commodity	Type of Study			Total
	Evaluation	Adoption	Impact	
Wheat	9	8	5	22
Barley	5	5		10
Chickpea	2	4		6
Lentil	2	2		4
Faba bean		2	2	4
Forages	2			2
Medics	4	1		5
Livestock		3		3
Total	**24**	**25**	**7**	**56**

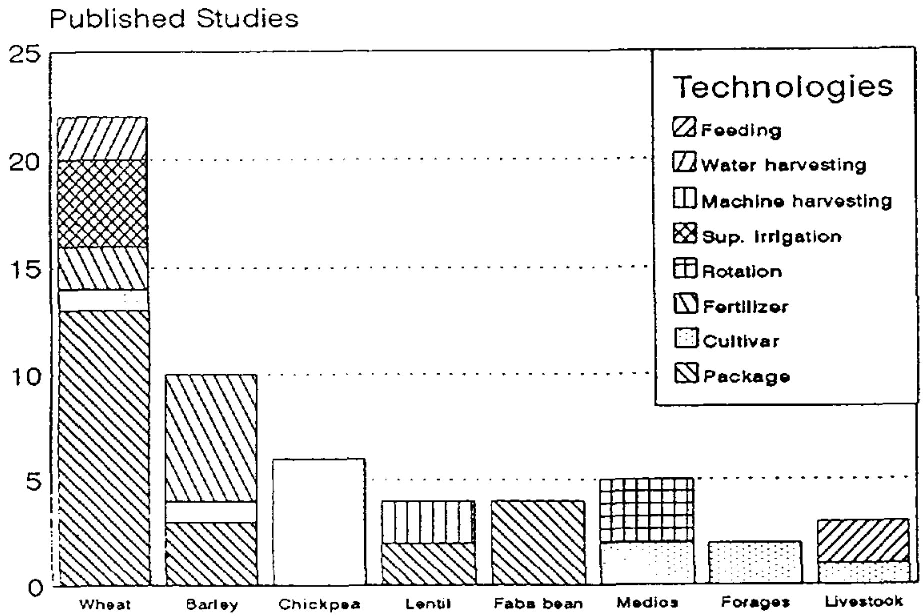

Figure 5.1.2. Technology evaluation, adoption and impact studies at ICARDA, Published studies

one type of wheat is grown. Perhaps surprisingly, little attention has been paid to improved wheat cultivars, *per se*. Rather, cultivars are usually considered as one component in a full package or as a variable included in a study of another production technology, such as supplemental irrigation. Similarly, the barley research is characteristically focussed on either full packages or fertilizer use. Improved barley cultivars by themselves are the subject of only one study.

In contrast, all six studies of chickpea have focussed on improved cultivars only. This largely reflects ICARDA's emphasis on the introduction of winter-sown varieties, and research has concentrated on a minimum package looking at on-farm varietal performance and adoption by farmers. Faba bean displays a different strategy that emphasizes complete packages rather than just one or two components. It is worth noting that all four faba bean studies come from the Nile Valley Regional Program, which expressly set out to develop full production packages. The lentil studies are a mixture of mechanical harvesting and package technologies.

Taken as a group, medic, forages, and livestock studies reveal the fairly early stages of development of the technologies concerned. Because medics and feed legumes are not presently major components of WANA farming systems, much of the work is one of evaluation and *ex-ante* assessment of adoption potential for cultivars, including fodder shrubs. ICARDA has done major work in the evaluation of medic pastures within cereal and food legume rotations. Two studies have evaluated feeding management practices for small ruminants.

5.1.4 Regional distribution

In addition to being unevenly distributed across commodities and technologies, evaluation, adoption and impact studies are unevenly distributed across ICARDA's geographical mandate (Figure 5.1.3). Predictably, Syria has received by far the most attention, although NVRP (Nile Valley Regional Project) has recently undertaken an important series of adoption and impact studies through the newly organized Socio-economic Research Network.

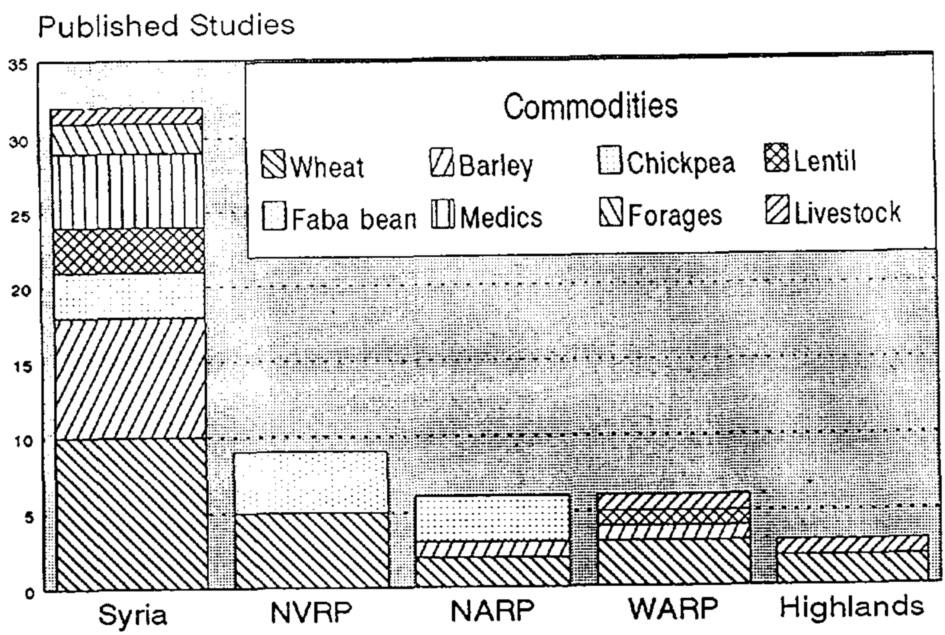

Figure 5.1.3. Technology evaluation, adoption and impact studies by ICARDA regional program

Wheat is the only commodity covered in all regional programs. Faba bean (NVRP), medic (Syria) and forages (Syria) are found in only one regional program. The same could be said for lentil except for an early adoption study undertaken by Jordanian researchers.

The distribution of studies across regional programs is a reflection of two factors: demand and supply. Demand stems from national programs and donor agencies seeking to quantify the adoption of new technologies and their impact. Supply refers to the financial and human resources available to undertake the research, as well as the availability of new technologies themselves. In the case of Syria, most of the research is either core funded or undertaken by graduate students. Outside Syria, research costs are increasingly drawn from external (special and bilateral project) funding and are undertaken either by temporary ICARDA staff (post-doctoral fellows and visiting scientists) or by national scientists with technical backstopping from headquarters in Aleppo. This arrangement is particularly noteworthy (and successful) in the NVRP, where it has become institutionalized as a formal network of social science researchers, and in the West Asia Regional Program (WARP), where the Mashreq Project and its successor, the Mashreq-Maghreb Project, include adoption and impact studies as an explicit component of their budgets and workplans.

5.1.5 Gaps in coverage

To date, ICARDA's technology evaluation, adoption and impact research has largely been a product of circumstances, many of them seized opportunistically. There has been considerable reliance on graduate students, temporary post-doctoral fellows, and visiting scientists to undertake the research with complementary funding. While this has proven effective and often cost efficient, it has not allowed strategic planning of this type of research, particularly in terms of adequate coverage of some commodities and geographical areas. In particular, thesis research must reconcile the often conflicting personal career needs of graduate students with the institutional needs of ICARDA. Continuity in focus, data collection, and methodology has been a problem. There is still no central database on quantified impact.

The establishment in 1987 of an Adoption and Impact Project in the FRMP core research program was an important milestone in giving such research a strategic place in ICARDA's agenda. This was later confirmed in the Medium Term Plan 1994-98 Project 20: Production Systems, Adoption and Impact. Similarly, the recruitment of a permanent P-level staff member with responsibility for adoption studies in 1990 put the work on a firmer footing. Nonetheless, serious problems in terms of resource availability persist. A number of important positions in social sciences, including P-, RA-, and GS-levels, are vacant and frozen. Without increasing headquarters and/or outposted staff in social science, there is little likelihood that the number studies done annually can be improved, even if national program researchers do most of the actual fieldwork and analysis.

The major gaps in coverage at the present time, in no particular order of priority, are summarized in Table 5.1.5.

Table 5.1.5. Gaps in coverage in WANA region

Commodity	Technology	Study	Location
Wheat	Packages*	Impact**	Morocco
Barley	Packages	Adoption	Tunisia
Barley	Packages	Adoption	Iraq
Chickpea	Cultivar	Adoption	Algeria
Lentil	Packages	Adoption	Morocco
Lentil	Packages	Impact	Ethiopia
Lentil	Packages	Impact	Turkey
Lentil	Packages	Impact	Sudan

* All packages should include variety as principal component.

** Impact studies include adoption information gathered as part of the impact study if not already available.

Gaps have been identified according to three criteria: (1) availability of the technology, (2) stage reached in the transfer process, and (3) area coverage. For example, improved wheat packages have been available for some time in Morocco, and the process of transfer to farmers is well advanced. Despite considerable research investment by ICARDA, there has not yet been an impact study, and there should be as a high priority to document definite impact by the center.

In terms of barley, improved packages have been developed for Tunisia and Iraq, but transfer is still in the fairly early adoption stages in both countries. The same is true for winter chickpea cultivars in Algeria.

Lentil is a rather special case. ICARDA holds a world mandate, and many cultivars and associated production packages have been developed. In the years 1987-1994, a total of 38 varieties coming from ICARDA were released by some 23 national programs. Twenty-three of these varieties were released by 13 WANA countries. And yet attention to documenting the adoption and impact of these lentil technologies has been limited to just one early adoption study in Jordan, two harvest mechanization evaluation studies in Syria, and one package adoption study in Syria already six years old. There have been no impact studies on lentil at all.

5.2 Economic Activities in the Muwaqqar Catchment (Jordan) and the Potential Application of Improved Water Harvesting Techniques

5.2.1 Problem definition

In 1985 the Faculty of Agriculture of the University of Jordan began a research project, in part supported by the European Union, to seek ways to help develop the arid lands of Jordan. The ecology of the arid areas is fragile and prone to serious degradation through improper exploitation. The University established a research station in the arid zone near the town of Muwaqqar, at the foot of the catchment area of the intermittant stream Wadi al-Mughayir. Research activities have been devoted to developing simple water harvesting techniques that could be applied throughout the catchment to capture runoff from the seasonal rains and utilize the water for productive purposes while sustaining the natural soil and plant resources of the area.

Four techniques were the focus of detailed research. The first is earth dams across wadi beds to capture floods following rain storms. Water stored in this way is then pumped to provide supplemental irrigation to field crops and trees using either sprinkler or drip systems. The second technique is small runoff basins prepared on gently sloping, almost level land. In the lower corner of each basin are planted fruit and nut trees or fodder shrubs. The third technique is contour ridges along hillsides. The area between ridges serves as a catchment surface, and the runoff is collected behind the ridge where forage shrubs and grasses are planted. The fourth technique is low stone walls erected across broad wadis to retard flood water, and behind the walls are planted trees and perennial forage plants. The first two techniques are aimed primarily at crop production, while the second two are viewed as more appropriate for rangeland improvement.

Following the completion of the first phase of funding, a follow-on project was developed with IDRC (Canada) to develop an integrated prediction-optimization model for water harvesting, storage, and utilization based upon the findings of experiments conducted earlier. The model aims to assist decision-makers and planners to evaluate the potential of future development projects by providing a tool to assess various land use scenarios based on the availability, at watershed level, of water provided by a harvesting system utilizing the techniques developed at Muwaqqar. The model seeks to incorporate relevant socio-economic considerations in assessing the feasibility of introducing water harvesting techniques for adoption by the local land users.

To provide the model with the required socioeconomic information, a modest survey of a representative sample of land users in the Muwaqqar catchment was conducted in the summer of 1994 by researchers from ICARDA, the University of Jordan, and the Ministry of Agriculture. The objectives of the survey were (1) to inventory traditional and contemporary land use activities, (2) to establish an economic baseline for evaluating relative returns from individual agricultural enterprises in the area, (3) to identify current water utilization, and (4) to obtain land user perspectives on water harvesting and the potential for utilizing innovative techniques. This report provides a review of the principal findings.

5.2.2 Description of site

The Muwaqqar catchment is roughly in the shape of a parallelogram, approximately 5 km wide in a north-south direction and 15 km long from west to east, with its north west corner 30 km southeast of Amman. The town of Muwaqqar is located in the southwest corner at an elevation of about 900m, and the University's Muwaqqar station is at the base of the catchment in the northeast corner. The land slopes gently to the east, and the 800m contour is some 10 km east of Muwaqqar, bisecting the catchment from north to south. Drainage moves with the general slope eastward, accumulating in the north east corner in the streambed of Wadi el-Maghayir. The general topography is gently undulating with low hills. The area is criss-crossed with gullies and shallow wadis. Slopes are mostly between 1% and 5%, and soils are highly calcareous, shallow on higher slopes, deeper on lower slopes and on gradients of less than 2%. Soil texture is generally silty clay. Soil surface structure is poor, prone to crusting, erosion, and water runoff. Rainfall events of less than 5mm can cause noticeable runoff flows.

In addition to Muwaqqar town, there are the nearby villages of Manshiyya al-Muwaqqar and Mughayr, also at about 900 m elevation at the head of the catchment area. The three settlements are connected by paved secondary roads, and the principal highway between Amman, Azraq oasis and the Saudi border bisects the catchment from west to east. Access to virtually every location in the catchment is easy using these paved roads or well established tracks.

Rainfall is iregular and unpredictable, with a long-term average of less than 200 mm per annum. Coming usually in the form of short, intensive storms between November and May. Only a small quantity of rain is retained by soil surfaces, and most is lost either through direct evaporation from the surface or through runoff into gullies.

Moisture loss through runoff is exacerbated by a general lack of vegetative cover. Although there may have been some natural stands of trees in the distant past, none exist at present. Low rainfall and heavy grazing pressure results in essentially ephemeral plant cover during January and part of February, although during this brief time a wide variety of native grasses and legumes can be observed. However, desities are low. Here and there are a few shrubs, but these remnants are rapidly disappearing due to collection for firewood.

5.2.3 Traditional economic activities and water harvesting

There has been a settlement at the site of Muwaqqar town at least since Nabatean times, and there exist fragmentary ruins of a country palace built there by the Omayyads in the eighth century. Other settlements in the catchment are more recent. The modern history of land use in the Muwaqqar area is dominated by nomadic pastoralism, with very little evidence of extensive arable farming until the last twenty to thirty years. As nearby Amman has grown from a small village to a large metropolitan area, Muwaqqar has increased from hamlet to town size with its offshoot the village of Manshiyya. One can speculate that population growth has led to an inevitably more intensive use of surrounding lands, initially by increasing sheep and goat grazing of natural vegetation and then, as pastures deteriorated, the introduction of barley cultivation to feed the local and migratory flocks. The recent expansion of barley cultivation has been encouraged by mechanization of tillage and by the growth of Amman as a market for livestock products.

Barley cultivation is restricted by natural conditions. The most favorable areas for barley in this unfavorable environment are the natural depressions among the low hills, where the traditional technique of "natural water harvesting" is commonly practiced. The cultivator sowsin the depression where ground surface is relatively level and soils are deepest. When the rains come, the precipitation falling directly on the field is augmented by water running off the surrounding uncultivated slopes. Heavy grazing on the slopes encourages more runoff by removing vegetation that would otherwise serve to retard the flow. Even with the additional moisture from natural runoff, local barley farmers do not expect reliable harvests. In fact, it is estimated that barley sown in the depressions will reach maturity in only one or two years out of five, and may be worth the labor to harvest grain and straw in only one of these.

Another important traditional water harvesting technique in the Muwaqqar area is the underground cistern. A large hole, excavated at the base of a sloping area, is lined with an impermeable material and roofed over, leaving a small entrance for the water. Shallow channels are dug along the contour to divert runoff into the hole. Water stored in these cisterns is used to water sheep. In the past, cisterns were also a critical source of water for human and domestic consumption in this area without springs or streams. In some locations near larger wadis, large open reservoirs were constructed to receive water diverted from spate flows. However, the only one of these old constructions still remaining is a restored tank from Roman times in the town of Muwaqqar. It still serves as a significant source for watering the animals during the winter and spring months.

5.2.4 Recent economic developments

Recent economic developments in the Muwaqqar catchment may be attributed to the phenomenal metropolitan growth of Amman and to government efforts to ensure domestic food security through subsidies and price supports to certain agricultural enterprises. To a lesser extent, the Muwaqqar area has been affected by the results of the Iraq-Kuwait conflict and the ensuing flight of people and capital from the Gulf region.

Small ruminant production has continued to be the mainstay of economic activities in the arid areas. Although it is readily observable that the rangelands are degraded and open grazing constitutes a shrinking proportion of the national flock's diet, sheep and goat numbers have increased sharply in the past ten years. To a great extent, natural grazing is being substituted with hand-fed concentrates, particularly barley grain, supplemented with barley straw. Until the mid-70s, barley production and consumption in Jordan were closely matched, but in the late 1970s the government embarked on a policy of importing barley and distributing it through government agencies to registered flock owners at subsidized prices. National barley grain consumption rose from around 50,000 metric tons in the late 1970s to over 250,000 tons in the early 1990s, although the national flock increased by only about 50%.

A noticeable trend in small ruminant management was the emergence of feedlotting, to fatten young animals rapidly before sale to urban markets for slaughtering. The Muwaqqar area has become a locus for open-air feedlots, with all the requisites, including grain, straw, water, and fencing, being brought in by trucks. The operations rely on local resources only as a place to keep the animals and a area to give them daily exercise. Although the animals may be seen roaming the hills in the catchment, grazing the degraded slopes is not a significant contribution to their diet. By and large, the operators of open air feedlots and the crews of shepherds that manage them are not native to the Muwaqqar area.

Parallel to the development of feedlots, the late 1980s and early 1990s witnessed the emergence of poultry production as a major economic activity in the Muwaqqar area. The government encouraged modern poultry enterprises to provide the population with a cheap source of animal protein, especially as an alternative to red meat. Subsidies were instituted, including the supply of feed through importation. Private investors responded, and the national poultry flock grew from about 20 million birds in 1972 to close to 60 million in the late 1980s. Like open-air feedlots, the poultry enterprises that are mushrooming across the Muwaqqar catchment are largely independent of local resources. The owners and operators are not local people, and the young birds, feed, water, and other necessities are all brought in from outside.

The other new addition to the Muwaqqar landscape is fruit and nut orchards, usually strongly walled and containing impressively modern weekend homes of wealthy investors. Olive trees predominate, but there are also pistachio and stone fruits. None of these "villa orchards" can yet be considered an economic enterprise, although each represents a considerable capital investment, particularly in irrigation systems. The typical system consists of an elevated reservoir (often the tank taken from a tanker truck) with PVC pipes feeding drippers for each tree. Much of the water is trucked in from outside the catchment. There are, however, a few drilled wells.

There are also a number of vegetable farms relying upon drilled wells and producing onions, garlic, squash, cauliflower, melons, and other perishables for the Amman market. They also tend to be enterprises founded and financed by non-local people, often hiring expatriate labor.

5.2.5 Profile of land users

According to the most recent census, approximately 6,650 people live in the catchment area, distributed among the three settlements of Muwaqqar, Manshiyya, and Mughayr. If the average household size is eight people, then there are 832 households. Based upon the 1991 livestock census, about a quarter of them own livestock (Table 5.2.1).

Table 5.2.1. Population estimates for Muwaqqar catchment

Settlement Name	Population	Livestock Owners	Sheep & Goat Population
Muwaqqar	4,000	155	38,803
Manshiyya	1,200	4	4,300
Mughayr	1,450	45	3,128
Total	6,650	204	46,231

These numbers indicate an average flock size of 227 animals, but with great differences between small and large flocks. Tthe average size for Manshiyya is over 1,000 animals, for Mughayr less than 100. It is difficult to determine with any precision how many animals actually graze within the catchment, in total and during different parts of the year. Most flocks are, in fact, highly mobile and move within and without the catchment, and certainly there are numbers that are based outside the catchment that use its rangeland.

There is no easily accessible cadastral of the catchment. It is difficult to determine land use in terms of areas devoted to crops, range, and non-use. Since 1989, there has been a marked increase in land utilized by capital intensive agricultural investments such as poulty farms, orchards, and vegetable fields. Data are available on land use in Muwaqqar district (Table 5.2.2). Although they cover an area much larger than the catchment, they are indicative of recent land use within the catchment. If no-productive and rangelands are excluded, then some 93% of the agricultural land is used for cereal crops, 3% for orchards, 3% for vegetables, and 1% for chicken farms.

Table 5.2.2. Growth of "investor enterprises" in Muwaqqar district

Year	Poultry farms No.	Orchards No.	Orchards Area (dn)	Vegetable farms No.	Vegetable farms Area (dn)
1989	na	0	0	1	120
1990	32	30	900	1	120
1991	37	45	1,300	3	1,120
1992	48	60	1,700	5	1,600
1993	50	81	2,920	6	2,309
1994	na	85	4,200	9	4,227

10 dunum (dn) = 1 hectare

The principal selection criterion for the survey sample was the adequate representation of the different agricultural enterprises in the catchment. Some fourteen land-use categories were identified among four different producer types (Table 5.2.3). The "traditional farmers" consist of cereal cultivators, sub-divided into those with no livestock, those with small flocks (<100 head of sheep and goats), those with medium-sized flocks (100<500 head), and those with large flocks (500+ head). The pastoralists are those with no cultivation who raise only sheep and goats, grouped by flock size. The "investors" are divided into four types of poultry enterprises, orchard owners, and vegetable producers. Others represents a residual category with mixed enterprises, including especially camels and cattle. Within each category, producers were selected at random for interviews. A total of 82 land users were interviewed.

Relatively few of the investors are resident in the catchment area. Generally speaking, investors have recently acquired land in the catchment and established their enterprises using hired labor and supervisors, often expatriates from Egypt. The poultry farmers can be distinguished from the orchard and vegetable producers on the basis of their relative economic dependence on their enterprises. Poultry farmers tend to have invested all their available capital in the enterprise and rely on poultry production for the bulk of their income. In contrast, the owners of orchard and vegetable enterprises obtain the bulk

Table 5.2.3. Sample distribution by principal enterprises, residence, and percentage dependence on on-farm income.

Producer type	Enterprises		% Resident in Muwaqqar	% Income on-farm
Traditional farmers	Cereals only	n= 5	80%	4%
	Cereals & small flock	n=11	100%	51%
	Cereals & medium flock	n= 7	100%	93%
	Cereals & large flock	n= 4	100%	95%
Pastoralists	Small flock	n= 7	100%	81%
	Medium flock	n= 7	100%	100%
	Large flock	n= 7	100%	99%
Investors	Poultry, small flock	n= 3	0%	87%
	Poultry, medium flock	n= 6	20%	91%
	Poultry, large flock	n= 3	0%	100%
	Poultry, layers	n= 2	0%	100%
	Trees	n=11	38%	0%
	Vegetables	n= 3	0%	33%
Others	Cows, camels, mixed	n= 6	67%	70%
Total sample		**n=82**	**67%**	**66%**

of their income elsewhere. In fact, no surveyed orchard had matured enough to realize an income. Among the vegetable producers, no-one was entirely economically dependent on the enterprise, although modest incomes are being realized.

All but one of the total 48 producers in the traditional farmer and pastoralist categories are resident in the catchment, and most of them are dependent on their agricultural enterprises for their family income. Non-agricultural income is most important for those without livestock and those with small flocks, particularly flocks of less than fifty sheep and goats. Army and government pensions are the most important source of off-farm income for smallholders. The data suggest a minimum threshold for flock size adequate to support a family; cereal cultivation alone appears insufficient. These observations are substantiated by the partial enterprise budgets presented below.

Two important land-user categories were not included in the survey sample because they were not present in the catchment area when the survey was conducted. The first is the nomadic pastoralists who are not based in the catchment but use the rangeland resources during late winter and early spring. The second is the open-air feedlot operators, although one of these was visited during a follow-up fieldtrip two months after the survey was conducted.

5.2.6 Production costs and returns

Barley production. Barley production is by far the most extensive and simplest of the enterprises utilizing land and water resources in the catchment. The twenty-seven farmers interviewed cultivated altogether about 754 hectares of barley in 1993-94, an average of 28.3 ha per farmer (or 283 dunums). Two farmers grew modest patches of wheat for household consumption.

However, barley alone is clearly not recognized as a viable economic basis for maintaining a household. In most years the rainfall is not sufficient to produce a harvestable crop, and seed is put in the ground initially with the intention of producing green grazing for the farmer's livestock. The farmer then waits to see what happens. If crop growth is sufficient, then the barley is harvested and the straw is stored for later use as feed. The grain may be used to feed the farmer's sheep and goats or it may be sold to government agencies, depending on that year's price policy and the availability to the individual farmer of alternative feed sources. The few barley producers without livestock of their own either sell harvested grain to government purchasing agencies and straw in the local market, if production justifies harvest costs, or rent the standing crop for grazing.

Rainfall in the 1993-94 season did not produce a harvestable crop, and all fields were grazed at the mature stage. With no harvesting cost, the variable costs of barley production were about the same across all producer categories (Table 5.2.4). Approximately 57% (or 0.88 JD/dn) of the costs were for purchased seeds, the remainder being divided between cultivation (33%) and labor for sowing (10%). Fertilizer is not used, and after sowing there are no additonal costs unless there is a harvest.

Table 5.2.4. Barley production conditions*

Producer type	Average cultivated area (dms)	Dunums grazing per head of farmers' flock	Variable costs (JD/dm)
Barley only, no animals	282	-	1.67
Barley & <100 heads	55	1.5	1.67
Barley & 100-500 hds.	273	1.3	1.25
Barley & >500 heads	933	1.2	1.57
Totals (avg)	283	1.3	1.55

* dm(s) = dunum(s), or one tenth of a hectare.
JD = Jordanian Dinar, or approximately USD 1.45

In 1993-94 the surveyed barley producers without sheep rented their barley fields to shepherds. Grazing rents varied, but the average was 1.79 JD/dm, or a net return of variable costs of 0.24 JD/dm. This is a benefit/cost ratio of 1.2 for barley production without harvesting.

Sheep and goat production. It is difficult to construct partial budgets for sheep and goat enterprises, for a number of reasons. First, the data were collected through a formal questionnaire, completed in an average of two hours per producer. Most of the figures provided by flock owners are therefore only rough estimates that could not be substantiated by more detailed observations. Second, there are a multiplicity of costs and benefits that had to be simplified for statistical purposes. For example, many owners of small flocks rely on their animals for household provisioning of meat, milk, and milk products. Estimates of the quantities obtained were converted to monetary values using market prices. Third, in terms of production costs, the value of grazing as a contribution to sheep diet could not be quantified in either physical or monetary terms and had to be omitted from variable costs. However, all flock owners reported using the catchment rangelands at some time during the year. Money paid as grazing rents was included in the variable costs of feeding livestock. No cost was imputed for unpaid family labor, but wages paid to shepherds were included. Gross returns to the flock included the value of products produced, including increases in flock size after deductions for animals dying of natural causes and not consumed.

As should be expected, there was considerable variation in economic performance among individual livestock enterprises (Table 5.2.5). Nonetheless, the data indicate that small ruminant production is fairly profitable in the catchment, substantiating the impression given by the large numbers of livestock in the area.

Table 5.2.5. Sheep and goat enterprises: variable costs, returns, and benefit/cost ratios

Producer types by enterprises	Variable cost per head in JD		Return per head in JD		Benefit /cost ratio
	Avg.	Range	Avg.	Range	Avg.
Cereals & Small Flock	35.8	11.9-55.5	55.7	9.0-119.4	1.6
Cereals & Medium Flock	32.2	22.6-51.7	39.7	20.8- 72.5	1.2
Cereals & Large Flock	37.8	12.9-42.1	34.8	31.1- 42.1	0.9
Average Cereal & Flock	32.8	11.9-55.5	43.4	9.0-119.4	1.3
Pastoral Small Flock	26.8	17.6-39.1	44.8	17.6-121.8	1.7
Pastoral Medium Flock	42.7	9.9-60.2	52.9	9.9- 73.3	1.2
Pastoral Large Flock	26.5	16.6-52.1	54.9	26.2- 86.1	2.1
Average Pastoral Flock	30.1	9.9-60.2	50.8	9.9-121.8	1.7
Average for All Flocks	31.8	11.9-60.2	47.1	9.0-121.8	1.5

The benefit/cost ratio is best for large pastoralist flocks, followed by small pastoralists and producers of cereals with small flocks. In 1993-94, the producers with cereals and large flocks fared the worst; and those with medium size flocks, with and without cereal production, fell in the middle. The reasons are various. However, it is important to note the considerable ranges reported in both variable costs and in the value of returns per head. A number of small flocks had very high returns per head. This indicates a high degree of management and a corresponding response in animal productivity. Medium-size pastoralists reported high variable costs relative to other pastoralists. Cereal producers with large flocks suffered from both high costs and low returns.

There are two factors that seem to be important in understanding economic performance differences. The first is mobility, and the second is flock size. Flock mobility is important in giving access to a wider range of feed resources, often at substantially lower prices than those available locally in the Muwaqqar area. Crop residues in the wetter agricultural areas to the west are an especially important source of feed for mobile flocks. The least mobile flocks are the small and medium-sized producers with both cereals and livestock and the small pastoralists. In terms of mobility, the cereal producers with large flocks were more akin to their medium and large pastoralist colleagues than to other cereal producers. Medium and large flocks are routinely transported in trucks over long distances.

Medium-size flocks are too large, on the one hand, to enjoy the advantages of small size, particularly the intensity of management and cost reduction from the use of unpaid family labor; too small, on the other hand, to take advantage of economies of scale that accrue to large flocks. Medium-size pastoralists have costs for the transportation of animals, feed and water similar to those of large flocks, because, above a certain number of animals, the same number of trucks and tankers must be hired or purchased. Also, veterinarians and shepherds charge on a per day basis, whether they are caring for 200 or 500 sheep.

The distribution of costs within producer types illustrates the relative higher costs of labor needed by medium producers (Table 5.2.6). Most small producers rely on family labor. Within the costs for purchased feed, similar patterns regarding the consequences of size and mobility emerge (Table 5.2.7). Crop residues, primarily located outside the local area, are important for medium and large flocks. Purchased barley grain costs are relatively high for barley producers, strongly indicating a potential incentive to increase their barley productivity.

<u>Poultry production</u>. Muwaqqar catchment poultry enterprises can be differentiated on the basis of size and products. Broiler production is much more prevalent than layer production, and there are significant difference in scale. The small broiler producers surveyed averaged about 26,000 birds during 1993-94. Medium producers averaged 66,000 birds, and large producers had an average of 148,00 birds. Egg producers, of which two were surveyed, averaged 56,000 layers.

Table 5.2.6. Distribution of variable costs within livestock enterprises (in percentage of variable costs)

Producer type	Feed costs*	Water costs	Labor costs	Other costs**	Total%
Barley & small flock	75	8	7	10	100
Barley & medium flock	68	8	13	11	100
Barley & large flock	81	2	10	7	100
Pastoral small flock	78	11	0	11	100
Pastoral medium flock	68	3	23	6	100
Pastoral large flock	70	5	9	16	100
Average	**72**	**5**	**12**	**11**	**100**

* Excludes delivery costs for purchased feed. These costs are included under labor and other costs.
** Includes veterinary costs

Table 5.2.7. Component cost of purchased sheep and goat feed (including delivery costs)

Producer type	Component contribution tin JD per head				Total feed cost JD per head
	Barley grain	Wheat bran	Barley straw	Crop residues	
Cereals & Small Flock	15.3	8.0	-	0.4	23.7
Cereals & Medium Flock	15.9	5.9	1.6	1.6	25.0
Cereals & Large Flock	19.2	5.1	-	2.5	26.8
Pastoral Small Flock	16.7	4.6	1.0	0.7	23.0
Pastoral Medium Flock	23.8	9.6	0.8	3.4	37.6
Pastoral Large Flock	14.8	4.8	0.7	1.9	22.2
All Flocks	17.4	5.8	0.7	2.2	26.1
% of total	67%	22%	3%	8%	100%

Broiler producers purchase young chicks from specialists in the greater Amman area, raise them for 2 to 3 months, and then sell them in the Amman wholesale market. They do not slaughter or process the birds. Egg producers raise chicks and keep them as layers for about 18 months before selling the birds. Droppings, as a by-product, can be sold as fertilizer. The principal feeds are maize, soy meal, and other concentrates purchased from government supply agencies. Other principal cost components are water, electricity, veterinary services (Newcastle disease is a common problem), containers for birds and eggs, and transport. As indicated earlier, all but one of the 14 poultry farms surveyed were owned and operated by people from outside the Muwaqqar area. Similarly, all the inputs needed and most of the outputs (chickens and eggs) are purchased and sold outside the area.

The survey data indicate that the poultry business is reasonably profitable, with roughly the same benefit/cost ratios across the different categories (Table 5.2.8). Fixed costs include an average purchase price of land at JD 963 per dunum. Water represented between 1.5 and 2.0% of variable costs. Veterinary costs were relatively higher for large scale enterprises than for medium or small scale. Relative feed costs were about the same for all enterprises, ranging from 60-70% of variable costs.

Table 5.2.8. Economic summary of poultry enterprises, 1993-94. (Average for each category of enterprise type)

Enterprise type	Number of birds	Establishment and fixed costs (JD)	Variable costs (JD)	Total returns (JD)	Gross margin (JD)	Benefit/ cost ratio
Broiler, small scale	26,000	14,015	27,963	32,302	4,339	1.16
Broiler, medium scale	66,000	28,426	56,643	73,495	16,852	1.30
Broiler, large scale	148,000	95,513	138,605	173,674	35,069	1.25
Layers	56,000	47,595	50,253	63,955	13,702	1.27
Averages for total	69,500	42,452	67,147	84,772	17,625	1.26

Orchards and vegetable production. There are currently no producing orchards in the catchment area, although many have been established in recent years. Olive trees predominate, but other fruits and nuts are grown. The costs of orchard establishment are high. First, there is the purchase price of land, since most orchard owners are not local residents. To plant seedlings, pits must be excavated in the shallow soil to a depth of about a meter. This often involves blasting and pneumatic drilling to remove stone. In most cases, a drip irrigation system is installed to deliver water to each seedling. Concrete block walls are erected around the orchard to protect the trees. Following establishment, water and maintence of the irrigation system are the major costs, together with hired labor to service the orchard (Table 5.2.9).

Based upon an observed average density of 20 trees per dunum and an expected olive harvest per tree in alternate years of 20 liters of olive oil (after paying pressing charges), the estimated return on olive orchards in the area is approximately JD 200 per dunum per year. With a total variable cost of JD 122 per dunum, the translates into a benefit-cost ratio of 1.6. However, one must consider the high establishment costs and the years with maintenance costs but no return while the trees mature.

Table 5.2.9. Distribution of variable costs for tree and vegetable enterprises, 1993-94 (calculated in Jordanian Dinars per dunum)

Enterprise	Estblshmnt & fixed costs	Variable costs (% total variable costs)					Total variable costs
		Cultivtn*	Fertlizr	Pest control	Water & irrigtn	Hired labor	
Orchards	1,054	1.8 (1%)	5.1 (4%)	4.7 (4%)	48.6 (40%)	61.5 (51%)	122.0 (100%)
Vegetables	963	20.0 (14%)	14.0 (10%)	14.0 (10%)	40.6 (29%)	53.5 (37%)	142.1 (100%)

* Cultivation costs include the cost of seeds for vegetables.

Vegetables give a much quicker return than orchards, and establisment costs are lower. Neither walls nor drip irrigation is common. Most often, vegetable fields are irrigated from elevated tanks using a gravity flow, flood system, supplied by tanker trucks.

Labor and irrigation make up over 10% of vegetable production costs. However, vegetables entail a considerable cost to the producer for post-harvest processing, transport, and marketing. These together equalled an additional cost of JD 34 per dunum on the average for surveyed producers in 1993-94. Average return from the sale of vegetables in the Amman wholesale market was JD 201 per dunum. The gross margin for vegetables was JD 25, giving a benefit/cost ratio of 1.14. Reducing the cost of water would substantially improve the profitablity of vegetables in the catchment area.

5.2.7 Current water use and economic incentives for water harvesting

Water is the most limiting factor for productive land use in the Muwaqqar catchment area. Population size and the intensity of agriculture, including animal husbandry, has far outstripped the benefits of relying on the simple traditional techniques for rainwater capture, storage, and utilization. Resorting to modern well drilling equipment and sophisticated drip irrigation has not produced, as yet, encouraging economic results, and there are many unanswered questions about the dependability and sustainability of underground water resources.

Although there is still use of traditional runoff storage cisterns to water livestock and natural water harvesting from low hillsides to increase moisture on barley fields, the majority of land users now depend on trucking in water from external supplies for both domestic and agricultural uses (Table 5.2.10). Only four of the land users surveyed had wells of their own, and another four had constructed earth dams and were pumping water collected in them for cereal and tree production.

Table 5.2.10. Water sources by principal enterprises (number of farmers using each source)

Producer type	Enterprises		Tanker trucks	Municipal supply	On-farm well	Earth dam
Traditional	Cereals only	n= 5	-	-	2	3
	Cereals & small flock	n=11	2	7	2	-
	Cereals & medium flock	n= 7	6	1	-	-
	Cereals & large flock	n= 4	4	-	-	-
Nomads	Small flock	n= 7	5	2	-	-
	Medium flock	n= 7	7	-	-	-
	Large flock	n= 7	7	-	-	-
Investors	Poultry, small flock	n= 3	3	-	-	-
	Poultry, medium flock	n= 6	6	-	-	-
	Poultry, large flock	n= 3	3	-	-	-
	Poultry, layers	n= 2	2	-	-	-
	Trees	n=11	10	-	-	1
	Vegetables	n= 3	3	-	-	-
Others	Cows, camels, mixed	n= 6	6	-	-	-
Total sample		**n=82**	**64**	**10**	**4**	**4**

The land users surveyed are aware of the research effort into water harvesting at the University of Jordan's Muwaqqar station, although there is considerably less knowledge about the specific techniques being developed. Most people surveyed assumed that water harvesting means building earthen dams across wadi beds to capture streams flowing after rainstorms. Other techniques being developed and tested, such as microcatchments for trees and shrubs, low bunds along contours, and other less dramatic measures, are not known or understood by the local population.

Generally, there is a very positive attitude towards the principle of water harvesting. Only 5 people out of the 82 surveyed thought that water harvesting was useless. However, there is an almost equal unanimity that water harvesting techniques would be expensive and beyond the means of most land users. All but one respondent thought that capturing wadi flows with dams and distributing the water to land users was a good idea, but 80% of the people felt that constructing the dams themselves was beyond the individual farmer's means. Some 26% felt that problems might rise over water distribution rights if dams were constructed, but a two-thirds majority did not think that this would be a problem. In summary, the initial perception of land users is that costs outweigh all other considerations as a hindrance to implementing water harvesting measures.

A number of land users are, nevertheless, spending considerable amounts of money in experimenting with water harvesting measures of their own. In the past couple of years, one sheep merchant and feedlot operator from outside the area has acquired land bordering the main streambed located in the middle of the catchment, and he has constructed a very large earth and rock dam that completely closes off the stream flow. This dam filled with water during the winter of 1993/94, and water remained in the dam well into September. It was observed that the water from it was being carried by tanker trucks to other locations, although the ultimate use was not determined. Local shepherds reported that sheep would not drink the water due to the presence of sediment and contaminates, but this could not be substantiated.

Another investor has constructed an elaborate system of weirs and concrete channels to divert the flows in two minor wadis to open-air storage tanks for later pumping to irrigate winter vegetables interplanted among olive and fruit trees. His Egyptian farm manager reports that the system worked successfully, but that there was a problem of supply at the end of the season, and water had to be brought by trucks.

There is evidence that a number of land users have attempted and failed to capture runoff water. Here and there, across the catchment, one sees the remains of earthen dams in wadi beds that have obviously been destroyed by spate floods. They were constructed using bulldozers to pile up accumulated loose sediment in an attempt to dam the flow of water, but the flows were too great for the strength of these makeshift constructions. It is clear that there is the willingness to innovate but that knowledge of proper techniques and technical specifications is needed.

A further consideration is the quality of harvsted water, especially that of wadi floods stored in dams. Water stored in traditional underground cisterns can be used for human and animal consumption because of the way it is collected and stored. The catchments are small and kept clean of most contaminating materials. The nature of the underground cistern allows sedimentation, and the fact that cisterns are covered means there is no sunlight to encourage the growth of unwanted micro-organisms. Water captured in a wadi dam, however, contains material swept along by the flood over a very large area and natural sedimentation is usually not sufficient to remove contaminants from the upper layers of the reservoir. Moreover, the openness of the reservoir means micro-organisms can grow and other material can easily enter the water supply long after the floods are over.

Shepherds reported that water stored in dams would not be potable for livestock, let alone humans. Poultry farmers had a similar observation regarding their birds. Nonetheless, traditional tanks storing flood water, such as the large Roman open cistern at Muwaqqar town, are used to water livestock. The issue of potability of water collected and stored in dams needs further research.

5.2.8 Conclusions

The capture and storage of flood water using earthen dams has obvious applications in the catchment area. The principles are well understood by the land users, and a number of people have already tried to implement the technique. The issues identified in the survey involve costs, technical feasibility, and water quality, and utilization and distribution rights. All these topics need further investigation before definitive conclusions can be drawn, but the use of dams is clearly the place to start involving local land users as participants in the research process.

The economic incentives for developing dams, assuming technically sound designs are followed, are readily apparent because of the potentially large amounts of water that can be collected. Supplemental irrigation of barley and tree crops would seem to be the most profitable form of use in the short term, if there are indeed quality constraints to using the water for livestock.

The technique of using small runoff basins to enhance tree production would also appear readily adaptable to local conditions. This may require some alterations in current planting densities in new orchards, but in situations where neither land nor establishment costs appear to be a limiting factor, it can be expected that investors would be willing to consider applying the technique. Using trucked water to maintain orchards, as is currently done, is a questionable long-term economic strategy.

In the case of field crops and orchards, the owners have clear rights and perogatives. They represent investments recognized by other land users, and in practice they are protected from depredations by people and animals whether or not they are fenced or guarded. Rangeland, however, is a different situation, presenting problems of both labor and capital investment.

The techniques of contour ridging and low stone walls across wadis are meant to improve rangeland grazing resources by providing additional moisture for the growth of forage shrubs and grasses. Presently, there is no significant incidence of forage shrubs existing in the catchment's rangeland, and shrubs would be an introduced and novel source of forage. Quite apart from the issue of whether or not animals would graze them, there are questions of proper grazing management of shrubs and whether or not the shrubs would be respected by land users other than those who established the plantations. Moreover, there is the very real economic question of whether the effort and cost involved in preparing the land and maintaining the shrubs is justified by the forage output.

Despite these concerns, providing feed to livestock is the major economic concern of the largest group of land users in the catchment. At present, their focus is on barley grain and straw. Improving barley production would seem to be the most obvious application of water harvesting. It could be done through the use of wadi dams, but there are many areas where topography and distance preclude this technique. The traditional "natural water harvesting" by planting in depressions is the most common practice. It is worth considering how to improve this traditonal technique, perhaps by improving runoff efficiency from surrounding slopes. In any event, this would necessarily involve barley producers as participants in the research effort. In terms of targeting local participation, the results of the survey indicate that barley farmers with small and medium flocks have the greatest economic incentive to improve their barley production, and that barley improvement would be of more short and medium interest to them than rangeland improvement. Moreover, working with barley farmers, as with orchard owners, would avoid entanglement in the uncertain area of property and access issues that characterize the rangeland. *[Rick Tutwiler]*

5.3 Factors Influencing Adoption of New Technology in Dry Areas of Syria: Fertilizer Use on Rainfed Barley

5.3.1 Introduction

Chemical fertilizers were introduced to Syria during the 1950s and were used primarily on high-value irrigated crops such as cotton and vegetables. In the dry areas of Syria (200-350 mm annual rainfall), barley is the principal crop, grown primarily for livestock feed. Diagnostic surveys found that grain yields averaged about 500 kg/ha (Mazid and Hallajian 1983) and only about 10% of farmers used fertilizer on barley (Somel, Mazid, and Hallajian 1984). Due to the low and variable rainfall, fertilizer use in these areas was perceived as risky, and supply and credit policies did not encourage its use (Mazid and Bailey 1992; Somel, Mazid, and El-Hajj 1992).

ICARDA research found that yields were low, not simply because of low rainfall, but because of the low availability of nutrients in the soils. On many farmers' fields, only 15% of the rain received was used by the crop, the remainder being lost to evaporation from the soil surface (ICARDA 1986). Results from research station trials over a range of years and sites showed that fertilizer application could increase water-use efficiency by around 75% (Cooper *et al.* 1987; Shepherd *et al.* 1987). Two mechanisms are involved in this yield increase (Jones and Mazid 1988):

a. a more rapid development of crop cover, so less water is lost by evaporation from the soil surface and more, therefore, is utilized by the crop;
b. a more rapid completion of growth cycle, so that a greater proportion of that growth is achieved under the moderate temperatures and higher humidity of early spring; and the higher temperatures and higher evaporative demand of late spring are at least partly avoided.

In 1984, FRMP and the Soils Directorate (SD) of the Syrian Ministry of Agriculture and Agrarian Reform, initiated a collaborative project by which the biological responses and economic viability of fertilizer use on barley in dry areas were assessed in a multi-season series of on-farm trials. The results confirmed that the positive responses to fertilizer found on research stations could be reproduced under the highly variable soil and rainfall conditions faced by farmers (Jones 1990; Jones and Wahbi 1991).

At the same time, economic studies indicated that fertilizer use on rainfed barley is profitable at the farm level, with positive potential impact at the National level (Mazid and Somel 19887) (Table 5.3.1).

Table 5.3.1. Estimated increase in national grain and straw production and net revenue due to fertilizer use on barley in zones 2 and 3

	Percent adoption		
	50%	70%	90%
Grain (thousand tonnes)	140.7	196.0	253.3
Straw (thousand tonnes)	280.4	392.6	504.7
Net revenue (million SL)	221.8	310.5	399.2

Source: Mazid and Somel 1988.

Adoption rate is clearly the most important factor influencing potential impact. Prior to the present study some rainfed barley farmers had adopted fertilizer, but others especially in drier areas had not. A study of factors influencing adoption was seen as very important for achieving increased barley production. For widespread use, a new technology must be appropriate and profitable to the end user, and within his means and abilities, culturally permissible, and not unreasonably risky.

Previous studies (Mazid 1980, Razzouk 1990) had indicated that new agricultural technology had been rapidly adopted in irrigated and wet areas of Syria, but adoption had been slow in the dry areas. Thus, a study of the factors influencing the adoption of new agricultural technology in the dry areas potentially has important implications for Syrian agriculture.

The main objective of this research was therefore to develop an approach and a model to identify, quantify and evaluate the factors that influence adoption of a new technology in the dry areas in Syria. It focused on fertilizer use on rainfed barley as a case study.

5.3.2 Methodology

The first step was to assess the appropriateness of fertilizer use on barley in dry areas. This was done before identifying the factors that influence adoption, since if the technology was found to be inappropriate for farmers' circumstances, more technical research would be needed before the adoption process could be studied.

Data for this research were gathered from 105 rainfed barley farmers chosen randomly, using a two-stage sampling procedure, in Aleppo, Idleb, Hama, Hassakeh and Raqqa provinces, which represent about 85% of the rainfed cropping area of Syria. Sixty farmers were located in agro-climatic zone 2 and 45 farmers in zone 3. Farmers were interviewed during February to April 1993. An adopter is defined, in this study, as a farmer who had adopted at least one component of the fertilizer package (ie, either phosphate or nitrogen, or both).

The main research hypothesis was that the time dimension is essential in understanding the adoption and diffusion process; it is an important aspect of any communication process. This factor was therefore investigated by studying the adoption rate and the diffusion process using Bass's Model and the Logistic Model. Discriminant function analysis was used to study the innovativeness of farmers in adopting fertilizer technology, ie the degree to which an individual is relatively early in the adoption of fertilizer technology as compared to other farmers.

Four major sets of factors were hypothesized as key issues for adoption behaviour of farmers, particularly the rainfed barley farmers: farming systems; farm resources; farmers' characteristics, including personal and psychological components; and institutional and communication factors. Each main factor was represented by a number of variables (Figure 5.3.1).

Every variable was investigated separately, using simple statistical methods such as correlation, T-test and Chi-square test, to compare the characteristics of farmers who have adopted the fertilizer technology with those who have not. Understanding adoption behaviour often requires the analyst to look beyond relationships between single variables. In the present study, descriptive analysis showed that individual variables were often interrelated. Therefore, a multivariate econometric approach was applied to identify the most important factors that influence adoption behaviour.

The behavioural adoption model is used as a conceptual framework within which to examine variables associated with

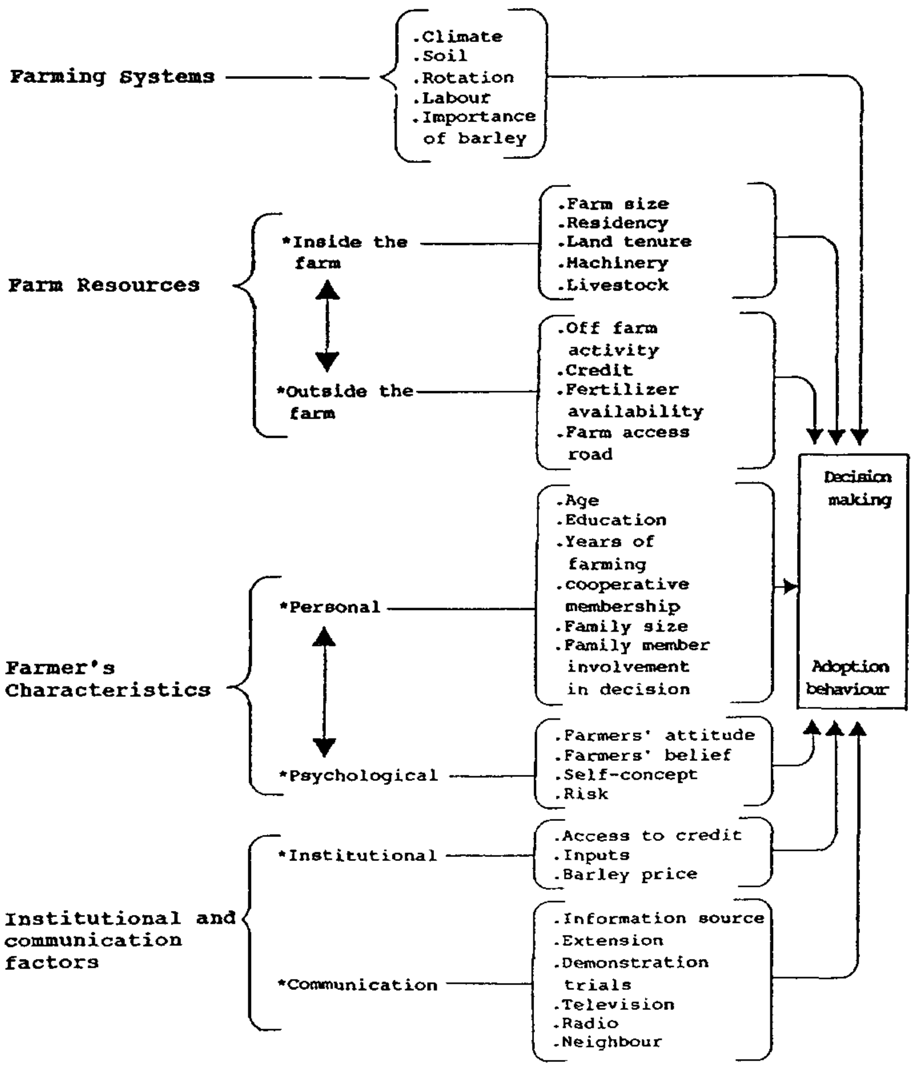

Figure 5.3.1. The factors that influence adoption of fertilizer use on barley

technology adoption, by looking at multivariate relationships. Ordinary multiple regression analysis has been most commonly used to describe multivariate relationships, but since adoption studies deal with categorical dependent variables, such as 'yes' or 'no', ordinary linear regression is inappropriate. Among the most generally used models for adoption studies are the Probit or Logit Models. In the Probit Model the probability of adoption follows a cumulative normal distribution function, while the Logit Model corresponds to a logistic distribution function. For most simple problems, the interpretation of the same data, whether estimated by Probit or Logit Models, will be very similar.

In this study the Logit Model was applied to analyze adoption patterns and to identify the most important factors influencing the adoption process. This model focused on a few key relationships that not only can help researchers to understand the adoption process but can also help to make agricultural policy, and the extension and research effort, more efficient in future.

5.3.3 Summary of findings

Diffusion. Both the Bass and Logistic models were used to study the diffusion of fertilizer. The Logistic Model fitted the fertilizer diffusion pattern much better than Bass's Model. Under the current situation, the annual adoption rate in zone 3 is much higher than in zone 2, but the upper-bound adoption of fertilizer is expected to be much greater in zone 2. Figure 5.3.2 presents the actual and predicted cumulative percentage of adopters from the estimated Logistic Model for 1975-92.

Innovativeness. Farmers who had adopted fertilizer were classified into three groups: early adopters, early majority and late majority adopters. Discriminant function analysis was applied to identify the factors which had influenced the innovativeness of farmers. The results indicated that, in zone 2, the following nine factors: "off-farm activity", "residence outside home village", "importance of income from barley", "agricultural cooperative membership", "having sharecropping arrangement", "percentage of barley area in the farm", "soil fertility", "how the farmer sees himself as progressive", and "how the farmer sees himself as efficient" were the most important factors. In zone 3, "off-farm activity", "residence outside home village", "agricultural cooperative membership", "soil fertility", "fertilizer availability", "farmer's attitude to rainfed farming", "seeing fertilizer demonstration trial",

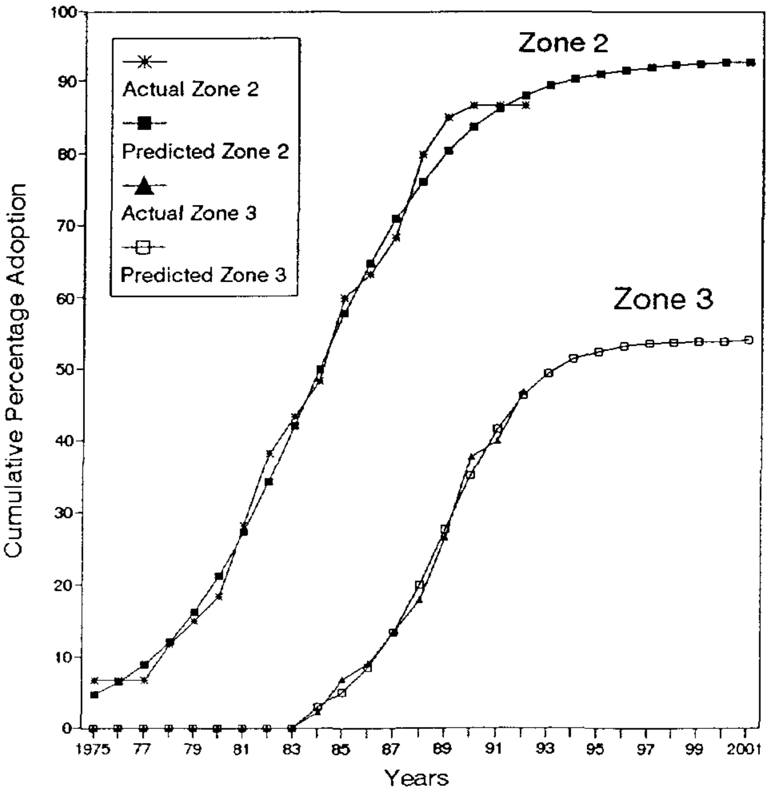

Figure 5.3.2. Actual (1975-92) and predicted (1975-2001) cumulative adoption from estimated logistic model for 1975-92

and "farmers were visited by extension workers" were the factors influencing innovativeness. At the <u>total sample</u> level, eight factors were identified: "completed elementary school", "agricultural cooperative membership", "percentage of barley area", "how the farmer sees himself as flexible", "credit availability", "fertilizer availability", "seeing fertilizer demonstration trial", and "farmer's attitude to rainfed farming job". Standardized discriminant function coefficients are summarized in Table 5.3.2.

Table 5.3.2. Standardized discriminant function coefficients values for zone 2, zone 3, and total sample

	Zone 2	Zone 3	Total sample
OFFA	-.393	-.786	-
RESID	-.437	1.019	-
BAHOU	.971	-	-
COOP	1.057	-.587	.841
SHH	-.533	-	-
PRBA	.249	-	.801
FRTI	-.353	2.617	-
SEPRTR	.408	-	-
SEEFNO	.321	-	-
FRAV	-	-.517	-.278
RFFARM	-	.949	-.418
DEMTRAL	-	-1.31	.028
EXTVISF	-	2.29	-
EDU1	-	-	-.333
CRAV	-	-	.242
SEFLX	-	-	-.166
Eigenvalue	2.053	1.665	0.542
Canonical-correlation	0.820	0.790	0.593
Wilks' lambda	0.241	0.375	0.572
Chi-square	64.10***	14.70*	37.21**
Grouped cases correctly classified	80.77%	85.71%	67.12%

*** Significant at 0.001% level; ** Significant at 0.01% level; * Significant at 0.1% level

Factors affecting adoption behaviour. **Farming system factors** which may influence fertilizer adoption behaviour were examined. There were significant relationships between adoption performance and climate conditions; farmers living in relatively wetter areas adopted fertilizer to a greater extent than those living in the drier areas. Soil factors were examined in terms of soil fertility, stoniness, land slope, and soil depth. There were some indications of a positive relation between soil characteristics and adoption behaviour.

The relative importance of barley in the farm and its influence on fertilizer adoption was investigated by examining two factors, percentage of barley area in the farm, and percentage of gross household income from barley. There was a positive and significant relationship between percentage of barley area and adoption behaviour in zone 2, but not in zone 3, and a rather weaker relationship between adoption and income from barley.

Two crop rotations are commonly used in the barley/livestock system in Syria: continuous barley cropping and barley/fallow rotation, but there was no noticeable effect of crop rotation on fertilizer adoption. Labour in the farming system, and its impact on adoption, was studied by testing two elements, number of labour units in the family and labour source, but no significant effect was found.

Eight **farm resource factors** were examined. It was found that the relationship between fertilizer adoption and farm size was weak and not significant. There was no relationship between adoption and residence outside home village in zone 2, but in zone 3 a positive and significant relationship was found.

With respect to land tenure, some farmers in the barley/livestock system operate a sharecropping arrangement with contractors, who usually live in other villages or towns and have the resources and machinery to farm large areas of land. The analysis concluded that when commercial producers sharecrop the land of smaller farmers, it is an arrangement that does not provide an incentive for fertilizer adoption.

Tractor ownership, an indicator of mechanization, apparently had no impact on the fertilizer adoption pattern. Livestock numbers, especially of sheep and goats and flock size, also showed no clear relationships with adoption.

Effects of credit availability, though greater in zone 3 than zone 2, were not significant; but, as would be expected, the relationship between adoption and fertilizer availability was very strong, positive, and significant.

The off-farm activity factor positively and significantly affected the fertilizer adoption pattern in zone 3, but not in zone 2, but suprisingly, farm road access did not influence fertilizer adoption.

Eight **personal characteristics** of farmers were examined for their influence on adoption behaviour. Age of farmer at adoption time showed a significant relationship with adoption behaviour, but this association was negative in zone 2 and positive in zone 3.

Relationships of adoption with farmer's education variables -- including years of schooling, literacy, and the completion of elementary school -- were generally negative, and some of these associations were significant. Years of farming was more important; farmers who had more experience in rainfed barley farming adopted fertilizer technology faster than farmers with less experience.

There was a significant relationship between adoption behaviour and cooperative membership in zone 2 and at the total sample level, but not in zone 3. Neither family size nor family members involvement in farming decisions had any significant effect.

Results from the analysis of factors associated with farmers' **psychological characteristics** indicated that the adoption decision is affected by a mechanism of different stresses, ie, influence from different directions. These stresses originate from a farmer's beliefs, his current situation and his Self-Concept.

Identification of farmers' attitudes towards various aspects of farming are meaningful in trying to understand farmers' behaviour. Farmers' attitudes were examined by asking farmers to state the degree to which they like or dislike the following six jobs: rainfed farming, irrigated farming, livestock raising, agricultural machinery, trade and government employment. Positive relationships were found between adoption behaviour and a farmer's attitude to rainfed farming work.

The influence of farmers' beliefs were examined by asking farmers to what extent they agree or disagree with specific statements. Significant relationships were found between adoption and agreement with the following statements: "a hard working man is good", "our father planted to feed us and we are doing the same for our children" and "the future of my family is very important for me", but for the statement of "money brings happiness" there was no significant difference between the attitudes of adopters and non-adopters.

Five elements under the past and ancestor component were examined to investigate the effect of traditionalism on adoption. The analysis indicated that traditionalism is not a consistent factor influencing adoption behaviour of farmers. It would appear that Syrian farmers in the dry areas are forward looking.

Three elements related to current situation were investigated: farmers' perception of characteristics of innovation, their attitude to agricultural research, and their satisfaction with their progress in farming. Most of the surveyed farmers who adopted fertilizer agreed with the view that "the current farming practices are much easier than those of the past", and "innovations are time savers". The difference between early adopters and other farmers was not significant. However, in zone 2, where fertilizer has been available for a longer time, there was a significant difference between adopters and non-adopters in their perception of innovation characteristics. The relationship between adoption behaviour and agreement with the statement that "research is necessary for agricultural development" was significant only in zone 3. Here, farmers who had adopted fertilizer technology believe that research is necessary to improve their agricultural production.

The Self-Concept, which is an individual's view of himself or herself and the view about how he/she is seen by other individuals, is regarded by many psychologists as a major factor underlying every individual's behaviour. The 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 (Ideal self). In studying farmers' decision making and consequent behaviour, it is important to identify these images. They create a frame of reference for every individual within the farming community to recognize himself or herself and to preselect both goals and behaviour.

A positive relationship between Self-concept and fertilizer adoption behaviour was anticipated. Each farmer was asked to appraise eight 'dimensional' phrases: "progressive", "efficient", "experienced", "fortunate", "flexible", "scientifically oriented", and "like to take risk" on a five-point scale in the context each of cognized, other and idealized selves (Mazid 1994). The overall analysis indicated that the more positive the attitude held by farmers about themselves the more positive their adoption behaviour. A significant part of the explanation of failure to adopt was the self image of farmers, which may influence their attitude to farm resources and communication factors.

To assess farmers' attitude to risk, two methods were used. The first measured farmers' attitude to risk directly by investigating farmers' response to statements about using new technology or innovation for the first time. The second measured farmers' attitude to risk indirectly by asking their views about the speed of adoption. However, neither method revealed a significant difference between adopters and non-adopters.

Nine **institutional and communication factors** were investigated. Credit did not significantly influence fertilizer adoption behaviour because most farmers depended on their own financial resources. Agricultural policy, specifically fertilizer allocation in the dry areas, was successful in meeting rainfed barley requirements for fertilizer in zone 2, but not for zone 3, where most adopter farmers obtain their fertilizer from the free market at a higher price. Most of the farmers surveyed perceived fertilizer as costly.

Sources, availability and costs of farming inputs (including barley seed, tractors, combine-harvester, seed-drill and farm transport) differed significantly between adopters and non-adopters. This difference was partly due to the role of sharecropping, where non-adopters depended on this arrangement to obtain their farming inputs. Farming inputs were easy to obtain by farmers, and in general did not significantly affect the fertilizer adoption action, but most farmers reported that farming costs were expensive; and there were, in some cases, significant differences between adopters and non-adopters in their perception of input costs.

No significant effect on adoption behaviour could be assigned either to farmers' perception of grain and straw prices or to the influence of agricultural extension, such as having an extension office in the village, visiting an extension office or being visited by agricultural extension workers. The mass media were also perceived as having no influence on fertilizer adoption in the dry areas, essentially because at the time of the survey there had been no specific farming programmes that focus on agriculture in the dry areas.

Neighbours were considered as a main source of farming information for farmers in the sample. Neighbours also had an important role in solving agricultural problems faced by farmers, but this factor apparently had no significant influence on fertilizer adoption.

Multivariate analysis. Logit models were first fitted to all the variables which might potentially influence adoption behaviour, first for total sample, second for adopters versus non-adopters in zone 2, third for the first 50% adopters versus other farmers in zone 2, and fourth for zone 3. Non-significant variables were then dropped, and models re-fitted to identify the key factors influencing the adoption process.

The results indicated that the two zones differed in respect of the factors influencing adoption behaviour. In zone 2, the four variables: "having sharecropping arrangement", "farm size", "farmer's age at adoption time" and "fertilizer source" were the key factors. The first three factors affected adoption negatively, while the fourth had a positive effect. In the same zone, six factors were important in explaining the behaviour of the first 50% of adopters *vis-a-vis* the rest. These included "cooperative membership", "how the farmer sees himself as progressive", "percentage of barley in the farm", "number of farming information sources", "having off-farm activities" and "how the farmer sees himself as flexible".

In zone 3, "fertilizer availability", "having off-farm activity", "farm size", "seeing a fertilizer demonstration trial", "soil fertility" and "fertilizer source" were key factors influencing adoption. At the total sample level, "cooperative membership", "fertilizer availability", "farmers' attitude to rainfed farming job", "how the farmer sees himself as progressive", "percentage of barley area in the farm" and "number of farming information sources" were the most important factors. Table 5.3.3 shows the estimated Logit Models for zone 2, zone 3 and the total sample.

5.3.4 Policy implications

The main stated objective of fertilizer policies in Syria is to increase agricultural production, which in turn would increase farmer's income, increase national food self-sufficiency, and reduce the balance of trade deficit by

Table 5.3.3. Estimated coefficients of Logit models

Label	Total	Zone 2	Zone 3	Variable	
	Sample	Case 1[a]	Case 2[b]		
COOP	1.203	-	4.444	-	Cooperative Membership
FRAV	1.266	-	-	2.746	Fertilizer availability
RFFARM	1.570	-	-	-	Attit. to rainfed farm.
SEPRTR	1.476	-	3.024	-	Progressiveness
PRBA	0.020	-	0.037	-	Percentage of barley
INFORM	1.229	-	2.996	-	Information source no.
SHH	-	-3.923	-	-	Having sharecropping
OFFA	-	-	-2.899	4.123	Off farm activity
HOLD	-	-.022	-	0.005	Total holding area
AGE	-	-.090	-	0.069	Farmer age at adoption
DEMTRAL	-	-	-	1.612	Seeing fertilizer trail
FRTI	-	-	-	3.092	Soil fertility
FRSOO	-	2.899	-	1.146	Fertilizer source
SEFLX	-	-	-2.275	-	Flexibility
Constant	-7.009	6.151	-9.584	-9.096	
-2 log likelihood	106.4	18.9	40.1	30.2	
Model Chi-square	38.9***	28.2***	43.0***	32.0***	
Goodness of fit	104.3	46.2	48.2	37.5	
Cases correctly classified	77%	97%	90%	89%	
Sample size	105	60	60	45	

[a] Adopters versus non-adopters
[b] The first 50% adopters versus other farmers
*** Significant at 0.1% level
- variable not included

increasing agricultural exports and reducing imports (Saade 1991).

The results of the present research has implications for national fertilizer policy. They could be used by policy-makers to further their objective by increasing the rate of fertilizer use on barley, by creating the conditions that would encourage farmers to adopt. Furthermore, since the Logit Model can be used to predict the percentage of fertilizer adopters, the effects of policy changes on fertilizer supply requirements can be estimated. Any changes in the percentage of fertilizer adopters provides the basis for estimating changes in planned fertilizer requirements.

The most significant result of this research is the identification of the key factors that influence adoption process. Some of these factors, such as fertilizer availability and number of farming information sources, can be affected by agricultural policy but others cannot, especially in the short run, such as farmer's age, having off-farm activity, etc. In order to increase the rate of adoption and diffusion of fertilizer use on rainfed barley, agricultural policy could seek to influence the following factors: cooperative membership, fertilizer availability, number of farming information sources, observation of demonstration trials, and encouragement to the farmer to see himself as progressive. The government still has a key role to play in enhancing the adoption of fertilizer technology among rainfed barley farmers in Syria. ***[Ahmed Mazid, Elizabeth Bailey, and Martin F. Seabrook, University of Nottingham, UK]***

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5.4 Mechanical Harvesting of Lentil in Syria: A Farm Survey on Adoption

5.4.1 Background

Although lentil represent only 4.3% of world's total area sown to pulses (FAO 1990), they assume considerable regional and local importance in many countries of West Asia and North Africa (WANA). In the early 1990s, lentils contributed 20% of the total pulse area in WANA's lentil-producing countries; they accounted for 64% of the total pulse area in Syria and Jordan, 36% in Turkey and Lebanon, 19% in Iran, and 12% in Morocco. The importance of lentils is recognized by their nutritional value (high content of protein -- a meat substitute) for human diets, and their straw is a nutritionally valuable animal feed. The crop is also an important component in the crop rotation prevalent in the wetter regions of rainfed dry lands in WANA, as it maintains soil fertility through dinitrogen fixation by its rhizobia.

In 1979-1980, a diagnostic farm survey of lentil production systems was conducted in Syria for (1) system characterization; (2) problem identification, and planning of experimental research; and (3) preliminary assessment of improvement potential. The problem of the hand harvest of the crop was reported by the majority of farmers as a major constraint to crop production. Therefore, a major goal of research at ICARDA since its inception has been the development of systems for the mechanized harvest of lentil (Papazian 1983; Friedrich 1988; Saxena *et al.* 1988).

The diversity in physical and socio-economic environments of lentil in WANA suggested that no single machine would be the universal solution. Accordingly, two major thrusts of research, conducted by a multidisciplinary team (breeder, farm management, socio-economist, and mechanical engineer) were followed: (1) restructure the crop production system to make existing combines (with modifications) economic, (2) taking the traditional system of production as a base-line, focus on the minimum changes required for the economic operation of mowers. Research to develop a new harvester specific to lentil was stopped because such equipment was found uneconomic for small-farmer use.

The economic operation of mowers was found to require a seedbed flatter than that of the ridges associated with traditional, broadcast lentil. A flat seedbed may be made using such equipment as a cereal drill, a heavy tractor-towed bar or a roller. On-farm research to compare hand harvest with a tractor-drawn, double-knife mower was undertaken in ten trials in northwest Syria from 1985/86 to 1987/88. The mower resulted in significant harvest losses of 9% seed and 17% straw compared to hand harvest. But losses from mechanical harvest by mower were compensated by reduced labor cost in comparison to hand harvest (Erskine *et al.* 1991).

The use of a combine on lentil was found to be more sensitive to an uneven seedbed than the mower. Consequently, drill sowing followed by rolling were found to be pre-requisites for a successful combine harvest (Friedrich 1988). Much of the straw is lost in a combine harvest.

Machine harvesting is improved in a tall standing crop. For example, the advantage in seed yield of cultivar 78S26002 over the local cultivar increased from 9% from a hand harvest to 39% with mowing because of its reduced lodging. This cultivar, with improved yield and standing ability compared to the local check, has now been registered as 'Idleb 1' in Syria, as 'Barakat' in Iraq, as 'Jordan 3' in Jordan and as 'El Saf Saf 3' in Libya. Other cultivars with improved yield and standing ability compared to the local check are 'Talya 2' (ILL 5588) in Lebanon and ILL 1939, which is in the final year of registration trials in S.E. Anatolia.

This report summarizes the findings of a farm survey conducted in the major lentil-producing areas of northern Syria (1993/94) to (1) assess farmers' adoption of mechanical harvesting and its complementary agronomic package (new variety, land levelling, and the use of seed drill; (2) investigate reasons for adoption or non-adoption; and (3) identify means for enhancing the adoption of mechanized harvesting.

5.4.2 Location and sample

Lentil is grown mainly in the northern provinces of Syria. Hasake province, northeast (NE), contributed about 49% of total area of the crop (131250 ha in 1990). Aleppo, Idleb and Hama, northwest (NW) contributed 43% of crop area, and only 5% of lentil area is located in the far south provinces of Deraa and Sweda (AASA 1990). Because it was well known (to the authors), from secondary data sources and personal observations, that the potential for mechanical harvesting of lentil is greater in the NE (due to larger crop area, lower chances for alternative crops, and predominance of share-cropping tenure), the sample was intentionally biased to that region. Another justification for this bias was that, although Hasake contributed 49% of total crop area, it contributed 72% of total production.

A sample of 77 farmers (65% from NE and 35% from NW) was randomly selected and interviewed by a team from ICARDA and the General Organization of Agricultural Mechanization (GOAM). The sample was agroclimatically distributed: 84% from zone 1 (rainfall is 350-600 mm, but not less than 300 mm in 66% of yearly observations), and 16% from zone 2 (rainfall is 250-350 mm, but not less than 250 mm in 66% of the years observed) (Figure 5.4.1). A structured, pre-coded questionnaire was adopted, designed to investigate the importance of lentil in the farming enterprise, farmers practices and the economics of crop production. Emphasis was given to issues related to mechanical harvesting and

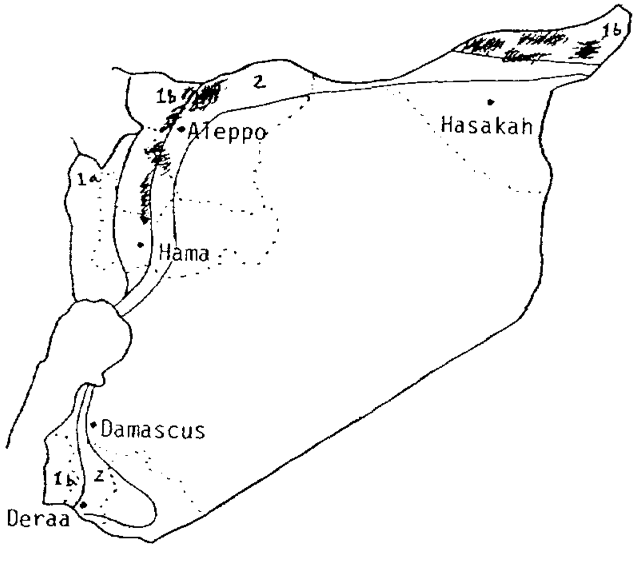

Figure 5.4.1. Research sites

associated agronomic practices. The Statistical Package for Social Scientists (SPSS) was used for data processing and analysis. The analysis was done at different levels, the sample as a whole, then to depict differences geographically (between NE and NW), agroclimatically (between zone 1 and zone 2), and between adopters and non-adopters of mechanical harvesting.

5.4.3 Major findings of the survey

5.4.3.1 Crop area

A short trend (of 5 years) indicated a decline from a mean of 10.0 ha of lentils/farm 5-years ago to 8.0 ha in 1992/93, then a rise to 9.2 ha in 1993/94. However, the variability in crop area was very high, the range was 0-70 ha, and the coefficient of variance (CV) was over 100% for the three years. NE farmers grew lentil on considerably larger areas than those in the NW, 11.2 and 5.5 ha, respectively. Although average farm lentil areas in zone 1 is higher than zone 2, differences were not significant. Farmers using mechanized harvesting (all from the NE) have larger areas of lentil (19.2 ha) than those who harvest the crop manually (9.2 ha).

Lentil area was 30% of total farm area for the whole sample, 34% in NE compared with 24% in NW, and 39% for adopters versus 30% for non-adopters of mechanized harvesting. Average land holding was 31 ha for the whole sample, 34 ha for NE, 24 ha for NW. In the NE, adopters of mechanized harvesting have larger land holdings than non-adopters (49 and 30 ha, respectively). However, the variability in land holdings is very high (CV is 100% or more for all groups).

Factors most influential on the area planted to lentil were 'economic considerations' and 'requirements of crop rotation', each reported by 46% of farmers. These factors were more emphasized by farmers of the NE and of zone 1. Other less influential factors were 'harvesting difficulties' and 'pests and diseases', reported by 17% and 6% respectively.

5.4.3.2 Agronomic practices for efficient mechanized harvesting

Local land races of lentil are generally short plants, tending to lodge and shatter at maturity. Therefore, an efficient solution to harvesting problems requires (1) a flat seedbed, (2) use of seed drill, (3) new cultivars taller and less prone to lodging and shattering than the locals, and (4) appropriate machinery, technically and economically.

Seedbed preparation, land levelling. Most farmers applied two preplanting cultivations using different equipment (mouldboard plough, ducksfoot cultivator, or disc plough). Another two cultivations (ayar and rdad) were done, directly before and after hand broadcast of the seed, usually with a ducksfoot cultivator that makes a relatively high-ridged seedbed, unsuitable for mechanized harvesting afterwards. Using the cereal seed drill, or the locally made Kesheshian harrow seeders, leaves the seedbed flat or with slight ridges.

About half (49%) of the sample farmers levelled lentil plots with a heavy tractor-towed bar (only one farmer used a roller, 33% of farmers believe that land levelling is not needed, and the other 18% did not use it for other reasons (cost, unavailability of equipment, or the practice is not known at all). Land levelling is more practised by NE farmers (58%) than NW (33%), and by adopters of mechanized harvesting (71%) than non-adopters (44%).

Lentil sowing. Lentil sowing is mechanized by a large majority (82%) of the sample farmers. Keshashian harrow seeders or cereal seed drill were used by 77% [96% of NE farmers, 41% in the NW, spinners by 5% (or 15% of NW farmers), and hand broadcast was practised by 18% (4% of NE farmers, but 44% in the NW)]. All adopters of mechanized harvesting also used mechanized sowing. The majority of NW farmers who hand-broadcast lentil seed were satisfied with this practice. Only 4 farmers in NW and one farmer in NE complained about drill unavailability.

New improved cultivars. Adoption of the new cultivar 78S26002 (registered as 'Idleb 1' in Syria) is the most distressing part of the mechanical harvesting story of lentil.

- Only one farmer of the sample grew Idleb 1
- 85% grew the local red cultivar
- 8% grew the local white (all in NW), and
- 6% did not grow lentil in 1993/94

The only farmer who adopted Idleb 1 was from Afrin, NW. He planted the new cultivar on his total lentil area (5 ha in 1993/94, and 10 ha in 1992/93). It was the second year of adoption. He was pleased with its performance and will continue its planting . Improved seeds were bought from a government source, were manually broadcast, and the crop hand-harvested. This farmer tried mechanical harvesting some 20 years ago, using a self-propelled harvester. The trial failed because of the shortness and lodging of the local cultivar. He did not try harvesting the new cultivar mechanically, but he might try in the future.

Two farmers have tried 'Idleb 1' and quit, one from Izaz (NW), and the other from Kahtaneya (NE). The farmer at Izaz grew it for 3 years and was very pleased with its yield. He quit only because clean seed was no longer available (his own stock of 'Idleb 1' having deteriorated due to mixing with weed seeds). He would have continued growing the new cultivar had clean, good quality, seed been available.

The other farmer (from NE) tried 'Idleb 1' for two years only because he had to take the seed, as an in-kind loan, from the Agricultural Bank. He considered the new cultivar needed a higher seed rate and had a greater tendency to shattering than the local red cultivar. This farmer has a land holding of 150 ha of which 30 ha is allocated to lentil. He harvested lentil, chickpea and vetch mechanically using a self-propelled harvester. He is satisfied with mechanical harvesting and believes that, if harvesting timely and the soil well-managed, yield losses can be no greater than those of manual harvesting. To facilitate efficient mechanized harvesting, this farmer ploughed his lentil plot several times: the first by a ducksfoot, the second and third by disc plough, to loosen and soften the soil. He then sowed with a Keshashian planter with tabban attached to it. His yield was close to the average of the NE region, even though he did not apply fertilizer.

Technology-transfer of the improved cultivar has gone, so far, very slowly and ineffectively. Idleb 1 has not been adopted because (1) farmers did not know of its existence (42% of the sample), (2) seed was unavailable (30%), (3) farmers disliked to change local cultivars (23%), and 3% gave other reasons such as poor yield and marketability.

Farmers' attitudes to changing agronomic practices. Of the 36% of farmers who adopted, or tried to adopt and quit, mechanical harvesting, only 17% tried the new cultivar 'Idleb 1'; 42% increased the number of ploughings; 72% levelled lentil plots; 64% cleared lentil plots from stones; and 78% used mechanical sowing.

However, taking the sample as a whole, a lare majority (75-91%) of farmers have (or would) change the agronomic practices, above, to facilitate efficient mechanized harvesting of lentil, if suitable machines became available. There were no significant differences between geographic or agroclimatic zones in this respect. It should also be emphasized that 78% of lentil, and 70% of chickpea, growers still considered manual harvesting as a problem to be solved. It can be concluded that the whole concept has so far not been well demonstrated, in addition to the fact that seed of the new cultivar has not been widely available. This is more of a technology transfer than a research problem.

5.4.3.3 Inputs (seed and fertilizer) rates

The seed rate was averaged around 140 kg/ha (SD 30.5 kg/ha). Significantly higher rate were used in the NW (170 kg/ha) than in the NE (130 kg/ha). This might be ascribed to sowing method (more hand broadcasting in the NW than in the NE). Farmers in zone 2 applied higher rates (160 kg/ha) than those in zone 1 (140 kg/ha), most likely because all zone 2 farmers were located in NW where hand broadcasting is most common. Variability in seed rate between farmers is not high (CV was 14% in NE, and 17% in NW).

Nitrogen was not applied by the majority (64%) of farmers. The average application, for the whole sample, was 21 kg/ha of urea, equivalent to about 10 kg/ha of N. However, the variability in N application was very high (CV 148%), particularly in the NW (CV 200%). No significant differences were found between geographical or agroclimatical zones. The majority (79%) of farmers used phosphorus fertilizer on lentil, with an average rate of 94 kg/ha (SD 81 kg/ha) of triple super phosphate, equivalent to 43 kg/ha P_2O_5.

In the NE, where mechanized harvesting was adopted by some farmers, there were no differences between adopters and non-adopters in terms of input rates (seed, N, and P).

5.4.3.4 Current situation of mechanical harvesting

Hand harvesting of lentil is still practised by 81% of the sample farmers, 72% of NE and 100% of NW farmers. In addition to the 19% adopters in 1992/93, another 18% (30% of NE and 4% of NW farmers) had tried mechanical harvesting for one or more (1-6) years but quit because of (1) high losses in grain and straw, (2) unavailability of appropriate machines at the proper time, (3) lodging, and (4) small area of lentil which can easily be hand harvested. The first two factors, (1) and (2), were also the main reasons for not trying mechanized harvesting at all. Other reasons were problematic soils (stony and rolling) and a lack of awareness of such a possibility.

Six of the 15 adopters of mechanical harvesting in 1992/93 used a cereal combine harvester (with modification), while the other 9 used large, self-propelled crop cutters. Most machines (47%) were farmers' own, 40% hired from other farmers, and 13% from GOAM.

Mechanized harvesting had been used for the first time by 8 farmers, for 2 years by 3 farmers, and for 4-7 years by 4 farmers, with an average usage of 2 years for adopters as a whole. However, it should be highlighted that 4 farmers (27% of adopters) intend to revert to hand harvesting because of large losses of grain and straw, and unreliable timing of machine availability.

Other legumes (chickpea, faba bean, vetches, and alfalfa) were also harvested mainly by hand. Mechanized harvesting was used by 30% of chickpea growers (26% of the sample farmers), faba bean (grown by 8% of sample farmers) was entirely hand harvested, while three of the five vetch growers and the single alfalfa producer used mechanical harvesting. Most growers of other legumes will adopt mechanized harvesting if proper machinery becomes available.

Lentil and chickpea area can be increased significantly (for most farmers) given effective mechanized harvesting. Faba bean is more governed by environmental limitations (rainfall), vetches and alfalfa by post-harvest processing (experience in hay and silage making), marketability and economic considerations.

5.4.3.5 Acceptable yield losses due to mechanization

Farmers, on average, are willing to sacrifice 13% of grain yield and 39% of straw for a suitable mechanized system of lentil harvesting. NE farmers would accept significantly higher losses of grain (16%) and straw (48%) than NW farmers (8% and 24% of grain and straw respectively). Indeed, about half of the NE sample would sacrifice up to 20-30% of their grain for mechanical harvesting, compared with only 4% in the NW. This, among other factors such as 'lentil area' and 'labor availability' may explain why all adopters of mechanization were from the NE.

5.4.3.6 Economics

Yield. The following figures represent average yields (grain and straw) obtained by the sample farmers in 1992/3, and in years of 'normal', 'good', and 'bad' harvest.

Season	Grain (kg/ha)	Straw (kg/ha)
1992/93	1570	1620
Normal	1230	1170
Good	2120	2070
Bad	550	580

Yield variability is lowest in good seasons (CV 32% for grain and 53% for straw) and highest in bad seasons (CV 73% and 81%, respectively). Yield differences between NE and NW were found significant only in normal season for grain (1150 vs 1380 kg/ha).

Supporting the statement of an adopter of mechanized harvesting that yield losses from mechanization, if well done, need be no higher than those of manual harvesting, no significant yield differences were found between adopters and non-adopters for either grain or straw in any season. Grain yields obtained by adopters were actually higher than non-adopters' in 1992/93 (1816 and 1600 kg/ha, respectively); both obtained almost the same yields in other seasons (normal, good and bad). Straw yields obtained by manual harvesting were higher than those from mechanized harvesting in all seasons including 1992/93, but differences were non-significant.

Harvest cost and economics of crop production. The frequency distribution analysis of yield data, below, show that in normal year about 50% of farmers produce more than 1000 kg/ha, increasing to 97% in good year and falling to only 7% in years of bad harvest.

Yield (kg/ha)	normal	good	bad season
	------- % of farmers -------		
0 - 500	4	0	58
501 - 1000	47	3	35
1001 - 1500	28	17	4
1501 - 2000	14	32	0
2001 - 2500	4	30	3
more than 2500	3	18	0
Total	100	100	100

Among agronomic factor, only the effect of P_2O_5 was significant. N application, land levelling, sowing and harvesting methods affected the yield, but nonsignificantly. Soil stoniness had significantly related to yield, but not other soil characteristics (depth, slope, and fragmentation).

Harvest cost and economics of crop production. Lentil production is a good farming enterprise economically. Lentil was ranked as the most profitable crop by 22% of the sample farmers, second only to wheat (66% of farmers). Moreover, lentil received the highest score (48% of farmers) as the second most profitable crop, followed by barley (25%), and wheat (22%). No differences, in this respect, were found between geographical locations, but more economic importance was given to lentil in zone 2 than zone 1, most likely because of a more restricted choice of cropping alternatives.

Net revenues vary widely between years according to yield variability and within the sample farmers in the same season:

Season	Net revenues (SL/ha)
1992/93	15820 (CV 72%)
normal	9710 (CV 99%)
good	25900 (CV 52%)
bad	-2625 (CV 280%)

Differences in net revenues between geographical areas were highly significant only in years of normal harvest (14570 SL/ha for NW compared to 7080 SL/ha in NE).

Lentil producers who have adopted mechanical harvesting have two advantages over their colleagues who harvest manually: lower harvesting costs, and economy of scale. Regardless of the season (normal, good, or bad), adopters of mechanical harvesting realized much higher profits than hand harvesters (Figure 5.4.2), although gross revenues were almost the same for the two groups. It should be highlighted that lentil production in bad years brings a net loss to all farmers except the mechanical harvesting group.

Average harvest cost, for the whole sample, of 5916 SL/ha (CV 42%), constituted 47% of the total production cost, 12654 SL/ha (CV 27%). Highly significant differences in harvest cost were found between NE (6588 SL/ha) and NW (4671). In the NE, mechanized harvesting cost was only 44% of hand harvesting cost (3235 and 7385 SL/ha, respectively), representing 35% of total production cost compared with 52% for hand harvest (Figure 5.4.3).

Considering the grain price of 16 SYL/kg, harvesting cost was equivalent to 202 kg and 461 kg of lentil grain for mechanical and manual harvesting, respectively. The following figures support the economic superiority of mechanical over manual harvesting:

Harvest cost as % of gross revenues	Sample	Mechanical	Manual
in 1992/93	21	10	25
in normal season	26	16	36
in good season	15	09	19
in bad season	59	33	73

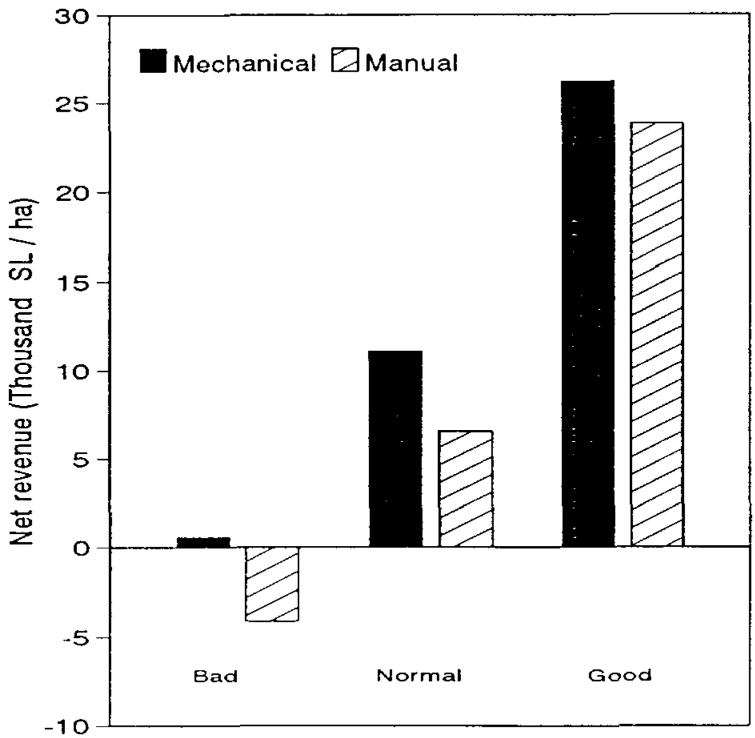

Figure 5.4.2. Differences in net revenue between mechanical and manual harvesting in years of bad, normal and good harvest

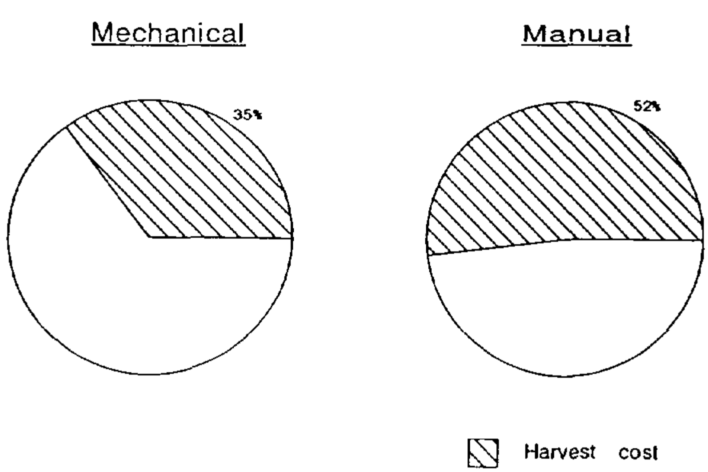

Figure 5.4.3. Harvest cost as % of total cost of production

<u>Gender issues</u>. Social scientists have always been concerned with the social aspects of mechanization. What is the level and trend of women's participation in hand harvesting? How important is the income obtained for participating women, and do they have a choice how they use it? Are there alternative income sources to compensate women for lost earnings arising from mechanization? Do women participate in the farm decision making of the household?

Hand pulling (or cutting) of the crop, which is the most tiring and costly step of the entire hand harvesting operation, is mainly a female task (96% of the sample farmers). Other steps, rajad, threshing, winnowing and bagging are mainly male tasks. Participation of women in rajad (transporting the harvest to a threshing floor) was reported by 14% of farmers, threshing by 22%, and winnowing and bagging by 33%. Generally, female participation is greater in the NW than in the NE. Increased involvement of women in harvesting (and in other agricultural activities) was reported by 60% of farmers, reduced involvement by 23%, and 17% of farmers considered it unchanged.

A large majority (88%) of farmers recognized hand harvesting of lentil as an important income source for women. However, 73% believed that alternative sources (agricultural and non-agricultural) are available, and it might be good to relieve women from such a heavy task. Women are free to dispose of their income from harvesting any way they like (80% of farmers), with no significant differences between NE and NW.

Participation of women in decision making, in general, was reported by 58% of the sample farmers. However, NE women apparently have better social status then in those of the NW (74% compared with 30% having a role in decision making).

5.4.3.7 <u>Conclusion</u>

Mechanical harvesting of lentil is now a problem of technology transfer more than research. Adoption has gone very slowly (19% of the surveyed producers), most likely becasue of the lack of technology transfer activities and, particularly, of availability of the improved cultivar seed. Another 18% tried the mechanical harvesting but quit due to unsuccessful performance, probably because another component of the package was not adopted.

Nevertheless, there is still a good potential for mechanized harvesting. This conclusion is supported by the following points:

* Despite drastic changes in the 1990s which have made lentil the first or second most profitable crop, most farmers still consider hand harvesting a problem, logistically and economically, especially for those with medium or large land holdings.
* The declining economic importance of lentil straw (about 50% of gross revenues in 1980s compared with only 13% in 1990s) encourages farmers to accept the greater losses of this by-product associated with mechanization.
* In practice, farmers who adopted mechanized harvesting gained net revenues considerably higher than those who harvested manually. Increases in net revenues were 45% in 1992/93, 69% in a normal season, but only 10% in a good season. In years of poor harvest, adopters realized a small profit margin (564 SL/ha), whereas non-adopters were subject to a serious loss (-4113 SL/ha).
* Currently, some components of the technology package are already applied by many farmers (49% levelled their soils, and 82% used mechanical sowing), and a large majority (more than 85%) expressed willingness to change one or more of their agronomic practices if efficient mechanized harvesting can be achieved.

It may be concluded that no more research is needed, except in breeding for better cultivars. Rather, an effective and efficient cooperation between GOAM, Extension Directorate, and ICARDA to demonstrate and transfer the recommended technological package for mechanized harvesting is required to solve the problem of lentil harvesting. ***[Abdul Bari Salkini, Willie Erskine, Afif Dakermanji (ICARDA), and the late Joana Haider (AUB) with special thanks to Mr Rizkalla Kebbe, Director of GOAM and his staff in Kamishly and Aleppo for their great support to this research]***

Dedication

This report is dedicated to the late Ms Joana Haider, our co-author, who passed away in a tragic accident before completing this report.

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5.5 Development of Sheep Fattening Schemes in Highland Balochistan, Pakistan

5.5.1 Introduction

The livestock sector in developing countries plays an important role in agricultural growth because of the large number of people involved in the production, trade and processing of livestock products. A major development challenge is how to encourage agro-pastoralists in semi-arid regions to take advantage of potential production and market opportunities.

Livestock development projects in the Balochistan province of Pakistan have launched small stock fattening as an income generating activity aimed at using crop residues, concentrates and rangelands in a timely and cost-effective fashion to take advantage of seasonal prices in livestock markets. Because most of the agro-pastoralists have insufficient financial resources to develop fattening schemes, they must rely on group organization. Five years of development experience in sheep fattening demonstrated differences between producers organized on a self-help basis and producers organized to take advantage of aid-supported livestock projects supported with flexible financial conditions. As project credit requirements became more rigorous the number of participants dropped. However, participants that accepted more stringent credit conditions showed remarkable technical, economic and social ability to succeed in the fattening schemes. To the knowledge of the authors, there is little published information on sheep fattening in West Asia (Nygaard *et al.* 1982) to complement that in the sub-Saharan Africa (McIntire *et al.* 1992).

Both biophysical and socio-economic factors determine the course of livestock development plans and, if any of them are ignored by those who implement development projects, the results are often less than desirable. This paper reports sheep fattening activities in Balochistan and discusses them as a part of sustainable livestock development projects. These projects have been adaptive, in the sense that farmers' conditions and abilities have varied across locations and time.

5.5.2 Recent developments at the Livestock Department and aid projects

In the mid 1980s the Balochistan Livestock Department formulated a policy to develop small-stock fattening schemes with assistance from the Commission of European Communities

(CEC) and the Asian Development Bank (ADB). The objective was to decrease the dependence of small stock on overgrazed rangelands and to improve the quality of animals marketed. One of the seven components of the Balochistan Livestock Development Project (BLDP), jointly funded by ADB-CEC, was for kid and lamb fattening (MPC 1990).

During the first phase of the project (1984-87), this component emphasized nutritional studies on government farms. Towards the end of the phase farmers' co-operatives for fattening lambs were formed. Nutritional studies showed that gains and conversion ratios were higher in lambs than in kids (HAC 1987). At the start of the second phase (1987-90), attention focused on the introduction of lamb fattening schemes to co-operatives and individual sheep owners, and project personnel monitored their economic performance. The first co-operatives were not viable. Though economic and technical criteria were met, differences of opinion among the participants hindered their performance. To overcome this problem, fattening units were formed among smaller groups of sheep owners able to make collective decisions. As realized at the end of the first phase, sustainable development in sheep fattening requires consideration not only of technical and economic constraints but also of social factors.

In parallel with developments in co-operatives, fattening experiments were also carried out on two government stations to test the response of animals to different feeding regimes (MPC, 1990).

In 1989, informal relations were established between BLDP and the Pak-German Self Help Project (PGSHP) to introduce sheep fattening to self-help organizations (SHOs) to generate additional income. The SHOs, by this time, had had three years of collective work, in contrast to co-operatives just formed for the purpose of sheep fattening.

Since 1991, the Balochistan Rural Support Program (BRSP), a non-government organization under the Pakistan Company Ordinance Act, has continued the work of PGSHP, including sheep fattening as one more activity in its development agenda (BRSP 1992a). Socio-economic and financial feasibility has been given greater emphasis by BRSP than by PGSHP.

5.5.3 The Balochistan livestock development Project (BLDP)

In 1987, five fattening units with no open yards and with a capacity for 250 to 300 animals were built in collaboration with the co-operatives of livestock owners in the districts of Loralai and Zhob. During 1989 and 1990, 28 more units, capable of handling 100-200 animals, were added. These districts were selected because their location in the 300 to 350 mm annual rainfall area provided greater availability of forage and crop residues than drier areas. Selection of specific fattening locations (Figure 5.5.1) was based on the managerial ability of the stock owners and their interest in joining the project. Most of the participants were larger

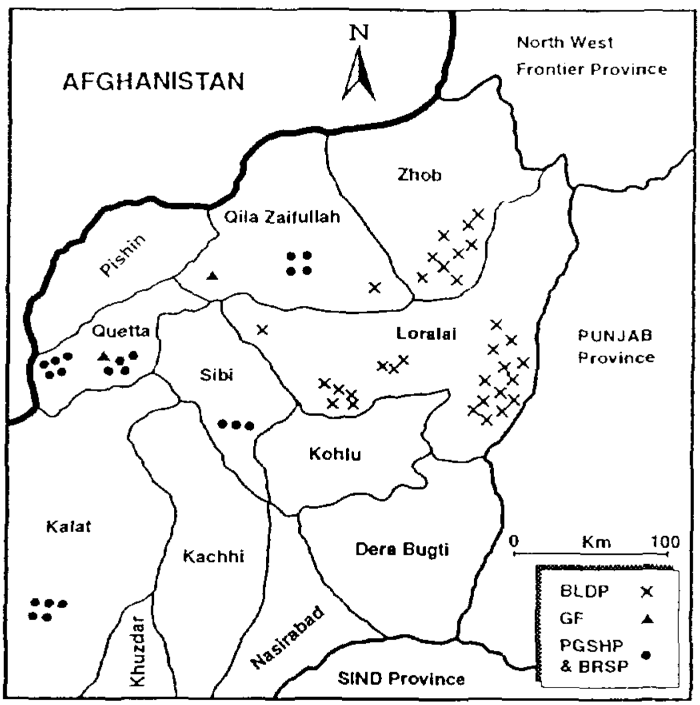

Figure 5.5.1. Location of the lamb fattening schemes in the Balochistan province, Pakistan. Balochistan Livestock Department Project (BLDP), Government Farms (GF), Pak-German Self-Help Project (PGSHP) and Balochistan Rural Support Programme (BRSO)

livestock owners, with land for cultivation and access to communal grazing. In addition, fattening activities were conducted on two government farms, located in the Quetta and Pishin districts to take advantage of the availability of suitable buildings.

Co-operatives comprised 5 to 15 members. Each member provided a predetermined number of animals and the corresponding quantity of dry fodder or roughage. Shared responsibility for herding and returns were proportional to the number of animals. Target animals were castrates or intact males of 6 to 12 months of age, weighing 15 kg. The objective was to achieve a liveweight gain of about 150 g/day over a 100-120 day period. Parasite control and vaccinations at the beginning of the fattening season were adopted as a standard procedure.

The timing of the fattening periods was based on annual price fluctuations of live animals, which are related to forage availability and the supply and demand for livestock. At least two fattening periods were planned, one from October to January, and the other for the three months before the feast of Eid-ul-Azha. This occurred on 23 June in 1991, and 11 days earlier in each succeeding year. Previously, monthly prices per unit of weight of sheep had peaked in August 1985, July 1988 and June 1991 (Figure 5.5.2). A third period could be scheduled for special local peaks of demand. High prices also occur in winter because of livestock shortages. To achieve a good return on investment it was considered important to have an equal or greater price per unit of weight for the final weight than for the starting weight.

The fattening project manufactured concentrates from those by-products of the cereal and oil-milling industry available in Balochistan. A typical concentrate mix had 25% cotton seed cake, 20% wheat bran, 17% rice polishings, 32.5% broken rice, 3% molasses, 2% limestone and 0.5% salt. This mix was estimated to contain 10.6 MJ metabolizable energy (ME)/kg and 103 g/kg of digestible crude protein (MPC 1990). An experimental ration fed to lambs weighing 25 kg and gaining 150 g/day included 730 g of concentrate mix, 1000 g of fresh lucerne and 200 g of air dry guar (leguminous oil seed) residue. This ration supplied an estimated 10.1 MJ

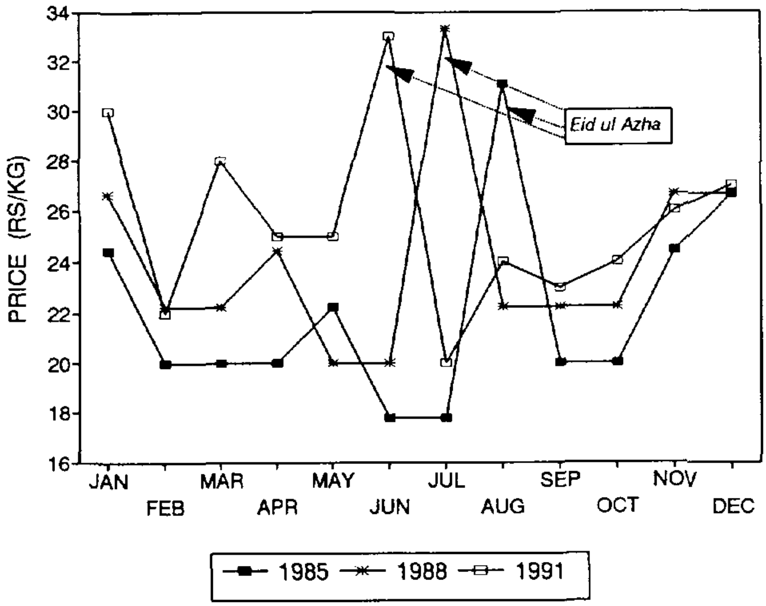

Figure 5.5.2. Monthly prices (Rs/kg) of live sheep in the Quetta livestock market. (Source: 1985 and 1988 prices, n=250, from PGSHP (1989) and 1991 prices, n=1200, from the Agricultural Economics Group, Arid Zone Research Institute, Quetta, Pakistan)

ME/kg and 230 g/kg of digestible crude protein (MPC 1990). The concentrate was offered in the mornings and evenings, and the animals grazed during the day, for 8 hours in summer and 3 hours in winter. On government farms, there was no access to grazing, and fresh fodder and dry roughage were supplied instead. Fodder and roughage intake were measured only in the government farms.

The cost of concentrate provided to participants gradually increased from Rs 2.4/kg to Rs 3.0/kg (21.3 Rs=1 US dollar in 1989). Housing costs in the first five units proved to be unacceptably high (ie about Rs 200/head) at the given throughput of animals. For the smaller units constructed later, this cost was reduced to about Rs 40/head. Labor cost per head for a group exceeding 200 animals was calculated at Rs 30/head. Transportation and marketing costs from the fattening units to the market were almost negligible, as livestock wholesalers were invited to the units to bid for lots of animals.

5.5.4 Pak-German Self-help Project (PGSHP) and Balochistan Rural Support Program (BRSP)

Technical and economic aspects of activities in PGSHP and BRSP were similar to those described above for BLDP. In the PGSHP there were four batches of a hundred or more animals in village organizations in four districts, Quetta, Kalat, Sibi and Qila Saifullah. Each member had between 5 and 20 animals, managed either by individual owners or pooled into larger groups. In the BRSP, batches comprising about 30 animals were distributed across Quetta and Qila Saifullah districts. Shelters with an attached open-air yard were constructed from locally available materials. Containers for feed and water were adapted from low-cost local designs. No green fodder was provided, but during shortages of winter grazing, sorghum straw was fed as roughage. All participants had land for cultivation or access to grazing. Credit restrictions were more rigorous in the BRSP than the PGSHP. In the PGSHP, loans were provided to participants without collateral for the purposes of purchasing animals and concentrates, whereas in the BRSP loans for these purposes were provided only if savings were available as collateral.

5.5.5 Biological and economic performance of fattening projects

The fattening activities reported here ran from October 1987 with BLDP to November 1992 with BRSP (Table 5.5.1). The number of animals fattened was greatest in the BLDP (2230 in 24 batches) and least in the BRSP (73 in three batches). Due to better animal care, mortality under SHOs was approximately half of that in the BLDP. Average initial body weight (BW) ranged from 16 to 19 kg/head with the exception of the 28.5 kg/head in the PGSHP. Final BW was 8.4 to 11.4 kg above initial BW, depending on the number of fattening days. PGHSP participants opted for purchasing heavier animals, as the maximum loan per participant was fixed by animal number and not by the size of the loan.

Average daily gains ranged from 98 g in the BDLP to 180 g on government farms (GF). The former was low because participants could not be convinced to increase the daily concentrate ration; in contrast, the animals in the experiment on government farms were stallfed, their diet including some green fodder and greater amounts of concentrate (Table 5.5.1). BLDP and PGSHP participants were reluctant to use target levels of concentrate even though the concentrate was provided by the development project. Gradually, participants grasped the idea that recommended intake of concentrate contributed to improved animal performance: average daily gains increased with greater concentrate intake. The differences in the duration of the fattening period arose largely from the organizational factors involved in starting a batch aimed at certain seasonal price peaks.

Table 5.5.1. Performance of lambs in different fattening projects in highland Balochistan (1987-1992)

Description	Project[1]			
	BLDP	GF	PGSHP	BRSP
Started	Oct 87	May 89	Apr 89	Mar 92
Ended	Nov 89	Jul 89	Dec 90	Nov 92
Type of organization[2]	COOP	GOV	SHO	SHO
No. of groups	24	4	32	6
No. of batches	24	2	4	3
Initial number of animals	2351	400	351	74
Final number of animals	2230	378	341	73
Mortality (%)	5.1	5.6	2.8	1.3
Green forage provided[3]	N	Y	N	N
Dry roughage provided[3]	Y	Y	N	Y
Grazing allowed[3]	Y	N	Y	Y
Concentrate (g/head/day)	444	624	496	482
Initial BW (kg/head)	18.2	16.1	28.5	18.8
Fattening days	89	56	73.5	92
Final BW (kg/head)	26.5	26.2	38.8	30.1
BW gain (kg/head)	8.4	10.1	10.3	11.4
Average daily gain (g/day)	98	180	142	124

(Source: MPC, 1990; PGSHP, 1989; BRSP, 1992b).

[1]Balochistan Livestock Department (BLDP), government farms (GF), Pak-German Self-help Project (PGSHP) and Balochistan Rural Support Programme (BRSP).

[2]GOV=government trial, COOP=co-operative, SHO=self-help organization

[3]Y=yes, N=no. Dry roughage was grass hay or sorghum straw or wheat straw.
Green forage was lucerne.

The initial costs of animals ranged from Rs 22.5/kg in the PGSHP to Rs 30.7/kg in the GF, and the final price ranged from Rs 22.9/kg to Rs 34.6/kg (Table 5.5.2). In both the BLDP and GF the initial price per unit weight was higher than the final price. This was, in part, due to prolonged droughts, which caused the supply of animals to grow faster than demand. In contrast, in the PGSHP and BRSP batches, the final price per unit of weight was higher than the initial price, reflecting an awareness of the seasonal price fluctuations and the scheduling of the fattening period. Value added ranged from Rs 188/head in the BLDP to Rs 486/head in the BRSP.

Table 5.5.2. Economic performance of the different fattening projects in highland Balochistan (1987-1992)

Description	Project[1]			
	BLDP	GF	PGSHP	BRSP
Initial price (Rs/gk BW)	23.4	30.7	22.5	29.2
Final price (Rs/kg BW)	22.4	28.0	24.2	34.6
Value added (Rs/head)	188	202	303	486
Cost of concentrate (Rs/head)94	77	89	172	
Concentrate conversion efficiency (kg conc./kg BW gain)	4.5	3.5	3.5	3.9
Ratio BW/concentrate	9.4	12.7	9.9	9.1
Ratio concentrate/BW gain (Rs/kg)	11.2	7.6	8.6	15.1
Returns to labor (Rs/head)	87	90	194	296
Returns to animal and concentrate costs (%)	17	16	27	40

(Source: MPC, 1990; PGSHP, 1989; BRSP, 1992b).
Nominal costs and revenues were used in all projects. The exchange rate of the Pakistani rupee changed from 18.2 Rs/$ USD in October 1987 to 25 Rs/$ USD in November 1992.
[1]Balochistan Livestock Department (BLDP), government farms (GF), Pak-German Self-help Project (PGSHP) and Balochistan Rural Support Programme (BRSP).

Concentrate conversion efficiency ranged from 3.5 to 4.5 kg/kg BW gain. These figures refer to concentrate intake only, and if total feed intake were taken into consideration they would probably be within the range of 4 to 11 reported by McIntire *et al.* (1992, p. 154) for local breeds of male sheep. The grazing component of the fattening projects was totally or partially free of direct cost to the producers; but it introduced uncertainty into the calculations of feed efficiency, since neither the quality of the rangeland forage nor the intake were measured.

The cost of concentrate/kg BW gain was lowest in GF and highest in the BRSP, reflecting an increase in both the amount of intake and its cost over time. High conversion efficiency of concentrate into liveweight, and a high liveweight-to-concentrate price ratio favored the high returns to labor.

Returns to animal and concentrate costs ranged from 16 in 40%, in contrast to analogous returns in Syrian enterprises of only 7% (Nyggard *et al.* 1982). [Small differences due to roughage and dry fodder costs were not included in Table 5.5.2].

5.5.6 <u>Adoption and economic impact of sheep fattening</u>

In spite of the attractive returns to fattening experienced in the PGSHP, the number of participant groups decreased by 80% under the BRSP. The two factors most limiting the adoption of the fattening technology were apparently the procurement of feed by members and the collateral requirement for loans to buy animals and feed.

Problems with recovery of loans led to the time gap between the end of activities of the PGSHP (December 1990) and the beginning of BRSP activities (March 1992). Participants in the BRSP hesitated to accept the more strict financial conditions. However, it is not realistic to provide credit without collateral. While the creation of collateral may be slower than desirable, the BRSP considers financial sustainability to be of foremost importance.

The economic impact of lamb fattening depends on the size of land holding and flock size of the owner. If a producer has about 30 sheep (Nagy *et al.* 1991) and is able to fatten 10 animals in two batches annually, he could increase his net income by Rs 3000, or 45% of the estimated annual livestock sales income of an average flock owner in highland Balochistan [25% offtake (Mahmood and Rodriguez 1993) at Rs 850/head (Rodriguez *et al.* 1994)].

The major factors that determine the profitability of sheep fattening are: the feed conversion efficiency of the sheep; the liveweight-to-feed price ratio; and the seasonality of liveweight prices. The high efficiency shown in the fattening operations can be sustained if livestock producers continue with the sound managerial practices learned so far. The marked seasonal price fluctuations in the Quetta livestock market (Rodriguez *et al.* 1994), reflecting the seasonal availability of forage and crop residues and the requirements of seasonal festivities, are likely to remain the most important factors in livestock supply and demand. Producers should be encouraged to take advantage of seasonal prices, even if the liveweight-to-feed price ratio drops to the same level as the feed and forage conversion efficiency.

It may be noted that the objectives of the various fattening projects has been oriented towards income generation, rather than to providing solutions for one of the most critical problems facing the rangelands of Balochistan, overgrazing. Attention has been paid to training and generating conditions whereby self-help organizations can cope with changing conditions. The challenge of the ongoing BRSP development project is to expand and popularize the self-reliance of the agro-pastoralists actively involved in these organizations to the majority who have so far not been able to cope with more restrictive credit conditions.

5.5.7 Conclusions

Five years of sheep fattening in different development projects in highland Balochistan have shown that it is possible to generate additional income for agro-pastoralists if animal production techniques and economic and social feasibility are pursued simultaneously. The supply of concentrates and grazing, which may be replaced partially or totally by green fodder and/or dry roughage, are the most important technical factors. The most important economic factor is the scheduling of the fattening period according to expected market price fluctuations. This factor may even outweigh the importance of achieving good biological performance with appropriate fattening rations.

Organization of livestock owners according to technical and economic considerations alone achieved lower economic performance than situations where livestock owners were chosen also for their ability to make collective decisions. Some of the participants operating in self-help organizations have demonstrated remarkable managerial abilities; however, the majority of participants could not cope with the more stringent credit conditions.

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[Abelardo Rodriguez in collaboration with Ludwig Mayer (Balochistan Rural Support Program, Quetta, Pakistan)]

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5.6 Price Expectations of Sheep and Goats by Producers and Intermediaries in Quetta Market, Pakistan

5.6.1 Introduction

Livestock production and marketing constraints have been identified as the major factors limiting animal offtake in the highlands of Balochistan Province, Pakistan (Nagy *et al.* 1991). Research and extension services, when available, have focused on the biological aspects of production, such as de-worming, vaccination, supplemental feeding and breeding. However, other aspects that affect animal offtake, such as the grazing rights of pastoral and agro-pastoral production systems, the existence of a ceiling price on retailed meat favouring urban consumers at the expense of producers, the lack of livestock and meat grading, and the lack of pricing information, have been seriously neglected (Rodriguez 1992).

In developing economies, price information is restricted mainly to personal interactions between market agents. The livestock price expectations of these agents are used to begin a bargaining process, whereby the knowledge or perceptions of the supply and demand situation, and the inherent attributes of the animals on sale, determine a final price. Analysis of these expectations can be useful, to elucidate the complexities of the price discovery mechanism between market agents and to identify factors that hinder market efficiency.

Development of the livestock subsector in highland Balochistan will be difficult as long as the signals sent by the market to improve offtake and quality are non-existent or are not perceived by the producers (Mahmood and Rodriguez 1993).

This study was conducted to evaluate the factors that determine the price expectations for small ruminants of producers and intermediaries (butchers, wholesalers and commission agents) in the Quetta livestock market. The underlying hypothesis was that the pricing mechanisms, or the breakdown of price expectations, of different market agents might provide valuable information to agricultural policy makers, extensionists, producers and intermediaries. The specific objectives were: (a) to quantify price expectations of producers and intermediaries on the basis of body condition, sex, breed, age, liveweight, meat and meatless days (during meatless days it is illegal to slaughter livestock or to sell red meat in butchers' shops or in restaurants), seasonality and forage availability; (b) to develop price expectation models for sheep and goats; (c) to test the homogeneity of the models with respect to market agents; and (d) to evaluate the potential impact of extension services to improve producers' awareness of market opportunities.

5.6.2 Livestock production and marketing

Balochistan is the largest, driest and least-developed province of Pakistan; it is located in the west of the country, sharing borders with Iran to the west and Afghanistan to the north. Crop and forage production are limited by low annual rainfall which averages from 50 to 150 mm in the lowland areas below 1000 m in the south, and from 175 to 350 mm in the highland areas above 1000 m in the north (Kidd *et al.* 1988). Most of the economic value of agriculture is contributed by fruit and vegetables produced under irrigation.

The province has 11.3 m sheep and 7.4 m goats, 0.8 m cattle and 0.24 m camels (GOP 1989). It is estimated that the livestock sub-sector contributes 25% to the Gross Agricultural Product (FAO 1983; GOB 1989). Two-thirds of the small ruminant population is concentrated in the highlands, in production systems that are largely transhumant (60%) or nomadic (25%). Even though the number of small ruminants in the Balochistan highlands represents 19% of the national flock, the estimated annual offtake represents less than 7% of the total mutton production in the country (Rodriguez *et al.* 1993). The estimated annual revenue from meat in the highlands is Rs 1800 million (US$ 82 million, using US$ 1=Rs 21.8, July 1990) and other products such as skin, bones, blood, and internal organs add a further Rs 315 million (US$ 14 million).

Marketing of livestock and meat involves many agents, and it is difficult to be precise about their numbers or their roles in the marketing process (Mahmood and Rodriguez

1993). Livestock producers are widely dispersed, and the majority dispose of their sheep and goats at the village level because they have no transport to take them to larger markets 20 to 150 km away. They also sell when they migrate in search of grazing resources or temporary employment. "Informal interviews with producers revealed that because they sell small numbers to meet urgent cash demands, the producers are not in a position to bargain very effectively. In a few cases, producers attempt to time animal sales to take advantage of seasonal fluctuations in demand. But, in general, the expected price was not the major determinant of the decision to sell" (Mahmood and Rodriguez 1993).

Village dealers purchase animals from surrounding areas and sell them to wholesalers in village markets. Wholesalers transport the livestock to Quetta, the major consumption centre in the province, and to centres in other provinces such as Karachi and Lahore, or to Iran and Afghanistan. Wholesalers sell to commission agents in the larger markets. In Quetta, wholesalers stated that commission agents were an essential link with the buyers (butchers) because of their role in bargaining and arranging livestock sales (Mahmood and Rodriguez 1993). No records of transactions are kept by officials of the Livestock Department or the municipal slaughterhouses which are adjacent to the livestock markets. Grading of livestock and carcasses is not practised.

Sheep and goat meat is sold fresh in butcher shops where there is an official ceiling price; however, this price is not easily enforced. Even though price regulation aims to protect urban consumers, the quality of meat is variable. Consumers have no way to convey their degree of dissatisfaction to producers through the marketing chain (Mahmood and Rodriguez 1993). Red meat in Pakistan is sold from Thursday to Monday. Tuesday and Wednesday are "meatless" days, introduced in Pakistan in the late 1950s to offset red meat shortages. Specialized merchants process and distribute skins and internal organs (Mahmood and Rodriguez 1993).

5.6.3 Price monitoring and procedures

Each month, from January 1991 to December 1992, the expected prices (that sellers expected to receive) of 100 sheep and

100 goats were recorded in the Quetta livestock market for two types of market agents: producers and intermediaries. For each animal species, 50 expected prices were collected from producers and 50 from intermediaries, between 10:30 a.m. and 12:00 noon. Producers and intermediaries knew that researchers were *not* buying animals and therefore only granted their time towards the end of the marketing day. Three to five days were necessary to collect the desired information each month. The sampling period was never extended beyond eight days in any one month.

Producers and intermediaries were asked the prices they expected to receive for their animals. Producers and intermediaries quoted prices for different animals; thus, these quotations can be considered as the price expectations at the beginning of the bargaining process for the average type of animals on offer. After the expected price for each animal was quoted, the following information was recorded: liveweight measured with an electronic portable platform balance, species, sex, breed, body condition (fatness), calendar day and month, and whether the data were collected on a meat or meatless day. Monthly rainfall data from five stations in highland Balochistan (Arid Zone Research Institute in Quetta, Agricultural Research Institute in Sariab, Tomagh, Kolpur and Mastung) were used as an indicator of forage availability, under the assumption that rangelands are the main source of livestock feed.

A modification of the model of Andargachew and Brokken (1993) was used to assess price expectations of sheep and goats:

$$\begin{aligned} \mathrm{WPRICE} = {} & \beta_1 + \beta_2\,\mathrm{JUL} + \beta_3\,\mathrm{LWT} + \beta_4\,\mathrm{LWT}^2 + \beta_5\,\mathrm{RAIN1} + \beta_6\,\mathrm{RAIN2} \\ & + \Sigma_i\,\beta_i\,\mathrm{MTH}_i + \Sigma i\,\beta_i\,\mathrm{MD}_i + \Sigma_i\,\beta_i\,\mathrm{BR}_i + \Sigma_i\,\beta_i\,\mathrm{S}_i + \Sigma_i\,\beta_i\,\mathrm{BC}_i \\ & + \Sigma_i\,\beta_i\,\mathrm{A}_i + \Sigma_i\,\beta_i\,\mathrm{LWT\ MTH}_i + \Sigma_i\,\beta_i\,\mathrm{LWT\ BR}_i + \Sigma_i\,\beta_i\,\mathrm{LWT\ S}_i \\ & + \Sigma_i\,\beta_i\,\mathrm{LWT\ BC}_i + \Sigma_i\,\beta_i\,\mathrm{LWT\ A}_i + \Sigma_i\,\beta_i\,\mathrm{LWT\ MA}_i + \Sigma_i\,\beta_i\,\mathrm{MA}_i \\ & + \Sigma_i\,\beta_i\,\mathrm{MA}_i\,\mathrm{JUL} + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{MTH}_i + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{MD}_i \\ & + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{BR}_i + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{S}_i + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{BC}_i + \Sigma_i\,\beta_i\,\mathrm{MA}_l\,\mathrm{A}_i + e_i \end{aligned}$$

where WPRICE is the price expectation per kg liveweight (Rs) obtained by dividing the price per head, quoted by producers or intermediaries, by the animal liveweight; JUL is the accumulated calendar day of two consecutive years, and LWT is the liveweight of the animals in kg. The accumulated rainfall of the month when the observation was made and the previous month is represented by RAIN1. Similarly, RAIN2 is the accumulated rainfall of the second and third month prior to the month of observation. Sets of dummy variables are used for month (MTH), meat days (MD), breed (BR), sex (S), body condition (BC), age (A) and market agent (MA). The twelve months of the year were used in MTH, meatless and meat days were used in MD, five breeds were used for BR in goats and six for BR in sheep. Females and males were used in S; good, average and bad body condition were used in BC, ages of <1, 1-2, 2-3 and >3 years were used in A. When an observation pertains to a variable in a dummy set, its value is 1; otherwise it is 0. For example, if the observation is from producers, the variable MA_1 in the set MA has a value of 1, alternatively, MA_2 is 0. βs and β_is are structural parameters in the equation. Interactions of liveweight with month, breed, sex, body condition, age and market agent are included. To account for producers' expectations the variable MA_1 interacts with other discrete variables.

The model was fitted for both sheep and goats using a general linear model procedure (SAS Institute 1988). Covariance analysis was used to test homogeneity (Johnston 1972) of price expectations between producers and intermediaries. The model above (unrestricted model U) was reduced into more restrictive models: (a) restricted model R2, by elimination of MA and MA_1 interacting with other variables in the U model; and (b) restricted model R1, with further elimination of the intercept MA in the R2 model. The homogeneity of expectations of intermediaries and producers, regardless of specific management variables, was tested comparing the R1 and R2 models, and the homogeneity of specific producers' management variables was tested comparing the U and R2 models. Overall homogeneity, combining the expectations of the market agents plus specific producers' management variables was tested comparing the R1 and U models. Similar procedures were used by Francis (1990) to compare different sheep markets in south-west Nigeria.

<u>Liveweights and prices of goats and sheep</u>. During 1991 and 1992, the liveweight of goats averaged 29.6 kg for producers and 28.8 kg for intermediaries, and the sheep

Table 5.6.1. Means of liveweight, price per head and price per kg liveweight of small ruminants in the Quetta livestock market by market agent and sex (numbers in parentheses are the coefficients of variation expressed in percentages)

Species	Market agent	Sex	Liveweight (kg/hd)	Price (Rs/hd)	Price (Rs/kg)	n
Goats	Producers	Female	29.0 (35)	671.0 (32)	25.3^{d} (38)	102
		Male	29.7^{a} (42)	841.9^{b} (55)	29.8^{e} (40)	967
	Intermed.	Female	30.8 (34)	698.5 (47)	23.4^{d} (36)	244
		Male	28.3^{a} (36)	706.6^{b} (58)	25.7^{e} (39)	1087
Sheep	Producers	Female	34.4^{g} (30)	828.4^{h} (30)	24.8 (26)	73
		Male	30.5 (42)	848.7^{i} (52)	29.4^{k} (43)	1111
	Intermed.	Female	29.7^{g} (36)	751.6^{h} (42)	26.5 (32)	217
		Male	31.1 (42)	816.4^{i} (50)	27.2^{k} (35)	999

Means with the same superscript were significantly different at $P \leq 0.01$.

liveweight 30.7 kg and 30.8 kg, respectively (Table 5.6.1). Seasonality of the average liveweights is shown in Figure 5.6.1. Notwithstanding some differences between goats and sheep, the liveweight of marketed animals generally increased from April to October and decreased during late autumn and winter. High liveweights in June were related to the Eid-ul-Azha[1], when small ruminants are slaughtered by most families. Seasonal variations in liveweight were also related to migratory movements from the highlands to the lowlands from September to November, and from the lowlands to the highlands from March to April. Unregulated imports and exports to Iran and Afghanistan throughout the year compounded the variation. The pattern and amount of rainfall in 1991 (321 mm) and 1992 (328 mm) were very similar and well above the long-term average of 235 mm (AZRI/ICARDA 1992 and 1993).

Mean price expectations for goats were Rs 837 and Rs 707 for producers and intermediaries, respectively. Those for sheep were Rs 847 and Rs 805 (Table 5.6.1). The dynamics

1. Moslem holiday to celebrate the return of pilgrims from Mecca in the Islamic month of Hajj.

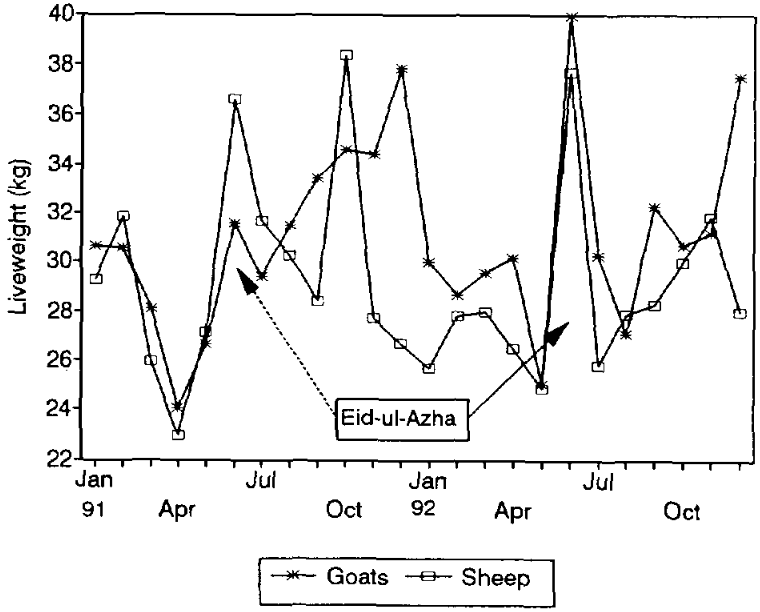

Figure 5.6.1. Goat and sheep liveweights in the Quetta livestock market

of producers' and intermediaries' price expectations are shown in Figure 5.6.2. During 1991 and 1992 there was a trend to increased prices: prices were highest from November to January and during the Eid-ul-Azha which occurred in June in both years. Furthermore, in March, when Eid-Iftr[1] occurred, the prices increased, reversing the trend from January to May. The high prices during November to January coincided with the lowest number of animals on offer at the Quetta market, although only qualitative observations of animal numbers were available.

The timing of sales, and possible production-scheduling, deserves more attention, as it can override the benefits of improved husbandry practices. Re-analysis of results of Nagy *et al.* (1990), to evaluate the impact of selling sheep 10% below the average price (poor timing) in above-average and below-average rainfall years, showed that

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1. Moslem celebration at the end of Ramadan

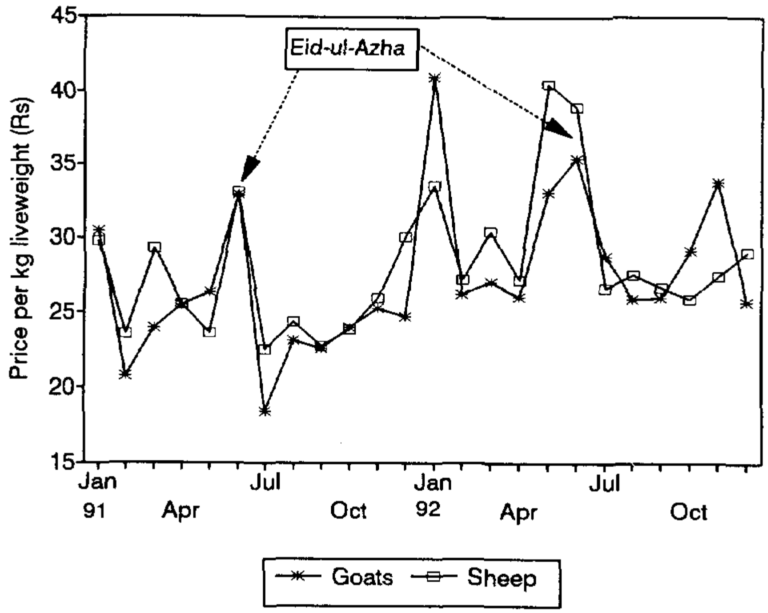

Figure 5.6.2. Goat and sheep prices per kg liveweight in the Quetta livestock market

the *economic returns of improved animal husbandry practices* were offset by poor timing. Lamb fattening schemes have been introduced to agro-pastoralists, through self-help organizations, in which scheduling is emphasized to take advantage of price seasonality and feed procurement (Rodriguez and Mayer 1993).

The differentials[1] between producers' and intermediaries' price expectations represent the bargaining space between these agents in the marketing chain. On average, the actual price received by the producers is somewhere between their price expectations and those of the intermediaries. Monthly price differentials, averaged for the two years are shown in Figure 5.6.3. The lowest price differentials for goats occurred in spring and were high

1. We do not refer to them as price margins since they are not actual prices.

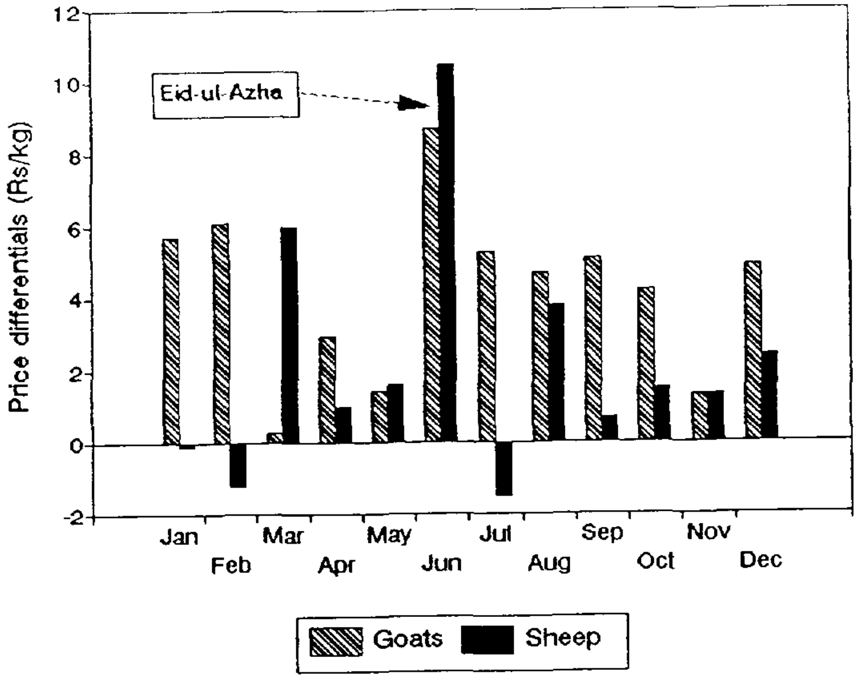

Figure 5.6.3. Price differentials between producers and intermediaries in the Quetta livestock market averaged for 1991 and 1992

during summer, part of autumn and during winter. Producers expected lower sheep prices than intermediaries in January, February and July but expected higher prices in March and June, when Eid-Iftr and Eid-ul-Azha occurred. Producers' expectations during the Gulf crisis in early 1991 were 25% below intermediaries' price expectations, and in February 1992 they were 10% below the price expectations of intermediaries. The average price differential for goats represented 14% (CV=55%) of the average price per kg liveweight expected by producers. In contrast, the price differentials for sheep represented only 8% (CV=145%) of the price per kg liveweight expected by producers. The goat market has more room for bargaining and is less volatile than the sheep market.

5.6.4 <u>Goats and sheep models of price expectations</u>

The parameters estimated for both goats and sheep for the unrestricted model (U) are shown in Table 5.6.2. The adjusted R^2 of the goat model was about 47% while for sheep it was about 39%. Analogous models for price per head had adjusted R^2 values of 67% and 66% for goats and sheep, respectively. Because of seasonal fluctuations in liveweight it was decided to present the results in prices per head adjusted to liveweight. Henceforth, price will refer to price per kg liveweight.

Table 5.6.2. Price perception models for sheep and goats (urestricted model U) in the Quetta livestock market

Parameters and interaction (x)	Goats		Sheep		
	Estimate	SE	Estimate	SE	
INTERCEPT	30.103***	8.831	40.515***	5.352	
Julian day	0.012***	0.001	0.012***	0.002	
Liveweight	-1.178***	0.260	-1.010***	0.158	
$(\text{Liveweight})^2$	0.014***	0.001	0.014***	0.001	
Month					
January	18.783***	2.740	15.420***	2.972	
February	-4.860*	2.818	-10.090***	3.509	
March	-0.222	3.460	-6.246	4.014	
April	-2.013	3.981	-9.614**	4.823	
May	-2.544	3.566	4.924	3.785	
June	2.691	3.500	10.335***	3.478	
July	-2.482	3.277	0.770	3.583	
August	9.252***	2.936	-4.019*	2.934	
September	3.852	2.859	-5.043*	2.756	
October	8.154***	2.720	-6.427*	2.984	
November	15.373***	2.733	-7.947*	2.666	
December	0.000		0.000		
Meat day					
Meatless day	0.849	0.620	-0.003	1.280	
Meat day	0.000		0.000		
Breed					**Breed**
Lehri	4.535***	1.600	-1.885	1.835	Harnai
Barbari	-1.458	1.871	-2.703	1.874	Other±
Other+	0.688	1.438	-5.165***	1.790	Afghani
Sind Desi	4.091**	1.723	1.141	2.444	Sherwani
Afghani	0.000		-1.063	2.597	Bagnari
			0.000		Mangli
Sex					
Female	-1.580	1.795	2.178	2.012	
Male	0.000		0.000		

Parameters and interaction (x)	Goats		Sheep		
	Estimate	SE	Estimate	SE	
Body condition					
Poor	7.978***	1.942	2.353	1.908	
Average	0.000		0.000		
Good	-1.856	0.049	-3.592*	1.955	
Age					
<1 yr	-6.862	8.444	4.962	4.525	
1-2 yr	-5.794	8.423	7.367	4.534	
2-3 yr	-5.777	8.475	4.089	4.585	
>3 yr	0.000		0.000		
Market agent					
Producer	27.028***	6.382	12.722***	3.516	
Intermediary	0.000		0.000		
Liveweight x Month					
January	-0.258***	0.088	-0.346***	0.078	
February	0.065	0.082	0.246***	0.072	
March	-0.077	0.086	0.172*	0.078	
April	-0.130	0.093	0.193*	0.078	
May	0.043	0.085	-0.066	0.075	
June	0.037	0.087	-0.038	0.070	
July	-0.013	0.092	0.024	0.078	
August	-0.160*	0.092	0.074	0.072	
September	-0.086	0.090	0.076	0.064	
October	-0.133*	0.082	0.102	0.072	
November	-0.324***	0.088	0.195***	0.065	
December	0.000		0.000		
Liveweight x Breed					**Breed**
Lehri	-0.112*	0.050	0.077	0.049	Harnai
Barbari	0.113**	0.053	0.089*	0.050	Other‡
Other^{+}	0.068	0.046	0.156***	0.046	Afghani
Sind Desi	-0.075	0.051	-0.033	0.069	Sherwani
Afghani	0.000		0.008	0.066	Bagnari
			0.000		Mangli
Liveweight x Sex					
Female	-0.034	0.057	-0.102*	0.060	
Male	0.000		0.000		
Liveweight x Body condition					
Poor	-0.272***	0.078	-0.183**	0.076	
Average	0.000		0.000		
Good	0.049	0.542	0.051	0.051	
Liveweight x Age					
<1 yr	0.095	0.239	-0.301*	0.136	
1-2 yr	0.056	0.238	-0.347*	0.136	
2-3 yr	0.089	0.239	-0.234*	0.137	
>3 yr	0.000		0.000		
Liveweight x Market agent					
Producer	-0.249***	0.043	-0.163***	0.040	
Intermediary	0.000		0.000		
RAIN1	0.042**	0.016	0.041**	0.017	
RAIN2	0.041**	0.016	-0.019	0.016	

Parameters and interaction (x)	Goats		Sheep		
	Estimate	SE	Estimate	SE	
Julian day x Market agent					
Producer	-0.004*	0.002	-0.002	0.002	
Intermediary	0.000		0.000		
Producer x Month					
January	5.900***	2.130	-6.894***	2.160	
February	0.679	1.821	-6.590***	2.543	
March	-6.608***	2.198	-2.273	2.237	
April	-3.612**	1.748	-5.568**	2.452	
May	-3.506*	1.833	-5.642***	1.915	
June	5.076***	1.791	7.076***	1.950	
July	-1.819	1.781	-8.497***	2.376	
August	-6.734***	2.086	-4.293**	2.043	
September	1.072	1.723	-3.032	2.047	
October	0.912	1.891	-3.793*	1.970	
November	-1.190	1.800	-3.427*	1.917	
December	0.000		0.000		
Producer x Meat day					
Meatless day	0.891	1.171	-1.189	1.437	
Meat day	0.000		0.000		
Producer x Breed					
Lehri	-2.281*	1.102	-1.062	1.312	Harnai
Barbari	-3.110*	1.342	-0.841	1.459	Other±
Other+	-3.090***	1.060	-1.306	1.318	Afghani
Sind Desi	1.404	1.179	0.771	1.628	Sherwani
Afghani	0.000		-0.233	1.817	Bagnari
			0.000		Mangli
Producer x Sex					
Female	2.638*	1.241	2.397	1.506	
Male	0.000		0.000		
Producer x Body condition					
Poor	-7.755***	1.709	-0.992	1.667	
Average	0.000		0.000		
Good	0.655	1.031	0.282	1.067	
Producer x Age					
<1 yr	-14.858**	6.118	0.405	2.491	
1-2 yr	-13.192**	6.099	-0.396	2.440	
2-3 yr	-16.538***	6.098	-1.644	2.558	
>3 yr	0.000		0.000		
Mean	27.316		28.093		
Adj. R^2	0.466		0.391		
N	2399		2389		

+ Other goat breeds were Kharasani, Khagani and Teddy
± Other sheep breeds were Balochi and Turkey
* $P \leq 0.10$; ** $P \leq 0.05$; *** $P \leq 0.01$

The coefficients for Julian day indicated that price expectations increased slightly above 1% per month. These trends were related to the average change in the official retail prices, from Rs 50/kg in January 1991 to Rs 60/kg in December 1992. For both goats and sheep, liveweight was negatively and liveweight-squared positively related to price, indicating how price decreased, but at a decreasing rate, as the animals got heavier. Comparable results were obtained by Andargachew and Brokken (1993) for sheep in the Ethiopian highlands.

Price seasonality for both producers and intermediaries was captured by monthly coefficients, and by the interaction of month with liveweight. The model was further adjusted for seasonality using coefficients of the interaction between producers and month to represent producers' expectations.

The coefficients for meat and meatless days, and their interaction with producers showed that producers expected higher prices for goats on meatless days compared to intermediaries, but expected lower prices for sheep.

Lehri and Sind Desi breeds of goats had higher prices than Afghani[1] goats, and Afghani[1] sheep fetched Rs 5/kg less than the Mangli sheep. Breeds interacting with liveweight also had a significant effect on price. Price of female goats was about Rs 1.6/kg below the price of male goats and, when liveweight interacted with sex, the price of female goats dropped Rs 0.3 per 10 kg. In contrast, female sheep were priced Rs 2.1/kg higher than male sheep based only on sex, but when liveweight interacted with sex the price of female sheep dropped about Rs 1 per 10 kg liveweight. With the information available it is not possible to explain the nature of the effect of the interaction between sex and liveweight with expected prices. Consumers' preferences need to be assessed to explain price expectations.

Price of goats and sheep declined with improvement of body condition, but when body condition interacted with liveweight, higher prices were obtained for goats and sheep

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1. The goats and sheep from Afghanistan seen in the Quetta market are a mixture of breeds but are recognized by the producers and intermediaries.

in good condition. Originally, there were *four* categories of body condition: poor, average, good and very good. The last two were not significantly different in liveweight or price, so they were collapsed into the good body condition category.

The coefficients for market agents in the unrestricted model U showed that producers expected higher prices for both goats (Rs 27/kg) and sheep (Rs 13/kg) compared to intermediaries. These coefficients, relatively large compared to the average price of livestock, were decreased by negative coefficients of the interactions liveweight with producer, producer by age and producer by month. The corresponding coefficients for producers in the R2 models, not shown in the table, were Rs 3.9/kg for goats and Rs 2.3/kg for sheep. Prices were further adjusted for producers with a negative coefficient for liveweight, -0.25 and -0.16 Rs/kg for goats and sheep, respectively.

Rainfall in the month of observation and the previous month had a positive effect on prices of both goats and sheep. Rainfall in the second and third months prior to the month of observation was positively related with goat prices but negatively related to sheep prices. This suggests that more abundant forage within a season increased price expectations in the short term: 100 mm in a two-month period, which is possible during November to April, can increase price by Rs 4.1/kg. Livestock must be held longer to take advantage of favourable grazing conditions, decreasing the number of animals on offer.

Nagy *et al.* (1990) observed that more livestock were sold in highland Balochistan in above-average rainfall years and less in below-average rainfall years. Our monthly visual observations of the animal numbers in the market did not allow the determination of intra-seasonal livestock supply responses which were strongly affected by religious festivals. A distinction between our results and the observations of Nagy et al. is that our model reflects intra-seasonal response to rainfall during two seasons with above-average rainfall (>320 mm), while Nagy et al. refer to inter-seasonal responses to rainfall. Long-term price-monitoring is required to verify the relationship between rainfall, feed availability and livestock prices.

5.6.5 Producers view

To examine how producers view price seasonality and animal characteristics, MA_I was incorporated into the model interacting with month, liveweight, age, body condition and sex.

A large proportion of the monthly coefficients in Table 5.6.2 were significant, suggesting that, using December as the base value, producers make further adjustments for seasonality. Producers also perceived prices of animals differently depending upon the breed. Sind Desi goats and Sherwani sheep had the highest prices. Goats and sheep in poor condition had the lowest price. These coefficients need to be added to those found for goats and sheep without discriminating between producers and intermediaries. For example, adding Rs 7.98/kg (goats in poor body condition for both market agents) and Rs -7.75/kg (goats in poor body condition for producers) yields Rs 0.23/kg premium for goats in poor condition. Body condition was scored by the enumerators and not by the market agents, and enumerators' perceptions may have been biased.

Producers assigned a premium for female goats and sheep, but this needs to be complemented with the interaction between liveweight and sex which gives a discount for each kg of female liveweight. Producers perceived that younger goats had lower prices than older goats. On the other hand, younger sheep had higher prices than older sheep.

The F and R^2 values of the homogeneity tests are shown in Table 5.6.3. In all cases the differences between the models were significant. The highest F values were found for the test of the intercept MA and lowest values were for the test of MA and MA_I interacting with other variables. These results suggest that indeed producers and intermediaries have different price expectations (U vs R1 models). The difference was related to their position in the marketing chain (R1 vs R2 models), or the average difference in expectations between producers and intermediaries, but it was also related to producers' perception of price seasonality and appreciation of animal attributes such as liveweight, age, breed, sex and body condition (R2 vs U models).

Table 5.6.3. Tests of homogeneity of price expectations of producers and intermediaries in the goat and sheep models for the Quetta market

	Comparing	Goats		Sheep	
		F	Adj R^2	F	Adj. R^2
Homogeneous intercept MA	($R1^a$ vs $R2^b$)	111.9^{**}	0.401^a	34.3^{**}	0.348^b
Homogeneity of MA and MA_1 interacting with other variables	($R2^b$ vs U^c)	6.9^{**}	0.428^b	5.1^{**}	0.357^b
Overall homogeneity	(U^c vs $R1^a$)	11.4^{**}	0.467^c	6.3^{**}	0.391^c

[a] Restricted model R1 where no intercept MA in the R2 model
[b] Unrestricted model R2 where MA_1 not interacting with other variables in the U model
[c] Unrestricted model U described in the procedures section.
** Significant at $P \leq 0.01$.

Based on the number of significant coefficients interacting with MA_I (Table 5.6.2) and the F value for the comparison of models R2 and R1 in Table 5.6.3, producers pay more attention to management of goats compared to sheep. Because there are more sheep than goats in highland Balochistan, the impact of improved extension services for sheep could be larger than extension efforts for goats. However, the bargaining space for the sheep market is more restricted and more variable than that of the goat market. In any case, improved extension services could prepare sheep producers to cope with tougher bargaining conditions.

5.6.6 Conclusions

Liveweight and seasonality had the strongest effect on producers' and intermediaries' expected prices. Seller's expected prices were positively related to rainfall in the current and preceding month, suggesting that livestock are retained to take advantage of favourable grazing conditions. Models of price expectations showed that producers adjusted expected goat prices ($P \leq 0.10$) for seasonality, liveweight, body condition, age, sex and breed, while they adjusted sheep prices for seasonality and liveweight only. High pay-offs for producers could be expected if extension efforts focused on factors that determine sheep meat quality; however, the retail ceiling price of meat and the lack of grading are a disincentive to work in this direction. Monitoring of prices and the number of animals could be useful to estimate producers' response to intra-seasonal prices. Assessment of consumers' preferences for meat can complement the understanding of marketing practices.

This study did not seek to demonstrate benefits of alternative livestock policies to improve market efficiency; it only analysed components of livestock price expectations of producers and intermediaries, to provide a baseline for market scheduling. However, scheduling of sales by transhumant pastoralists may be difficult to achieve, because sales are made to raise cash rather than to maximize sales revenues. The livestock policy environment in Balochistan, and in the rest of Pakistan, needs to be evaluated in accordance with provincial and national development goals. ***[A. Rodriguez in collaboration with I. Ali, N.A. Shah, M. Afzal and U. Mustafa (Arid Zone Research Institute, PARC), supported by the USAID Mission to Pakistan through the Management and Agricultural Research Technology/Arid Zone Component (MART/AZR) project]***

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6. TRAINING AND AGROTECHNOLOGY TRANSFER

During 1994, FRMP conducted a number of training activities at headquarters and in-country. They may be summarized as follows:

6.1 Headquarters Training Courses

6.1.1 Short-term group training

Water harvesting for agriculture: This regional course was conducted during the period 6-17 November 1994. It was attended by fourteen participants from Algeria, Egypt, Iran, Iraq, Jordan, Libya, Syria, and Tunisia.

6.1.2 Individual non-degree training

Participant	Country	Subject	Duration
Delphine Marty	France	Supplemental Irrigation	3 months
Haitham Adaileh	Jordan	Tillage and residue Management	2 weeks
Ikhlas Abu Nasser (Ms)	Jordan	Tillage and residue Management	2 weeks
Jawdat Tawalbeh	Jordan	Tillage and residue Management	2 weeks
Mahmoud Ali Salim	Jordan	Tillage and residue Management	2 weeks
Maher Khalid Elaian	Jordan	Tillage and residue Management	2 weeks
Adel M. Zaghloulah	Syria	Economic analysis of field trials	2 weeks
Amer M. Katnaji	Syria	Economic analysis of field trials	2 weeks
Abdul Kader Kurdi	Syria	Agronomy field experiments	6 weeks
Adeeb Sa'ad	Syria	Plant analysis	1 week
Amal Bardakji (Ms)	Syria	Plant analysis	1 week
Mahmoud Baghdadi	Syria	Plant analysis	1 week
Majed Shahhoud	Syria	Plant analysis	1 week
Ahmed M. Rostom	Syria	Soil & plant micronutrients	1 week
Amal Ismail (Ms)	Syria	Determination of mineral N in Soils	1 week
Nadia Pijoun (Ms)	Syria	Determination of mineral N in Soils	1 week
Salam Yacoub (Ms)	Syria	Determination of mineral N in Soils	1 week
Walid Seuifei	Syria	Determination of mineral N in Soils	1 week
Maher Hamoudeh	Syria	Supplemental irrigation	16 months
Mohamed Fares	Syria	Use of Laboratory Equipment	2 weeks

6.1.3 Individual degree training

Name	Country	Degree	University	Topic
Zuheir Masri	Syria	PhD	Kuban/Russia	Soil physical status in rotations
Maher Hamoudeh	Syria	MSc	Cukurova	
Suzanne Pecher	Germany	MSc	Hohenheim	Barley marketing in Syria

6.2 Non-headquarters Training Courses

Farm survey methodologies: This was an in-country course conducted in Muscat, Oman, during the period 20 March-6 April 1994. It was attended by 14 participants working in the General Directorate for Agricultural Research.

Farm survey methodologies: Another in-country course on farm survey methodologies was conducted in Maragheh, Iran, during the period 30 April-6 April 1994. It was attended by 21 participants, mainly from the Dryland Agricultural Research Institute (DARI).

7. FRMP PUBLICATIONS, 1991-95

No recent FRMP report has listed staff publications. To remedy this deficiency we print here an up-to-date list from 1991 to 1994 and including some 1995 items, either already published or in print.

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8. FARM RESOURCE MANAGEMENT PROGRAM

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المركز الدولي للبحوث الزراعية في المناطق الجافة

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