Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas

Proceedings of an International Workshop
Ankara, Turkey, 15-19 May 1989

Hazel C. Harris
P.J.M. Cooper
M. Pala

editors

ICARDA

International Center for Agricultural Research in the Dry Areas

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 focuses its research efforts on areas with a dry summer and where precipitation in winter ranges from 200 to 600 mm. 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, and pasture and forage crops and the associated farming systems.

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 are offered extending from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and by specialized information services.

Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas

Proceedings of an International Workshop held in Ankara, Turkey
May 15-19, 1989

Editors

Hazel C. Harris
P.J.M. Cooper
M. Pala
ICARDA, Aleppo, Syria

Sponsored by
Minister of Agriculture, Forestry, and Rural Affairs
MAFRA, Ankara, Turkey

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

Centro International de Mejoramiento de Maiz y Trigo
CIMMYT, Apda. Postal 6-641, 06600 Mexico, D.F., Mexico

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

1991

Local Organizing Committee

Baydur Yilmaz Mengu Guler Nedret Durutan Mehmet Karaca	Field Crop Improvement Center (TARM) P.K. 226 Ulus/Ankara
Mustafa Doyuk	Research Planning and Coordination Council, Ministry of Agriculture, Forestry and Rural Affairs (MAFRA), Ankara

Publication Editor
M.A. Jones

Contents

Foreword

In the past two or three decades there have been intensive programs of research aimed at producing new, high-yielding varieties of crop species. Special attention has been given to breeding for resistance to diseases and insect pests and a good deal of success has been achieved. Superior varieties are now available to farmers; nevertheless, in many places the yields of farmers' crops remain low.

This is largely because the management of crops has not been improved. It is well recognized that, in general, crop yields can be increased much more by good management than by new varieties. It is also true that no matter how good new varieties might be, they will not achieve their potential and will usually not bring appreciable increases in yields unless they are well managed.

In the harsh environments of the Mediterranean Region, the factor which ultimately limits yield is the availability of water. A variable supply of water due to seasonal differences in rainfall leads to equally variable crop yields. However, research has shown that good management practices can considerably increase the efficiency with which the limited amount of water available from rainfall is used. That is, more production can be gained from each millimetre of rain which falls if crops are well established and adequately fertilized, weeds are controlled, and use is made of the beneficial effects of crop rotations. This is as true at the upper (>400 mm) end of the rainfall range as at the lower (approx. 250 mm).

It is not enough, however, to manage crops. If production is to be sustained in the long term, attention must also be paid to the correct management of the soil in which they grow. Soil is a resource which is not renewable. Unless it too is well managed, losses through wind and water erosion may lead to a decline in agricultural production. The recent widespread introduction of mechanized farming in many areas has many potential benefits, such as timely soil preparation and sowing of crops, but it also carries the risk of increased soil loss unless appropriate tillage methods are used for particular soil types and in various agricultural zones.

To review what is known of improved soil and crop management, and to consider how this knowledge can be passed on to farmers, the Ministry of Agriculture, Forestry and Rural Affairs of Turkey (MAFRA), the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Maize and Wheat Improvement Center (CIMMYT) jointly sponsored a workshop on **Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas** in Ankara, Turkey, May 15-19, 1989. The workshop was attended by research administrators, senior research scientists and extension administrators from countries within the region of West Asia and North Africa. Leading scientists from outside the region were also invited to present papers and participate in the discussion.

Following an introductory session, which provided an overview of dryland agricultural systems and the challenges involved in achieving sustained increases in production, the workshop addressed six major issues in the field of soil and crop management:

- Tillage and Stubble Management
- Crop Establishment
- Fertilizer Management
- Weed Control
- Crop Rotations
- Transfer of Information to Farmers

In each session, an introductory theme paper provided a general overview and was then followed by one or more examples of on-going research. Each session concluded with the presentation of a case study that illustrated successful research and farmer adoption.

In the evenings, Working Groups (three working groups for each topic) met and, following carefully prepared terms of reference, produced their comments and recommendations. These recommendations were synthesized for each of the six topics and were presented (by the relevant session Chairperson) on the final day. A summary of these recommendations is presented in the final chapter of these proceedings.

We believe the workshop was a success and provides an up to date review of what is and what is not yet known about the potential for improved soil and crop management in the rainfed farming systems of West Asia and North Africa. Equally, if not more, important is the output from the Working Groups who were required to identify under-researched topics, and examine appropriate research strategies and the constraints faced by National Research Systems in conducting such research. We are pleased to see the publication of these proceedings and hope that research planners, research scientists and extension agents throughout the region will find them a useful reference source.

Dr. N. Demir
Deputy Under-Secretary
MAFRA, Turkey

Dr. N. Fadda
Director General
ICARDA, Syria

Dr. D. Winkelmann
Director General
CIMMYT, Mexico

Acknowledgements

The International Workshop for Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas stemmed from an initiative by Turkish national scientists and was co-sponsored by the Turkish Ministry of Agriculture, Forestry and Rural Affairs (MAFRA), the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA). We acknowledge their support with sincere appreciation.

We also are grateful for the efficient collaborative work of the Steering Committee which was comprised of representatives from all three institutions and for the support of the local Turkish Organizing Committee which ensured that this large workshop ran smoothly and was both enjoyable and successful. On behalf of all the participants we would especially like to thank Ms. Hatice Eyuboglu, Ms. Emel Karagullu and Mr Veli Bostanci for their unfailing day to day assistance during the meeting.

Lastly, of course, we thank all the participants for their excellent presentations, their lively contributions to discussions and especially their very enthusiastic and solid support of the working groups, the output of which made this workshop such a success.

The Editors

Introduction

Soil and Crop Management for Improved Water Use Efficiency in Dry Areas. The Challenge

A. VAN SCHOONHOVEN

ICARDA, P.O.Box 5466, Aleppo,Syria

Introduction

Farming in dry areas is associated with high risk both in terms of year to year fluctuation in yield, and long-term decline in productivity from the erosion of the resource base. The dry areas are characterized by fragile ecosystems where soil erosion, overgrazing, and depletion of water reserves can threaten long-term productivity.

The following presentation discusses the geographic region of West Asia and North Africa, its population, and its resource base, its food gap, and the agricultural challenges it faces. The presentation is largely based on ICARDA's Strategic Plan, which outlines its long-term research strategy. ICARDA is funded to support agricultural research in improving the sustainable productivity of farming systems in dry areas of West Asia and North Africa (WANA) which have a Mediterranean climate, characterized by winter rainfall and hot, dry summers.

Geographic Area

The geographic area with a Mediterranean climate is located principally in North Africa and West Asia, although similar climatic conditions occur in southern parts of Australia, Latin America and Africa and in the north-western United States. ICARDA's research focuses mainly on the West Asia-North Africa region (called WANA). It stretches from the Atlantic to the Indian Ocean, from Morocco to Pakistan, covering a land area of 17 million km^2.

Population

In 1985, WANA's population was estimated at about 416 million, ranging from 0.3 million in Qatar to about 96 million in Pakistan. In the first half of the 1980s population was growing at the fast rate of 2.6% per year. World Bank projections (1987) indicate that the region's population will rise to over 620 million by the year 2000 and stabilize at 1.5 billion by 2030.

The prospect of a threefold increase in population in less than 40 years, between 1990 and 2030, particularly in the poorer countries of the region -- Ethiopia, Sudan and Pakistan -- is a cause for serious concern. Arresting the trend through family planning is faced by difficulties arising from the local culture and, in many cases, economic necessity. Paradoxically, the rural poor prefer large families, as labour to supplement their earnings and, in the absence of social security, as an insurance for old age, an attitude that can hardly change unless poverty is alleviated.

With the exception of the oil exporting countries, the WANA region is among the less affluent parts of the world. In 1985, the average annual GNP for the region as a whole was estimated at USD1200. Some of the poorest countries in the region are also the poorest in the world. Average per capita GNP for the low-income countries of WANA is just under USD 300, in comparison with USD 1100 for the middle-income and USD 9000 for the high-income countries.

About 60% of WANA's population lives in rural areas and 50% of the labour force is engaged in agricultural pursuits. In general, the poorer the country the higher the proportion of its rural population, which reaches about 80% in Ethiopia and the Sudan and ranges between 30% and 50% in the larger countries where oil is not a major source of income. Although current trends would indicate that urban population will increase at a faster rate than rural, 3.8% against 1.1% per annum, the agricultural work force will increase in terms of absolute numbers. By contrast, the contribution of agriculture to GNP will remain relatively small, averaging only 23% for the region as a whole.

The Resource Base

The climate of WANA -- principally a Mediterranean climate -- is characterized by cool to cold winters and hot to extremely hot and dry summers. Winters are milder in the coastal areas of the Atlantic and Mediterranean than in inland Asia. The severest winters occur in the highlands and at northern latitudes where frosts can cause serious damage to crops, and reduce the number of growing days. In spring, there is a sharp rise in temperatures, and crops at the same location may experience first cold, then heat stress.

Rainfall is highly erratic in both time and space. It ranges from under 50 to over 1200 mm annually, the highest amounts occurring in coastal and highland areas. Our research, and the concern in this symposium, is limited to areas receiving below 500 mm average rainfall. The variability in amount and seasonal duration is reflected in the length of the growing season, which ranges from 0 to 200 days depending on incidence of precipitation, frost and soil depth. The substantial between-year variations in climate increase the risks to crop production. More efficient use of this low and erratic rainfall forms an underlying theme of this workshop.

The region's soils are generally calcareous and low in phosphorus, nitrogen and organic matter, and nutrient deficiencies of the major plant nutrients (N and P) are widespread. In many areas, shallow soil limits the amount of water which can be stored in the soil profile during the winter months, thus shortening the effective growing season. Capping or crusting after rain can lead to serious problems of run-off and poor seedling emergence. Soil erosion caused by run-off is often serious and so is erosion caused by winds during the long dry summers.

The area of land suitable for agriculture in WANA is both small and fragile. Only about 128 million hectares, 8% of the area's 1.7 billion hectares, is thought to be arable. Another 375 million hectares (22%) are permanent pasture. Small areas are used for perennial crops and forests, leaving the bulk of the remaining 70% as desert or semi-desert (steppe). Much of the land (40%) is at high altitude and extensive areas have steep slopes and/or shallow, rocky or saline soils that are unsuitable for cultivation without extensive and expensive reclamation work. Irrigated land, at 35 million hectares, is only 2% of WANA's total area, but constitutes 27% of its arable land.

The areas with high agricultural potential are generally also those of high population density. They fall into two categories: pockets or strips of fertile land in which population density already exceeds 100/km^2, and more extensive plains or highlands with variable but still fertile soils in which population density is between 40 and 100/km^2. Among the former are the Mediterranean seaboard areas of Lebanon, Morocco, Algeria and Tunisia, the Caspian and Black Sea coasts of Iran and Turkey, the irrigated Nile, Euphrates, Tigris, and Indus valleys, other scattered irrigated areas, and oases. Among the second category are areas of northern and western Turkey, the northern parts of Iraq, north-west Africa (Maghreb), western Iran, eastern Lebanon, northwest Syria and the Adana plain of Turkey. It is these areas that offer promise for major increases in food production.

The WANA region's remaining productive land consists largely of more sparsely populated medium- to low-potential areas in which dryland farming or pastoralism are the dominant forms of land use. Dryland farming is characteristic of the interior of the Maghreb, the Anatolian plateau of Turkey, northern Syria, Jordan, northern Iraq and eastern Iran. Pastoralism is practised over areas of steppe that are widespread in almost every country. There are opportunities for increasing crop and livestock production from both land types through use of improved crop genotypes and crop and livestock management, but they may be accompanied by severe environmental degradation, unless proper attention is given to resource conservation. This issue of sustaining increases in agricultural production through resource conservation is an integral and vital component of the objectives of this meeting.

The Food Gap

The WANA region was a net food exporter less than 40 years ago but has become the largest food importing region in the developing world (Oram 1988), due to a rapidly growing population and, in many instances, rising incomes, at a time when agricultural production was growing at a sluggish rate of less than 1%. Agricultural imports now account for over 25% of the region's total import bill and more than 40% of the value of all food imports by the world's developing countries.

If current trends in production and consumption persist, the region will continue to be a deficit area in all important food commodities -- cereals, sugar, vegetable oils, meat and milk. The main shortages will be for wheat and barley imports, which between the 1980s and the year 2000, will grow from 22 million tonnes of wheat and 5.5 million tonnes of barley to 34 and 11 million tonnes, representing increases of about 57% and 100%, respectively. The faster growth in demand for barley is attributable to the expected rise in the demand for livestock products, and thus for animal feed, as income rise. Sheep meat imports to the region, which have doubled in the last 15 years, now account for 25% of the world's exports of this commodity. In spite of huge livestock numbers amounting to 354 million head of sheep and goats, 122 million cattle and buffaloes and 30 million horses, mules, donkeys and camels, the annual deficit in all types of meat currently stands at about 1.5 million tonnes and the gap is not expected to be bridged. Milk imports will also continue to grow, from a current level of 6.5 million tonnes to 11.4 million tonnes by the end of the century. IFPRI (Oram 1988) estimates that, in monetary terms, the deficit in livestock products could grow sixfold in this period.

In the remaining years until 2000, demand for vegetable oils will grow from 4.7 million to 8.9 million tonnes, and the deficit from 2.5 million to 5.7 million tonnes, an increase of 128%. Demand for sugar is projected to increase from 12.1 million to 20.7 million tonnes and the deficit from 4.3 million to 7.8 million tonnes, an increase of over 80%. Demand for pulses will rise modestly and all countries of the region, with the exception of Turkey, will remain net importers of this group of crops, which is an important source of protein for the rural population and the urban poor.

These deficits are not equally spread among the countries of the region. For any one commodity covered by ICARDA's research program only three countries out of the region account for 65% to 83% of its total production (Table 1), with Turkey being a lead producer of this group of commodities.

Table 1. Distribution of production in the WANA region (1984-86)

Commodity	Major producers (in order)	Share of regional output accounted for by major producers (%)
Chickpea	Turkey, Pakistan, Ethiopia	83
Lentil	Turkey	74
Faba bean	Ethiopia, Egypt, Morocco	82
Wheat	Turkey, Pakistan, Iran	69
Barley	Turkey, Morocco, Iran	70
Sheep	Turkey, Iran, Ethiopia	65

Source: FAO (1987); TAC (1988)

The Challenge

There can be little increase in the area of arable land in the WANA region. FAO (1987) estimates that only 7% of the overall increase achievable in crop production can be brought about by expanding the area cultivated. A further gain of some 21% is thought possible from more intensive cropping, through fallow replacement and multiple cropping, leaving 72% to be achieved by increasing productivity. Increases from the latter two sources would need to be sustained at over 5% a year to meet the projected food gap, a level virtually unmatched in modern agricultural history.

The countries of the region have in general recognised the importance of agriculture in supplying food and raw materials to agro-industries, and contributing to the national economy through creation of job opportunities, income generation, and substitution of imports. They have done much to improve their agriculture through modernisation based on the introduction of new technology leading to a more efficient use of their limited land and water resources. Improved crop varieties, especially of wheat, have increased production in higher-potential areas. Mechanization had already been introduced in the 1940s and continued, with policy and credit incentives, until it became well established during the 1970s. The WANA region is now a major producer and consumer of rock phosphates. Commercial fertilizers are widely used in higher-potential areas and are now being introduced elsewhere, although they remain only sporadically available in some countries and districts. Herbicides are frequently used on cereals. Through contractors or cooperatives, these technologies are available to small as well as large farmers, and their use is likely to grow still further in the future (Cooper *et al.* 1987).

Lack of a seed production capacity, however, remains a serious handicap in many countries, and livestock services are also underdeveloped. Moreover, production-oriented agricultural research has not been sufficiently developed, nor maintained at a level that would ensure its effectiveness. Often it lacks direction and purpose and tends to be a mere extension of work started during training in other countries with different problems and needs.

New technology has sometimes had negative consequences. For example, use of tractors, while suited to the WANA region's extensive lowland plains, increases the risk of residues are removed for animal feed and ploughing is carried out immediately after harvest, the land is left prone to wind erosion until the following rains.

In spite of modernization, farming throughout much of the WANA region remains a hazardous venture. Avoiding the risk of crop failure is often more important to farmers than maximizing their yields in good years. Producers in drier areas minimize risk by growing drought-tolerant feed crops, such as barley, and also by grazing marginal land that would otherwise lie unproductive. In such areas cropping is opportunistic. In good rainfall years, both grain and straw are harvested, whereas in drought years mature and immature crops are grazed in the field. Many farmers still include fallow, one of the themes of this workshop, in their crop rotations, not only to restore soil fertility, control pests, diseases and weeds, but also in an attempt to store soil moisture as a buffer to rainfall variability. Research on these aspects conducted in developed countries is not always relevant to the WANA conditions, and the required technologies often remain to be developed.

In response to the region's rising demand for food, and especially for livestock products, there is an increasing tendency to abolish fallows, to cultivate marginal land and to overgraze natural pastures and steppe. These trends, all of which may increase productivity in the short term, also increase the variability and risks of production and are unlikely to abate. Such a course of events will further intensify the pressure on land and water resources, at least in the medium term. In the longer term this trend might be offset if peri-urban livestock production in higher-potential areas were to grow fast enough through the substitution of fallow by a fodder crop to provide more animal feed. All these issues pose challenges for which research is called upon to find answers.

These trends seriously threaten the long-term sustainability of agriculture in the WANA region. In taking measures to curb imports and increase domestic production, new combinations of policy and technology must be found, calculated to increase land and labour productivity simultaneously, without damaging the environment. Solutions will come only from a commitment to improve the economic incentives, as well as the technical options to producers. Ways will have to be found of introducing or subsidizing resource conservation measures currently uneconomic for individual farmers. National agricultural research and other services have a crucial role to perform. It is imperative that they be strengthened and provided with the human and financial resources appropriate to an onerous task.

The foregoing would clearly indicate the importance of this workshop and of the task that was put upon us. We are not only addressing ways of achieving the essential increase in food production, but at the same time, we must consider all these ways against their long-term effect on yield trends and on the conservation of the resources the farmers have available to them today and upon which future generations will depend.

References

Cooper, P.J.M., Gregory, P.J., Tully, D. and Harris, H.C. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 113-158.

FAO, 1987. Agriculture: Towards 2000. FAO, Rome, Italy.

Oram, P. 1988. Prospects for Agricultural Production and Food Deficits in West Asia and North Africa. The Role of High-Elevation Areas. IFPRI, Washington, DC, USA.

Concepts of Water Use Efficiency

P.J. GREGORY

Department of Soil Science, University of Reading, London Road, Reading, RG1 5AQ*, England

Abstract

Water use efficiency can be defined in several ways but for agronomic purposes it can be seen to comprise two major terms. First, a biological component that expresses the amount of dry matter produced per unit of transpiration (sometimes referred to as the "transpiration efficiency") and second, a management term that specifies the fraction of the total water supply used for transpiration.

The transpiration efficiency is affected by the saturation deficit of the atmosphere and the biochemical pathway used in photosynthesis; C_4 species produce more dry matter per unit of transpiration than C_3 species. Recent measurements in field experiments have also indicated that there might be useful variations between genotypes in transpiration efficiency. In dry regions with Mediterranean climates, less than half of the seasonal rainfall may be transpired and considerable increases in water use efficiency can be achieved by changing crop management. Applications of fertilizer, weed control mulching and improved tillage can all increase the amount of water transpired and crop production.

Estimates of potential productivity at a dry site in northern Syria show that water supply and temperature are major constraints to barley production. Given a seasonal rainfall of 280 mm, the calculations suggest that production without fertilizer is about one-third the potential level, but with fertilizer, production is almost two-thirds of potential.

What Is Water Use Efficiency?

The term "water use efficiency" has been employed very loosely by plant scientists and agronomist "to refer to observations ranging from gas exchange by individual leaves for a few minutes, to grain yield response to irrigation treatments through an entire season" (Sinclair *et al.* 1984). It is used to quantify the relation between growth and water use but is not strictly an "efficiency" (a dimensionless term) because the two processes are not energetically linked so that a theoretical, maximum value cannot be calculated. For this reason, some workers prefer to speak about a dry matter: water use ratio or coefficient (eg. Monteith 1986). For agronomists, water use efficiency (WUE) is commonly defined as:

$$\mathrm{WUE} = \frac{\text{Yield per unit area}}{\text{Water used to produce yield}} \qquad (1)$$

* Current address: Dryland Crops and Soils Research Unit, Laboratory for Rural Research, Private Bag, P.O. Wembley, WA 6014, Australia.

although both the numerator and denominator can be specified in several ways.

Yield is frequently expressed as grain yield alone but in many arid regions the straw has a high economic value as feed for livestock. In such areas, then, the yield is better represented by the total shoot weight; this utilization of economic criteria ignores the fact that plants have roots and crops must use assimilates to produce them. Typically root dry weight is 10-20% of total crop weight at maturity (Brown *et al.* 1987) but a value as great as 42% has been measured for a rainfed crop of winter wheat in Western Australia (Hamblin *et al.* 1989). Root weight as a percentage of total plant weight is commonly 40-50% during early growth of both cereals and legumes (Gregory *et al.* 1984; Gregory 1988).

The quantity of water used to produce the yield may also be expressed in several ways. In long-term agronomic studies, it is common to express the use as the total water input (precipitation plus irrigation) since this allows an evaluation of management practices in making water available for crop growth. Expanding equation 1 (and ignoring roots), the seasonal, above-ground, dry matter production (N) can be written as:

$$N = T \times (N/T) \qquad (2)$$

where T is the amount of water transpired. If grain alone is the economic product, then a partitioning coefficient (the harvest index) can be introduced into the equation (Passioura 1977). The water balance equation states:

$$E + T + R + D + I - P = O \qquad (3)$$

where E is evaporation, R is runoff, D is drainage and I is interception by the crop canopy. So, if water use is expressed as precipitation (P) then equation 1 may be re-written as:

$$WUE = \frac{T \times (N/T)}{E + T + R + D + I} \qquad (4)$$

or simplifying:

$$WUE = \frac{N/T}{1 + ((E + R + D + I)/T)} \qquad (5)$$

Frequently, however, water use is measured as the residual term (E + T) in the water balance equation especially in seasonal studies. In those parts of the Mediterranean region where soils are deep and precipitation low so that R and D are zero, then E + T is often almost equal to the annual precipitation (Cooper *et al.* 1987b). Equation 5 then simplifies to:

$$WUE = \frac{N/T}{1 + (E/T)} \qquad (6)$$

Equations 5 and 6 highlight the ways in which WUE might be increased. Increasing the ratio N/T (the transpiration efficiency) or the ratio of T to other pathways of loss will both increase WUE. Moreover, increasing the total supply of water will not increase WUE unless T is increased proportionately more than (E + D + R + I).

Factors Influencing Transpiration Efficiency

Stomata allow the simultaneous exchange of carbon dioxide and water between the atmosphere and sub-stomatal cavity. Because the ratio of CO_2 concentration in the intercellular spaces of leaves to that in ambient air is maintained almost constant depending on plant species (Tanner and Sinclair 1983), the amount of dry matter produced per unit of water transpired varies only with the gradient of water vapour concentration between the sub-stomatal cavity and the air. Ample evidence from field experiments show that this gradient is approximately equal to the saturation deficit of the atmosphere (Bierhuizen and Slatyer 1965; Tanner and Sinclair 1983) so that:

$$\frac{N}{T} = \frac{k}{D} \qquad (7)$$

where k is a crop specific constant and D is the saturation deficit of the atmosphere. Equation 7 shows that transpiration efficiency is determined by both biological and atmospheric factors. Generally, crops grown in temperate regions will have higher transpiration efficiency than those grown in arid regions because they are growing in conditions of smaller saturation deficits.

Monteith (1989) has suggested that a convenient way of expressing the influence of D on N/T is to "normalise" the amount of water by multiplying by D_0 (1 kPa). If this is not done, k has dimensions of pressure which can be confusing. The amount of dry matter equivalent to one unit of normalized water is simply N/T x D which has units of g dry matter per m^2 per mm of normalized water (numerically equal to g dry matter per kg normalized water). Several workers (eg. Tanner 1981 for potato; Day *et al.* 1987 for barley; Monteith 1989 for pearl millet and groundnut) have shown that differences in saturation deficit between seasons explain inter-seasonal differences in transpiration efficiency. Table 1 summarizes values of N/T x D reported in the literature and shows lower values for C_3 species compared with C_4 species. This is as expected because of the lower inter-cellular CO_2 concentration of C_4 species (approximately 230 and 100 ppm in C_3 and C_4 species, respectively). However, the values for C_3 species grown in cool climates (eg. Day *et al.* 1987; Wilson and Jamieson 1984) are less than would be expected on this basis alone and Monteith (1990) suggests that this is possibly because of the difficulty in estimating the mean value of D when D is low (in cool, temperate conditions) compared with when it is much larger (in hot, arid conditions).

The physiological basis underlying equation 7 strictly deals only with the diffusion of CO_2; its assimilation and conversion into dry weight have been assumed to be proportional to this. While this proportionality may be true for individual species, different species will vary because of the varying composition of dry matter particularly in the reproductive organs This

Table 1. Values of normalized transpiration efficiency (N/T x D x D_o)

Author	Crop	Location	N/TxDxD_o g/kg
Monteith (1989)	Pearl millet	Various	9.4
Tanner and Sinclair (1983)	Maize	mid-west USA	9.5
Walker (1986)	Maize	Ontario, Canada	7.4
Day *et al.* (1987)	Barley	Rothamsted, UK	2.9
Monteith (1989)	Groundnut	Various	3.9
Tanner (1981)	Potato	Wisconsin, USA	6.5
Wilson and Jamieson (1984)	Wheat	Lincoln, New Zealand	3.1

is an important consideration because 1g of primary assimilate converts to about 0.83g of carbohydrate, 0.40g of protein and 0.33g of lipid. Because of the different composition of seeds, 1g of primary assimilate will give about 0.75g of temperate cereal grain but only 0.5g of sunflower seed; this is one of the main reasons for lower seed yield and WUE in protein and oilseed crops compared to temperate cereals (Perry 1987).

Although transpiration efficiency is largely determined by photosynthetic pathways, composition of dry matter and saturation deficit, recent research suggests that there may be some useful genotypic differences that can be utilized by breeders (Richards 1987). The most promising technique for exploring these differences is the use of carbon isotope discrimination. During the assimilation of carbon, the naturally occurring isotope ^{13}C is discriminated against relative to ^{12}C because of its greater molecular weight (resulting in a smaller diffusion coefficient) (Farquhar *et al.* 1982). The discrimination (Δ) will be least in plants that assimilate the greatest amount of carbon per unit of water transpired (ie. transpiration efficiency should be inversely related to Δ). This theory applies only to C_3 species because Δ in C_4 plants depends not only on the intercellular CO_2 concentration, but also on the transfer of carbon from the bundle sheath to the mesophyll cells. Controlled experiments (where no E or D was allowed) with wheat (Farquhar and Richards 1984) and groundnuts (Hubick *et al.* 1986) have confirmed the theory and suggest that this technique might provide a selection technique. In field trials in which water was not a limitation to growth, Δ was positively related to grain yields of wheat (Condon *et al.* 1987) and a similar relation was found in rainfed conditions with several genotypes of barley at Breda and Bouider, northern Syria (Acevedo and Ceccarelli 1989). The latter workers concluded that ^{13}C discrimination "would be an excellent screening tool for transpiration efficiency under dry conditions".

Factors Affecting the Proportion of Water Transpired

Management of soils and crops has a large influence on WUE largely because of its effects on the proportion of water that is transpired. Evaporation (E) directly from the soil surface is a very important component of the total water use of crops grown in Mediterranean environments. Cooper *et al.* (1983) estimated that E was 35-55% of the seasonal water use of barley grown at two sites in northern Syria, and Hamblin *et al.* (1987) estimated it at 34-61% for wheat crops in Western Australia. Similarly, French and Schultz (1984) found that E averaged 33% of total water use for wheat crops grown on a range of soil types over an 11 year period in South Australia. This substantial loss of water by evaporation has led several workers to suggest that management to reduce E will lead to improved yields and WUE in such areas (Cooper *et al.* 1987b; Perry 1987).

Many techniques exist for reducing E and increasing the supply of water to crops (Table 2) and several of these are described in detail in the papers presented at this meeting. Essentially, any management practice that reduces losses via other routes and increases the leaf area index of crops will result in increased interception of radiant energy, decreased E, increased yield and increased WUE. As an example, I shall briefly describe the effects of fertilizer on WUE in northern Syria. Experiments conducted over many years and at several sites have shown that even in apparently water-limited environments, substantial increases in growth are consistently obtained through the application of fertilizers (particularly P and, in wetter years or at wetter sites, N) (Cooper *et al.* 1987b; Shepherd *et al.* 1987). Table 3 shows fertilizer applications increased growth but water use was generally unaffected so that WUE was increased substantially. Water use was only increased by fertilizer applications at the wettest site when rain penetrated to depths >1.5m. In the drier, barley-growing regions of northern Syria, crops generally extract water only to the current season's depth of wetting and

Table 2. Agronomic practices used to increase water use efficiency

Reducing evaporation from the soil surface	Increasing total water supply to crops
Application of fertilizer	Application of fertilizer
Early sowing	Cultivation to improve infiltration
Modifying plant population and spacing	Fallowing Multiple/relay cropping
Mulching	Selecting varieties with deep roots
Selecting varieties with rapid early growth	Supplementary irrigation Water harvesting Weed control

Table 3. Effects of fertilizer on shoot weight, water use and water use efficiency of barley crops grown in northern Syria (from Shepherd *et al.* 1987)

Season	Site	Fertilizer	Shoot weight (t/ha)	Water use (mm)	WUE (kg/ha/mm)
1981-2	Jindiress	+	8.66	314	27.6
		-	4.35	322	13.5
	Breda	+	6.18	232	26.6
		-	3.89	232	16.8
	Khanasser	+	2.64	209	12.6
		-	1.32	208	6.3
1982-3	Jindiress	+	10.24	332	30.8
		-	6.92	308	22.5
	Breda	+	4.54	235	19.3
		-	2.62	228	11.5
	Khanasser	+	4.88	227	21.5
		-	2.87	224	12.8

the depth of water extraction remains unaffected by fertilizer applications. The principal effect of fertilizer is to allow more rapid expansion of the leaf canopy (through increased leaf size of the main stem plus increased tillering) leading to a larger canopy that intercepts more radiation, shades the soil surface and reduces the proportion of water that is evaporated (Cooper *et al.* 1987a; Allen 1989). Increasing transpiration during the cool winter and spring of Mediterranean regions is particularly beneficial because of the low saturation deficits during these periods; water that is not transpired would otherwise be evaporated directly from the soil surface so that additional growth during this period is essentially "free" in terms of water use.

Similar effects of fertilizer on WUE have been reported for the semi-arid regions of West Africa (ICRISAT 1985; Onken *et al.* 1989). Table 4 illustrates the interaction that can occur between water and fertilizer applications. At all levels of soil water, applying fertilizers increased yields and WUE (expressed as grain yields only) but comparing levels of fertilizer at different water levels reveals more complex interactions. With no N, yields were increased by irrigation but WUE decreased; with 25 and 90 kg N, yields again increased but WUE initially rose before falling slightly again. Maximum yield may not be synonymous with maximum WUE and at low levels of fertility, irrigation may be wasteful of water because it maintains a moist soil surface that increases E considerably more than T.

Table 4. Effects of fertilizer and supplementary irrigation on grain yield, water use and water use efficiency of sorghum (from Onken *et al.* 1989)

Treatment	Rate of N (kg/ha)	Grain yield (t/ha)	Water use (mm)	WUE (kg/ha/mm)
Rainfed	0	3.3	415	7.95
	25	3.5	440	7.95
	90	4.0	440	9.10
50% of ET replaced weekly	0	4.1	550	7.45
	25	5.5	550	10.00
	90	6.3	550	11.45
100% of ET replaced weekly	0	4.2	700	6.00
	25	6.0	700	8.57
	90	7.8	700	11.14

Scope for Improving Yield and WUE

In this section I shall be deliberately speculative in an attempt to give some assessment of the improvements in yield and WUE that might be possible in the area of northern Syria close to ICARDA's headquarters in Aleppo. Although the climatic measurements that I shall use are site specific, the methodology I shall employ is applicable to other areas within the Mediterranean region.

I have shown earlier in this paper that N/T x D is conservative. Monteith (1986, 1990) also shows that another conservative quantity is the amount of dry matter produced per unit of radiation intercepted by foliage (e). The amount of radiation intercepted is the product of two quantities: first, the amount of radiation incident on a crop per unit surface area (S) and second, the fraction of the radiation that is intercepted (f). The quantity of dry matter produced is therefore:

$$N = e \times f \times S \qquad (8)$$

and the main determinant of the rate of growth is f, which depends on the area and arrangement of the foliage as influenced by such factors as plant population and water and nutrient availability. Combining equations 7 and 8, it is possible to define the transpiration as:

$$T = \frac{D \times e \times f \times S}{k} \qquad (9)$$

which as Monteith (1986) has pointed out, makes clear the dependence of atmospheric demand on the size of the canopy.

Fig. 1 illustrates the changes of D with time during three growing seasons at Breda. Typically D is 0.3 kPa during the winter period rising rapidly during the spring to values >1.2 kPa during grain-filling. Intermittent periods of drought and rain during the spring lead to peaks and troughs in D. The mean saturation deficit from sowing to maturity for the three seasons was almost constant at 0.54, 0.55 and 0.57 kPa despite seasonal rainfall of 284, 204 and 278 mm. Cooper *et al.* (1987a) estimated that for the 1982/83 season, N/T was 5.7 g/m^2/mm for crops given fertilizer and 5.1 g/m^2/mm for those that were not given fertilizer. Taking the average of these values gives a value for N/T x D of 2.9 g/kg normalized water, identical with the value determined by Day *et al.* (1987) at Rothamsted, England.

To estimate the potential for increasing yields and WUE, I shall use the climatic data recorded at Breda during 1982/83. The maximum yield available from this site, assuming that radiant energy is the only limiting factor and that all incident radiation is intercepted, can be calculated from equation 8. The value of e determined from field experiments lies between 1.3 and 1.6 g/MJ (Russell *et al.* 1988); choosing e = 1.4 g/MJ and f = 1 gives a potential dry matter production of 37.8 t/ha. If on the other hand, we assume that water is the only limiting factor, equation 7 can be used to calculate the maximum production assuming that all rainfall is transpired. For 1982/83, seasonal rainfall was 284 mm, k = 2.9 kPa which gives a potential

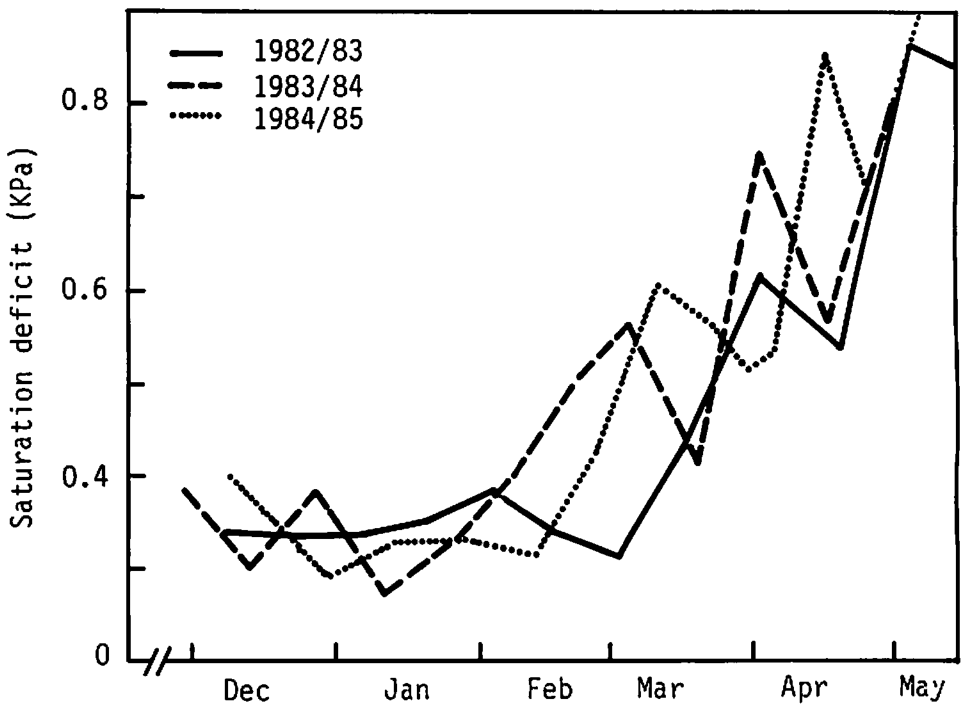


Fig. 1 Seasonal changes in saturation deficit at Breda, Northern Syria, 1982/82, 1983/84, and 1984/85.

dry matter production of 15.2 t/ha. Clearly then, water supply is far more limiting to potential productivity than radiant energy.

Both of the preceding calculations assume that f = 1; this is most unlikely for the whole growing period. f can be calculated from the leaf area index (LAI) using:

$$f = 1 - \exp^{-K \times LAI} \qquad (10)$$

where K is the extinction coefficient (0.37 for barley in northern Syria, Cooper *et al.* 1983). In the absence of water and nutrient stresses and disease, the primary factor controlling the rate of leaf area growth is temperature. Increase in leaf area generally proceeds exponentially at first but then almost linearly before decreasing again (eg. Squire *et al.* 1984). In the absence of detailed information for completely non-stressed crops in Syria, I have used the information on irrigated and fertilized crops of barley grown at Rothamsted (Lawlor *et al.* 1981). I have approximated leaf growth in three linear phases: first, emergence to LAI of 0.6 (requiring 350 °C d (base temperature 0 °C)); second, LAI 0.6 to anthesis (LAI increases by 0.0105 per °C d); and finally, anthesis to maturity when LAI decreases linearly from its maximum to 0 at maturity. Fig. 2 shows the potential dry matter production compared with

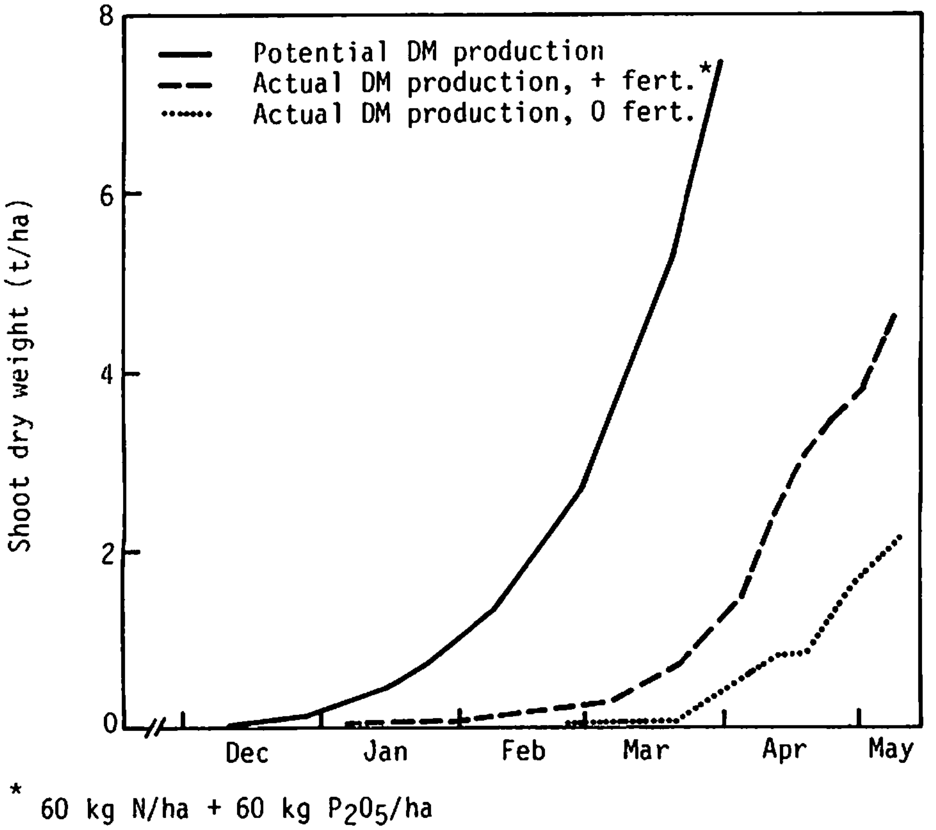


Fig. 2 Comparison of potential dry matter production at Breda, Northern Syria assuming no water limitation, and the actual production observed.

that observed; the agreement is not good mainly because the potential conditions overestimate growth during the winter to give a potential yield of 18.7 t/ha.

However, if the temperature and water limitations to production are combined by estimating the time course of potential transpiration using equation 9, a more realistic estimate of potential production is obtained. Given the rainfall, transpiration can only continue until the end of March to give a potential dry matter production of 7.5 t/ha; this compares with 4.5 t/ha achieved by crops given fertilizer and only 2.6 t/ha in crops without fertilizer (Fig. 2). The potential for dry matter production after anthesis (when radiation receipts and atmospheric demand are high) appears from this analysis to be very limited. These calculations confirm the suggestions of several workers (Cooper *et al.* 1987b; Acevedo and Ceccarelli 1989) that most attention in improving yields should be given to the pre-anthesis period to ensure that the phenology of the crop is suitable (short growing season), and that the soil surface is covered (i.e.f approaches unity) as soon as possible. Such measures will increase both yields and WUE.

Finally, while maximum yields and maximum WUE may coincide, farmers are most interested in the economic viability of their enterprise and in the well-being of their families. The monetary costs of any management practice required to achieve maximum yield must be considered, and this will lead farmers to aim for the best economic return; this may mean accepting a less than optimum WUE.

Acknowledgements

I thank the Overseas Development Administration of the UK for financial support for collaborative work with ICARDA.

References

Acevedo, E. and Ceccarelli, S. 1989. Role of physiologist-breeder in a breeding program for drought resistance conditions. Pages 117-139 *in* Drought Resistance in Cereals. CAB International, Wallingford, England.

Allen, S.J. 1989. Measurement and estimation of evaporation from soil under sparse barley crops in northern Syria. Agricultural and Forest Meteorology 49: 291-309.

Bierhuizen, J.F. and Slatyer, R.O. 1965. Effect of atmospheric concentration of water vapour and CO_2 in determining transpiration-photosynthesis relationships of cotton leaves. Agricultural Meteorology 2: 259-270.

Brown, S.C., Keatinge, J.D.H., Gregory P.J. and Cooper, P.J.M. 1987. Effects of fertilizer, variety and location on barley production in northern Syria. 1. Root and shoot growth. Field Crops Research 16: 53-66.

Condon, A.G., Richards, R.A. and Farquhar, G.D. 1987. Carbon isotope discrimination is positively correlated with grain yield and dry matter production in field-grown wheat. Crop Science 27: 996-1001.

Cooper, P.J.M., Keatinge, J.D.H. and Hughes, G. 1983. Crop evapotranspiration- a technique for calculation of its components by field measurements. Field Crops Research 7; 299-312.

Cooper, P.J.M., Gregory, P.J., Keatinge, J.D.H. and Brown, S.C. 1987a. Effects of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. 2. Soil water dynamics and crop water use. Field Crops Research 16: 67-84.

Cooper, P.J.M., Gregory, P.J., Tully, D. and Harris, H.C. 1987b. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 113-158.

Day, W., Lawlor, D.W. and Day, A.T. 1987. The effect of drought on barley yield and water use in two contrasting years. Irrigation Science 8: 115-130.

Farquhar, G.D., O'Leary, M.H. and Berry, J.A. 1982. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Australian Journal of Plant Physiology 9: 121-137.

Farquhar, G.D. and Richards, R.A. 1984. Isotopic composition of plant carbon correlates with water-use efficiency of wheat genotypes. Australian Journal of Plant Physiology 11: 539-552.

French, R.J. and Schultz, F.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Australian Journal of Agricultural Research 35: 743-764.

Gregory, P.J. 1988. Root growth of chickpea, faba bean, lentil and pea and effects of water and salt stresses. Pages 857-867 *in* World Crops: Cool Season Food Legumes (Summerfield E.J., ed.). Martinus Nijhoff, Dordrecht, Netherlands.

Gregory, P.J., Shepherd, K.D. and Cooper, P.J.M. 1984. Effects of fertilizer on root growth and water use in northern Syria. Journal of agricultural Science, Cambridge 103: 208-215.

Hamblin, A., Tennant, D. and Perry, M.W. 1987. Management of soil water for wheat production in Western Australia. Soil Use and Management 3: 63-69.

Hamblin, A., Tennant, D. and Perry, M.W. 1990. The cost of dry matter partitioning changes with seasonal supply of water and nitrogen to dryland wheat. Plant and Soil 122: 47-58.

Hubick, K.T., Farquhar, G.D. and Shorter, R. 1986. Correlation between water-use efficiency and carbon isotope discrimination in diverse peanut (*Arachis*) germplasm. Australian Journal of Plant Physiology 13: 803-816.

ICRISAT 1985. Pages 298-301 *in* Annual Report 1984. Patancheru AP502324, India.

Lawlor, D.W., Day W., Johnston, A.E., Legg, B.J. and Parkinson, K.J. 1981. Growth of spring barley under drought: crop development, photosynthesis, dry-matter accumulation and nutrient content. Journal of agricultural Science, Cambridge 96: 167-186.

Monteith, J.L. 1986. How do crops manipulate water supply and demand? Philosophical Transactions of the Royal Society, London A 316: 245-259.

Monteith, J.L. 1990. Steps in crop climatology. Pages 273-282 *in* Challanges in Dryland Agriculture. A Global Perspective. Proceedings of the International Conference on Dryland Farming, Amarillo/Bushland, Texas, August 1988. (Unger, P.W., Jordan, W.R., Sneed, T.V., and Jensen, R.J., eds). Texas A&M University, College Station, Texas, USA.

Onken, A.B., Wendt, C.W. and Halvorson, A.D. 1990. Soil fertility and water use efficiency. Pages 441-444 *in* Challanges in Dryland Agriculture. A Global Perspective. Proceedings of the International Conference on Dryland Farming, Amarillo/Bushland, Texas, August 1988. (Unger, P.W., Jordan, W.R., Sneed, T.V., and Jensen, R.J., eds). Texas A&M University, College Station, Texas, USA.

Passioura, J.B. 1977. Grain yield, harvest index and water use of wheat. Journal of the Australian Institute of Agricultural Science 43: 117-120.

Perry, M.W. 1987. Water use efficiency of non-irrigated field crops. Pages 83-99 *in* Proceedings of the 4th Australian Agronomy Conference. Australian Society of Agronomy, Parkville, Victoria, Australia.

Richards, R.A. 1987. Physiology and the breeding of winter-grown cereals for dry areas. Pages 133-140 *in* Drought tolerance in winter cereals (Srivastava, J.P., Porceddu, E., Acevedo, E. and Varma, S., eds). John Wiley, Chichester, UK.

Russell, G., Jarvis, P.G. and Monteith, J.L. 1988. Absorption of radiation by canopies and stand growth. Pages 21-40 *in* Plant Canopies: Their Growth Form and Function (Russell, G, Jarvis, P.G. and Marshall, B., eds). Cambridge University Press, UK.

Shepherd, K.D., Cooper, P.J.M., Allan, A.Y., Drennan, D.S.H. and Keatinge, J.D.H. 1987. Growth, water use and yield of barley in Mediterranean-type environments. Journal of agricultural Science, Cambridge 108: 365-378.

Sinclair, T.R., Tanner, C.B. and Bennett, J.M. 1984. Water-use efficiency in crop production. Bioscience 34: 36-40.

Squire, G.R., Marshall, B., Terry, A.C. and Monteith, J.L. 1984. Response to temperature in a stand of pearl millet. VI. Light interception and dry matter production. Journal of Experimental Botany 35: 599-610.

Tanner, C.B. 1981. Transpiration efficiency of potato. Agronomy Journal 73: 59-64.

Tanner, C.B. and Sinclair, T.R. 1983. Efficient water use in crop production: research or research? Pages 1-27 *in* Limitations to Efficient Water Use in Crop Production (Taylor, H.M., Jordan, W.R. and Sinclair, T.R., eds). American Society of Agronomy, Madison, USA.

Walker, G.K. 1986. Transpiration efficiency of field-grown maize. Field Crops Research 14: 29-38.

Wilson, D.R. and Jamieson, P.D. 1984. Models of growth and water use of wheat in New Zealand. Pages 211-216 *in* Wheat Growth and Modelling (Day, W. and Atkin, R.K., eds). Plenum Press, New York, USA.

Implications of Climatic Variability

HAZEL C. HARRIS

ICARDA, P.O. Box 5466, Aleppo, SYRIA

Abstract

Rainfed areas are defined for the purpose of this workshop as those where water stress is experienced in part or all of a crop growth season. Mediterranean-type climates are briefly described with special reference to the spatial and temporal variability which exists in them. Similarities and differences between different geographical areas having this type of climate are noted.

Introduction

Rainfed areas are those in which agricultural production is directly and solely dependent on precipitation. They cover more than 80% of the land area used for cropping throughout the world (Schilfgaarde and Rawlins 1983) and produce some 60% of total production. Moisture regimes range from humid to arid. The most productive systems are found at moderately high, or low, latitudes where precipitation is abundant and some drainage of excess water may be necessary. Their productivity may be limited by low temperature or low insolation in some seasons.

Sub-humid, semi-arid and arid systems are found chiefly at mid-latitudes where the major limitation to their productivity is a variable and often inadequate water supply. Precipitation may be seasonally adequate but of limited duration, variable in amount both from year to year and from season to season within years, or chronically deficient.

Many authors draw a distinction between 'rainfed' and 'dryland' areas, defining the latter as those in which moderate to severe water stress occurs during a substantial portion of the year and which require special cultural techniques and adapted crops for sustained production (e.g. Oram 1980; Steiner *et al.* 1988). In these terms humid areas would be defined as 'rainfed', and sub-humid and semi-arid ones as 'dryland'. Attempts have long been made to delimit boundaries between and within these broad classes on the basis of climatic information. Numerous methods using annual or monthly mean data have been developed for the classification of rainfed environments. Some, for example the indices of Thornthwaite (1984) and Emberger (1955) have been widely used, but none more so than the growing period estimates of the Food and Agriculture Organization of the United Nations (FAO 1978). This approach links conditions of the atmosphere with plant and soil characteristics to estimate the length of periods when growth is possible. While the method can be criticized on the grounds of imprecision (Steiner *et al.* 1988) and its use requires a good deal of intuitive integration, it has proved useful for land use, research planning, and population support studies.

Kassam (1981) identified 10 major climates in northern Africa and west Asia. More than half of the region (960 of 1500 million hectares) was classified as lying in the cool or cold subtropics with winter rainfall - the Mediterranean-type climate - of which some 125 million hectares receive between 200 and 600 mm of annual rainfall and have an estimated growing period ranging from 75 to 210 days per year. This meeting focuses principally on this region, which in the above terms is a dryland area, and on other parts of the world where similar climates are found, *viz* the west coast of the Americas at mid-latitudes, and southern Australia. Where we stray outside it to sub-tropical areas with summer rainfall in north-eastern Africa and the Arabian Peninsula the concepts of management for water use efficiency are equally applicable.

Characteristics of Mediterranean Climates

While areas with Mediterranean-type climates share the feature of winter-dominant rainfall and therefore have farming systems based on temperate cereals and legumes, and livestock (mainly small ruminants), there is also considerable diversity of conditions within them. It seems worthwhile to remind ourselves briefly of this diversity as it will influence the way we view and interpret the topics of discussion at this meeting.

The climate of the Mediterranean Basin and surrounding areas has been described in broad terms by such authors as Brichambaut and Wallen (1963), Megis (1964), and Kassam (1981, 1988), and Agroclimatic Atlases have been prepared for the Arab Nations (AOAD 1978), and for individual countries of the region. Detailed analyses by agriculturalists to support decision-making in agriculture and agricultural research, such as that of Mizrak (1988) for Turkey, are, to the best of my knowledge, rare.

It is a characteristic of the region that precipitation is variable in space, being highest in coastal areas, but the seasonal average (approx. September to June in Northern Hemisphere; April to December in the Southern Hemisphere) declines quickly with distance inland. In many places the 200 mm isohyet, which can be regarded as the dry boundary of arable agriculture, lies within one to two hundred kilometers of the coast. These general patterns are modified by topography and are exaggerated by orographic effects where mountains lie adjacent and parallel to the coast. In West Asia where the mountains of Turkey are perpendicular to the eastern coast of the Mediterranean and the direction of movement of the main rain-bearing influences, the zone of higher precipitation extends inland to form the 'fertile crescent' of Syria, Iraq and western Iran.

The intraseasonal distribution of rainfall varies with longitude, and the wettest month is delayed from December in Morocco and Algeria, to April in northeastern Iraq and Iran (Fig. 1). Similar variation occurs elsewhere. For example, rainfall in the southwest of Western Australia is essentially winter-dominant, but there is a greater summer component in the south of the eastern states.

There is a temperature continuum across the Mediterranean region from quite mild winters in North Africa to severe conditions with several months of snow cover in the highlands of Turkey, Iran, Baluchistan and Afghanistan. A continental influence causes cold winters in the lowlands of West Asia, and conditions resemble those in the Atlas Mountains of North Africa. Winters in southern Australia are as mild as, or milder than in North Africa, whereas those in the Pacific northwest of the USA with snowcover and freezing are more like

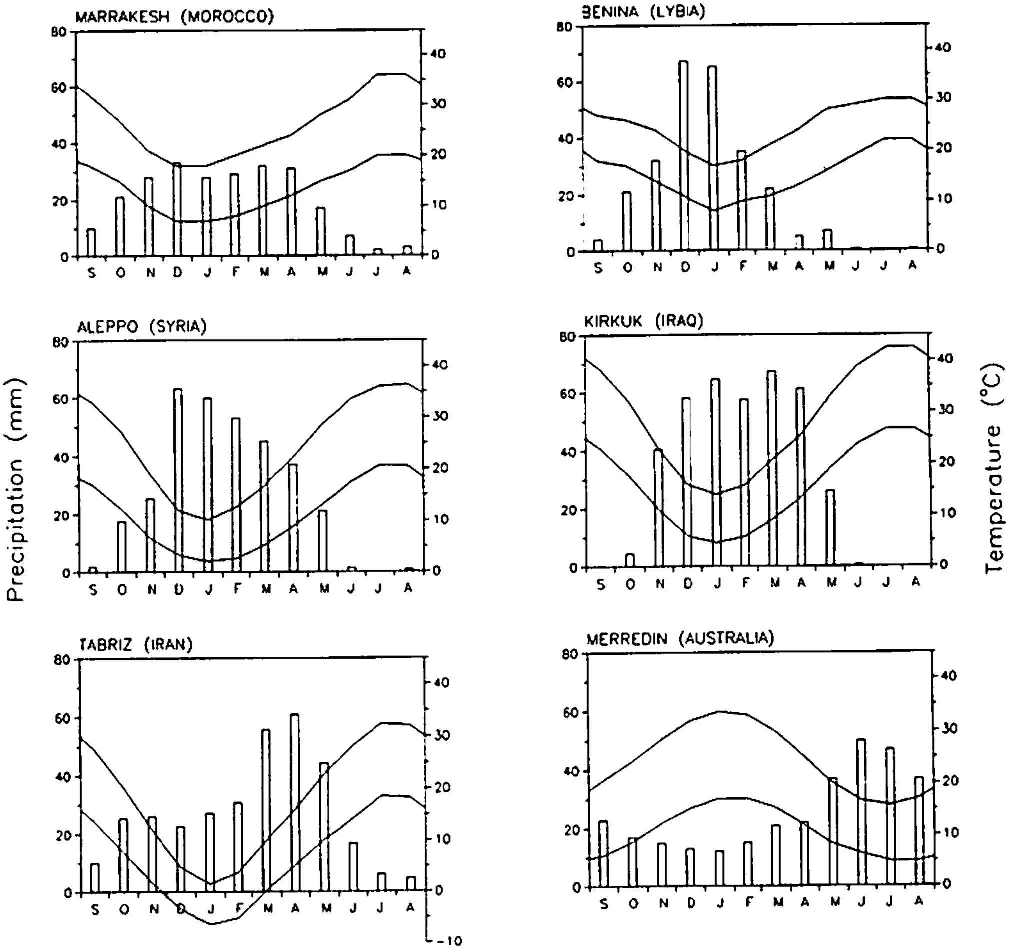


Fig. 1 **Monthly mean precipitation and maximum and minimum temperatures at locations with Mediterranean-type climates in North Africa, West Asia and Australia.**

the highlands of West Asia. Summer temperatures follow the same trend with altitude, but the continental influence in West Asia causes higher summer maxima there than in North Africa.

The significance of these temperature differences is, of course, that there are differences in the rate of physiological development of crops from region to region. Regardless of the pattern of precipitation, crops in all environments reach maturity at the end of the humid period and almost universally suffer drought stress in the post-flowering phase of development. The challenge to managers of cropping systems is to devise strategies to minimize the impact of these weather-induced stresses and year-to-year variability on productivity.

Variability in Time

Variability in Precipitation Spatial variability in precipitation has been indicated in the preceding section. However, year to year variability in precipitation at any one location is probably of even greater significance in semi-arid environments (Fig. 2). In Syria, for example, it is possible to account for almost 70% of the variability in national wheat yields by a very crude estimate of crop season rainfall from only four recording stations (Cooper *et al.* 1989). A further feature of rainfall patterns in semi-arid areas, described by Russell (1977) as medium-term climatic variation, is the trend for a run of above-average wet, or below-average dry seasons to occur (Fig. 2). Knowledge of this allows research findings to be placed in the context of variability, and should influence the way in which research is carried out so that the range of probable deviations from mean conditions can be encompassed in the evaluation of management practices. Detailed (daily, 5-day, or, at most, 10-day) long term weather records are extremely valuable for estimation of these effects. Techniques for their analysis now are becoming available through the spread of computer technology. For example, the package INSTAT, developed by the Department of Applied Statistics at the University of Reading in England, contains specialized routines for analysis of weather data. The package is available to national meteorological services through the World Meteorological Organization.

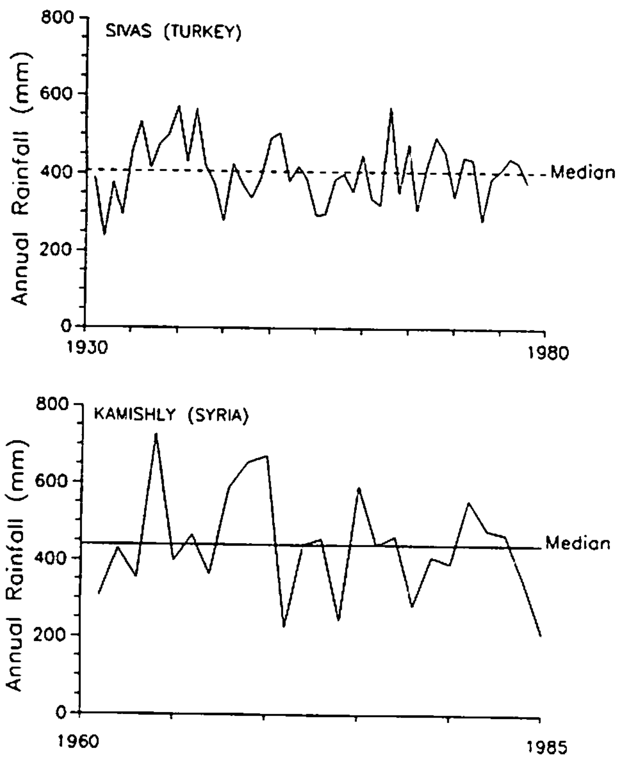


Fig. 2 **Annual precipitation at two locations in West Asia, showing year to year variability and persistence of above or below average values.**

Start of Season It is widely recognized that delays in the establishment of crops cause a reduction in the potential yield (Hall *et al.* 1979). Early establishment is of particular importance in highland areas where cereals reaching the 2- to 4-leaf stage before snow cover survive the winter better than less developed plants. However, the chances of crop establishment are largely governed by the weather, and the time of onset of precipitation in the autumn is quite variable.

Weather records can be used to evaluate sowing date recommendations, or the potential value of techniques that might be devised to make early sowing more reliable. Such analyses require some knowledge about the relationships between precipitation and soil water at sowing depth. At the end of the summer in most Mediterranean environments, the surface layers of the soil are in equilibrium with the water content of the atmosphere. In northern Syria, the high clay soils usually have a water content of about 0.1 cc/cc in mid-September before the first rains. The lower limit of plant extractable water (equivalent, for surface soil, to the permanent wilting point) is approximately 0.17 cc/cc. Estimates indicate that crop establishment requires a water content of about 0.25 cc/cc. Thus 0.15 cc/cc, or 15 mm per 10 cm of soil depth, of water needs to be stored to start the crop growth season. These values will vary with the soil type and the evaporative demand of the environment, but can be approximated by experienced agronomists for their own localities.

Figure 3 illustrates rainfall analyses for several environments. The length of the records used was 48 years for the Turkish sites, 42 years for Irbid, and 25 years for Kamishly. The assumption made is that establishment will be possible when the first 3-day rainfall total for the season reaches the amounts indicated. For each location the different specified rainfall amounts can be viewed as representing either requirements for different soil types or the effect of different efficiencies of storage on a single soil type.

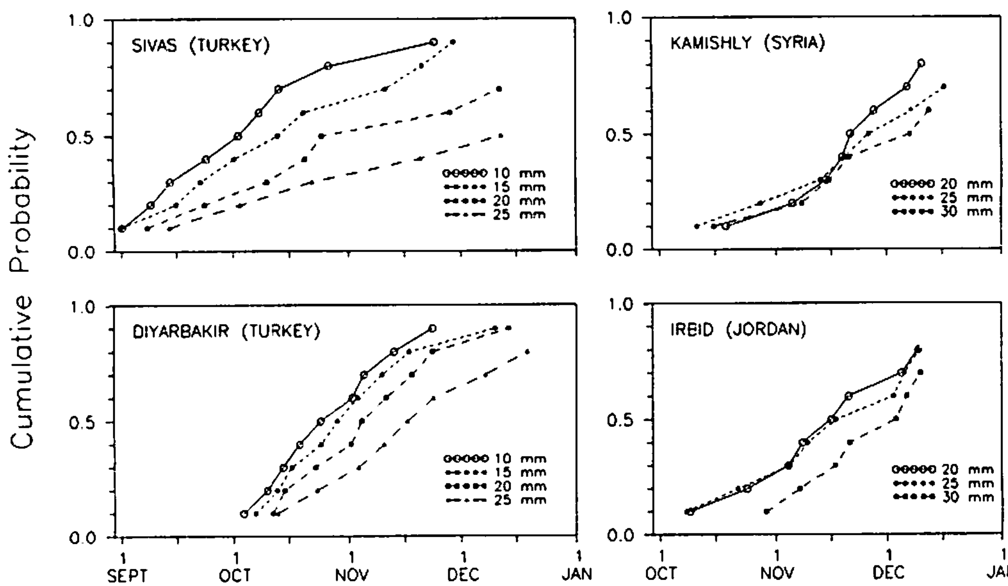


Fig. 3 **The cumulative probability of the time of the start of the growing season as determined by the time of rainfall events. (For explanation of conditions see text).**

The data plotted in Fig. 3 are the probability that the specified amount of rain will be received, conditional on it falling in a three-day period, each period being independent (i.e. the periods do not overlap). At the higher specified rainfall amounts these conditions are not necessarily met, leading to maximum probabilities much less than one. As would be expected, the smaller the rainfall specified, the earlier establishment will be possible. However, at all locations there is little difference in the latest sowing date regardless of rainfall levels, indicating the variability in the time of the start of precipitation from year to year. At Sivas in eastern Turkey the analysis suggests that autumn planting would only be possible in about four years in ten, as it would need to be complete by the end of September to avoid freezing. Whether this is realistic is a matter for judgement by those familiar with the area. There is an interesting contrast between Sivas and Diyarbakir, with the season quite clearly starting one month later in Diyarbakir.

A second aspect of variability in early season rainfall is that it may occur as high intensity thunderstorms. Data on rainfall intensity are not readily available but 16 years' data from the Aleppo Airport in Syria indicate that there is a recurrence interval of 1 year in 7 for intensities in excess of 100 mm/hr for a five minute duration, and of 1 year in 4 for 70 mm/hr for the same duration (Sabet 1986). Observations of severe soil erosion in many places suggest that events of this nature may not be uncommon, but better information on rainfall intensities is needed to clarify how significant such events are. Studies on micro-plots (1m x 1m) using a rainfall simulator (Sabet 1986) suggested that simple cultural practices, such as light cultivation at right angles to the direction of the slope of the land, were effective in preventing runoff from high intensity rainfall events (90 mm/hr for 30 min.) on the Calcic Rhodoxeralf soils of ICARDA's main station, Tel Hadya, but this type of work needs to be confirmed on a larger scale, and extended to other soil conditions.

Intra-seasonal Variability Variability in the distribution of precipitation within the season is illustrated in Figure 4. In general in this part of the region once the rainfall season begins and crops are established there it is a period when water deficits are unlikely. During the winter, evaporation rates are small due to low temperatures and relatively high humidities and growth rates are slow because they are temperature limited. During the period there is almost always sufficient water to meet crop demands. The water balance of the system remains positive for a variable length of time, and water is stored in the soil profile. The time and quantity of maximum storage vary with the intra-seasonal distribution and total rainfall for the rainy season (Table 1). In the last 10 years at Breda in northern Syria, the time of maximum profile recharge has ranged from early January to the end of March and the quantity for 30 mm to 150 mm. An almost twofold difference in the water use efficiency (WUE) of barley crops has been recorded, but the WUE is not necessarily directly related to crop season rainfall (Table 1).

As temperatures increase in the spring, the evaporative demand rises, crops begin to rely in part on the stored water for their rapid spring growth, the water balance becomes negative, and soil water reserves are quickly exhausted. Some stress appears inevitable in the post-anthesis stage of growth.

It is not clear to me how far this pattern is repeated in other parts of the region, especially in North Africa where winter growth is more vigorous in the milder conditions. Data from Morocco (El Mourid 1988) show crops severely stressed in early March in the

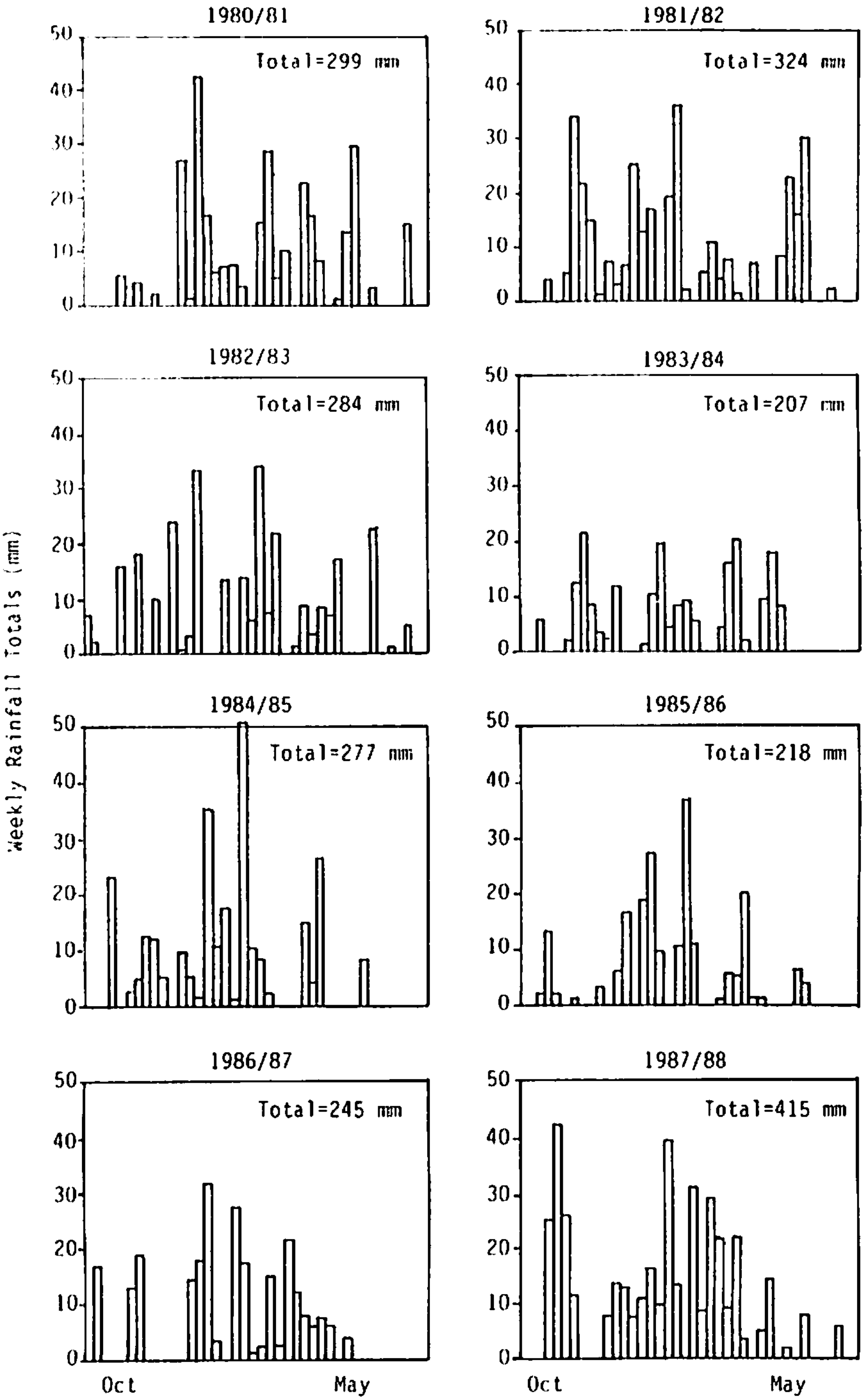


Fig. 4 Weekly rainfall during eight seasons at Breda (Lat. 35°56'N Long. 37°10'E) Northwest Syria.

Table 1. The maximum amount of water stored in the soil profile during the rainy season (mm), date of maximum storage, seasonal (Sept. to June) rainfall (mm), and water use efficiency (kg/ha/mm) of barley crops at Breda (Lat. 35° 56'N; Long. 37°10'E) northern Syria, from 1983/84 to 1988/89.

Crop Season	Maximum Stored Water mm	Date of Maximum Storage	Seasonal Rainfall mm	WUE[1] of Barley kg/ha/mm
1983-84	35	Feb 9	207	14.2
1984-85	107	Feb 10	277	19.8
1985-86	83	Feb 16	218	20.8
1986-87	52	Feb 9	245	11.0
1987-88	148	Mar 14	415	21.8
1988-89	38	Jan 18	195	10.0

1. Calculated on total above-ground biomass.

1986-87 season. It seems probable that stress occurs at similar growth stages in all environments but comparative studies would be needed to confirm this.

Variability in Temperature Variability in temperature is a second source of yield variation. Data for Tel Hadya (Fig. 5) show quite regular conditions early in the season, but differences in the rate of accumulation of thermal time (TT=0.5 [Tmax+Tmin]) in the spring can have major impacts on yields. For example, in successive years with identical effective rainfall with

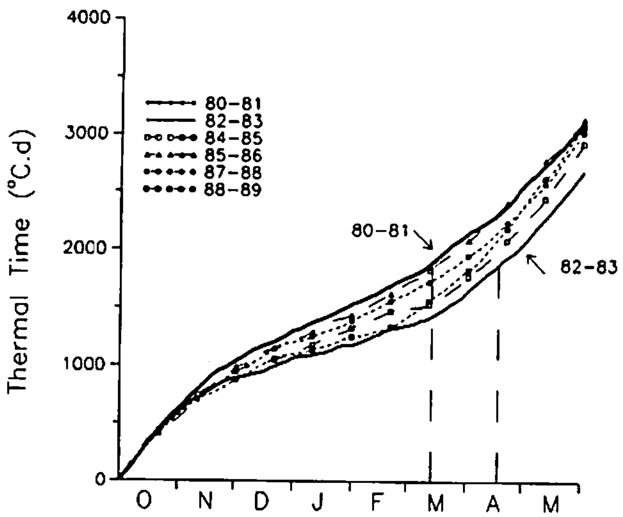


Fig. 5 Season to season variability in temperatures at the Tel Hadya Research Station, expressed as thermal time (°C.d).

a very similar intra-seasonal distribution (1985/86 and 1986/87), yields of lentil were 450 kg in the first year but three to four times greater in the second (ICARDA-FRMP 1987). The difference was that spring temperatures were mild in the second season, the evaporative demand was not so severe, and harvest was three weeks later allowing a longer period for flowering and pod filling.

While such overall seasonal effects are important, the major impact of temperature on yield variability probably arises from short term extreme events. Of these, frost is significant at two growth stages in the Syrian environments. While the degree of damage caused by frost varies depending on the extent to which plants have been cold hardened, temperatures of less than about -8°C in the vegetative stage can cause severe loss of leaf area or can kill whole stems. When this happens, the maturity time of cereals is delayed as a second population of tillers is developed, causing maturation to take place under less favourable conditions. In the highlands, alternative freezing and thawing during vegetative growth, accompanied by soil freezing and heaving, can cause severe damage or total crop failure.

The second stage at which frost is especially damaging is in late stem elongation and at heading of cereals when the familiar effects of partial or total loss of grain sites causes yield reduction. Legumes which flower at the same time may be damaged also. It is difficult to quantify this effect; temperatures measured in a standard recording screen and temperatures at the vulnerable positions in the crop may be quite similar, or crop temperatures may be several degrees lower than screen temperatures. In semi-arid environments in general, frost risks are greater than in humid conditions because the clear atmospheric conditions promote greater radiative loss of heat.

Extreme high temperatures in the spring, often associated with strong winds, can be equally damaging. Again, the impact of such events is difficult to quantify, and varies with the growth stage. High temperature stress at flowering can cause sterility. At other times its effect is expressed more in the indirect effect on the water balance. Some data suggest that after flowering a short high temperature stress may trigger senescence and shorten the maturation phase.

Integrated Precipitation and Temperature Analyses If we are to improve the efficiency of management of farming systems it is essential that we thoroughly understand how water and temperatures interact to determine the pattern of crop growth. There are several ways in which we can study these interactions.

One way in which the combined effects of variability in precipitation and temperature can be quantified is through the use of research sites deliberately chosen to span known gradients of water supply and temperature. The work does not need to be done on research stations; on-farm trials on carefully chosen sites in a range of rainfall zones and with varying soil depth can provide information on the response of crops to variable water regimes (ICARDA 1986). If appropriate, sites with different altitudes will provide variable temperatures (Anderson *et al.* 1978). It is not even essential that special research plots be used. Measurements taken in well established farmers' crops, perhaps with superimposed management factors, can yield valuable data. It is essential, however, that the conditions of the site are characterized so that predictive relationships between site variables and crop response can be developed. Data on weather conditions and soils are most important. Farmers, given rudimentary training, can become enthusiastic and reliable weather observers.

An alternative way to study the interactions of water and temperature is through the use of computer simulation models of crop growth and yield in conjunction with historical records of weather. These models incorporate much of what is known about the response of crops to environmental conditions, including some management practices, in a mathematical form, and allow us to 'grow' crops on the computer. In this way, by using long term weather records from a number of sites we can study the effects on crop yields of variability of conditions in space and time. Depending on the purpose, variability in soil type and soil depth may or may not be included.

For example, we can look at variability in time at one place. Figure 6a shows, for a location near Aleppo, that there is little relationship between the length of the growing period of a single wheat cultivar and the seasonal rainfall. In this simulation, where soil water storage capacity was assumed to be non-limiting, the length of the growing season is determined by the time of the start of the rain in autumn, the temperature throughout the season, and to a lesser degree the photoperiod and the time of the end of the rains. At this site there is no relation between the time of the start of the season (simulated germination date) and the total seasonal rainfall (Fig. 6b); nor is there, in the main, a relationship between the length of the growing period and crop yield (Fig. 6c). Not surprisingly, the factor having the greatest influence on yield is seasonal rainfall (Fig. 6d).

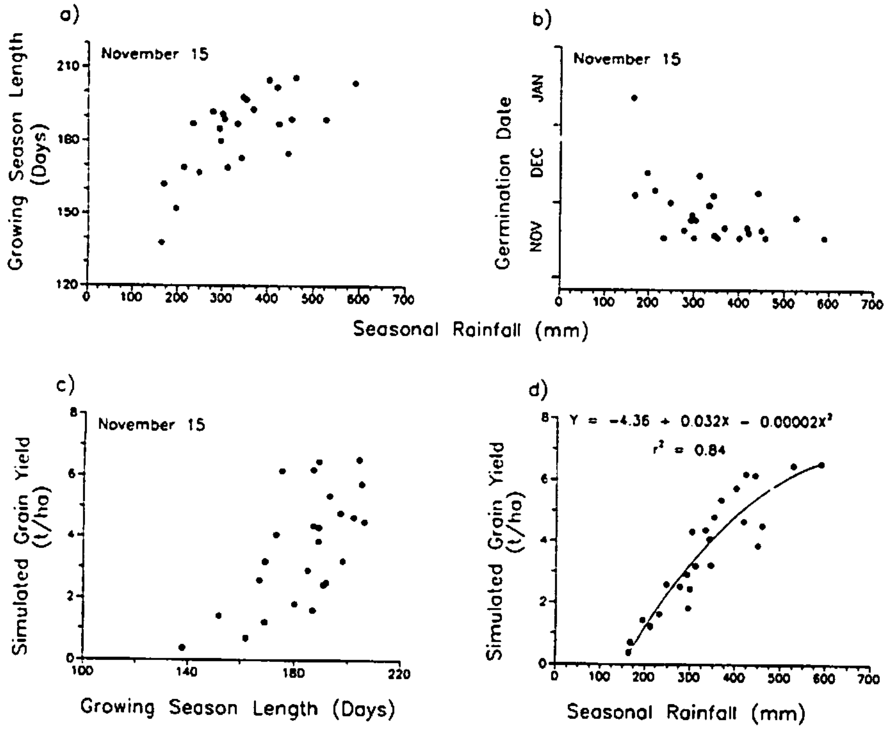


Fig. 6 Computer simulation studies of crop-environment interactions: a) Simulated length of the growing season; b) Simulated germination date; c) Relationship between simulated growing season length and simulated grain yield; d) Relationship between seasonal rainfall and simulated grain yield.

In another study, a simulation model of wheat growth and yield was used to examine differences in water and temperature regimes between lowland sites in West Asia and North Africa. All conditions except the weather were assumed to be the same at both sites, and a single cultivar of wheat was used. The simulations indicate a large difference between the sites in the dryland yield potential (Fig. 7a). While the yields are very variable in both environments, at Khouribga rainfall accounts for only 45% of the variability, whereas at Muslmieh, it accounts for 85%. The model was set to irrigate liberally after germination in order to identify the proportion of the yield variability due to temperature. This is relatively small at Muslmieh, but large at Khouribga (Figure 7b). Examination of the crop development patterns simulated by the model led to the conclusion that the cultivar is poorly adapted to the warmer winters of Morocco because it flowers too early to make full use of the water resources of the environment. From this analysis it was possible to suggest characteristics which cultivars need to fit their growth pattern to the environment of Morocco (Harris 1990).

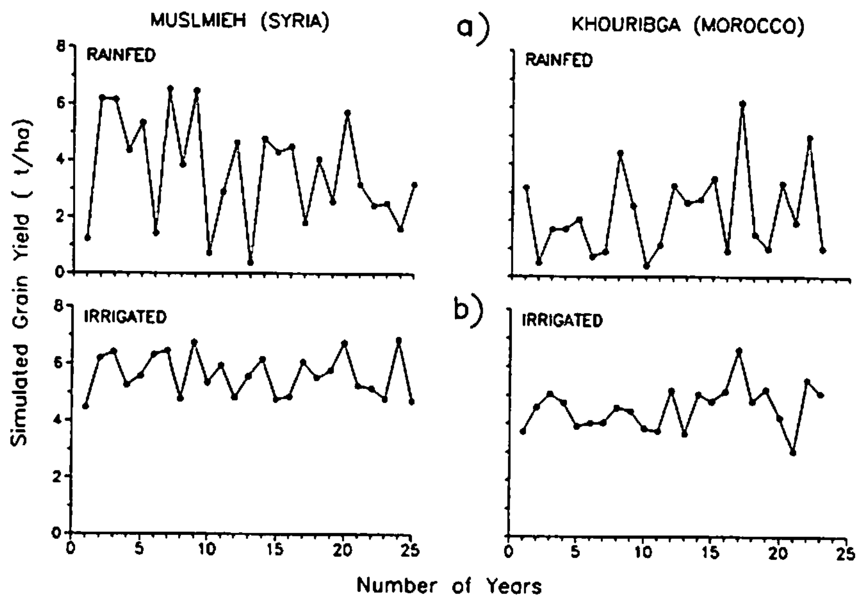


Fig. 7 a) The impact of variability in rainfall and temperature on simulated grain yield (t/ha) at two sites.
b) The impact of variability in temperature on simulated grain yield (t/ha) at two sites.

A third example shows how a model can be used to assist in management decisions. We know that the previous crop can influence the amount of nitrogen which is available in the soil for the next crop. The question is: can we use this knowledge to improve fertilizer recommendations? The growth of wheat was simulated for two sites with contrasting rainfall regimes, and for two preceding crops. Soil nitrogen levels are greater after summer crops than after lentil, and these differences were included in the data to run the model. The growth and yield of unfertilized crops, and of those fertilized at the recommended rate, were simulated.

The results (Fig. 8) clearly show that at the wetter site, Jindiress, fertilization with nitrogen at the recommended rate will increase yield regardless of the previous crop. However, where there is less rain, at Muslmieh, there is no response to nitrogen after a summer crop, and therefore little point in recommending its application.

Simulation models are powerful tools which can help us to understand variability and to learn how to manage within it. They provide a way to evaluate findings from short term research in the light of long term variability. And they allow us to extrapolate site specific research findings across space to areas with somewhat different weather conditions and soils. However, they cannot replace sound agronomic research as the truth of their predictions always needs to be tested against good agronomic data.

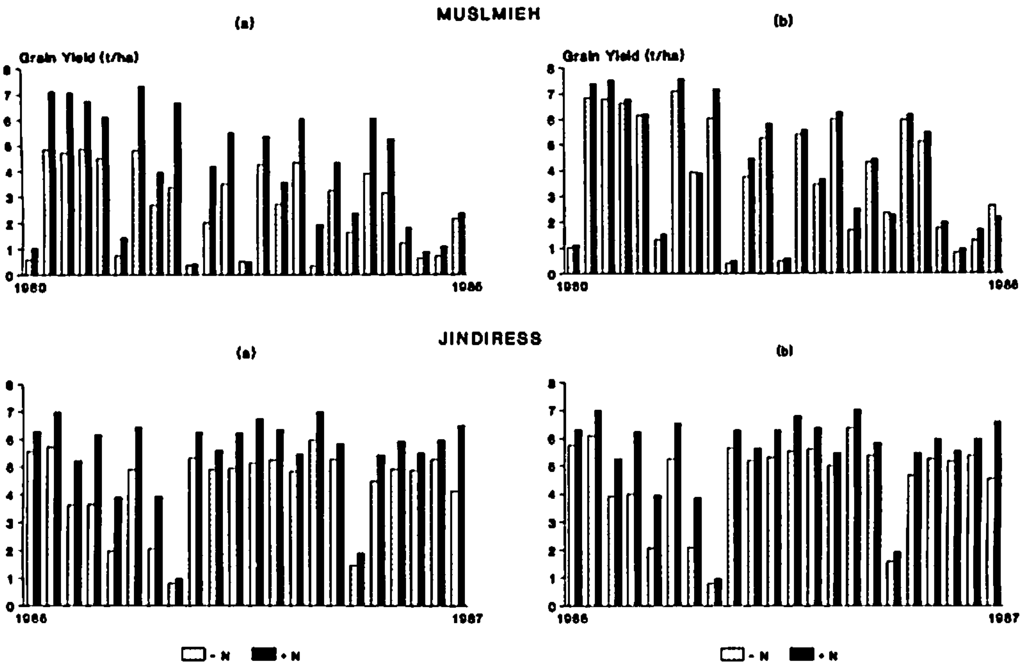


Fig. 8 Simulated grain yield (t/ha) of Sham 1 wheat following (a) lentil and (b) melon at two sites in Northwest Syria using long term daily weather data.

The left hand bar for each pair (years') of data is for zero N and the right hand bar for 80 kg N/ha.

References

Anderson, W.K., Smith, R.C.B., and McWilliam, J.R. 1978. A systems approach to the adaptation of sunflower to new environments. I. Phenology and development. Field Crops Research 1:141-152.

AOAD (Arab Organization for Agricultural Development) 1978. An Agroclimatic Atlas of the Arab World. AOAD, Khartoum, Sudan.

Brichambaut, G. de and Wallen, C.C. 1963. A study of agroclimatology in the semi-arid and arid zones of the Near East. World Meteorological Organization, Geneva, Switzerland.
Cooper, P.J.M., Harris, H.C. and Goebel, W. 1989. Climatic variability and food security in West Asia and North Africa. *in* Proceedings of an International Symposium on Climate and Food Security, New Delhi, India. February 1987, IRRI, Los Banos, Philippines.
El Mourid, M. 1988. Performance of wheat and barley cultivars under different soil moisture regimes in a semi-arid environment. Unpublished Ph.D. Thesis, Iowa State University, Ames, Iowa, USA.
Emberger, L. 1955. Une classification biogeographique des climats. Recherches et Travaux des laboratories de botanique, de geologie et de zoologie. Faculty of Science, Montpellier, Serie botanique 7:3-43.
FAO (Food and Agriculture Organization of the United Nations) 1978. Report on the agroecological zones project: Methodology and the results for Africa. World Soil Resource Report 481. FAO, ROme, Italy.
Gregory, P.J. 1991. This volume
Hall, A.E., Foster, K.W., and Waines, J.G. 1979. Crop adaptation to semi-arid environments. Pages 148-179 *in* Agriculture in Semi-arid Environments (Hall, A.E., Cannell, G.H., and Lawton, H.W., eds). Springer-Verlag, Berlin, Germany.
Harris, Hazel C. 1990. The relative impact of water and temperature constraints in lowland areas of West Asia and North Africa. Paper presented at an International Symposium on Breeding/Physiology of Winter Cereals for Stressed Mediterranean Climates. Montpellier, France, July 3-6, 1989.
ICARDA 1986. Pages 27-28 *in* Annual Report for 1986. Aleppo, Syria.
ICARDA-FRMP 1987. Pages 41-69 *in* Annual Report for 1987. Farm Resource Management Program. Aleppo, Syria.
Kassam, A.H. 1981. Climate, soil and land resources in North Africa and West Asia. Plant and Soil 58:23-28.
Kassam, A.H. 1988. Some agroclimatic characteristics of high-elevation areas in North Africa, West Asia, and Southeast Asia. Pages 1-32 *in* Winter Cereals and Food Legumes in Mountainous Areas (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds). ICARDA, Aleppo, Syria.
Megis, P. 1964. Classification and occurrence of Mediterranean-type dry climates. *In* Land Use in Semi-Arid Mediterranean Climates. Arid Zone Research 26. Unesco, Paris, France.
Mizrak, G. 1988. Agroecological zones of Turkey and their importance in wheat research. Pages 33-40 *in* Winter Cereals and Food Legumes in Mountainous Areas (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds). ICARDA, Aleppo, Syria.
Oram, P. 1980. What are the world's resources and constraints for dryland agriculture? Pages 17-78 *in* Proceedings of the International Congress on Dryland Farming. South Australian Department of Agriculture, Adelaide, South Australia, Australia.
Russell, J.S. 1977. Introduction. Pages 3-5 *in* Soil Factors in Crop Production in a Semi-arid Environment (Russell, J.S. and Greacen, E.L., eds). University of Queensland Press and Australian Society of Soil Science, St. Lucia, Queensland, Australia.
Sabet, Y. 1986. [Research on the infiltration capacity of soils cultivated for dry farming under the climatic conditions of north-west Syria, Aleppo region: use of a sprinkling infiltrome-

ter]. Unpublished PhD Thesis, Institute National Agronomique Paris-Grigon, France. (In French: Arabic and English abstracts).
Schilfgaarde, J. van and Rawlins, S.L. 1983. Water resource management in a growing society. Pages 517-530 *in* Limitations to Efficient Water Use in Crop Production (Taylor, H.M., Jordan, W.R. and Sinclair, T.R., eds). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, USA.
Steiner, J.L., Day, J.C., Papendick, R.I., Meyer, R.E. and Bertrand, A.R. 1988. Improving and sustaining productivity in dryland regions of developing countries. Advances in Soil Science 8:79-122.
Thornthwaite, C.W. 1948. An approach towards a rational classification of climate. Geographical Review 38:55-94.

An increase in WUE may be achieved through improved crop management or through changing the plant itself. Any improvement in management will result in improved WUE, although the precise practice will depend on local conditions. Simply increasing water supply through irrigation will not necessarily increase WUE because there is frequently an interaction between water supply and fertilizer: if water supply is increased without increasing fertility WUE may decrease (Gregory, Jabbour).

Many C_4 crops, which are more efficient than C_3 because of different photosynthetic pathways, cannot be grown in the Mediterranean region; their temperature requirements are not matched to the seasons when water is available. When there is precipitation it is too cold for growth and frost will kill C_4 plants. Changing the photosynthetic nature of C_3 crops so that they can produce as much dry matter as C_4 crops is not possible, but there is variability within C_3 species in transpiration efficiency. ^{12}C and ^{13}C discrimination studies may identify those genotypes with greatest transpiration efficiency, but attempts to isolate them have so far proved unsuccessful (Acevedo). Phenotype and environment certainly need to be matched carefully: earliness of heading and shape and angle of flag leaf are likely to be particularly important (Gregory, Khan, Kun).

Increasing leaf area to increase total dry matter will not have a negative effect on grain yield, even in dryland areas. On the contrary, work in this region and in Australia has demonstrated the desirability of increasing early growth (leaf area); this has the effect of covering the soil surface, thus reducing evaporation and increasing growth without additional water use (evapo-transpiration). Provided that water is available at anthesis and pollination, grain yields will increase. In general, large grain yields are a consequence of large crops. If the potential for high yield is not achieved by anthesis then grain yield will be low (Mosseddeq; Gregory). However, it is essential physiological development of the cultivar is well matched to the conditions of the environment.

Early crop establishment, so that as much of crop growth as is possible takes place before the VPD becomes large in the spring, is one way to improve WUE. The use of supplementary irrigation to guarantee early establishment may be a very efficient way to use limited water resources (Bolton). If fallows are replaced by a legume, leading to continuous cropping, water applied in this way may substitute for fallow stored water, which can be used by crops very efficiently (Jones). The practice would be expected to be most effective on light soils where the water added as supplementary irrigation would be stored at depth in the profile.

The stage of crop growth at which water stress will most affect yield is in the period just before flowering and at flowering (and pod set in legumes). Use of cultivars that will flower as early as is possible and still avoid the risk of frost damage, is one way to minimize the risk of water stress at this critical stage. Another way may be to select for plants which have a rapid rate of grain filling. The use of supplementary irrigation as suggested above on coarse textured soil, or direct application of supplementary irrigation where it is available, would prevent stress. But for rainfed crops in regions of variable rainfall distribution there will always be a risk that yields will be reduced by water stress around flowering.

Another stage where water stress can limit yields is in early seedling growth when a dry spell may reduce the plant population. Farmers rely on deep seeding to ensure that germination does not occur until there is enough water stored in the soil to prevent damage from a dry spell at this stage (Shehadah).

Tillage and Stubble Management

Tillage and Stubble Management

FLOYD E. BOLTON

Department of Crop Science, Oregon State University, Corvallis OR 97331-3002, USA

Abstract

Conventional or clean tillage has a long traditional and historical basis in rainfed cropping areas of the world. Exploitation of the organic matter to mineralize nitrogen and other plant nutrients was used for many decades before yield levels began to drop. When fertilizer materials became available, the tradition of clean tillage was strongly ingrained and is still widely used today. In the past, stubble residues were used for feed, fuel, and if in excess, were burned. In developing countries, crop residues are still used for animal feed and fuel. Rapid declines in organic nitrogen and carbon are often the result of removing all crop residues. When residues are returned to the soil, even by turning under, this decline is reduced.

Conservation tillage, which requires that stubble residues remain on or near the soil surface, is becoming more widely used. A general rule for erosion control is to leave 30% of the surface covered for water erosion and/or 1120 kg/ha of stubble on the surface for wind erosion control.

Minimum and no-till cropping systems, which leave most of the stubble residues on the soil surface, have not been entirely successful in semi-arid regions. In humid regions where spring-planted crops (corn, soybeans) are grown in wide rows, these systems are being widely adopted. Research is being conducted on stand establishment, fertilizer placement, weed control, and stubble management for better adaptation to semi-arid conditions.

The ultimate cropping systems will probably be a compromise between clean tillage, minimum tillage, and no-tillage, with each being used as circumstances permit.

Historical and Traditional Tillage Practices

The first cultivation of virgin land was done by turning over the sod surface to expose the bare soil underneath. Clean cultivation became the normal or conventional practice. Because of the high levels of organic matter in virgin soils, the more tillage, the more nitrogen was mineralized and the greater the crop yields. The tradition of clean cultivation with multiple tillage operations was considered the mark of a "good" farmer. Because the release of plant nutrients was so great and crop yield response was good, the concept of clean tillage became firmly ingrained in farmer practices.

Removal of crop residues for feed or bedding for animals, or for fuel, building material and other uses was commonplace. When more crop residues were present than needed for these other purposes, then they were burned in the field. In many cases, the burning released more plant nutrients, and further increased crop yields, thus further enhancing the concept or tradition of clean cultivation. In the humid Eastern United States, this quickly led to depletion of soil fertility and the land was "worn out". Because of the abundance of land, the farmer could clear a new field and begin the cycle again. As the history of both the world and the United States shows, this was a widespread practice until most of the land resources were used.

Research on tillage practices lagged far behind the development of agriculture in the United States. Most of the techniques and practices used were those that early settlers had learned from agriculture in Europe. These practices were developed in the more humid regions and had to be adapted to the drier environments of the Western United States. Agricultural research on farming practices began in the United States in the 1890s with the establishment of the land grant college system under President Abraham Lincoln. By this time, much of the Western United States was under cultivation and more land was being tilled each year.

The effect of tillage, especially ploughing, over long periods of time has been documented in only a few research studies. One such study has been conducted in Oklahoma, with a 96 year history of ploughing annually after producing a wheat (*Triticum aestivum*) crop (Webb *et al.* 1980). The changes in organic matter and nitrogen over time are illustrated in Fig. 1. There was a rapid decline in organic matter and nitrogen for the first 30 years (1893-1924) with a gradual levelling off for the next 30 years (1924-1954). Since about 1957, organic matter and nitrogen have remained relatively stable.

It was found in early years that phosphorus applications increased wheat yields, but through 1957 no yield increases resulted from application of nitrogen, potassium ,or lime. These findings further indicate that ploughing or clean cultivation resulted in mineralization of the organic matter into sufficient nitrogen to maintain wheat yields. In summarizing the results, Webb *et al.* (1980) stated that:

1. After 87 years of cultivation, both nitrogen and phosphorus are required for maximum yields.

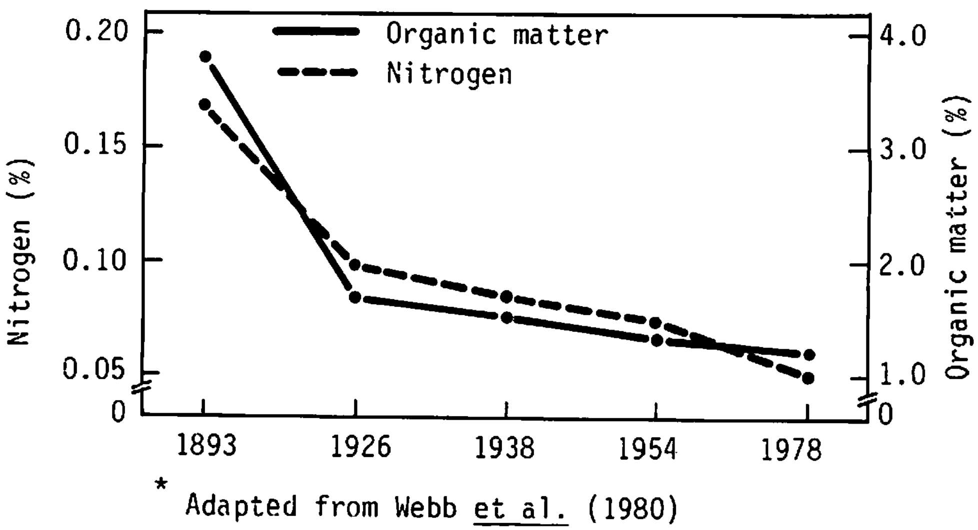


Fig. 1 Changes in organic matter and nitrogen content of surface soil on unfertilized soil, 1893-1987*.

2. Yield levels have increased with each fertilizer treatment, but the largest increase was on plots that received both nitrogen and phosphorus.
3. Commercial fertilizers and barnyard manure gave equal yields when the amount of nitrogen in each material was equivalent.
4. Potassium and lime have had no significant effects on wheat yield.
5. Soil organic matter seems to have reached a stable level and shows no further decline.

The overall conclusion reached in this long-term study is that wheat yields can be maintained at maximum levels as long as adequate plant nutrients are available to the crop under a clean tillage (ploughed) system. It should be noted that all the crop residues remaining after harvest were left in place and turned under during cultivation.

The effect of removing the crop residues, as is common in many countries, was not addressed in the above study. No long-term studies of residue removal were found, but several studies involving burning of residues after harvest have been conducted. Biederbeck *et al.* (1980) found that in Saskatchewan, Canada, burning of cereal straw as compared to incorporation for 20 consecutive years, reduced total nitrogen, carbon, water conductivity, and aggregate stability, and increased soil compaction. In contrast, it was found that 34 years of either burning or incorporation of stubble had little effect on the structure of a friable gray swelling clay (Dexter *et al.* 1982).

A long-term crop residue study (Rasmussen *et al.* 1980), initiated in 1931, and involving seven residue treatments (Table 1) provides some significant insights into the effects of tillage and residue management. This trial, located in the Pacific Northwest of the United States on

Table 1. History of crop residue treatments, 1931 to 1976, on a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxerolls) near Pendleton, OR, USA[1]

Symbol	Descriptive of residue management[a]	Nitrogen applied, kg/ha/crop
AB	Wheat straw burned in autumn	0
SB	Wheat straw burned in spring	0
-N	Straw incorporated into soil	0
+N	Straw incorporated into soil	34(45)[b]
++N	Straw incorporated into soil	90[c]
PV	Straw plus 2.24 t/ha of dry pea vines incorporated into soil	0
M	Straw plus 22.4 t/ha of strawy manure incorporated into soil	0

[a] All treatments mouldboard ploughed to the 20-cm depth in spring of fallow year. Pea (*Pisum sativum*) vines or strawy manure incorporated in late March or early April when wheat straw was incorporated.

[b] From 1931-66, 34 kg N/ha; from 1967-76, 45 kg N/ha.

[c] Initiated in 1967.

[1] Adapted from Rasmussen *et al.* (1980)

a relatively deep silt loam soil under semi-arid conditions, showed large losses of organic matter during the first 50 years of cultivation. Only the addition of 22.4 t/ha of manure to straw residue before incorporation prevented a decline in soil nitrogen (N) and organic carbon (C) (Fig. 2).

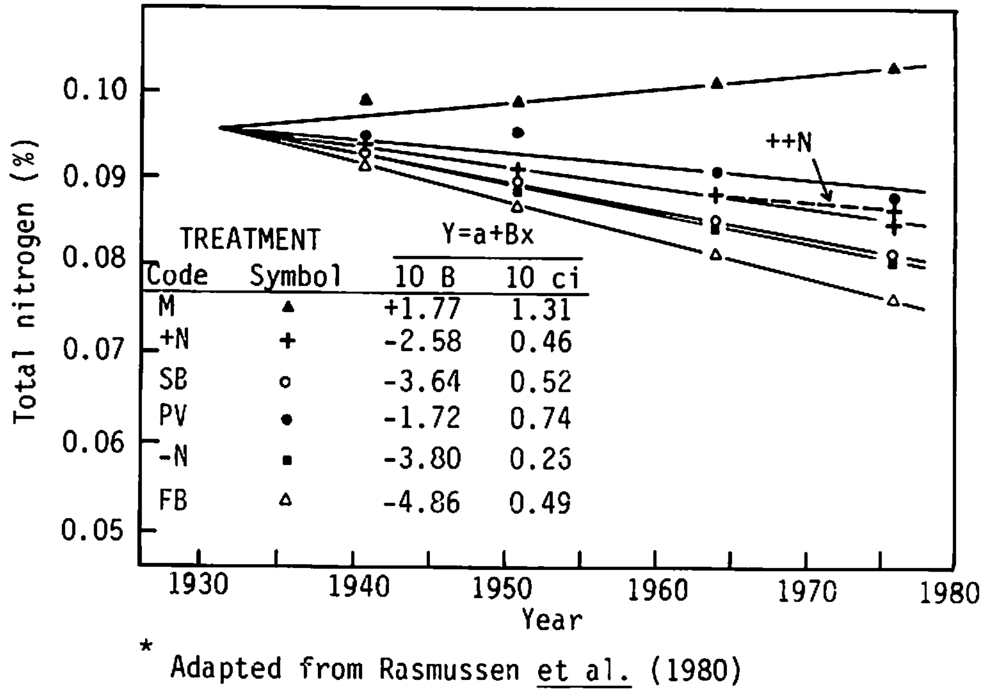


Fig. 2 Soil N level at 0-30 cm depth as related to crop residue treatment in a Walla Walla soil in wheat-fallow rotation 1931-76*

It was found that changes in N and C were primarily confined to the top 20 cm of the soil. Soil C:N ratios differed between treatments in proportion to the rate of N loss; they were highest in burn or straw only treatments (AB, SB, -N, + N, PV) and lowest in the manure (M), treatment. The amount of organic C supplied by each treatment was highly correlated with changes in soil C regardless of the type of residue applied. It was concluded that about five t/ha/year mature crop residues are required to maintain soil organic matter at its present level when cropped in a wheat-fallow rotation in this climatic zone.

In a later study on these same plots (Pikul *et al.* 1986), it was determined that crop residue and/or manure added to the soil over a 54 year period greatly increased the saturated hydraulic conductivity. Autumn burning of stubble after harvest greatly increased bulk density and compaction and reduced the saturated hydraulic conductivity. The treatments involving stubble incorporation or spring burning had only a moderate effect on these parameters. Most of the differences in physical or chemical parameters were confined to the top 30 cm of the soil profile.

A 44-year study, in the same region as the above trials, involving three primary tillage treatments, conventional (plough), stubble mulch (disc) and stubble mulch (subsurface sweeps) showed little difference in nitrogen fertilization effects (Rasmussen and Rohde 1988a). However, organic nitrogen and organic carbon in the top 7.5 cm were 26 and 36% higher, respectively, in the two stubble mulch systems than in conventional tillage. Below 7.5 cm the three tillage treatments were equal in organic nitrogen and carbon. All crop residues were either turned under (22 cm depth) or incorporated in the top 15 cm of the soil surface. Since nitrogen fertilizer effects on organic nitrogen and carbon were identical for the tillage systems, it was suggested that nitrogen transformations were the same for all three primary tillage systems.

It is apparent that conventional (plough) tillage systems over time have significant effects on the soil surface. Infiltration of water is usually reduced, organic matter and soil nitrogen levels are lowered, and soil compaction is increased. However, most studies show that grain yields are usually equal to or greater than stubble management systems that leave the residues on or near the surface (Hammel 1987; Rasmussen and Rohde 1988b). When the crop residues are completely removed or burned, crop productivity is lowered over time because of the effect on the physical and chemical properties of the soil surface.

There are certain advantages to conventional or clean tillage systems that cause farmers to continue to use them. Weed problems are minimal, seedbed preparation is not hampered by residues, certain diseases that are carried in residues are controlled, and stand establishment is usually good. There is also the tradition of a clean tilled field having a certain aesthetic value, and the concept of what constitutes a "good" farmer. In addition, in most cases the productivity is consistently maintained at a relatively high level. It is a time-honored tillage method with less risk than most stubble mulch systems. However, the conventional clean tillage system has a major disadvantage; it leaves the soil vulnerable to the hazards of wind and water erosion (Douglas *et al.* 1987a).

Wind and Water Erosion

There is no doubt that an exposed soil surface (clean tilled) is more subject to wind and water erosion than a soil covered with crop residues. Ample evidence of world-wide soil erosion is to be seen everywhere that soils are cultivated. Clean tillage over a wide area, coupled with drought conditions for several seasons led to severe wind erosion in the Central Great Plain of the United States in the 1930s. Efforts to control erosion brought about the establishment of the Soil Conservation Services (SCS) in 1935. The primary function of the SCS was to control wind and water erosion throughout the United States. A system of subsidy payments for using soil conservation practices was initiated which paid farmers for using approved techniques. Meanwhile, the U.S. Department of Agriculture began extensive research programs at research stations located in different regions around the country. Conservation tillage, residue management, contour farming, terracing, watershed management programs and conservation practices were developed. Many farmers used conservation practices as long as the subsidy payments were available, but reverted to traditional and conventional practices when the payments stopped. However, large numbers of farmers accepted conservation practices and continue to use them today. There is still a considerable proportion (40-50%) of farmers using conventional (clean tillage) methods and an even greater percentage (75-85%) using clean tillage on a portion of their land every year.

Estimates of soil loss due to wind and water erosion can vary widely and lead to some disagreements between researchers, soil conservationists, and farmers (Johnson 1988). The terms "soil erosion" and "soil loss" are often used with synonymous meanings when they are actually not the same. Soil can be eroded without being lost from the system. The Universal Soil Loss Equation (USLE) and the Wind Erosion Equation (WEE) are used to estimate soil erosion, but not necessarily soil loss. The equations measure soil movement or conditions that lead to soil movement but not soil loss. Soil may be deposited near the erosion site, but may never leave the farm or field. The actual loss, i.e., the movement of soil in sediment off the farm or field, ranges from 1 to 30% of the amount actually eroded. This may often lead to exaggerated estimates of soil loss. The increased awareness of the general public to environmental issues and the mission and zeal of soil conservationists to control erosion, often comes into conflict with those practices which the farmer feels are necessary to remain productive and economically viable. Most farmers are keenly aware of soil erosion and its effects on productivity and make great efforts to control it. However, the complete control of soil erosion is difficult to achieve and may not be possible without removing land from cultivation. The reduction of soil loss to minimum or acceptable levels is a goal that can be achieved, but requires very careful management of the soil resources. The management of crop residues on or near the soil surface in a manner which reduces the hazards of soil erosion, yet allows the farmer to maintain his productivity, is the key to good soil management.

Conventional Tillage versus Minimum or No-till Systems

The question often asked is how much tillage is actually necessary for economic crop production? The answer to this question usually ranges from "none" to "a lot"! The true answer probably lies somewhere in between. The variation from field to field, season to season, crop to crop, region to region is such that any one system will probably not work every time in every location. It is apparent that some tillage is required in any system that is to remain productive. It is also apparent that the careful use of crop residues to control erosion and maintain productivity is a complicated process requiring a relatively high degree of soil management skill (Fenster and Peterson 1979).

Most of the recent research data comparing yields of cereal grains (mostly wheat) grown under conventional tillage systems with minimum or no-till systems, show an advantage to conventional tillage (Wilhelm *et al.* 1982; Raming *et al.* 1987; Varvel *et al.* 1989). The term "conventional" does not always mean ploughing or clean tillage, as often heavy discs and cultivators are used many times to reduce stubble residues lying on the surface to minimum levels equal to ploughing. The main difference is that the residues are mixed in the upper 10-15 cm rather than buried 15 to 20 cm in depth. In many instances, multiple tillage operations which thoroughly mix crop residues result in as much yield as from ploughing.

Conservation tillage has been defined by the Conservation Technology Information Center (CTIC) as "any tillage and planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, at least 1000 pounds of flat, small grain residue per acre (1120 kg/ha) is on the surface during the critical erosion period".

Past experience has shown that in semi-arid regions, where yields of grain and stubble aftermath are not usually very great, only a few tillage operations will reduce residue below the recommended levels (Douglas *et al.* 1987a). In better yielding regions, the reduction of crop residues to manageable levels for seeding operations becomes a major problem and may require multiple tillage operations (Elliot *et al.* 1987; Klepper *et al.* 1987).

Using the CTIC definition of conservation tillage as the standard for stubble management, i.e. 30% soil cover for water erosion and 1120 kg/ha surface residue for wind erosion, it becomes apparent that several problems still remain to be solved before minimum or no-till systems can equal the production of conventional systems.

Tillage, Residue Management, and Water Use Efficiency

Water use efficiency (WUE) in it simplest terms is defined as follows:

$$\frac{\text{Economic Product}}{\text{Precipitation}} = \text{Unit of Product/Unit of Water}$$

Tillage and residue management are primarily concerned with two factors: 1) maximum infiltration of water into the soil profile and 2) the storage of that water for later crop use. Several studies have shown that use of crop residues increases infiltration and reduces evaporation resulting in increased water storage in the soil profile (Fenster and Peterson 1979; Wilhelm *et al.* 1982; Hammel 1987; Ramig *et al.* 1987). However, in only a few instances did this additional water increase the yield or WUE. The probable reasons for these results are that the crop residues reduced stands or seedling vigor (Douglas *et al.* 1987b; Klepper *et al.* 1987), caused weed control problems (Hanway 1976; Hammel 1987) and/or affected fertilizer responses (Varvel *et al.* 1989). Research in these areas is continuing and hopefully solutions will be found. Increased water storage without increased yield or WUE is of little value.

The Future for Tillage and Stubble Management

The conservation of the soil resource must be of the highest priority. There is little or no "new" land suitable for cultivation left in the world to be exploited as in the past. Research during the past 20 years has clearly shown that stubble management can control or reduce soil erosion, help maintain the soil's productivity, increase water storage and reduce production costs. The difference in yields between conventional (clean tillage) and conservation tillage has become smaller each year. The tradition of conventional tillage systems is slowly being overcome as new research information is obtained. As with most innovations, a compromise between the new concept and the old system will be required. Minimum or no-till systems may require a conventional (clean tillage) cycle every so often before returning to a cycle of reduced tillage. A stubble management system is certainly going to be more complex and require more management skill. For example, the uniform distribution of residues at harvest will be required in order to manage the soils properly for the subsequent crop (Douglas *et al.* 1987b). New types of tillage and seeding equipment have been and are being developed that will solve some of the early problems (Hyde *et al.* 1987) in using conservation systems. New fertilizer materials and delivery systems will become available to help overcome fertility problems (Power *et al.* 1986), and decomposition of crop residues will be better understood in the future (Douglas *et al.* 1980).

The conventional system of the past was and is a fairly reliable and consistent tillage system. Many of the problems now faced in conservation systems were merely turned under the soil surface. However, we can no longer afford to subject the diminishing soil resources to erosion, declining fertility and reduced productivity. Each season brings a different set of challenges. We need to develop the knowledge to meet these challenges and use it to preserve our soil resources.

All will agree that the use of crop residues in soil management systems is vital to maintain productivity. The proper tools and equipment, and the management ability to recognize when and how to use them, will allow us to continue to produce food for the future. Maintaining our soil is a task too important to ignore: without a reliable, constant source of adequate food, all the rest of the world's goods have little meaning.

References

Biederbeck, V.O., Campbell C.A., Bowren, K.E., Schnitzer M., and McIver R.N. 1980. Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. Soil Science Society of America Journal 44:103-111.

Dexter, A.R., Hein, D., and Hewitt, J.S. 1982. Macrostructure of the surface layer of a self-mulching clay in relation to cereal stubble management. Soil Tillage Research 2:251-264.

Douglas, C.L., Jr., Allmaras, R.R., Rasmussen, P.E., Ramig, R.E. and Roager N.C. Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Science Society of America Journal 44:833-837.

Douglas, C.L., Jr., Ramig R.E., Rasmussen, P.E. and Wilkins, D.E. 1987a. Residue management: Small grains in the Pacific Northwest. Crops and Soils, Vol. 39, No. 9:22-24.

Douglas, C.L., Jr., Rasmussen, P.E., Allmaras, R.R. and Baarstad, L.L. 1987b. Residue distribution behind combines. Pages 557-559 *in* STEEP-Conservation Concepts and Accomplishments (Elliot, L.F., ed.) Washington State University Press, Pullman, WA, USA.

Elliott, L.F., Stroo, H.F., Papendick, R.I., Douglas, C.L., Campbell, G.S. and Stott, D.E. 1987. Decomposition of surface managed crop residues. Pages 81-91 *in* STEEP-Conservation Concepts and Accomplishments (Elliott, L.F., ed.) Washington State University Press, Pullman, WA, USA.

Fenster, C.R. and Peterson, G.A. 1979. Effects of no-tillage fallow as compared to conventional tillage in wheat-fallow system. Nebraska Agricultural Experiment Station Research Bulletin 289.

Hammel, J.E. 1987. Long-term effects of conservation tillage on wheat production in Northern Idaho. Page 240 *in* American Society of Agronomy Abstracts.

Hanway, D.G. 1976. Cultural advances in integrated dryland production systems. Pages 210-227 *in* Proceedings of Great Plains Conservation Tillage Workshop. August 10-12, 1976, Fort Collins, Colorado, USA.

Hyde, G.M., Wilkins, D.E., Saxton, K., Hammel, J., Swanson, G., Hermanson, R., Dowding, E., Simpson, J. and Peterson, C. 1987. Reduced tillage seeding equipment development. Pages 41-56 *in* STEEP-Conservation Concepts and Accomplishments (Elliott L.F., ed.) Washington State University Press, Pullman, WA, USA.

Johnson, R.R. 1988. Putting soil movement into perspective. Journal of Production Agriculture 1:5-12.

Klepper, B.L., Rickman, R.W. and Chevalier, P.M. 1987. Wheat plant growth in conservation tillage. Pages 93-107 *in* STEEP-Conservation Concepts and Accomplishments (Elliott L.F., ed.) Washington State University Press, Pullman, WA, USA.

Pikul, J.L., Jr., and Allmaras, R.R. 1986. Physical and chemical properties of a Haploxeroll after fifty years of residue management. Soil Science Society of America Journal 50:214-219.

Power, J.F., Wilhelm, W.W. and Doran, J.W. 1986. Recovery of fertilizer nitrogen by wheat as affected by fallow method. Soil Science Society of America Journal 50:1499-1503.

Ramig, R.E., Saxton, K.E., Massee, T.W., Campbell, G.S. and Thill, D.C. 1987. Water conservation under reduced tillage systems. Pages 125-136 *in* STEEP-Conservation Concepts and Accomplishments (Elliott, L.F., ed.). Washington State University Press, Pullman, WA, USA.

Rasmussen, P.E., Allmaras, R.R., Rohde, C.R. and Roager, N.C., Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Science Society of America Journal 44:596-600.

Rasmussen, P.E. and Rohde, C.R. 1988a. Long-term tillage and nitrogen fertilization effects on organic nitrogen and carbon in a semiarid soil. Soil Science Society of America Journal 52:1114-1117.

Rasmussen, P.E. and Rohde, C.R. 1988b. Stubble burning effects on winter wheat yield and nitrogen utilization under semiarid conditions. Agronomy Journal 80:940-942.

Varvel, G.E., Havlin, J.L. and Peterson, T.A. 1989. Nitrogen placement evaluation for winter wheat in three fallow tillage systems. Soil Science Society of America Journal 53:288-292.

Webb, B.B., Tucker, B.B. and Westerman, R.L. 1980. The Magruder plots: Taming the prairies through research. Bulletin B-750. Agricultural Experiment Station, Oklahoma State University, Stillwater, OK, USA.

Wilhelm, W.W., Mielke, L.N. and Fenster, C.R. 1982. Root development of winter wheat as related to tillage practice in western Nebraska. Agronomy Journal 74:85-88.

Application of Known Conservation Tillage Practices in "Developing Country" Semi-arid Environments

C.S. OFORI

Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy

Abstract

While conventional tillage has been the main mechanized agricultural system practised to date, recent developments of soil conservation tillage practices have been successfully applied in many farm enterprises in developed countries, in particular in the United States of America and Australia.

However, there are constraints to the transfer of conservation tillage packages to semi-arid zones of many developing countries where livestock is an important part of the farming system. Crop residue, an essential component of conservation tillage, has many economic uses other than for soil and moisture conservation in these countries. Provision of other sources of feed for livestock has to be given more attention if crop residues are to be made available for soil and moisture conservation.

Research results obtained from some semi-arid regions indicate the need for conventional tillage on certain soils, especially sandy ones.

Training of farmers and technicians in conservation tillage and crop residue management is considered a prerequisite for prevention of further soil degradation and increasing crop yields.

Introduction

Extensive areas of cultivable agricultural land occur in semi-arid climatic zones. The climate, and soils of generally low inherent fertility, limit rainfed crop yields. A major constraint to production in these areas is the availability of soil moisture for plant growth. Annual rainfall in the dry-land areas ranges from 200 to 600 mm. Although this rainfall amount is relatively small, the intensity of the storms causes serious soil erosion particularly in periods when the soils have no vegetative cover. Farming practices ensuring soil and moisture conservation therefore are essential if the soils are to be protected from further degradation and crop yields improved.

Populations in the semi-arid regions are large and increasing at a fast rate. Although agricultural productivity in these areas is low,it is reasonably stable, and characterized by low-risk technology. This includes use of low input-levels such as little or no fertilizers, hand labour for weeding and other farm operations, and use of cultivars which are adapted to the variable climatic conditions and low inherent fertility of the soils. Increasing populations now require greater productivity per capita and unit of land. The traditional system which was satisfactory with low population pressure and could be easily accommodated by area expansion should now give way to a more intensive system of production.

Dryland farming practices have been well developed in countries such as the United States of America and Australia. However, the farming systems in these countries are different in many ways from those of most developing countries with similar agro-ecological zones. In the United States, for example, livestock is not a component of the present arable farming system. Crop residue management therefore is principally directed towards soil conservation practices with the objective of soil moisture conservation and erosion control.

Increased food production is a major concern in all the developing countries. To improve food production, increases in land productivity are essential, and for this purpose technological innovations that reduce costs are required. Tillage practices for seedbed preparation, weed control, conservation of moisture and erosion control are some of the important developments in modern agriculture. These practices are closely linked with developments and improvements in agricultural machinery.

In the last three decades, many developing countries, in the attempt to increase their agricultural production, have introduced large-scale mechanization and imported sophisticated agricultural machinery and technological packages. Almost all these packages were developed in countries other than where they are being employed. In many cases, the expected impact has not been achieved.

The purpose of this paper is to examine some of the conditions under which these technological packages, particularly conservation tillage, have been developed vis-a-vis the areas they are being transferred to, and to assess some of the prerequisites that need to be addressed for more successful application.

The Semi-Arid Environment

Climate.

Much has been written on the climate of the semi-arid environments, which in essence are characterized by high temperatures, high evapotranspiration rates, low total rainfall, high wind velocities and high solar radiation. While rainfall distribution is unreliable, it may fall with high intensity and therefore cause considerable erosion, particularly during the period when there is no, or inadequate, vegetative cover (Harris, this volume). These climatic attributes greatly influence crop production practices and farming systems. Crop varieties that can be grown under rainfed agriculture in these regions must have growing periods that fit into the climatic conditions. The season of the rainfall, whether summer or winter, plays an important role in moisture storage and availability to the following crop. This is an important factor to consider in transferring technological packages from one area to another. It is therefore essential to recognize the constraints imposed by the climate in developing suitable cropping strategies.

Soil.

It is well recognized that soil moisture availability is one of the major limitations to crop production in semi-arid areas. The soils in these areas vary from calcium-rich Luvisols (Alfisols) of the temperate zone to the base-depleted low activity clay Lixisols (Alfisols) in the semi-arid tropics. There are also extensive areas covered by black clay soils (Vertisols).

Some of the soils are sandy or sandy loam and tend to form surface crusts which limit water infiltration and increase surface runoff thereby causing erosion. Crusts may also interfere with seedling emergence and crop establishment. The texture of the soil and the effective depth of tillage are two important parameters which influence the amount of moisture that can be stored in the soil profile. The surface management practices of these soils must aim at increasing infiltration rates and conserving moisture for crop use. One approach is the maintenance of a surface mulch by leaving crop residues after harvest. The inherent fertility status of the soils in the semi-arid areas is poor with low values of organic matter and nitrogen, particularly in the tropics. Moreover, plant residues are either burnt or removed and therefore hardly contribute to the build up of the organic matter levels. Phosphorus and nitrogen deficiencies occur in many areas; there may also be micronutrient deficiencies, particularly zinc.

Dryland areas.

The limited data available has made the classification of dryland climates difficult. One useful classification, which indicates potential for land use, is into arid and semi-arid zones. These two zones, characterized by the length of growing period, are namely, the arid climates with less than 75 days of soil moisture sufficient for plant growth, and semi-arid climates with from 75 to 120 days (FAO 1987). The equivalent precipitation amounts to less than 200 mm in winter rainfall areas or less than 400 mm in summer rainfall areas for the arid zones. The semi-arid zones receive 200-500 mm of winter rainfall or 400-600 mm of summer rainfall.

The total extent of dryland areas in the world is extensive and they support a large population, as shown in Tables 1 and 2. Agricultural production in terms of both crop and livestock could be increased considerably if the major constraint, moisture availability, could be overcome.

Mechanized Agriculture in Semi-Arid Areas

Tillage practices have been well researched and developed in dryland farming areas of the United States of America. These practices have been introduced to a few countries in the

Table 1. Drylands in developing countries within regions (million hectares (%))

Growth days	Africa[1]	Southwest Asia	Southeast Asia	Central America	South America	East Asia	Total
1-74	488.0 (17%)	72.6 (11%)	47.4 (5%)	62.3 (23%)	114.6 (6%)	27.7 (3%)	812.6 (11%)
75-119	231.8 (8%)	61.8 (9%)	54.9 (6%)	14.5 (5%)	142.8 (8%)	70.4 (7%)	586.2 (7%)
Total Drylands	719.8 (25%)	134.4 (20%)	102.3 (11%)	76.8 (28%)	257.4 (14%)	98.1 (10%)	1388.8 (18%)
Total	2878.1	677.4	897.6	271.6	1770.2	954.6	7449.5

1 Excludes South Africa
Parentheses show percent of total land areas for each region, e.g. Africa
Source: FAO 1987.

Table 2. Human population in drylands in developing countries within regions (millions, 1975 (%))

Growth days	Africa	Southwest Asia	Southeast Asia	Central America	South America	East Asia	Total
1-74	33.1 (9%)	15.9 (12%)	46.1 (4%)	8.5 (8%)	9.3 (4%)	N.A.	112.9 (6%)
75-119	37.8 (10%)	24.3 (18%)	101.1 (9%)	3.7 (3%)	20.4 (9%)	N.A.	187.3 (10%)
Total Drylands	70.9 (19%)	40.2 (29%)	147.2 (13%)	12.2 (11%)	29.7 (14%)	N.A.	300.2 (15%)
Total (all lands)	380.2	136.3	1117.7	106.6	215.8	N.A.	1956.6

Parentheses show percent of total land area for each region, e.g. Africa.
Source: FAO 1987.

semi-arid regions with a view to increasing their agricultural productivity. With differences in the farming systems, climate and the soils, the desired effects of these practices, particularly on soil and moisture conservation, are yet to be fully assessed before their wider application can be recommended.

Currently practised conservation tillage.

Adoption of conservation tillage practices in the United States of America has been gradual. It is estimated that in 1982, conservation tillage was practised on about 25% of the tilled land, and the projection for 2010 is 50 to 80% (Office of Technology Assessment 1982). Several factors have contributed to the adoption of this technology to date, including awareness of serious national soil erosion problems, energy cost and higher production per unit of land (Allmaras and Dowdy 1985). Even in highly mechanized agricultural production systems, adoption of conservation tillage has been relatively slow. It is likely that this technology will take a much longer time to be adopted in many countries where mechanization has been introduced only recently. The two important conservation tillage practices that have been widely studied and tested, and which offer good prospects, are reduced or stubble-mulch tillage and no-tillage systems.

Reduced tillage.

Reduced tillage practices are improvements over conventional tillage. Not only are there considerable savings in energy requirements and investments in machinery and equipment, but also the physical effect of machinery on the soil is very much reduced through fewer passes, with a consequent decrease in soil compaction and damage to soil structure.

Reduced tillage may improve soil moisture availability throughout the growing season of the crop by increased infiltration and reduced evapotranspiration, particularly if residue remains on the surface, or by increased soil surface roughness as a result of seedbed preparation.

In the United States, for example, residue management is an important component in reduced tillage systems, but there are no uses for residues other than for soil and moisture conservation. In contrast, in many dryland areas of Africa, the Near East and Asia, reduced tillage practices should aim at good seedbed preparation with a rough soil surface, which will be effective in controlling water erosion and reducing wind velocity at ground level to check wind erosion. Crop yields in the dryland areas of Africa, the Near East and Asia are generally low with equally low residue yield. Moreover in many areas of the Near East and Africa, the residues are a main source of feed for relatively large herds of animals which may not belong to the farmer on whose land they graze. Therefore, there is usually no residue left in the critical period when the soil must be protected.

The amount of residue required to check erosion effectively has been estimated in many investigations. Various crops produce different amounts of residues. Crop rotation therefore is important in residue management and erosion control irrespective of the tillage system used. Results of studies on maize and soyabean (Siemens and Oschwald 1976; Mannering 1979), showed that the amount of soil loss was substantially larger from soyabean fields than from maize fields.

Reduced tillage practices are gradually being seriously considered in the crop production systems in some developing countries where advanced mechanization has been introduced. Much applied research work along with wide scale testing under local soil and climate conditions needs to be undertaken. In the Near East Region, results of tillage work in Northern Iraq indicated that spring tillage to a depth of 7-10 cm during a fallow period, followed by autumn tillage for seedbed preparation would be the most appropriate under the dryland farming system of cereal/fallow/cereal, in which the fallow lasts for 16-18 months and during which three ploughing operations are normally undertaken (El Fakhry and Sultan 1980).

The use of the traditional hoe for cultivation, widely practised in Africa, appears to affect soil structure much less than tractors and/or animal draught cultivation. Hoe cultivation, however, is less suitable for the present day cropping systems if yield levels are to be substantially increased while, at the same time, conserving the soil. Ridging or mounding for seedbed preparation, widely undertaken by the small farmer, are good tillage practices which are effective in conserving soil moisture. Mounding is more effective in building up soil fertility for the particular crop but appears less effective as a conservation measure to check water erosion.

No-tillage system.

One of the principles of the no-tillage system is the non-inversion of the soil. Surface residues assume an important role in soil and water conservation and herbicides are widely used to control weeds. Similar to reduced tillage, the objective is an effective control of wind and water erosion and reduction of evaporation losses. To achieve this it is essential to use the proper equipment with sufficient amounts of residue. The residues as already indicated are limited in the semi-arid areas and furthermore have alternative economic values in semi-arid areas in the Near East, Asia and Africa. In some cases the cash return for residue sold on a farm is higher than the income from the grain produced.

No-tillage systems have been widely studied in recent times with very positive results even though their adoption is still slow. The degree of success of this system is very much soil dependent. Results obtained on Lixisols (Alfisols) in the various agro-ecological zones of West Asia differ, depending on the climate, from semi-arid to humid zones. Lal (1986) listed the following as soil properties that favour the no-tillage system:

1. coarse textured surface horizon or self-mulching clayey soils with high initial porosity;
2. low susceptibility to soil compaction and crusting;
3. good internal drainage;
4. high biological activity of earthworms and other soil fauna; and
5. friable consistency over a wide range of soil moisture contents.

In many countries of West Africa, intensive soil surface management studies by IRAT in the semi-arid regions (Charreau and Nicou 1971; Charreau 1972; Nicou 1974a, 1974b; Chapart and Nicou 1976; Nicou and Chapart 1979; and Chapart 1981) indicate that no-till systems do not compare favourably with deep tillage and soil inversion in terms of decreasing losses due to water runoff and conserving water for plant growth. Although some of the results may be conflicting there is a strong indication that this is especially so on structurally inert soils of the Sahel region which benefit markedly from tractor or animal draught tillage (Charreau 1977). On the mostly sandy soils of the semi-arid regions in Botswana, Willcocks (1979a, 1979b, 1981) indicates that reduction in bulk density by mechanical tillage and by periodic subsoiling operations gives greater benefits than no-tillage practices. It would appear therefore that there is a need for additional research work on no-tillage systems on some of the soils in the semi-arid regions of Africa.

In India, some of the results reported by Boole *et al.* (1972), Malik *et al.* (1973) and Subramanian *et al.* (1975) indicate that the beneficial effects of tillage outweigh those of zero tillage.

A major problem in comparing results from many of these tillage experiments is the absence of the use of crop residues in the no-tillage treatments. Although in most of these semi-arid farming areas the use of crop residues for soil and water conservation may not be widely adopted under present-day practical farming conditions, it is essential to ascertain whether the system has advantages.

Adoption of Conservation Tillage and Agronomic Packages

The increasing cost of fuel and high investment in machinery and equipment are factors which will enhance the adoption of reduced tillage systems in countries already highly mechanized and in others improving their agricultural production systems. Animal draught power could be efficiently adapted to reduced-tillage systems. It is important, however, to re-examine the suitability of the implements in relation to the soils being cultivated.

Mechanized agriculture is gaining ground, albeit at a slow rate, in many developing countries. There is ample evidence that in most cases the basic principles of soil and water conservation are far from being properly applied. The producer, unfortunately, has not been made aware of the necessity of introducing some of these measures, which are not translated to him in terms of increased productivity. There are instances of mechanization in countries without the appropriate choice and matching of equipment to the soil conditions and more important still, adequate training of the producers -- the farmers and technicians -- in the proper use of these machines and equipment.

Tillage systems cannot achieve the desired goal of good seedbed preparation for increased crop yield and soil and water conservation without appropriate agronomic practices, particularly crop rotations. Stubble-mulch tillage requires crops in the rotational system that produce adequate amounts of residue.

Organic matter maintenance is of utmost importance in the soils of the semi-arid areas. Residue management, where this is available, is one method of soil and water conservation. Water conservation affects soil temperature and promotes soil biological activities. Recycling of organic wastes returns most of the nutrients that were removed by the crop to these soils low in inherent fertility.

Reduced tillage if systematically introduced offers good prospects of adoption on a large scale. This, apart from its substantial savings in energy cost and machinery investment compared to conventional tillage, will improve crop production in this agro-ecological zone and be more effective in soil and water conservation.

No-tillage systems require more detailed study in relation to local conditions before a wholesale transfer of technology can be recommended. Response to no-till can be quite soil- and cropping system-specific and requires considerable management skills. The benefits of no-tillage agriculture are partly due to the physical, chemical and biological effects of mulch and partly to the maintenance of pore channels created by decaying roots and burrowing soil fauna (Lal 1986).

The competing uses of the crop residues, for example for fuel, roofing, fencing or fodder, as well as low residue yield, are major constraints in introducing the system in many semi-arid regions in developing countries. The development of an efficient crop rotation system producing adequate residue would contribute greatly to overcoming some of these constraints. In addition, fodder production for livestock through ley farming or medics could greatly reduce the competitive use of crop residue by livestock owners on the one hand, who have no title to the land (e.g. Fulanis in West Africa, and Bedouins in the Near East), and the farmers on the other hand. Such issues must be taken into account in any technology transfer if it is to be successful.

In most of the countries in semi-arid areas there is a great need to improve crop production systems if a reasonable level of crop yield is to be achieved. The simple tools presently in use not only require drudgery and hard work but are hardly suitable for enhancing good crop growth. Large scale mechanization without careful planning and backing by research is also not the answer. For any proven technological package transfer to be successful, intensive educational and training programmes must accompany it.

Conclusion

Increased food production and intensification of agriculture in semi-arid areas can be achieved through mechanization as long as tillage and moisture conservation are taken into account. Fuel cost, labour problems and timeliness of farm operations are factors which favour the introduction of conservation tillage as opposed to the conventional tillage practices commonly in use. Experience gained so far has shown that more attention needs to be paid to the choice of equipment on different soils. Most of the soils in the semi-arid developing countries of this region are of low inherent fertility and often have surface management problems. Residue management and use of herbicides for weed control are essential in conservation tillage systems. In many countries, however, there are other economic uses of residues such as fodder for the livestock and fuel for heating and cooking, so that residues are hardly ever utilized for soil and moisture conservation purposes. Fodder production therefore is a key element in the development of conservation tillage in these areas.

The transfer of an appropriate tillage "package" must be accorded top priority to match food production with population increase, but this must be undertaken with due understanding of the environment and socio-economic conditions. Indeed, socio-economic and human environments play as important a role in successful transfer of practices from one area to another, as do considerations of the physical environment.

References

Allmaras, R.R. and Dowdy, R.H. 1985. Conservation tillage systems and their adoption in the United States. Soil and Tillage Research, Vol. 5, No. 2: 197-220.

Boole, E.D., Patel, R.M. and Patel, J.R. 1972. The longterm effect of ploughing treatments under no-manure practice - A statistical assessment. B.A. College of Agriculture Magazine 24: 67-76.

Chapart, J.L. 1981. Le travail du sol au Senegal. Institut Senegalais de Recherches Agricoles (ISRA), Bambey, Senegal.

Chapart, J.L. and Nicou, R. 1976. Influence du labour sur le developpement radiculaire de differentes plantes cultivees au Senegal - Consequences sur leur alimentation hydrique. L'Agriculture Tropicale 31: 7-28.

Charreau, C. 1972. Problemes poses par l'utilisation agricole des sols tropicaux par des cultures annuelle. L'Agriculture Tropicale 27: 905-929.

Charreau, C. 1977. Some controversial technical aspects of farming systems in semi-arid West Africa. Pages 313-360 *in* Proceedings. International Symposium on Rainfed Agriculture in Semi-Arid Regions. (Cannell G.H., ed.). University of California, Riverside, CA, USA.

Charreau, C. and Nicou, R. 1971. L'amelioration duc profil cultural dans les sols sableux et sable argileux de la zone tropicale seche Ouest Africaine et ses incidences agronomiques. L'Agriculture Tropicale 26: 209-255; 565-631; 903-978; 1184-1247.

El Fakhry, A.K. and Sultan, A. 1980. Studies on crop rotations and tillage practices on wheat production under rainfed conditions in Northern Iraq. Pages 59-65 *in* Rainfed Agriculture in the Near East and North Africa. FAO, Rome, Italy.

FAO. 1980. Rainfed agriculture in the Near East and North Africa. FAO, Rome, Italy.

FAO. 1987. Improving productivity of dryland areas. Committee on Agriculture, Ninth Session. FAO, Rome, Italy.

Lal, R. 1986. No-till and surface tillage systems to alleviate soil related constraints in the Tropics. Pages 261-317 *in* No-Tillage and Surface-Tillage Agriculture. The Tillage Revolution. (Sprague, M.A. and Triplett G.B., eds) John Wiley & Sons, New York, USA.

Malik, A.S., Kumarand, V. and Moolani, M.K. 1973. Dryland research in Northwest India. 1. Effect of variable pre-planting tillage on soil moisture, growth and yield of pearl millet. Agronomy Journal 65: 12-14.

Mannering, J.V. 1979. Conservation tillage to maintain soil productivity and improve water quality. Cooperation Extension Service Publication AY-222, Purdue University, W. Lafayette, IN, USA.

Mannering, J.V. and Fenster C.R. 1983. What is conservation tillage? Journal of Soil Water Conservation 38: 141-143.

Nicou, R. 1974a. Contribution to the study and improvement of the porosity of sandy-clay soils in the dry tropical zone. Agricultural consequences. Agronomie Tropicale 29: 110-127.

Nicou, R. 1974b. The problem of caking with the drying out of sandy and sandy-clay soils in the arid tropical zone. Agronomie Tropicale 30: 325-343.

Nicou, R. and Chapart, J.L. 1979. Water management in sandy soils of Senegal. Pages 248-257 *in* Soil Tillage and Crop Production (Lal R., ed.). IITA Proceedings, Series 2. IITA, Ibadan, Nigeria.

Office of Technology Assessment. 1982. Impacts of technology on US cropland and range productivity. Office of Technology Assessment, US Congress, Washington DC.

Poulain, J.F. and Tourte, R. 1970. Effects of deep preparation of dry soils on yields from millet and sorghum to which nitrogen fertilizers have been added. African Soils 15: 533-537.

Siemens, J.C. and Oschwald, W.R. 1976. Corn-soybean tillage systems: Erosion control, effects on crop production, costs. American Society of Agricultural Engineers, Paper No. 76-2552.

Sprague, M.A. 1986. No-tillage and surface-tillage agriculture. Pages 1-18 *in* No Tillage and Surface Tillage Agriculture. The Tillage Revolution. (Sprague, M.A. and Triplett G.B., eds) John Wiley & Sons, New York, USA.

Subramanian, S., Loganathan, S., Ravikumar, V. and Krishna-Moorthy, K.K. 1975. Effect of tillage and organic amendments on the physical properties of the soil and yield of bajra. Madras Agricultural Journal 62: 12-14.

Willcocks, T.J. 1979a. Tillage energy requirements for semi-arid crop production in Botswana. Pages 303-323 *in* Soil Tillage and Crop Production (Lal, R., ed.). IITA Proceedings, Series 2. IITA, Ibadan, Nigeria.

Willcocks, T.J. 1979b. Semi-arid tillage research in Botswana. Pages 127-146 *in* Proceedings of Appropriate Tillage Workshop, 16-20 January 1979. IAR, Zaria, Nigeria. Commonwealth Secretariat, UK.

Willcocks, T.J. 1981. The tillage of clod forming sandy loam soils in the semi-arid climate of Botswana. Soil Tillage Research 1: 323-350.

Tillage and Crop Management in Dryland Farming Regions of Iran

S. SHAHOEI, J. MOHAMMADI and P. ABDOLMALEKI

Soil and Water Research Institute, North Karegar Ave., Tehran, Iran.

Abstract

The Soil Moisture and Temperature Regime map of Iran (Fig. 1) was used as the basis for differentiating agroclimatological regions suitable for dryland farming. The potential of these areas for wheat production has been evaluated according to the severity and length of cold and drought periods. Conventional tillage practices and new trends are also explained and the dominant soil types in different areas are described. Results of an experiment conducted in the four main dryland farming areas of Iran on the effects of different tillage practices of soil moisture conservation for early germination are presented. WUE of different common rotations is calculated and the potential of areas with cool winters for wheat and barley production as well as possible ways for increasing WUE in such environment are discussed. The potential of annual rainfall for crop production in the Dry Oak Forest region is evaluated.

Introduction

The history of agriculture and dryfarming in the fertile crescent of the Middle East goes back ten thousand years. Archaeological investigations at Alikosh village in South-west Iran have unearthed domesticated barley and wheat dating from 6759-7500 B.C. (Evans *et al.* 1975).

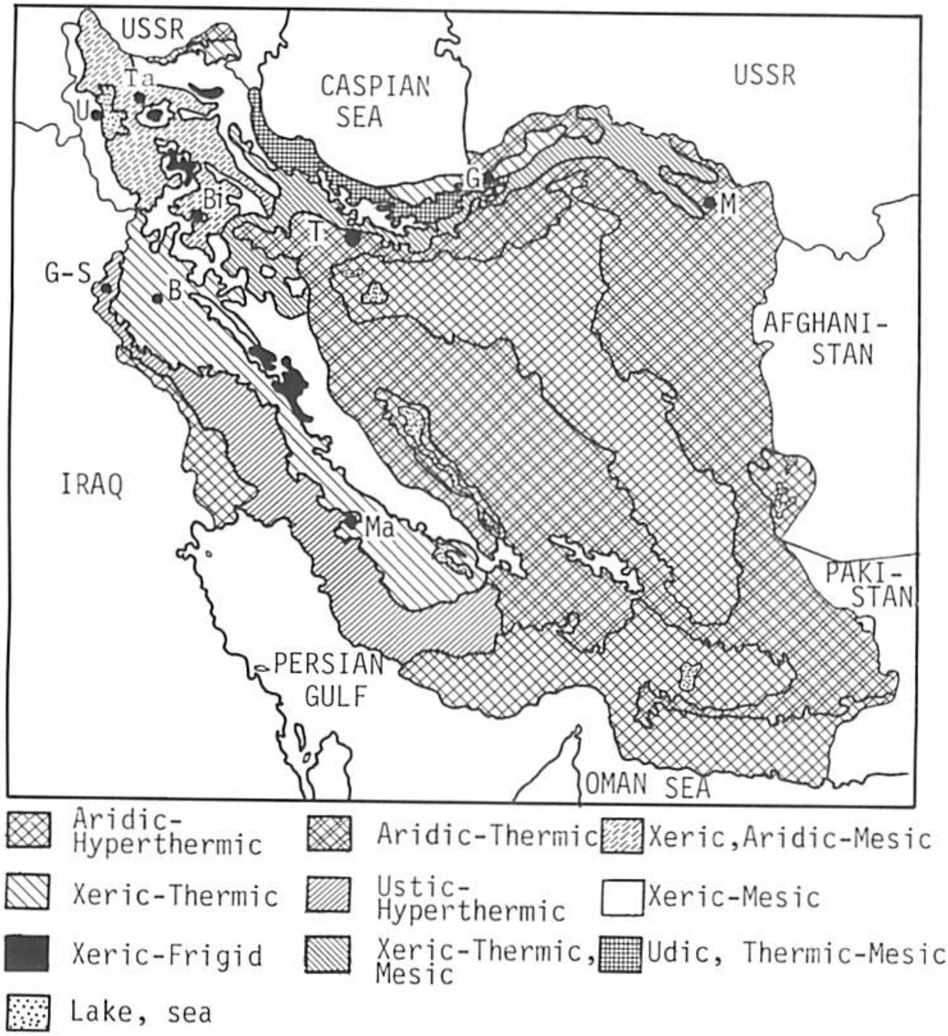
Rainfed agriculture is one of the main sources of food, feed, and fiber in Iran and is second to irrigated agriculture in the Gross National Product (GNP). In some of the north-west provinces of the country, for example Zanjan, Kurdestan and East Azarbyjan, rainfed agriculture makes the greatest contribution to GNP.

The main dryland farming regions of the country are located in the foothills of the Alborz range of mountains in the north and the Zagros ranges stretching from north-west to south-east, and in the west of the country, the elevated areas between these ranges.

The total area of dryland farming in the country exceeds ten million hectares. The area under rainfed wheat, barley, and food legumes in 1985 was 4, 1.2, and 0.5 million hectares, respectively. The fallow land in the same year was approximately five million hectares (Bureau of Agriculture 1985).

Climate

Except for the dryland farming areas in the north which are under the influence of the Caspian Sea, the climate of the remaining dryfarming areas is Mediterranean. For practical purposes this climate can be divided according to winter and summer temperatures into the following agrometeorological regions:



U=Urumieh; G=Gorgan; Bi=Bijar; T=Tehran; M=Mashad;
G-S=Ghasr-Shirin; B=Bakhtaran; Ma=Mamasani; Ta=Tabriz

Prepared by M.H. Banai, Soil Institute of Iran, 1977.

Fig. 1 Soil moisture and temperature regime map of Iran.

1. *Cool winters and prolonged hot dry summers.* This climate prevails at low altitude on the western slope of the Zagros mountains in the west and south-west of the country, where the annual rainfall varies from 200-500 mm. The total area of this region is approximately 11 million hectares.

The soil moisture and temperature regime of this environment is Ustic Hyperthermic (Banai 1980); the absolute minimum temperature will not usually go below -6°C and the maximum summer temperature may rise to 46°C. The climatological data of Ghasr-Shirin and Norabad-Mamasani as examples of this climate are shown in Fig. 2(A and B).
In this environment wheat and barley have short winter dormancy: 90% of precipitation coincides with crop growth and the potential evaporation during the summer season is very high. The potential of fallowing for moisture conservation is therefore very low.

2. *Cool winters with relatively hot summers.* This environment is typical of the northern provinces of the country on the Caspian coast. The annual rainfall is more than 450 mm and precipitation can be expected in summer months. The total area of this region is approximately 6.5 million hectares. The soil moisture and temperature regime of this environment is usually Xeric-Mesic or Xeric Thermic.
The climatological data of Gorgan are shown as an example in Fig. 2 (D). In this environment the precipitation coincides with crop growth but the summer drought is less severe than region 1. Cotton, soybean and sunflower are commonly grown, in addition to wheat and barley.

3. *Cold and very cold winters with dry summers.* This environment is found on the southern slope of the Alborz range and the slopes of the Zagros range, and the elevated area between these ranges. Three different soil moisture and temperature regimes have been recognized here (Banai 1980):

   a. Xeric, Mesic Regime. This regime is dominant in cold winter areas. The climatological data for Urumieh are given in Fig. 2 (F) as an example. The total area of this region is 14.5 million hectares.
   b. Aridic, Xeric-Mesic Regime. This regime is specific to the north-western plateau of the country where the altitude is usually above 1600 m. Conditions are illustrated (Fig. 2E) with data from Bijar. The total area of this region is approximately six million hectares. In these areas in some years autumn rains begin very late when temperatures are already too low for crop establishment and tillering. In addition, the temperature for crop growth is not suitable till mid-spring, and when the rains have stopped at the end of spring the crop will suffer from drought stress. In some years when the winter is very severe crops may be destroyed completely and farmers will plow them out. Legumes or spring wheat and barley will be planted instead.
   c. Xeric, Thermic Regime. This region is well known as Dry Oak Forest, which is distributed along the Zagros mountains. The climatic data of Bakhtaran are given as an example in Fig. 2 (C). The total area of this regime is 12 million hectares.

Soils

The soils of the regions with cold winters are derived from calcareous formations and the

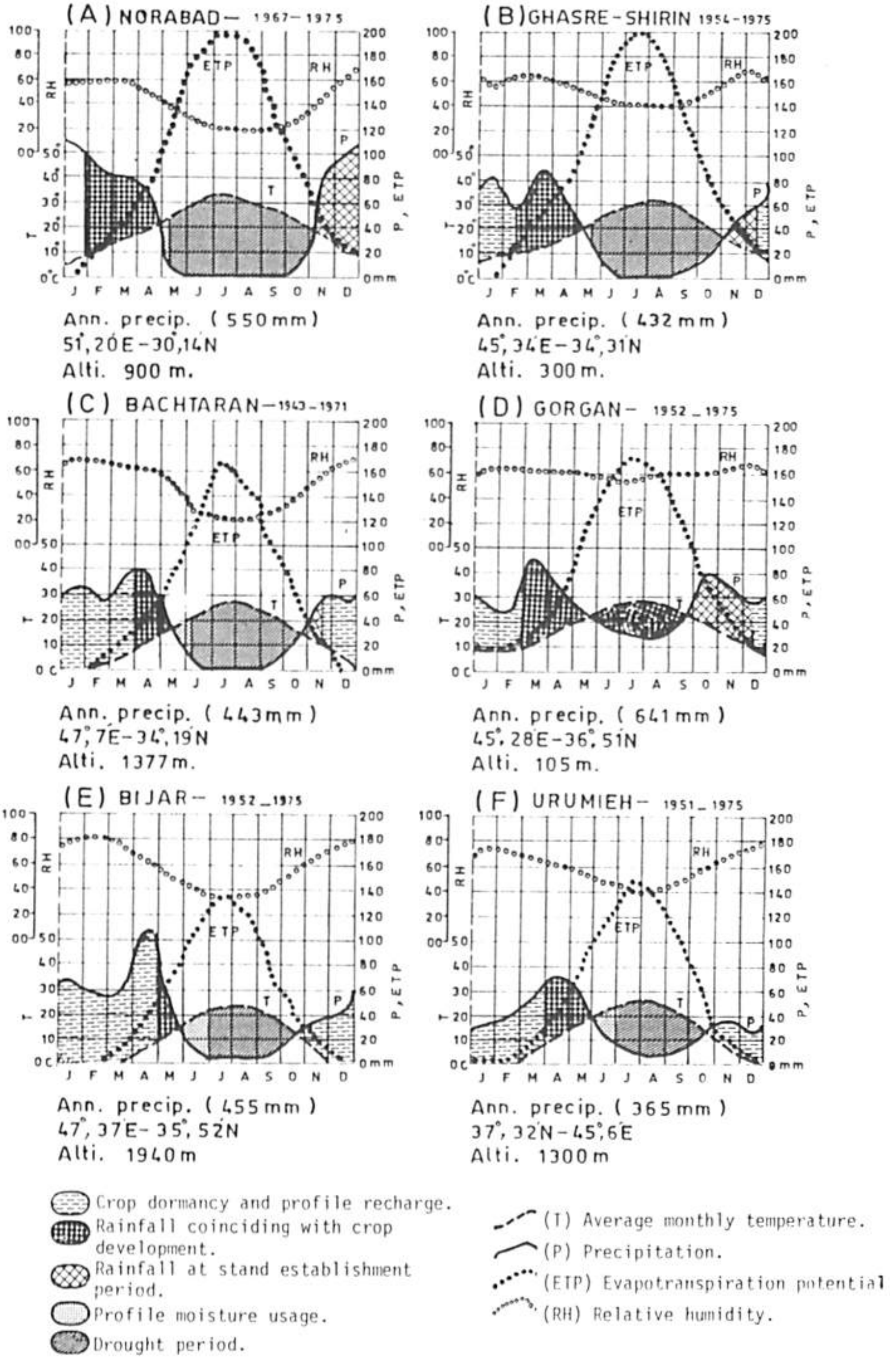


Fig. 2 **Average monthly temperature and precipitation data for main dryland farming areas of Iran.**

dominant soil is Calcixerollic Xerochrept. In the Xeric Thermic regime the Xerochrepts, Calcixerollic Chromoxererts and Xerofluents can be distinguished. In the Gorgan dryfarming region the Xerolls are present and in areas with prolonged hot, dry summers the Ustifluents and Ustochrepts are prevalent.

Tillage Practices

There is a close integration of livestock and arable farming in all parts of Iran. Cereal stubble is used for grazing and in some instances it is saved or ensiled for winter feeding. The grazing of fallow areas by livestock for more than two months is common and for this reason the initial tillage is postponed.

The most common tillage practices in dryfarming include spring ploughing of fallows with a mouldboard plough, followed by disking for breaking the clods and making a uniform seed-bed. Planting operations consist of broadcasting the seed (seeding rate 100 kg/ha), and a second disking for covering the seeds. Also, chemical fertilizer is used at rates of 30 kg P205/ha and 30 kg N/ha. Phosphorus is used at the time of planting and a part of the nitrogen is topdressed in early spring. Herbicides are not usually used.

National longterm average yields of dryfarmed wheat and barley are 0.64 and 0.59 t/ha respectively (Bureau of Agriculture 1985).

In recent years, changes in tillage practices during the fallow period have been introduced into farming areas with cold winters. The primary tillage is done in autumn when a chisel plough is used with the object of conserving water from snow and early spring rains. The land is then harrowed in the spring, and again in the following autumn for seedbed preparation (Hepworth *et al* 1975). Planting is carried out with a deep furrow drill.

Rotations

In environments with cool winters and long hot dry summers (region 1 above) the common rotation is wheat-chickpeas, and in areas with less than 300 mm rainfall the fields are fallowed after the wheat crop.

In areas with cold winters wheat-fallow is the most common rotation but in some regions with more precipitation a two-course rotation of wheat-food legumes occupies 10-20% of the land.

In regions with cool winters and less extreme summers, like Gorgan in the northeast of the country, common rotations are wheat (barley)-cotton or wheat (barley)-soybean or wheat-cotton-soybean.

Results of On-going Research

Areas with cold winters

The onset of autumn rains in these areas is uncertain and usually too late for wheat establishment and tillering. Studies on tillage management were carried out for preparing a dust-mulch in summer fallow for moisture conservation in seed beds in four main dryfarming regions, as shown in Table 1. Different autumn, spring and summer tillage tools were used in the main plots, subplots and sub-subplots, respectively, in a split, split plot design with three replicates. The soil water at planting time was determined gravimetrically. After analyzing the results of conserved moisture and yield of wheat in the subsequent year we came to the following conclusions (Shahoei *et al.* 1988):

Table 1. Different treatments of summer fallow experiment and characteristics of soil and climate in 4 main dryland farming regions in Iran

Location of experiment	Kuhin (Gilan)	Taiarak (Hamadan)	Sararod (Bakhtaran)	Mamasani (Fars)	Imour (Fars)
Altitude (m)	1350	1700	1250	960	700
Annual precipitation (mm)	330	350	500	600	450
Moisture regime	Xeric	Xeric-Aridic	Xeric	Ustic	Ustic
Maximum temperature (°C)	39	39	41.5	44	45.5
Minimum temperature (°C)	-16.5	-32	-12.7	-6.5	-2
Temperature regime	Mesic	Mesic	Thermic	Hyperthermic	Hyperthermic
Soils*	1	2	3	4	5
Different autumn practices**	Control	Control	Control	moul	moul
	ch	ch	ch	ch	ch
			S	disk	disk
Different spring practices	moul	moul	moul	moul	moul
	diss	diss	diss	ch	ch
	sw+h	sw-pl	sw-pl	disk	disk
Different summer practices	rod+h	rod	2rod+h	-	-
	sw+h	sw	ch.wd.c.	-	-
	2rod		sw+h	-	-
	rod+sw+h	sw+rod	rod+h	-	-

* *Soils1:* Moderately deep silty clay; 2: Moderately deep sandy clay; 3: Fairly deep clay loam; 4: Shallow gravelly sandy clay loam; 5: Deep clay.
** *Practices* ch: Chisel plow; S: Subsoiler; moul: mouldboard plough; diss: Dissected mouldboard; sw: Sweep; h: Harrow; rod: Rodweeder; 2rod: Rodweeder twice; ch.wd.c.: Chemical weed control.

1. Dust-mulch did not allow the retention of enough moisture in seed-bed for germination and early establishment before autumn rains. For example, in Kuhin Experimental Station which has soils of Silty-clay texture with a Xeric-Mesic soil moisture and temperature regime, the maximum retained moisture was only 14-15%, which is not enough for germination.
2. In Kuhin Experimental Station following the fallow year of 1981/82, the difference in tillage treatments in moisture conservation at time of planting and the yield of wheat in the following year, 1982/83, were significant at 5% and 1% respectively (Table 2). Scarcity of rainfall in the growing season (1982/83) was the main reason for this response. The crop was established on 49mm of rain in autumn and tillering was possible before winter dormancy. The amount of precipitation in the dormancy period was 128mm and only 30mm coincided with wheat growth in spring, therefore the yield depended on stored moisture from the last fallow.
3. In some places primary tillage with the mouldboard plough significantly increased wheat yield in the next year without a significant increase in stored moisture at time of planting (Table 3). Better soil aeration, mineralization and the preparation of an appropriate base for seed beds may be the main reasons for better yields in this treatment.

Table 2. The amount of water stored in soil profile by different summer tillage treatments at two depths (10-20 and 20-80 cm) under fallow at time of seeding in 1981/82 and its contribution to wheat yield in 1982/83 at Kuhin Experimental Station

Tillage treatment	Stored water (%) 10-20 cm	20-80 cm	Wheat yield kg/ha
Rod weeder (C1)	11.0	13	1015
Rod weeder + Rod weeder (C3)	11.0	14.5	1200
Sweep + harrow (C2)	9.5	14.5	1015
Chemical fallow (C4)	9.5	14	635

Table 3. The effect of different spring tillage treatments on wheat yield in following year at Kuhin Experimental Station

Tillage treatments	Stored water (%) 0-20 cm	20-120 cm	Wheat yield kg/ha
Mouldboard + harrow (B1)	12	15.5	1355
Dissected Mouldboard + harrow (B2)	12	15.5	1209
Sweep + harrow (B3)	11.5	15.5	1153

4. In upper terraces and high plateaux in the north-west of the country topographic parameters like length, degree and shape of slope make soil erosion highly likely, and it is obvious that cropping management in these areas must take account of soil conservation for rational use of available nutrients and moisture content in the soil.

In some places the expected rainfall is more than 450 mm and the autumn and spring temperatures are appropriate for growth. In these circumstances when the recharge of moisture in the soil profile during the dormancy period is possible, fallow can be reduced or omitted. In Sara-rod Experimental Station at Bakhtaran with a Xeric-Thermic regime, a study for selecting the most suitable rotations started in 1984. Different two-course rotations like wheat-fallow, wheat-chickpea and wheat-lentil and continuous wheat over two years gave yields of 2.38 t/ha wheat; 1.23 t/ha wheat + 0.73 t/ha chickpea; 1.15 t/ha wheat + 0.5 t/ha lentil; and 1.3 t/ha + 1.85 t/ha wheat, respectively (Sayadian, K., personal communication). Assuming 500 mm for precipitation and 1/3 and 1/2 for harvest index of wheat and food legumes, respectively, the WUE of these treatments are 7.12, 5.14, 3.50 and 9.44 kg/mm, respectively. However, these results are in contrast to those obtained in other areas of the region, where cereals following cereals are the lowest yielding treatments (ICARDA-FRMP 1986; Meyveci 1988).

Areas with cool winters and prolonged hot dry summers

In Mamasani and Famour Experimental Stations the effect of different autumn and spring treatments, presented in Table 1, was not significant in moisture conservation (Shahoei *et al.* 1988).

The precipitation efficiency of a two-year rotation of wheat-fallow in this study was only 1.6 kg/ha/mm for grain and 4.8 kg/ha/mm for TDM of wheat crop (the grain yield was 1.66 t/ha with 520 mm rainfall). The research carried out by ICARDA in Jindiress, with a similar environment, is most promising. At this site, by early establishment of the crop and using fertilizer the transpiration efficiency increased, and by early development of the crop canopy the soil evaporation decreased and consequently WUE rose to 33.2 kg/ha/mm with 454 mm of rainfall (Cooper *et al.* 1987).

Areas with cool winters and relatively hot summers

A study in Western Australia (Hamblin *et al.* 1987) under similar conditions, indicates that ley-farming has great potential in increasing WUE. Wheat following medics produces more TDM than a wheat-fallow rotation. Interruption of disease and pests, better weed control and high fertility from organic matter are the main reasons for the superiority of ley-farming.

We are familiar with this system and steps for its establishment in appropriate environments like Gorgan and Mazandaran provinces have been taken, but have not been successful so far.

Conclusion

The elevated dryfarming areas with Aridic, Xeric-Mesic regimes in the north-west of the country have prolonged and very cold winters which is a serious constraint in winter wheat cropping and causes very low WUE. Supplementary irrigation and use of chemical fertilizer can increase WUE of winter wheat in these areas. Establishing alfalfa is the next best possible way for maximum use of soil moisture and nutrients. It is also a conservation measure for control of soil erosion which is a high risk in the region.

In the Mediterranean Dry Oak Forest region with a Xeric-Thermic soil moisture and temperature regime, precipitation is generally more than 450 mm, there is no need for fallowing the land and rotations of wheat-food or feed legumes have the highest profit.

In areas like Mamasani, with a Ustic, Hyperthermic soil moisture and temperature regime, selection of varieties with rapid early growth and establishment, weed control and fertilizer management are the key factors in increasing WUE.

Acknowledgements

We wish to thank the authorities of the Agricultural and Natural Resources Research

Organization of Iran for nominating us for the workshop. The valuable guidance and comments of Dr. M.H. Roozitalab, the Director General, Dr. H. Siadat and engineer M. H. Banai, the Deputy-Director Generals Research, of the Soil and Water Research Institute of Iran (SWRI) are sincerely appreciated. We also thank our colleagues, engineer F. Kalantari and engineer Sayadian of the regional offices of SWRI in East Azarbyjan and Bakhtaran for their valuable help, and must mention the kindness of Ms. Espandi who typed this manuscript.

References

Banai, M.H. 1980. Soil Moisture and Temperature Regime Map of Iran. Soil Institute of Iran, Pub. no. 579, Tehran, Islamic Republic of Iran.

Bureau of Agriculture Information and Statistics. Agricultural Statistics of 1984-1985 (In Persian). 1986. Ministry of Agriculture, Islamic Republic of Iran.

Cooper, P.J.M., Gregory, P.J., Tully, D. and Harris, H.C. 1987. Improving water use efficiency of annual crops in rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 113-115.

Evans, L.T., Wardlaw, I.T. and Fischer, R.A. 1976. Wheat. Pages 101-149 *in* Crop Physiology: Some Case Histories (Evans, L.T., ed.) Cambridge University Press, Cambridge, UK.

Hepworth, H.M., Zinn, T.G., and Anderson, W.L. 1975. Improved techniques for dryland agriculture means more wheat from fallow farming (2nd Edition). Ankara, Turkey; USAID/Oregon State University Team.

ICARDA-FRMP 1986. Pages 97-100 *in* Farming Systems Program Annual Report for 1986. ICARDA-108 En, Aleppo, Syria.

Meyveci, K. 1988. Orta Anadolu bolgesi kosullarinda ikili ekim nobeti sisteminde toprakta nem ve inorganik azot formlarinin belirlermesi. PhD Thesis, Faculty of Agriculture, University of Ankara, Turkey.

Shahoei, S., Alinia, M.H., Rahimi, M.B., Jamejam, E. and Asadi, V.A.N. 1988. Effect of dust mulch in summer fallow on soil water conservation and its final effect on wheat yield in dryfarming areas of Iran (In Persian). Soil and Water Research Institute of Iran Pub. no. 753, Tehran, Islamic Republic of Iran.

Tillage and Stubble Management: On-going Research in USA

R.I. PAPENDICK[1], J.F. PARR[2] AND R.E. MEYER[3]

[1]*USDA/ARS, 215 Johnson Hall, Washington State University, Pullman, WA 99164-6421, USA*

[2]*USDA/ARS, Room 414, Bldg. 005, BARC-West, Beltsville, MD 20705, USA*

[3]*S&T/AGR, USAID, Rm 408, 5-18, U.S. Department of State, Washington DC 20523, USA*

Abstract

There is considerable emphasis on conservation tillage research in the U.S. in response to growing concern over soil erosion and its adverse effects on productivity and environmental quality. Conservation tillage can reduce erosion by 50% or more and at the same time conserve water which has significantly increased crop yields and reduced farming risks in the dryland areas. U.S. farmers are now applying conservation tillage practices to about one-third of the nation's croplands. Approaches to conservation systems receiving more emphasis include no-till fallow, increased cropping intensity for more soil cover, no-till into cover or sod crops, and ridge-till. Adaptive research on tillage methods include slot mulching, paraplowing, and basin pitting. Studies of fertilizer placement with conservation planting show generally that banding the fertilizer near the seed row of crops is superior to broadcasting or banding some distance away from the row. A new combination seed-fertilizer drill opener termed "cross-slot" has been developed that is capable of efficiently operating over a wide range of conservation tillage conditions. Yields with the cross-slot opener were comparable or superior to those with standard double disc or hoe-type openers. Conservation tillage alone as used with many conventional cropping systems will probably not change the current status of nitrate leaching and thus, the potential for groundwater contamination. The status with pesticide contamination of water is less certain and no clear cut distinction between conventional and conservation tillage yet exists.

Water Conservation and Erosion Control

Tillage and crop residue management are high priority research objectives in U.S. agriculture because of their important impacts on the nationally prominent issues of soil and water conservation, and water quality. Soil erosion is regarded as the greatest single threat to sustaining the productivity of the nation's 170 million hectares of croplands. A national survey conducted in 1982 estimated that wind and water erosion on U.S. croplands exceeded 2 billion tons annually (Soil Conservation Service 1982). If this erosion is allowed to continue it is expected to undermine steadily the productivity of many soils. Inefficient use of precipitation in dryland areas and impairment of surface and groundwater quality by agrochemicals and/or sediment are also major national problems that are often associated with improper management practices.

In recent years much research emphasis has been given to both technology development and adaption of conservation tillage systems for water conservation and erosion control. The Conservation Technology Information Center (CTIC) in West Lafayette, Indiana, USA, defines conservation tillage as "any tillage and planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, at least 1000 pounds of flat small grain residue per acre (1120 kg/ha) is on the surface during the critical erosion period". Five types of conservation tillage systems are now identified: no-till, reduced tillage, mulch tillage, strip tillage, and ridge till. The first three types, and to a lesser extent strip tillage, have application to dryland farming systems. Ridge till is mostly being applied to the more humid northern climates with row cropping of maize (*Zea mays*) and soybeans (*Glycine max*) for example.

According to estimates determined by CTIC, conservation tillage results in an average 50% reduction in soil erosion compared with many conventional tillage practices (Brosten 1988). However, the range may vary from 30 to 90% depending on the specific form of conservation practice and other factors including soil type and the tillage system formerly in use. For example, no-till with a good residue cover may reduce erosion by 90% or more, whereas stubble mulching may reduce it considerably less (e.g. 30 to 40%), compared with clean cultivation. It is apparent that broad-scale adoption of conservation tillage could have significant impact in reducing erosion, especially if applied to highly erodible lands.

Conservation tillage has also been shown to benefit water conservation markedly, and enhance crop yields in dry farming systems. Table 1 presents water storage efficiencies for different fallow systems at Akron, Colorado, USA. Storage efficiency is defined as the percent of the precipitation that is stored during the fallow period (in this case 12 months) and

Table 1. Effect of different tillage systems on the efficiency of water storage in fallow, Akron, Colorado, USA (Greb *et al* 1979)

Tillage system	Years in use	Number of tillage operations	Efficiency*
Maximum tillage. Plow and Harrow	1915-30	7 to 10	16 to 22
Conventional bare. Shallow disc, rodweed or harrow	1931-45	5 to 7	20 to 24
Modified conventional. Disc (once) chisel, rodweeder	1946-56	4 to 6	24 to 27
Stubble mulch. Sweep, rodweeder	1957-70	4 to 6	27 to 33
Minimum tillage. Herbicide to replace one or more tillages	1968-77	2 to 3	33 to 38
No-till	1975-77	0	45 to 55

* Defined as the percentage of precipitation stored in the soil

made available to the subsequent crop. Storage efficiencies increase as the number of tillage operations decrease and more crop residues are retained on the soil surface. Water storage with the minimum tillage and no-till systems was also improved through better weed control with herbicides. The average wheat (*Triticum aestivum*) yields have doubled over the 45-year period during which improvements in fallow systems were occurring (Table 2). Some of the yield increase was attributed to improved varieties, and planting and harvesting methods, but most was due to increased fallow efficiency (Greb 1979).

Table 2. Wheat yields for 2 locations in the Central Great Plains as a result of improved technology. (Greb *et al* 1979)

	Average of Akron, CO and Colby, KS	
Decades	Average precipitation mm	Wheat yield Mg/ha
1926-35	432	1.2
1936-45	455	1.6
1946-55	472	2.0
1956-65	472	2.2
1966-75	427	2.7

Another example showing the effect of improved tillage and residue management on water conservation and wheat yields is demonstrated by changes in fallow practices in the western Nebraska drylands. Wheat yields doubled (from 0.7 to 1.5 t/ha) during the late 1930s when stubble grazing was eliminated and mulch tillage and improved weed control were introduced in the wheat-fallow cropping system (Fenster 1989). Fertilizer usage was an important but secondary factor contributing to this yield increase. The change in farming practice amounted to a "snowball" effect, i.e. without grazing there was more surface cover and this, coupled with good weed control, substantially increased the available water, which in turn produced more crop residues for additional water conservation benefits and higher yield. The increase in yield was sufficient to justify separating the production of livestock and grain on the same land in many USA dryland areas. This to a large extent is the practice today. Moreover, retention of surface stubble reduces wind and water erosion, which improves the long-term sustainability of the soil.

Current Research and Farmer Adoption

Much research and development on soil and crop management is currently directed towards no-till and minimum tillage systems. Economics has been the major incentive in promoting their use on croplands. Though the use of no-till is increasing, farmer adoption of this practice has been relatively slow. According to the 1988 CTIC survey, no-till is being applied to about 10% of the 88 million hectares of croplands that are presently under some form of conservation tillage. Some of the limitations of no-till include poorly understood biological factors that retard crop growth in surface residue systems; increased weed infestations and costs of controlling weeds; increased plant diseases associated with residues on the surface; and problems with equipment and stand establishment with seeding in badly prepared seedbeds and hard soil.

Long-term no-till promotes a build-up of organic matter on the soil surface. This helps to reduce surface crusting and increase the infiltration rate of many soils. Some researchers also report increased worm and insect activity with continuous no-till or limited tillage which improves intake of rain or irrigation water (Griffith *et al.* 1986). The increase in surface organic matter is accompanied by an increase in soil organic nitrogen. Some researchers report that although less nitrogen may be available for crop uptake with no-till, at any one time the season-long availability is improved compared with conventional tillage systems (Conservation Impact 1988).

Cropping/residue Management Systems

Chemical fallow

There has been considerable research on technology development for complete no-till (chemical) fallow in the dryland areas. The potential benefits of no-till fallow are near-elimination of soil erosion, higher water storage and grain yields, and lower energy costs per unit of production. Most success with chemical fallow has been achieved in summer rainfall areas such as the Great Plains. In the winter precipitation zones such as the Pacific Northwest, without tillage there is substantial loss of seedzone moisture during the summer (Lindstrom *et al.* 1974). This reduces the chances of early autumn establishment of wheat, and the farmer must then rely on late planting with lower yield potential. Under these conditions the greatest potential for no-till fallow is on sandy soils (Hammel *et al.* 1981). These soils tend to self-mulch upon drying, making the effect of tillage in reducing water loss less important than for finer-textured soils.

Annual or double cropping systems

Conservation tillage is increasing the potential for double cropping, and increased annual cropping in traditional wheat-fallow areas. For example, maintaining standing stubble during the overwinter noncrop period may increase water storage enough from snow catch and reduced evaporative loss to permit annual cropping in the transition zones between subhumid and semiarid areas. The practice may also allow annual cropping in years of above-normal precipitation in the semiarid areas.

No-till is also moving the potential for double cropping, e.g. soybeans after wheat, into the subhumid northern areas with shorter growing seasons. With no-till, soybeans can be successfully seeded into wheat stubble immediately after harvest, which minimizes moisture loss, and assures quicker stand establishment from residual moisture than can be accomplished with a tilled seedbed, which tends to dry out.

Cover crops

In some of the more southern regions cold-tolerant crops such as rye (*Secale cereale*), crownvetch (*Coronilla varia*), or Austrian winter peas (*Pisum sativum*) are grown during the winter months to reduce runoff, erosion, and nutrient loss. These are especially beneficial in preventing erosion on steep land which would otherwise lack cover in winter. The vegetation is chemically killed in early spring to control moisture use and a crop such as maize is later no-till seeded into the mulch which helps prevent runoff and evaporation. A limitation to the use of cover crops is moisture use, which may reduce the amount of water available for the succeeding crop, especially in water-deficient areas or in dry years. Another practice being adopted by farmers in some areas is no-till seeding of grain crops in sod following take-out of a grass or legume crop grown for seed or forage. One example is in eastern Washington where pulses are no-till seeded into killed sod of bluegrass after several years of seed production.

Ridge-till with surface residues for maize and soybeans

Ridge till (planting row crops on a preformed ridge) has been gaining popularity as a conservation practice for maize and soybean production in the midwest states. Advantages are decreased erosion, water conservation, reduced fuel and equipment costs, and faster seedbed warmup in the spring. The row crops are sown in the spring on ridges formed by cultivation of the crop during the previous growing season. The ridges and residues which are usually shredded in the autumn are left intact overwinter.

The planting operation moves 2 to 3 cm of soil, weeds, manures, and crop residues from the ridge top where seed and starter fertilizer are placed into the interrow or wheel track area. As the corn or soybeans grow a later cultivation is used to control weeds and preform the ridges for the next year's cropping. The mulch in the interrow area helps prevent runoff and erosion.

Tillage Methods

No-till planting can result in water runoff, especially from frozen or eroded soils, and where residue amounts are low. This is also of concern where soil compaction results from the continued use of heavy no-till drills which require large powerful tractors. Where these conditions exist it may be necessary to use a supporting practice to enhance water infiltration into the soil. Some special form of tillage and residue management may also be necessary on parts of the landscape where topsoils are thin and erosion continues to expose the less permeable subsoils.

Slot mulch

A concept of tillage and residue management termed "slot mulch" has been under test in the Pacific Northwest wheat region as a supporting practice for no-till to control runoff (Saxton *et al.* 1981). Conceptually, the approach is to compact loose residues and chaff from the harvested grain crop into a narrow slot approximately 7 to 13 cm wide and 20 cm or more deep, formed on the hillside with the loose soil forming a berm on the downslope side. The practical distance between slots might range from 6 to 8 m. The straw in the slot is left exposed at the surface. The straw mulch maintains macroporosity for intercepting runoff from rain or melting snow and also insulates the slot so that the bottom remains unfrozen during the winter. Theory and field experiments have confirmed that the slot mulch prevents runoff on steeply sloping land over a wide range of conditions. The operation also facilitates no-till planting because the loose residues that may interfere with planting and crop establishment are removed and packed into the slot.

Paraplow

The paraplow is a subsurface tillage implement that shows promise for water conservation by reducing runoff. The design is a slant-shank chisel plow with tools mounted on a frame much like that of a moldboard plow. The purpose of the paraplow is to loosen the soil to a depth of 30-40 cm while leaving the surface residues mostly intact. The tillage operation creates large fractures and macropores which help maintain high infiltration rates even after heavy rains or while the soil is frozen. It has the potential for improving water infiltration on steep slopes where there is little surface residue and water intake is slow.

Research in a 350 mm precipitation area in eastern Washington shows an additional 30-60 mm of water is stored overwinter with autumn paraplowing as compared with no-tillage (Table 3). Maximum benefits were achieved during a winter when several runoff events

Table 3. Overwinter soil water storage (mm) as affected by paraplow tillage and residues (180 cm depth)*

Residue management	Tillage		Gain with paraplow
	Paraplow	No-till	
Standing Stubble	165a	123bc	42
Chopped Stubble	150ab	119bc	31
Burned stubble	95dc	65d	30
LSD	35		

* Average of 3 years

occurred on frozen soils. Highest water gains were with surface residues present. Field demonstration tests in Ohio showed that maize yields with paraplowing equaled or surpassed those with moldboard plowing, chisel plowing, and no-till (Conservation Impact 1987). The tillage benefit in this case enabled the farmer to reduce erosion sufficiently and remain in compliance with the erosion control requirements of the 1985 Food Security Act for highly erodible lands. The paraplow requires about 50 horsepower per chisel which covers a width of approximately 50 cm. The beneficial effects of paraplowing for infiltration may last for several seasons which makes it work well for a minimum tillage system.

Basin pitters

Furrow dammers, or basin pitters, are increasing in use as a means for enhancing water infiltration and storage in soil. The operation consists of forming small furrows or miniature basins that hold water on sloping positions during rain or snowmelt events. For example, the basin pitter can be used on tilled or untilled stubble as a means to improve infiltration or hold snow. Field testing has included sowing winter wheat with a disc drill following pitting, or pitting after the sowing operation. More research is needed to determine the feasibility of this tillage practice over a range of soil, slope, and cropping conditions.

Seeding and Fertilizer Methods

Considerable progress has been made on the development of no-till drills that can simultaneously apply seed and fertilizer, and current research is underway on herbicide banding, all in a single pass. Machines are now available that can operate in heavy residues and hard soil, and deep band all or part of the crop fertilizer requirement between or below the seed rows. The commercial machines currently in use are equipped with either hoe-type or heavy-duty double disc openers, the latter sometimes being offset to facilitate cutting through crop residues or penetrating hard, dry soil.

Fertilizer placement

There has been considerable research to develop fertilizer placement technology for conservation tillage systems. Although crop response to fertilizer placement depends on a number of factors, early access to nutrients by roots of seedlings has been shown to be particularly important. In general, banding fertilizer in proximity to the seedzone produces greater yields for most grain crops than broadcasting the fertilizer. Banding the fertilizer some distance away from the seed row can reduce the fertilizer response compared with banding closer to the row (Table 4). As a result, a method of seed-fertilizer placement

Table 4. Effect of fertilizer band placement on wheat yield in a no-till winter wheat - spring wheat rotation with 41 cm row spacing

	Wheat yield	
Fertilizer placement	Winter wheat	Spring wheat
	——— Mg/ha ———	
5 cm below seed row	3.8	2.9
5 cm below and 20.5 cm to side of seed row	2.9	2.2

Source: G.M. Hyde, Washington State University, Pullman, WA, USA. Unpublished results.

emerged in commercial practice with double disc drills and is referred to as "paired row" planting. The seeds are placed in pairs of rows 10 to 18 cm apart with a wider space of 33 to 40 cm between the next pair. This configuration allows a single band of fertilizer to supply nutrients efficiently to two closely spaced rows of the small grain crop. With paired row planting the fertilizer is placed 6 to 9 cm below and only 5 to 9 cm to the side of the seed row. In this particular arrangement the crop roots tend to envelop the fertilizer band, thereby increasing fertilizer use efficiency, and possible crop competition against weeds. Recent research indicates that the paired row fertilizer placement does not give a greater fertilizer response in wheat than banding directly below each wheat row. The main advantage with paired row seed-fertilizer placement is that one fertilizer band can be used to supply two rows of the crop. It also allows for improved trash clearance with no-till seeding.

Cross-slot seed-fertilizer placement technology

A new combination seed-fertilizer drill opener termed "cross-slot" has been developed that is capable of planting a range of crops in tilled and untilled soil. The opener, first developed in New Zealand and followed by adaptive research in the U.S., features a single 56 cm diameter sharp disc to penetrate residues and soil (Baker and Saxton 1988). Two winged side blades situated on opposite sides of the disc create a cavity at the seeding depth for simultaneous placement of the seed and fertilizer. Two packer wheels running at a slight angle flank the rear of the disc and both close the disc slot and firm the soil over the seed. The wheels also maintain the seed opener depth. Performance of this opener with regard to seed placement is significantly different from conventional double-disc or hoe-type openers. Unique advantages include minimal disturbance of surface residues and soil, minimum plugging problems, superior stand establishment under marginal moisture conditions compared with disc or hoe openers, and lower horsepower requirements than most other no-till drills that place seed and fertilizer. Field tests show that the full complement of fertilizer can be placed with this opener at seeding time without adversely affecting stand establishment of cereal crops. Yields of wheat, peas (*Pisum sativum*), and barley (*Hordeum vulgare*) from plantings with this opener are equal to or greater than with standard double disc or hoe-type openers that are commonly used.

Conservation Tillage and Water Quality

Contamination of water by runoff or chemical leaching is a growing nationwide concern. Baker and Johnson (1983) report that conservation tillage reduces the volume of runoff by 25%, but the degree of reduction is highly variable and site specific. This means that there is a greater potential for increased infiltration and hence, movement of water and soluble chemicals through the profile. Fox and Bandel (1986) concluded that there is a greater potential for nitrate leaching in no-till than in tilled soils. The greater loss in no-till was explained on the basis of increased drainage losses in the undisturbed soil. However, other studies indicate lower nitrate concentrations with no-till as a result of greater denitrification and immobilization than in tilled soil (Doran 1980; Rice and Smith 1984; Fox and Bandel 1986). This compensating effect would offset the greater leaching potential with no-till.

The effect of conservation tillage on pesticide leaching is complex with many confounding factors. On the one hand the increased infiltration along with increased use of pesticides with conservation tillage could increase the risk of pesticide leaching. On the other hand a moister soil environment associated with conservation tillage could increase the microbial degradation rate of pesticides in soil compared with conventional clean tillage. Much research yet remains to be done to establish the impact of conservation tillage on the quality of surface and groundwater.

References

Baker, C. John, and Saxton, K.E. 1988. The cross-slot conservation grain drill opener. American Society of Agricultural Engineers. Paper No. 88-1568. Winter Meeting. St. Joseph, MI 49085-9659, USA.

Baker, J.L. and Johnson, H.P. 1983. Evaluating the effectiveness of BMP's from field studies. *In* Agricultural Management and Water Quality. (Schaller, R.W. and Bailey, G.E., eds). Iowa State University Press, Ames, USA.

Brosten, Dennis. 1988. How much can we lose? Agrichemical Age. Pages 7-8 *in* HBJ. Farm Publications, Inc. 731 Market Street, San Francisco, CA 94103-2011, USA.

Conservation Impact. 1987. Paraplowing to increase yields: 2000 acres of family operation. Conservation Technology Information Center, 1220 Potter Drive, Room 170, Purdue Research Park, West Lafayette, IN 47906-1334, USA. December 1987.

Conservation Impact 1988. Researchers study long term effects of no-till. Conservation Technology Information Center, 1200 Potter Drive, Room 170, Purdue Research Park, West Lafayette, IN 47906-1334, USA.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Science Society of America Journal 44:765-771.

Fenster, C.R. 1989. Fifty years of tillage practices for winter wheat. Pages 150-151 *in* Challenges in Dryland Agriculture. A Global Perspective. Proceedings of the International Conference on Dryland Farming. (Unger, P.W., Jordan, W.R. Sneed, T.V and Jensen, R.J. eds). Texas A&M University, College Station, Texas, USA.

Fox, R.H., and Bandel, V.A. 1986. Nitrogen utilization with no-tillage. Pages 117-148 *in* No-Tillage and Surface Tillage Agriculture. The Tillage Revolution. (Sprague, M.A. and Triplett, G.B., eds). John Wiley & Sons. New York, USA.

Greb, B.W., Smika, D.E. and Welsh, J.R. 1979. Technology and wheat yields in the central Great Plains: Experiment station advances. Journal of Soil and Water Conservation 34:264-268.

Griffith, D.R., Mannering, J.V. and Box, J.E. 1986. Soil and moisture management with reduced tillage. Pages 19-57 *in* No-Tillage and Surface Tillage Agriculture. The Tillage Revolution. (Sprague, M.A. and Triplett, G.B., eds). John Wiley and Sons, New York, USA.

Hammel, J.E., Papendick, R.I. and Campbell, G.S. 1981. Fallow tillage effects on evaporation and seedzone water content in a dry summer climate. Soil Science Society of America Journal 45:1016-1022.

Lindstrom, M.J., Koehler, F.E. and Papendick, R.A. 1974. Tillage effects on fallow water storage in the eastern Washington dryland region. Agronomy Journal 66:312-316.

Rice, C.W. and Smith, M.S. 1984. Short-term immobilization of fertilizer N at the surface of no-till soils. Soil Science Society of America Journal 48:295-297.
Saxton, K.E., McCool, D.K. and Papendick, R.I. 1981. Slot mulch for runoff and erosion control. Journal of Soil Water Conservation. 36:44-47.
Soil Conservation Service. 1982. National Resources Inventory. U.S. Department of Agriculture, Washington DC, USA.

Increasing Water Use Efficiency through Fallow Soil Management Under Central Anatolian Conditions

M. GULER, N. DURUTAN, M. KARACA, A. AVCIN, M. AVCI and H. EYUBOGLU

Field Crops Research Center (TARM), P.K. 226, Ankara, Turkey

Abstract

Research has shown that in most parts of Central Anatolia water must be conserved during the fallow period through an appropriate soil management system, in order to stabilize cereal production against scarce and unpredictable precipitation. Experiments carried out on the timing, frequency and depth of tillage, and on the most effective tillage implements, established that the best system was initial tillage in early spring as soon as the soil was ready, with a mouldboard plough at a depth of 18-20 cm, followed by several tillages, depending on crust formation and weed density, with sweep + harrow at a depth of 8-10 cm. A six-year series of trials compared different soil management systems; stubble mulch, modified stubble mulch, soil mulch and modified soil mulch; and it was concluded that soil mulch was the most effective system.

Introduction

Small grains are the most important crops in Turkey in both production and area. Fifty percent of the wheat is being grown in Central Anatolia in an area of more than five million hectares.

Inland Turkey, particularly the Central Anatolian Plateau, has a dryland character. Although there is some variation among the provinces in terms of annual precipitation, scarcity of rainfall and its seasonal distribution are the most important characteristics of the region. The average annual precipitation ranges roughly from 250 mm to 450 mm, depending on the locality. There are also great differences among years. This unpredictability always carries the threat of drought. Seasonal distribution of the annual precipitation is given in Fig. 1. The dry season with higher temperatures and lower humidity begins around mid-June and continues until October.

Fifty-six percent of the Central drylands have clay and clay loam and 40% have loam soils. Generally they are poor in organic matter and P_2O_5 content and phosphorus and nitrogen fertilizer application has become a standard practice in most areas. Soil salinity and alkalinity are not a serious problem on the Central Plateau.

In winter dominant low rainfall areas cropping is based on a fallow-cereal rotation using a 14-month fallow period. Wheat and barley are the main cereals. Almost all of the total wheat yield is produced in this area under dryland conditions. The fallow period begins just after the harvest of cereals in July and continues for 14 months until cereals seeding time in October.

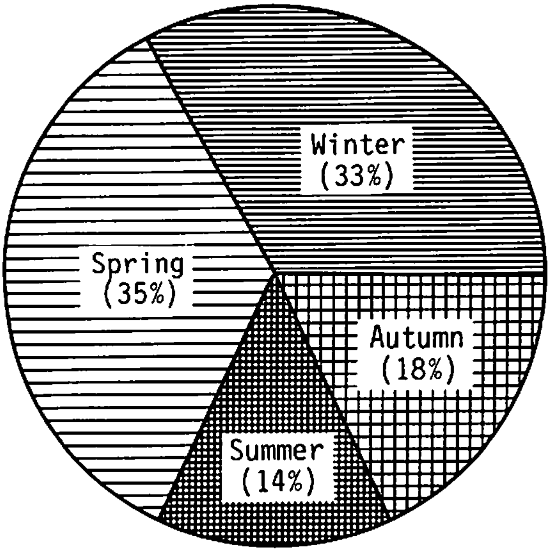


Fig. 1 Yearly precipitation distribution in the main dryland area 1930-80.

The rainy period begins in October-November. Almost all the precipitation in December and January occurs as snow, since the average temperature in these months is around 0°C. The amount of precipitation in February and March is relatively lower and it may fall as snow or rain. Heavier rainfall occurs in April and May. The dry season usually begins in July.

On the Plateau, since the water intake rate is low and the downward movement into the subsoil is very slow, soil must be tilled to enhance the infiltration rate before the beginning of the intensive precipitation period, as the initial operation. The main purpose of this initial operation is to decrease runoff from high intensity rains on the slowly permeable soils of the region, to extend the water retention period on the soil surface, and to improve water intake by increasing surface roughness and total porosity.

Soil losses caused by runoff are also closely related to the degree of slope. On the Plateau cereal production is recommended for the areas with less than 8% of slope, and perennial forage crop production is encouraged for steeper areas.

During long dry periods, capillary continuity is the main factor responsible for evaporative moisture loss, since the upward liquid flow is quite strong in the fine textured soils of the region. Evaporation rate must be reduced by the formation of a layer on the surface to increase the resistance to upward movement thus disrupting capillary continuity. This layer must also insulate the deeper layers thermally during hot dry weather.

Weed growth on fallow land is the primary cause for water loss by transpiration, therefore fields must be kept clean throughout the fallow period.

The subsequent operations of fallow tillage are aimed towards prevention of evapotranspiration.

Research on Fallow Soil Management

With the initiation of the National Wheat Research Project in 1969 special emphasis was given to soil moisture conservation in dryland areas of Turkey. Research which was reorganized in 1969 has been based on some findings of previous work of the 1930-1968 period (Berkmen 1961; Gerek 1968).

Research after 1969 was directed toward determination of the various components of a fallow soil management system in initial and succeeding operations (Bolton 1974; Yesilsoy 1974; Dogan *et al.* 1977; Pehlivanturk *et al.* 1977; Guler *et al.* 1978; Tuzuner and Yoruk 1978; Unver 1978; Karaca 1980; Pala *et al.* 1980; Durutan 1982; Pala 1982; Guler *et al.* 1983).

The findings of this research for dryland areas of the Central Anatolian Plateau are summarized below:

1. Autumn tillage did not increase infiltration significantly, because of the low intensity of autumn rain and the slow melting of snow (Fig. 2).
2. Initial tillage should be done in early spring as soon as soil conditions permit, with a mouldboard plough at a depth of 18-20 cm (Figs 3 and 4). The earlier tillage was found to reduce the number of weeds (Fig. 5).
3. Summer tillage is needed at the beginning of the dry period to prevent evapotranspiration and should be repeated several times, depending on crust formation and weed density. Without summer tillage yield was reduced by 44% and weed density increased by 38% (Fig. 6). Although no particular implement made any significant difference to yield (Fig. 7) a sweep + harrow combination at a depth of 8-10 cm was recommended because the rodweeder caused problems (Fig. 8).

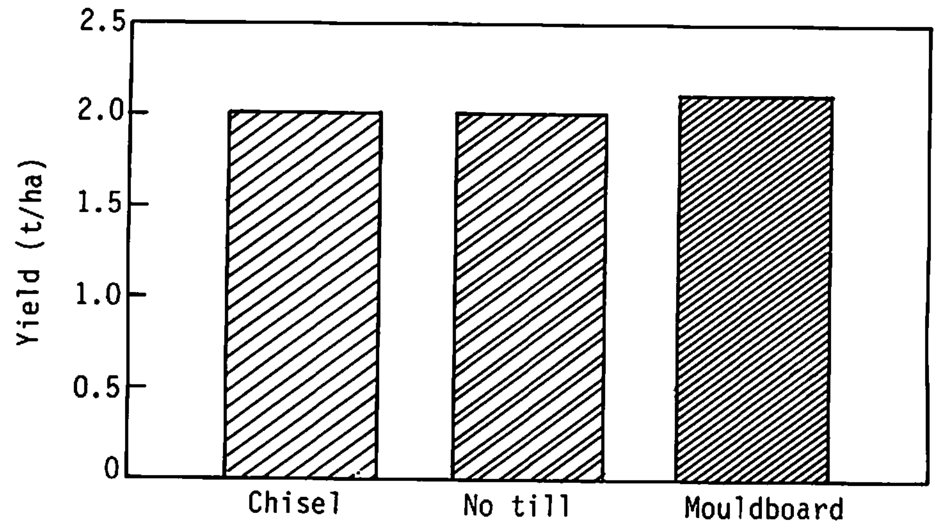


Fig. 2 The effect of autumn tillages on wheat grain yield

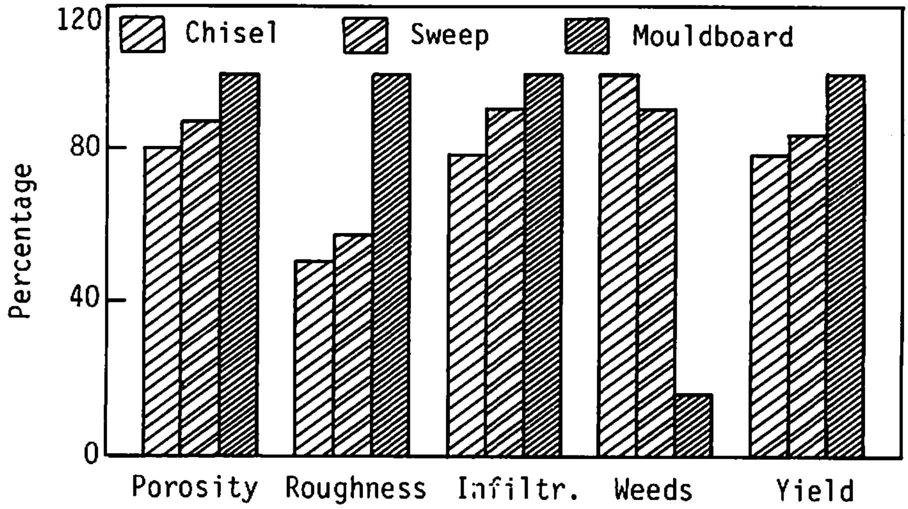


Fig. 3 The effect of initial tillage implements on some agronomic and soil physical properties.

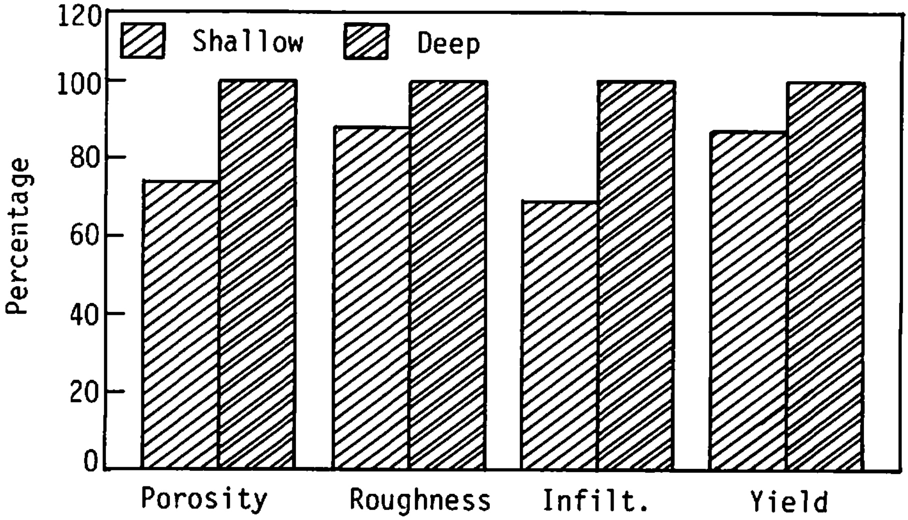


Fig. 4 The effect of depth of initial tillage on some agronomic and soil physical properties.

Comparison of different soil management systems

A series of detailed experiments were conducted for six years in order to test different soil management systems as a whole, as practised in different dryland areas of the world (Bolton 1974).

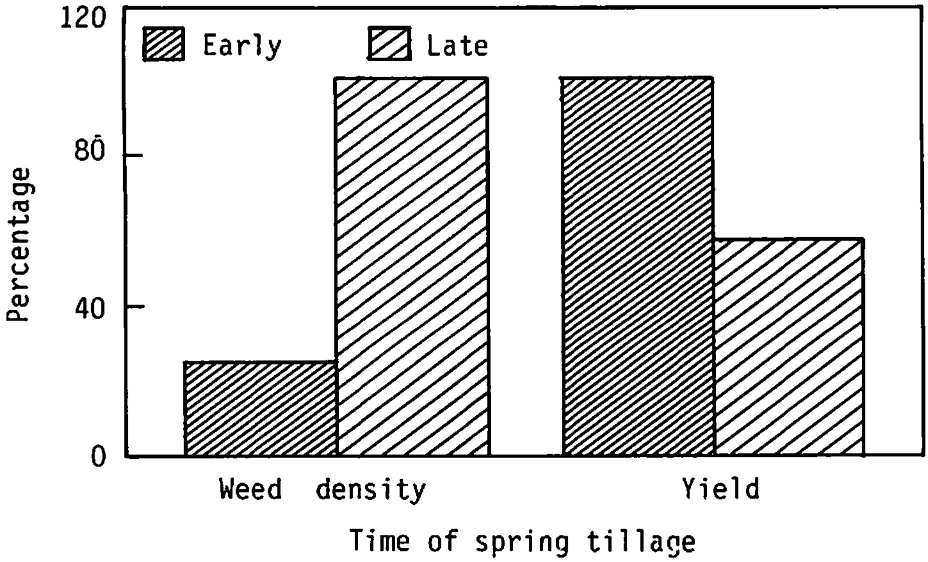


Fig. 5 The effect of time of spring (initial) tillage on yield and weed density (in crop year).

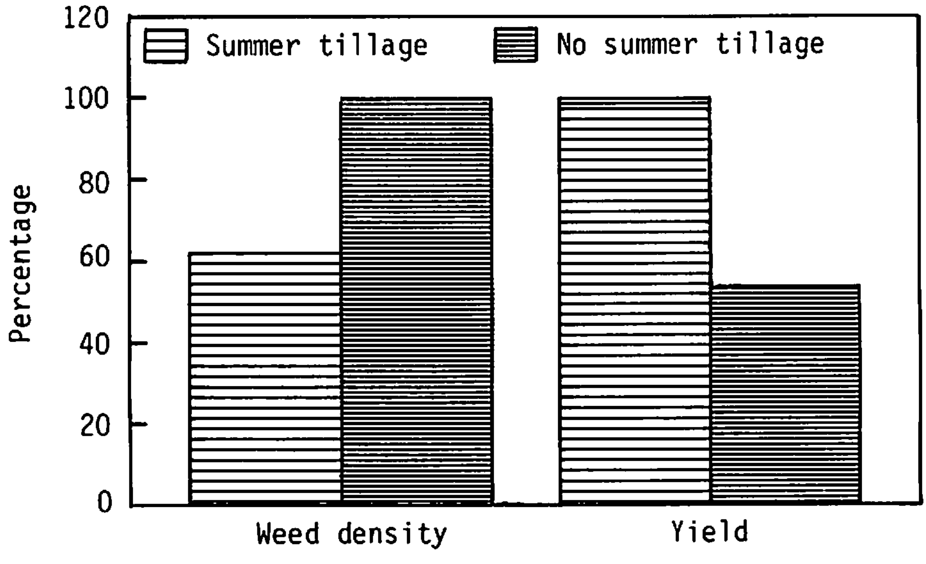


Fig. 6 The effect of summer tillages on grain yield and weed density (in crop year).

The treatments were as follows:

1. *Stubble mulch system:* Initial tillage and succeeding tillages with large sweep (noble blade) at a depth of 5-8 cm.
2. *Modified stubble mulch system:* Initial tillage with common sweep at a depth of 18-20 cm; succeeding tillages with sweep and harrow combination at a depth of 8-10 cm.
3. *Modified soil mulch system:* Initial tillage with reduced surface mouldboard at a depth of 18-20 cm; succeeding tillages with sweep and harrow combination at a depth of 8-10 cm.
4. *Soil mulch system:* Initial tillage with mouldboard plough at a depth of 18-20 cm; succeeding tillages with sweep and harrow combination at a depth of 8-10 cm.

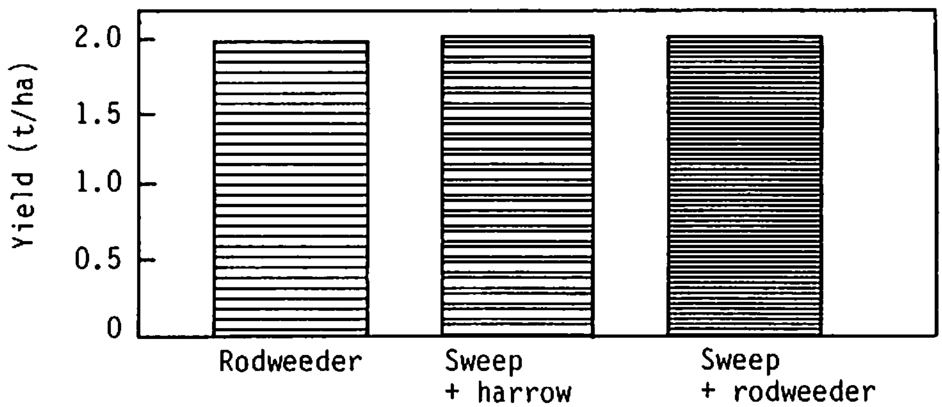


Fig. 7 The effect of summer tillage implements on grain yield.

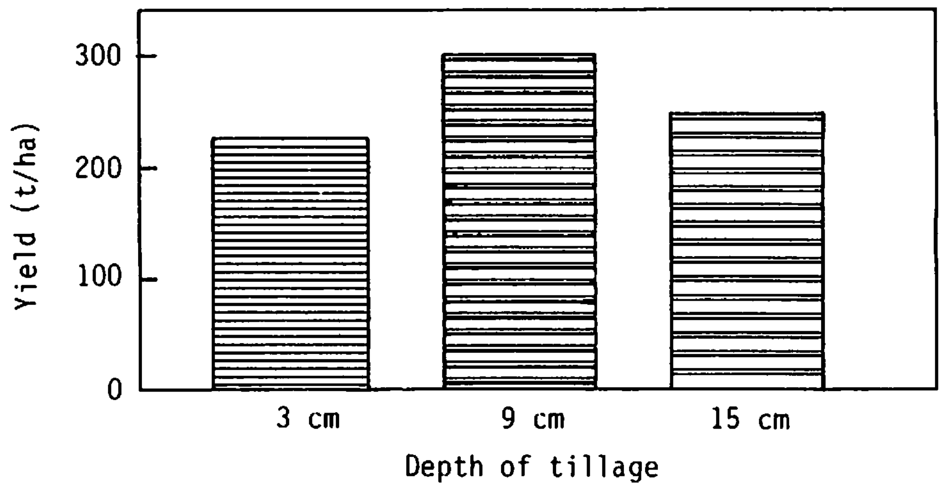


Fig. 8 The effect of depth of summer tillage on grain yield.

The soil mulch system was found to be the most effective, providing the highest cumulative infiltration, fallow efficiency and lowest weed (*Bromus tectorum*) density in the crop year (Fig. 9). The grain yield results revealed that the positive effects of the soil mulch system began to be pronounced after the first cycle, increasing with each cycle, confirming the results obtained before (Fig. 10).

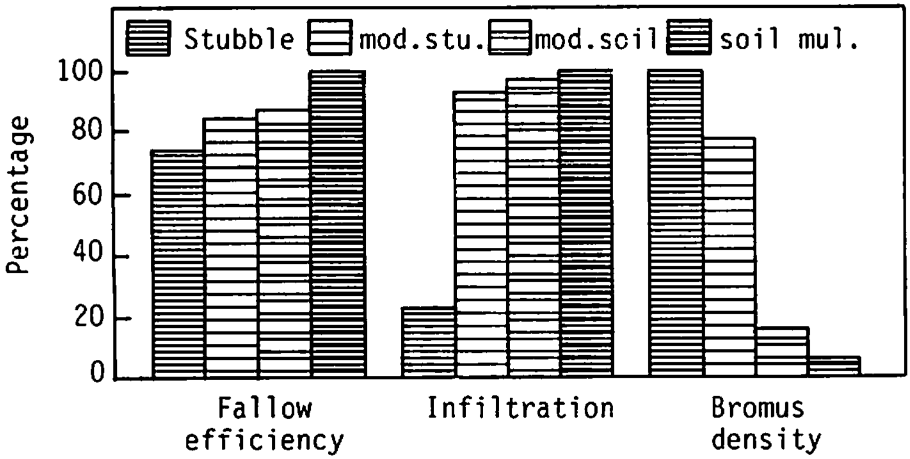


Fig. 9 The effect of fallow management systems on some agronomic and soil physical properties.

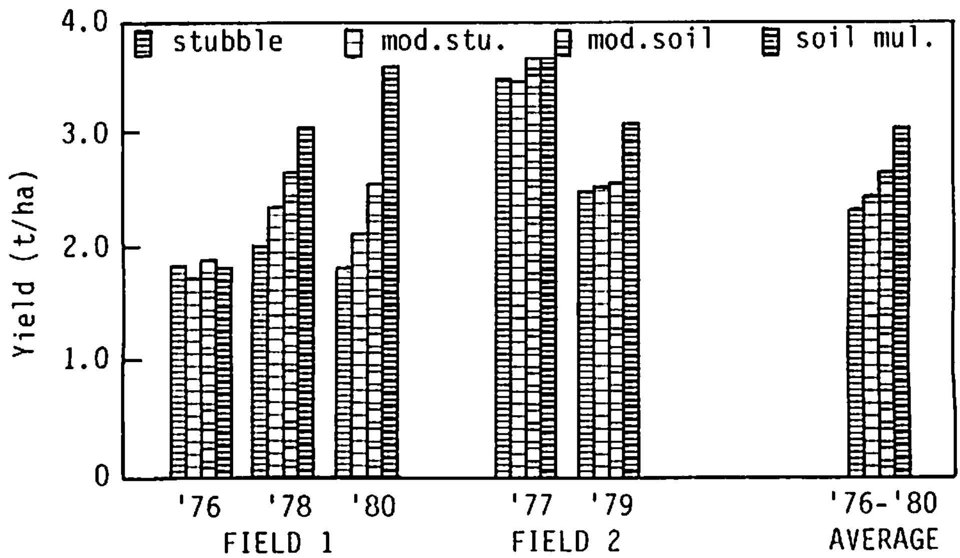


Fig. 10 The effect of fallow management systems on grain yield

References

Berkmen, N. 1961. Ankara Zirai Arastirma Enstitusu Calismalari, 1931-60. Tarim Bakanligi Ankara Zirai Arastirma Enstitusu. Calismalari No. 4, Ankara, Turkey.

Bolton, F. 1974. Tillage and cultural practices for wheat under low rainfall conditions. Proceedings of 2nd Regional Wheat Workshop, May 6-11, Ankara, Turkey.

Dogan, O., Cimilli, B. ve Gucer, C. 1977. Orta Anadolu Iklim Kosullarinda Nadas-Bugday Tarim Yonteminin Uygulandigi Yorelerde En Uygun Sonbahar Islemi, Aniz Bozma Aletleri, Yaz Islemleri ve Bu Aletlerle Uyusabilen Mibzer Cesitlerinin Saptanmasi Uzerinde Arastirmalar. Merkez Topraksu Arastirma Enstitusu Mudurlugu Yayinlari, Genel Yayin No. 45, Ankara, Turkey.

Durutan, N. 1982. Orta Anadolu Bugday Ekim Alanlarinda Brom (*Bromus tectorum* L.)'un Yayilisi, Biyoekolojisi ve Mucadele Olanaklarinin Arastirilmasi, Ankara Universitesi Ziraat Fakultesi, Doktora Tezi, Ankara, Turkey.

Gerek, R. 1968. Dryfarming Istasyonu Tarafindan Yapilmis olan Nadas Hazirlama ve Toprak Verimliligi Denemeleri. Eskisehir Tohum Islah ve Deneme istasyonu, Nesriyat No. 6, Eskisehir.

Guler, M., Unver, I., Pala, M., Durutan, N. ve Karaca, M. 1978. Orta Anadolu'da 1972-1977 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari. Orta Anadolu Bolge Zirai Arastirma Enstitusu Mudurlugu Yayinlari, No. 78-1 Agronomi Rapor No. 2.

Guler, M., Pala, M., Durutan, N., Karaca, M. ve Unver, I. 1983. Orta Anadolu Bolgesinde Nadas Toprak Isleme Yontemlerinin Bugday Verimine Etkileri. Orta Anadolu Bolge Zirai Arastirma Enstitusu Tarla Bitkileri Yetistirme Teknigi Sonuc Raporu, Ankara, Turkey.

Karaca, M. 1980. Nadas Toprak Islemesi Derinlik ve Yontemlerinin Infiltrasyona Etkileri. Ankara Universitesi Ziraat Fakultesi, Doktora tezi, Ankara, Turkey.

Pala, M. 1982. Yaz Toprak Isleme Derinliklerinin ve Kullanilan Araclarin Toprakta Nem ve Sicaklik Degisimine Etkileri Uzerinde Bir Arastirma. Ankara Universitesi Ziraat Fakultesi, Doktora Tezi, Ankara, Turkey.

Pala, M., Guler, M., Unver, I., Durutan, N. ve Karaca, M. 1980. Orta Anadolu'da Nadas Donemi Ilkbahar Toprak Isleme Zamaninin Bugday Verimine Etkisi. Tarimsal Arastirma Dergisi, Cilt 2, Sayi 2.

Pehlivanturk, A. Izgin, C.N., Guler, M., Unver, I. ve Pala, M. 1977. Orta Anadolu'da 1970-76 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari. Orta Anadolu Bolge Zirai Arastirma Enstitusu Mudurlugu Yayinlari, No. 77-2, Agronomi Rapor No. 1.

Tuzuner, A. ve Yoruk, M. 1978. Orta Anadolu Kosullarinda Bugday Uretiminde Gelistirilmis Tarim Teknigi ile Geleneksel Ciftci Uygulamalarinin Karsilastirilmasi. Toprak ve Gubre Arastirma Enstitusu Mudurlugu Yayinlari, Rapor Yayin No. 14, Ankara, Turkey.

Unver, I. 1978. Nadas Toprak Islemesinde Zaman, Derinlik ve Yontemlerinin Topragin Rutubet ve Sicaklik Degisimine Etkileri. Ankara Universitesi Ziraat Fakultesi, Doktora tezi, Ankara, Turkey.

Yesilsoy, S. 1974. The influence of tillage practices on moisture conservation and the wheat yield in Central Anatolia. Proceedings of 2nd Regional Wheat Workshop, May 6-11, Ankara, Turkey.

The literature on tillage and stubble management shows conflicting results. This is because soils and conditions differ from place to place and the best practices are specific to environments (Gharbi). However, some general principles appear to be emerging which need to be considered in the region.

In general, reduced tillage appears to lead to yields that are as good as those from some widely used practices such as deep ploughing; it is less costly of fuel; it can be done more quickly thereby improving the timeliness of operations; and, it does less damage to the soil. However there may be special environments or soils for which this is not true and some deep ploughing may be essential in some places.

Traditional animal powered tillage methods may be appropriate (Khaldi) but because they are slow they are not always completed in time. A reduced frequency of tillage and the retention of some surface cover can dramatically reduce soil erosion. For example in Australia stubble retention with minimum tillage reduced soil loss to < 1t/yr from 29 t/yr with conventional tillage (Reeves).

The main reason for tillage is seed bed preparation. With the improvement of planters for direct drilling of both seed and fertilizer, the need for seed bed preparation is reduced and it may become possible to eliminate tillage to help to control soil erosion. But for erosion control it is necessary to consider the whole system. Overgrazing is one of the main factors contributing to erosion (Bouzza).

The advantages of having crop residues on the soil surface to counter erosion are appreciated, but in WANA at present this simply isn't possible. Until other adequate feed is provided every bit of stover will be used to feed animals. (Osman).

Crop Establishment

The Effect of Crop Management on Increased Production through Improved Water Use Efficiency at Sowing

MUSTAFA PALA

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

Abstract

Crop management factors at the time of sowing should increase transpiration efficiency and reduce evaporation from the soil surface, consequently increasing crop water use efficiency (WUE). This paper focusses on such factors as choice of cultivar, sowing date, sowing method, seed rate and row spacing. Examples are given of many experiments comparing traditional and improved sowing methods in West Asia and North Africa (WANA), particularly Turkey, Syria and Cyprus, and in other parts of the world. The results of these experiments suggest the optimum management practices for the dryland farmers of the WANA region, always taking its diverse environmental conditions into account.

Introduction

The rainfed farming systems of West Asia and North Africa (WANA) have developed over centuries in areas receiving annual rainfall between 200 and 600 mm, with wide temporal and spatial variability. The area under rainfed farming occupies approximately 75% of the total cropped area (FAO 1986).

Cereals are the principal crops grown in the region (Table 1), with wheat (*Triticum aestivum, T. turgidum* var. *durum*) covering about 50% and barley (*Hordeum vulgare*) 20% of the cropped area. Pulses, mainly faba bean (*Vicia faba*), chickpea (*Cicer arietinum*) and lentils (*Lens culinaris*), the second most important group of crops, occupy around 6% of the total arable rainfed cropped area.

A cereal-fallow rotation integrated with livestock is the most common system in the region. In most countries weeds and volunteer cereals are allowed to grow on the fallow and provide a valuable and cheap source of winter and spring grazing for livestock. However, in some areas (e.g. Turkey) clean fallow is practised, and the increased water storage during the fallow has resulted in substantial yield increases in the subsequent cereal crop (Unver 1978; Guler *et al.* 1979; Pala *et al.* 1980; Pala 1982; Avci *et al.* 1987)). This rotation is most common in the drier areas of the region. In more climatically favourable areas, food legumes and summer crops are often grown in the place of fallow, either in a two-year rotation with cereals, or less frequently, in a three-year rotation including cereals, legumes and summer crops (water melon (*Citrullus lanatus*), melon (*Citrullus colosynthis*), sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*), sesame (*Sessamum indicum*), cotton (*Gossypium hirsutum*), and maize (*Zea mays*), depending on the locality).

In rainfed agricultural systems, soil and water resources largely determine the level of production. The climate and soils of the region have been discussed by several authors

Table 1. Land use in West Asia and North Africa in 1986 (x 1000 ha)

Country	Arable Crops	Perman. Crops	Irrig. Crops	Rainfed Crops	Cereals	Wheat	Barley	Pulses
Algeria	7000	610	338	7272	2754	1550	1050	169
Libya	1787	340	234	1893	415	280	130	9
Morocco	7880	521	523	7878	5220	2223	2472	429
Tunisia	3398	1525	215	4708	1059	540	442	114
Egypt	2320	166	2486	-	1906	507	58	196
Ethiopia	13200	730	94	13836	4690	600	800	916
Sudan	12420	58	1700	10778	6612	151	-	83
Cyprus	365	67	94	338	70	10	60	6
Iraq	5250	200	1750	3700	2433	1100	1250	38
Jordan	380	38	43	375	95	71	24	14
Lebanon	210	90	86	214	17	12	4	9
Syria	5038	585	652	4971	2710	1098	1548	167
Saudi Ar.	1100	75	415	760	614	565	8	4
Yemen AR	1261	90	247	1104	844	65	48	65
PDR Yemen	147	20	62	105	69	10	2	-
Afghanistan	7910	144	2660	5394	3124	2100	300	25
Pakistan	20100	400	15440	5060	11284	7403	193	1621
Iran	14100	730	5740	9090	9083	6458	2200	384
Turkey	24606	2935	2150	25391	14747	10000	3500	1742
Total	128472	9324	34929	102867	67746	34743	14089	5991

Source: FAO Production Yearbook, 1986.

(UNESCO/FAO 1963; Meigs 1964; FAO 1978; Kassam 1981; Cooper *et al.* 1987) who indicated that rainfed crop production takes place against a background of limited, variable and often chronically deficient rainfall which occurs mainly during the cool or cold winter, and to a lesser extent during the warmer spring. Present levels of crop yields are far below their potential in the region (FAO 1986) and this is generally attributed to insufficient supply of water. However, yields could be improved substantially through more efficient use of this limited water.

Agronomists often express water use efficiency (WUE) as the ratio of yield (Y) to evapotranspiration (ET) in field experiments (Dregne and Willis 1983). Definition of WUE and ways to improve it have been reported in detail by Bolton (1981), Cooper (1983), Cooper and Gregory (1987) and Cooper *et al.* (1987).

The water use efficiency and yield level of rainfed crops are determined by environmental factors (climate, soil), crop genotype (cold, drought and disease resistant) and agronomic practices (tillage, seedbed preparation, sowing date, sowing method, seed rate, row spacing, fertilizer use, control of weeds, insects and diseases, and crop rotation). Agronomic practices need to be geared firstly, to increase the amount of water stored in the soil through increased infiltration and reduced evapotranspiration, and secondly, to maximize the use of stored water and subsequent precipitation.

Adapted Cultivars

Water use efficiency and hence crop yield levels can be increased by using the genotypes best adapted to the dry areas. Breeding programs have similar goals in improvement: crops that are tolerant to cold, drought, and heat; resistant to insects and diseases; of good quality; and high yielding.

However, there is a general agreement among plant breeders dealing with dryland conditions that the genotype x environment interaction may reduce progress in improving yield under rainfed conditions due to site-by site and year-by-year variability (ICARDA-CP 1986). Desirable selections to overcome this constraint for rainfed conditions have been made from crosses of high yielding lines with adapted landraces and parental lines previously identified as possessing drought tolerance as well as earliness and disease resistance. Cultivars with high drought tolerance, yield potential and WUE, also tolerant to cold, are being sought. However, to verify yield potential, crop cultivars need to be carefully tested under the differing, often adverse, conditions of these dry areas; climate is particularly erratic, but soil and management conditions also vary. New breeding strategies will have to be developed if such cultivars, combining stress tolerance and yield potential, are to be produced. In addition, specific adaptation of cultivars must be taken into account. This is being done at ICARDA and elsewhere in the region. Research conducted in Turkey since 1970 has shown that the utilization of early cultivars with high yield potential, wide adaptation, disease resistance and high quality has contributed to production increases. For example, the data in Fig. 1 show the effect of cultivar and cultural practices on wheat grain yield at two different locations in the Central Anatolian Plateau (Durutan *et al.* 1987).

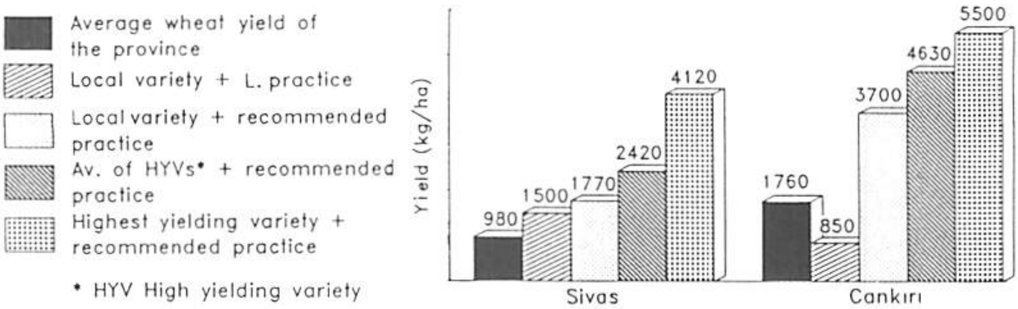


Fig. 1 Effect of cultivar and growing techniques on wheat grain yield (kg/ha) at two locations in the Central Anatolian Plateau, Turkey, 1984 (Durutan *et al.* 1987).

Another example can be given from ICARDA's Tel Hadya Research Station (Nachit 1988), showing the differences in grain yield and WUE of a high yielding durum wheat cultivar, Korifla, compared with Hourani, a low yielding variety (Table 2).

An example of the progress made in genotypic improvement for dryland conditions in the Pacific Northwest, USA was reported by Bolton (1981). At a site with 240 mm average annual rainfall, the increases in WUE for grain yield for the period 1953-74 compared with 1931-52 were mainly due to improved soil and crop management rather than the cultivar. However, as the precipitation increased (400 mm average rainfall zone), the contribution of improved cultivars to WUE became almost twice that in lower rainfall zones. In addition, the author reported that the effect of improved crop management on WUE decreased to less than half of that in the drier site, indicating that genotypic improvement plays a larger role in WUE in more favourable areas.

The new stress-tolerant cultivars developed at ICARDA and at the NARS of WANA are showing that improvement is now an important tool in increasing and stabilizing dryland production. However, improved cultivars may not help to increase yield through increased WUE unless management practices are appropriate and timely. A combination of stress-tolerant cultivars and better agronomic recommendations should assist dryland farmers to increase productivity and thus to improve their economic welfare.

Sowing Date

Establishment is the most important step in crop production and sowing date is one of the most important factors in achieving this, provided there is a properly tilled seedbed. Once we

Table 2. Comparison between the grain and WUE of high and low yielding wheat varieties, Tel Hadya (Nachit 1988)

Year	Variety	Grain (kg/ha)	% Increase	Seasonal rain (mm)	WUE kg/ha/mm
1982/83	Korifla	2162	17	324	6.7
	Hourani	1852	-	324	5.7
1983/84	Korifla	1546	7	230	6.7
	Hourani	1445	-	230	6.3
1984/85	Korifla	1586	9	373	4.3
	Hourani	1451	-	373	3.9
1985/86	Korifla	2289	18	316	7.2
	Hourani	1933	-	316	6.1
1987/88	Korifla	3439	22	504	5.8
	Hourani	2827	-	504	5.6

have an improved cultivar, the best sowing date, method and plant densities are necessary to achieve increased production through improved WUE.

In dryland crop production in winter rainfall areas, optimum sowing date may have a substantial effect on WUE by ensuring that the growth of the crop is adjusted to the availability of soil moisture.

There are many indications in the region and in similar areas of the world, that early crop establishment and early canopy development of crops are associated with higher yields, obviously resulting from more efficient use of water (Berkmen 1961; Darwinkel *et al.* 1977; Guler *et al.* 1977; Bolton 1981; Cooper *et al.* 1981, 1983; Photiades and Hadjichristodoulou 1984; Saxena 1987; ICARDA-FRMP 1987, 1988). However, early sowing will only prove to be an advantage if germination also occurs early and if the crop can survive potential drought conditions at the seedling stage. For germination, moisture must penetrate the upper soil profile over the range in seeding depth of 2-12 cm, depending on the sowing method used. Whether such moisture penetration will occur will depend upon several factors: the amount of rain, the number of days over which it falls, the associated atmospheric demand for moisture over those days, and the relative dryness of the soil surface (Keatinge *et al.* 1986). Therefore date of sowing should be related to farming systems as well as to environmental factors such as temperature and moisture (Bolton and Booster 1978).

Fallow-Cereal Systems

A fallow-cereal rotation is common in drier areas of both highlands and lowlands of the region. The main goal in practising this rotation is to conserve the maximum amount of water in the soil during the fallow period, which lasts about 14 to 18 months from harvesting to sowing of cereals. However, fallow efficiency of 25-35% is achieved only in the highland areas while the maximum in lowland areas is of the order of 15% (Yesilsoy 1974; Unver 1978; OSU 1979; Aktan 1981; Guler *et al.* 1981; Pala 1982; ICARDA-FRMP 1988).

Where fallow efficiency is high enough the soil profile below 8-10 cm of top soil generally has a water content above the wilting point (Guler *et al.* 1981). Therefore, when the crop is sown early about 5-7 cm deep in dry soil, the first precipitation of about 10 mm will be enough to fill the moisture gap in the top layer of light textured soils to allow early establishment of the crop.

The data in Fig. 2, which are averages of many trials over a period of years, show the optimum range for stand establishment in eastern Oregon (Bolton 1981). The author indicated through long-term observations of precipitation in relation to grain yields that whenever significant rainfall occurred during the optimum period for stand establishment (September 15 to October 15), grain yields were significantly higher. Similar results were obtained in the Central Anatolian Plateau of Turkey through multi-season, multi-location trials (Guler *et al.* 1977). The data in Fig. 3, which are averages of 12 trials over a five-year period, show the effect of early seeding into dry soil compared with delayed sowing after rain into wet soil. The data in Fig. 4, which are averages of eight demonstration plots from on-farm trials in a two-year period, also show the advantage of early seeding into dry soil on a larger scale (ORZA 1985, 1986).

Proper fallow tillage practices as well as sufficient precipitation will permit early stand establishment of early sown crops and result in higher yield by extending the period for vegetative growth. Delaying the sowing date will prevent crop germination and seedling

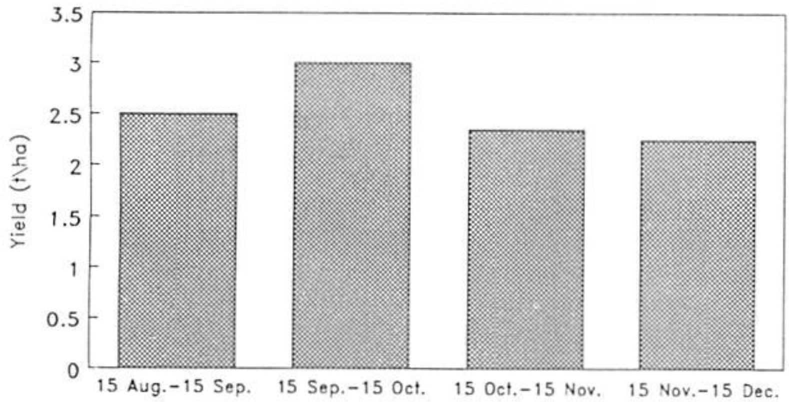


Fig. 2 **Effect of stand establishment on grain yield (t/ha) in Eastern Oregon, USA (long term average) (Bolton 1981).**

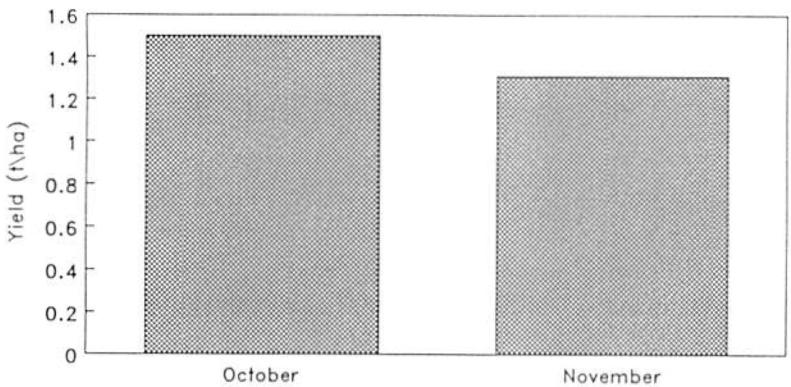


Fig. 3 **Effect of sowing time on grain yield (t/ha) in the Central Anatolian Plateau (average of 12 trials in 5-year period 1972-77) (Guler *et al.* 1977).**

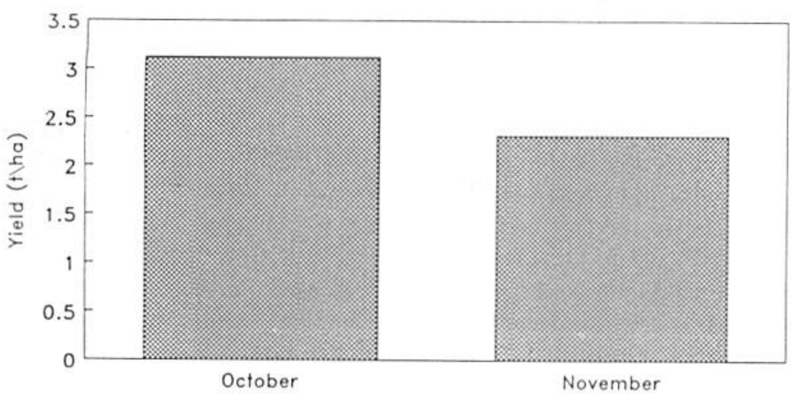


Fig. 4 **Effect of sowing date on grain yield (t/ha) in Central Anatolian Plateau, Turkey, in larger scale demonstration plots under farmer conditions (8 demonstration sites in 2-year period 1984-86) (Orza 1985, 1986).**

establishment in high elevation areas because of a rapid drop in air temperature starting generally in November (Fig. 5).

Appropriate fallow tillage practices will also result in a seedbed which will allow early sowing, rather than waiting for rainfall before being able to cultivate soil full of clods caused by incorrect tillage during the fallow period. What is appropriate tillage will depend on soil type, topography and the slope of land, expected weather patterns (especially the intensity of early rainfall), and on the crop sequence. It is therefore largely specific to localities and will need to be determined experimentally on a sub-regional basis within nations.

Seeding into dry soil is risky, and presents problems with crusting after rains and

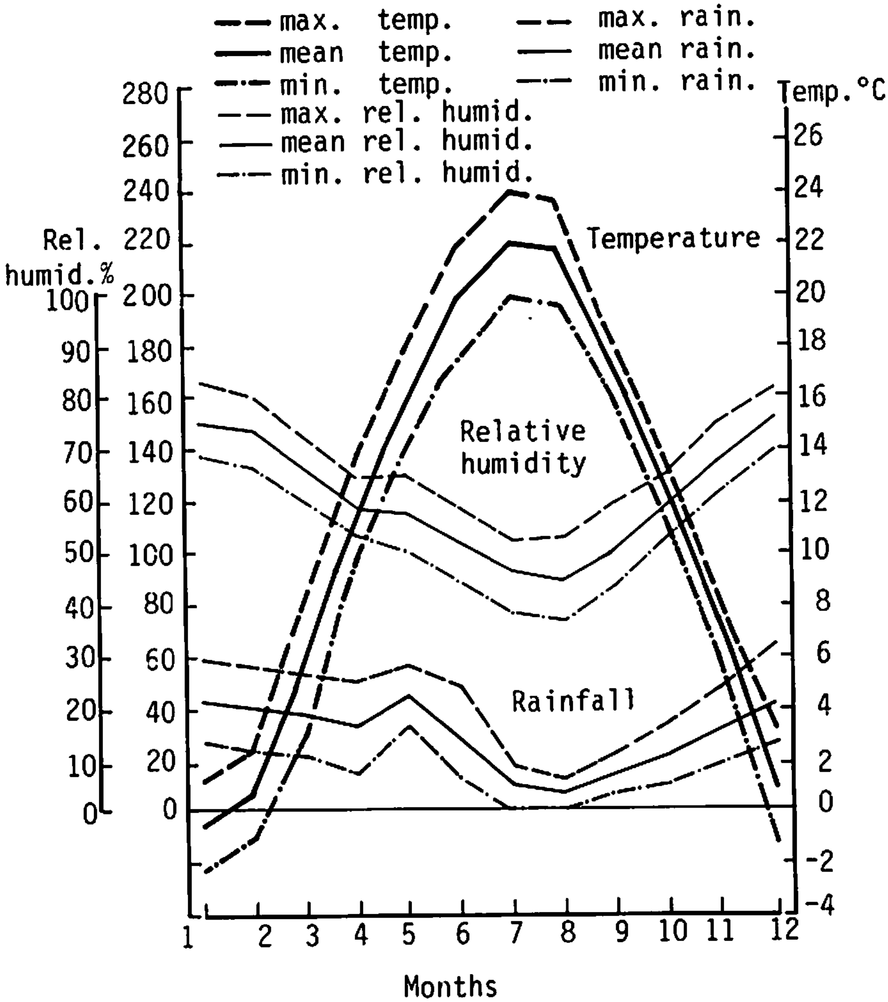


Fig. 5 **Distribution of rainfall, temperature and relative humidity in the Central Anatolian Plateau (long term average) (Mizrak 1983).**

sometimes with weed control. However, reductions in yield in relation to late stand establishment are well documented and consistent. The risk of reduced yields from crusting or weeds is not predictable. It would seem that timely seeding under dry soil conditions outweighs any advantages from waiting for adequate moisture to wet the seed zone (Bolton 1981).

Continuous Cropping Systems

Continuous cropping is practised mainly in more favourable areas of both highlands and lowlands of the region where annual rainfall is above 350-400 mm, taking the other climatic data into consideration.

Under these conditions, almost all extractable water is used by crops every year and further evaporation during the summer decreases soil water far below the wilting point (Guler *et al.* 1981). Therefore sowing of crops is mainly dependent on receiving sufficient precipitation in autumn for crop germination and stand establishment.

Rainfall models are available (Stern *et al.* 1982) which allow examination of a wide range of alternative definitions of the events capable of causing crop germination. Keatinge *et al.* (1986) selected two such definitions based upon observations of crop germination at five sites in Syria over four growing seasons. The first definition, of 10 mm in three days, represents the minimum amount of rain likely to cause partial crop germination if the soil is very dry. The second definition, of 20 mm in three days, represents the type of event seen to cause complete crop germination even under the very dry soil conditions usually found at most of the sites in early November. From the data shown in Table 3, germination at the wettest site, Jindiress (average mean annual rainfall 480 mm) can be expected to occur 20-40 days earlier than at the driest site, Khanasser (average annual rainfall 180 mm). This will then confer a potential yield advantage on the wetter site by extending the duration of the effective

Table 3. Median dates for rain events causing germination after selected sowing dates (Keatinge *et al.* 1984, 1986)

Sowing date	Jindiress	Azaz	Tel Hadya (Aleppo)	Breda	Khanasser
	a) more than 10 mm rain in 3 days				
1/10	25/10	27/10	29/10	4/11	12/11
1/11	7/11	11/11	15/11	20/11	27/11
1/12	4/12	6/12	9/12	13/12	18/12
	b) more than 20 mm rain in 3 days				
1/10	6/11	16/11	22/11	1/12	25/12
1/11	21/11	25/11	3/12	8/12	1/1
1/12	12/12	14/12	22/12	27/12	16/1

growth period, as the rains end at a similar time at all five sites. This yield advantage derives from the higher temperatures early in the season which cause more rapid seedling emergence and canopy development which in turn generally result in improvements in crop water use efficiency (Cooper 1983). For this effect to be of importance, seedling emergence needs to occur before air temperatures fall to normal winter levels usually in December and January (Keatinge *et al.* 1986). However, if germination is to be followed by even and vigorous stand establishment, it is necessary for the germinating rain event to be followed by a second rain of sufficient quantity to maintain an adequate reserve of soil water. The risk of experiencing temporary drought at the seedling stage is small at relatively wetter sites but not insignificant at all sites. Its importance as a risk factor doubles if germination occurs at the beginning, rather than at the end of November.

Photiades and Hadjichristodoulou (1984) reported that in Cyprus, sowing later than 15 November reduced cereal grain yield and sheaf weight because heading is delayed by 10 days for every 15 days delay in sowing. Grain filling is thus deferred into the period of the season when rainfall is less frequent or has ceased, and crops suffer greater water stress. A similar analysis of data from over 200 experiments in South Australia showed that for each week's delay in sowing after the optimum time, wheat grain yield was reduced by 200-250 kg/ha (French and Schultz 1984). At one site (with 307 mm rainfall), where sowing was delayed by 2.5 months, dry matter yield was reduced from 12.2 to 4.6 t/ha and WUE from 29.4 to 18.9 kg/ha/mm.

Long term tillage trials with different sowing dates depending on the systems have been conducted at ICARDA on a wheat/lentil rotation for several years. In general, whatever the rainfall distribution (Table 4 and Fig. 6), the highest wheat grain yield was achieved by

Table 4. Effect of sowing date and tillage system on wheat grain yield (kg/ha) at Tel Hadya, Syria (1979-1989)

Tillage System	Grain yield, kg/ha						
	1979/80	1981/82	1983/84	1985/86	1986/87	1987/88	1988/89
Conv. E. (Oct)	1970	1479	429	1339	1722	2466	1122
Conv. M. (Nov)	2393	1702	653	2968	1753	2960	1415
Conv. L. (Dec)	1741	1746	466	2216	1519	2577	675
Zero E. (Oct)	1243	569	156	910	1332	1976	769
Zero M. (Nov)	848	693	621	1578	1461	2899	983

E = Early; M = Middle; L = Late

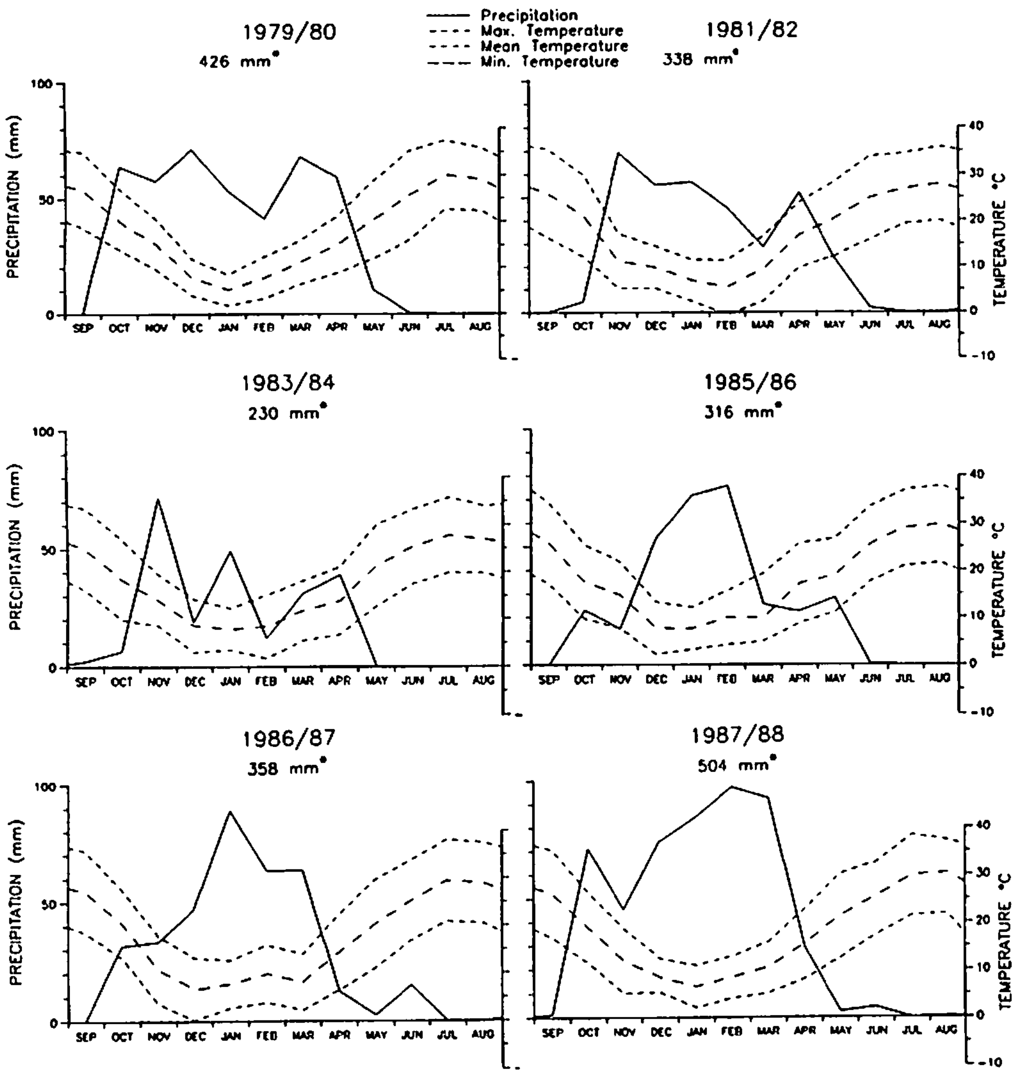


Fig. 6 Distribution of monthly rainfall, and maximum, minimum and average temperatures for growing seasons, 1979-88 at Tel Hadya, N.W. Syria (284 m, 36°01'N, 36°56'E).

sowing in November, compared with October or December-January plantings under conventional tillage or zero-till practices. However, it should be remembered that under these conditions, an early sown crop is also affected by the rainfall distribution within the first months of the growing season, and further, by possible frost events. Currently, farmers in the Mediterranean region tend to sow crops later than the optimum time because of unreliable initial rains (Dennet *et al.* 1984), because they want to control weeds by pre-sowing tillage operations, and possibly because of a risk of frost damage to early sown crops.

When we consider the legume phase in the rotation, it is clearer that it is the longer growing season resulting from early sowing that increases the WUE and thus the yield

(Saxena 1981; Saxena *et al.* 1983). In the period from 1983 to 1988 trials at ICARDA's main station, Tel Hadya, and on farmers' fields in northwest Syria have shown consistently that lentil sown in mid-November will give 20% to 25% more seed yield than when it is sown in January or February. Straw yields may be proportionally even greater, and in the above work the straw yield advantage was 68% on-station and 26% on-farm (Silim *et al.* (a); Pala and Mazid 1988) (Fig. 7).

Comparison of winter and spring sown chickpeas has also been reported in detail (Saxena 1983; Keatinge and Cooper 1984; Pala and Nordblom 1987). Winter planting results in the development of plants with a larger vegetative frame capable of supporting a bigger reproductive structure, leading to greater water use efficiency and increased productivity (Cooper and Gregory 1987).

In spite of the many potential advantages of early winter over late winter or spring sowing of legumes, a number of problems have to be resolved, namely development of cultivars with cold tolerance and disease resistance, and control of greater infestation by weeds and insects.

In highland areas of Turkey with cold winters but with sufficient rainfall early in the growing season (Mizrak 1983), under the continuous cropping systems, sowing of cereals should be done from September to the first week of October to ensure higher WUE and thus higher crop yields (Dogu Anadolu Bolge Zirai Arastirma Enstitusu 1984; Kalayci *et al.* 1985).

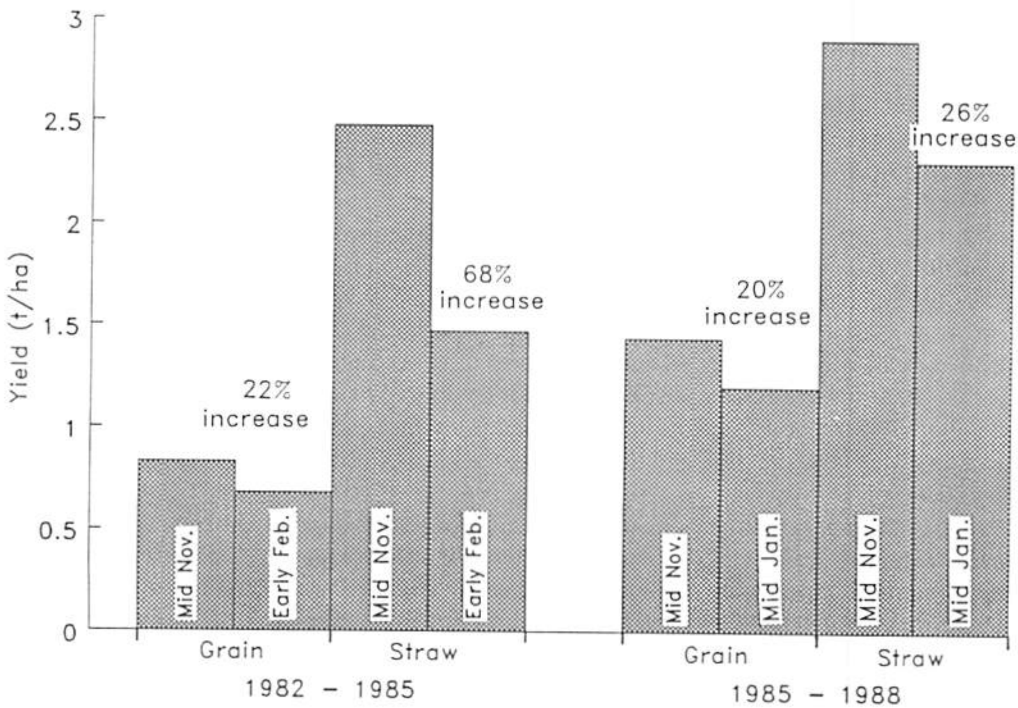


Fig. 7 Effect of sowing date on grain and straw yield (t/ha) of lentil in Northern Syria, 1982-85 and 1985-88 (Silim *et al.* (a) unpublished; Pala and Mazid 1988).

However one should not forget the difficulty of seedbed preparation in continuous cropping systems. Hard surfaced soil caused by very low moisture content after harvest usually needs heavier and stronger equipment and high powered tractors to achieve a good seedbed. Otherwise, the sowing either has to be delayed until the rainy period which decreases crop yield (because of lower temperature conditions preventing germination and seedling establishment before winter), or seedbed conditions are poor, indirectly impairing seedling establishment. The best option for such conditions, in order to seed the crop at the right time, may be the improvement and use of no-till planters. Even if seeding has to wait for the rain, it is clear that direct drilling, because it requires only one pass over a previous crop, can be used to sow a crop quickly after rain and hence gain rapid establishment and minimize soil evaporation, leading to higher WUE.

Sowing Method

Sowing method is another important component of crop management which may lead to a range of stand establishment depending on the method used.

Drilling seed should result in uniform seed depth, high germination and a uniform stand with desirable row spacing. In addition, phosphorus fertilizer can be placed in a band close to seeds, thus increasing P availability.

Broadcasting seed is a common practice in the region, due to either the unavailability of drills or to the small field size, generally 0.5 to 2.0 ha. In broadcasting, distribution of seeds in the soil is not uniform, therefore crop germination and stand establishment will be uneven. Irregular plant density will reduce yields and WUE by either increasing soil evaporation where stands are thin or increasing water stress where the density is too great. The equipment used to cover the seeds after broadcasting will determine the seed depth from the soil surface down to 15 cm. Seeds left on the soil surface will probably be eaten by birds or will not germinate, and seeds placed too deep will germinate but not emerge. Farmers in general are aware of the problems, hence they apply 1.5 to 2 times the recommended seed rate (Durutan *et al.* 1982; Tully and Rassam 1985).

The data in Figure 8a, which are averages of nine demonstration plots from on-farm trials over a three-year period, show that yields from drilled plots were 11% greater than from the broadcast in which though the seed rate was 1.5 times higher. (ORZA 1983, 1985, 1986).

Ducksfoot cultivators, disc harrows or mouldboard ploughs are commonly used in the region to cover the seeds broadcast on flat land. However, in Syria, farmers often broadcast seed on ridged land and then split the ridges by ducksfoot cultivator (one set) with 45-47.5 cm row spacing.

In a comparison of the effect of drill use and common farmers' practice in Syria at two locations for two seasons 1986-1988, it was found that drilled wheat yielded an average of 29% more than that sown by the farmers' method (Fig. 8b) (ICARDA-FRMP 1988). The main difference between the two methods was not only the distribution of seeds on and in the soil, but also the row spacing, which was 17.5 cm when drilled and 45 cm when broadcast. The wider row spacing has two effects. It reduces the efficiency of light interception, and it exposes a greater bare soil surface to radiation. The net result of this is that crop growth rates are reduced, the development of complete canopy cover is delayed, more water is lost as direct evaporation from bare soil surfaces than as transpiration, and yields and WUE are reduced.

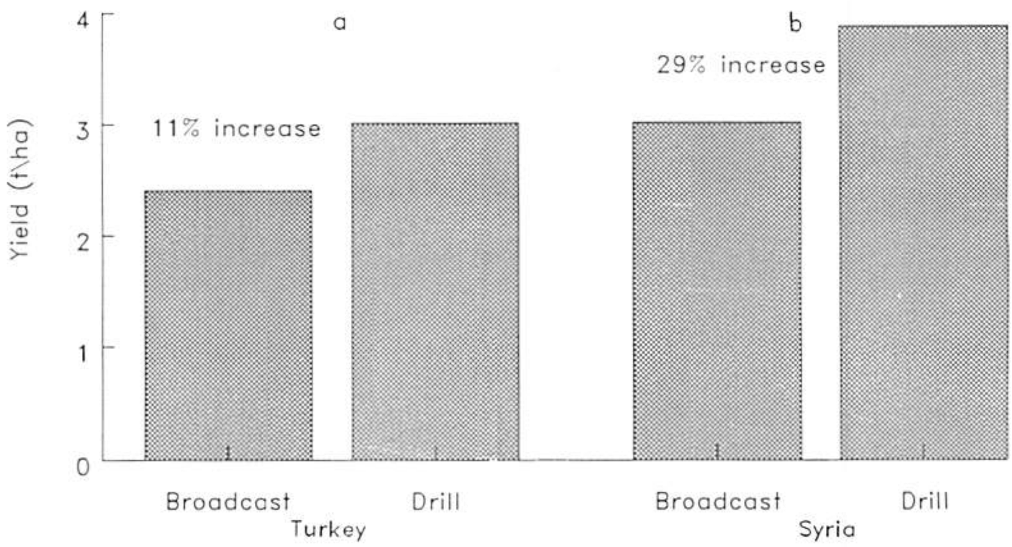


Fig. 8 **Effect of sowing method on wheat grain yield (t/ha) (Orza 1983, 1985, 1986; ICARDA, FRMP 1988).**

Table 5. Effect of different methods of seeding on the yield (kg/ha) and plant stand/m^2 at harvest in spring sown kabuli chickpea (ILC 482) at Tel Hadya, 1985 (Saxena 1987)

Method of sowing	Yield		Plant Stand
	Seed	Total biological	
Hand seeding	637	1316	16
Cereal drill	717	1455	24
Pneumatic precision seeder	853	1600	28
S.E. $\pm$	27.1	47.1	0.9
C.V. (%)	7.5	6.6	8.1

In the case of legume crops, farmers in WANA usually use the broadcast method: use of drills is still not very common. Both lentil and kabuli chickpeas have been shown to establish better, and give more yield (Table 5) when plant distribution is made more uniform by the use of seed drills (Saxena 1981; 1987) (Fig. 9).

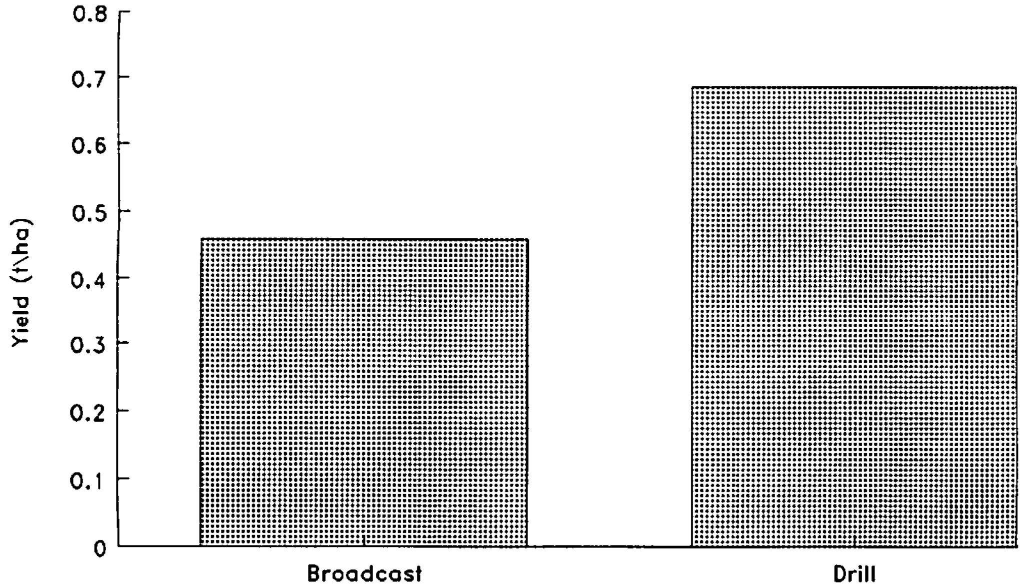


Fig. 9 Effect of sowing method on the seed yield (t/ha) of Syrian local small lentil at Tel Hadya, N.W. Syria, 1977-79 (Saxena 1981).

Row Spacing and Plant Density

Distribution and density of the crop in a given field are important factors in exploiting the yield potential of a genotype, by maintaining an appropriate crop stand.

The maximum economic yields per unit area should arise from plant densities that minimize inter-row and intra-row competition, which widely depend on environmental conditions (Donald 1968; Bolton 1981). Under dry conditions, planting pattern may substantially affect the WUE and subsequent grain yield. However, most of the seed drills have 15 to 20 cm row spacing which has been proved to be the optimum for cereals in particular with an optimum seed rate for a given cultivar (Singh *et al.* 1979; Tosun and Yurur 1981; Durutan *et al.* 1982; Hogras 1986; Gecit *et al.* 1987). Seeding rates should therefore be determined by the seed size, seed quality, the stand desired depending on environments, and the characteristics of the specific cultivar. Also, seeding rate should be adjusted to fit the growing conditions, including whether or not the crop is grown as a sole crop, mixed crop, or intercrop. It may be necessary to adjust seeding rate to fit seedbed conditions, time of sowing, and method of planting. Broadcast sowing takes more seed than drill sowing, poor seedbeds need more seed than a well prepared seedbed (Hall *et al.* 1979). With crops that have the capacity to tiller, seeding rates are less critical than with plants that are nontillering. Population densities should be high enough to take advantage of favourable years, but low enough to survive and be productive in dry years.

Bolton (1981) reported that for cereals, seeding rates and row spacings have been traditionally used for two purposes which are not actually related to the best plant population for maximum yield: (i) seeding rates within the row are usually greater than necessary in order to provide ground cover for wind and water erosion control, (ii) close row spacings are often preferred to provide greater competition for weeds that may grow between the rows. These concepts may have been partially successful in their purposes, but undoubtedly contribute to reduced grain yields in many seasons, or to yields no more than the optimum seed rate required.

Cereal grain yield is the product of three components: (i) heads per unit area, (ii) kernels per head, and (iii) 1000 kernel weight. The seeding rate and plant distribution in a given area have substantial effects on these components. Increasing seeding rates can increase heads per unit area but reduce the other two yield components (Puckridge and Donald 1967; Guler 1975; Darwinkel 1978; Karaca *et al.* 1980; Joseph *et al.* 1985).

Among yield components, there is compensation which tends to minimize yield loss when one component is reduced, but such compensation may not be complete. Therefore in any related study all yield components must be considered interactively. Tillers per plant, seeds per spike and 1000 kernel weight decrease in general in higher plant densities (Guler 1975; Darwinkel 1978; Frederick and Marshall 1985). However, number of plants and spikes per unit area increase at higher seed rates. Usually the percentage of productive tillers is less at higher than at lower plant densities.

For example Guler (1975) reported that in northwest USA the optimum seed rate to produce maximum grain yield ranged between 160 to 320 seeds per m^2, depending on the wheat cultivars. Research conducted in the Central Anatolian Plateau to find out the optimum economic seed rates of different cultivars found that the range of seed rate changed from 275 to 667 seed per m^2 for different cultivars (Guler *et al.* 1977; Karaca *et al.* 1980; Gecit *et al.* 1987). It has been reported in a study carried out at ICARDA in northern Syria that 300 seeds per m^2 provided the highest yield, which was 23% more than that of 100 seeds per m^2, related mainly to higher head number (ICARDA-FRMP 1988).

In the case of legume crops, responses of lentil and chickpea to sowing density differ depending upon environmental conditions and genotype. A sowing density of 300 to 450 germinable lentil seed per m^2 generally resulted in the highest yield. The effect of increased sowing rate was more perceptible in the earliest sowing date, which also resulted in the highest yield, becoming less as the date of sowing was delayed (Saxena 1981). Lentil yields are less responsive to row spacing (Silim *et al.* (b)) but there is evidence that a wider row spacing of 30 cm proved better than narrower spacings when the seasonal rainfall was below the average 350 mm (Saxena 1981).

Compact and erect chickpea genotypes tend to respond better to increased plant density than the spreading types (Saxena 1980; Singh 1981; Keatinge and Cooper 1984). Singh (1981) reported that these tall genotypes in Syria provided significantly increased yield when population was raised from 33 to 50 plants per m^2 by narrowing row spacing from 30 to 20 cm, whereas under similar conditions, a density of 33 plants per m^2 was optimum for the spreading types of chickpea. However, a population level of 33 chickpea plants per m^2 appears to be optimum for a wide range of environments, and the crop shows considerable plasticity in yield response to plant density. These responses are dependent on moisture supply and aerial environment as well as plant architecture (Saxena 1981).

References

Aktan, S. 1981. Guneydogu Anadoluda Nadas Alanlarinin Daha Etkin Kullanilma Olanaklari. Kuru Tarim Bolgelerinde Nadas Alanlarindan Yararlanma Simpozyumu, TUBITAK Yayin No. 593, 28-30 Eylul, Ankara, Turkey.

Avci, M., Guler, M., Pala, M., Durutan, N., Karaca, M., Eyuboglu, H. 1987. Yetistirme Teknigi Paketi Ogelerinin Orta Anadolu Bolgesi Kurak Kosullarinda Bugday Verimine Etkileri. Turkiye Tahil Simpozyumu, TUBITAK, 6-9 Ekim, Bursa, Turkey.

Berkmen, N. 1961. Ankara Zirai Arastirma Enstitusu Calismalari, 1931-60, Sayi 4, Ankara.

Bolton, F.E. 1981. Optimizing the use of water and nitrogen through soil and crop management. Plant and Soil, 58: 231-247.

Bolton, F.E., Booster, D.E. 1978. Tillage, moisture conservation and water use efficiency for dryland cereal production in winter rainfall regions. International Symposium on Rainfed Agriculture in Semi-Arid Regions. University of California, Riverside, USA.

Cooper, P.J.M. 1983. Crop management in rainfed agriculture with special reference to water use efficiency. Pages 19-35 *in* Proceedings of the 17th Colloquium of the International Potash Institute, May 1983, Rabat, Morocco.

Cooper, P.J.M., Allan, A.Y., Harmsen, K., Keatinge, J.D.H., Nygaard, D., Saxena, M. and Islam., R. 1981. Soil water and nutrient research 1979/80. ICARDA Project Report 3, ICARDA, Aleppo, Syria.

Cooper, P.J.M., Keatinge, J.D.H. and Hughes, G. 1983. Crop evapotranspiration: a technique for calculation of its components by field measurements. Field Crops Research 7: 299-312.

Cooper, P.J.M., and Gregory, P.J. 1987. Soil water management in the rainfed farming systems of the Mediterranean region. Soil Use and Management Vol 3, No. 2: 57-62.

Cooper, P.J.M., Gregory, P.J., Tully, D., Harris, H. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 117-158.

Darwinkel, A. 1978. Patterns of tillering and grain production of winter wheat at a wide range of plant densities. Netherlands Journal of Agricultural Science 26:383-398.

Darwinkel, A., ten Hag, B.A., Kutzenga, J. 1977. Effect of sowing date and seed rate on crop development and grain production of winter wheat. Netherlands Journal of Agricultural Science 25: 63-94.

Dennet, M.D., Keatinge, J.D.H., and Rodgers, J. 1984. A comparison of rainfall regimes at six sites in Northern Syria. Agriculture for Meteorology 31:319-328.

Dogu Anadolu Bolge Zirai Aras. Ens. 1984. Ulkesel Serin Iklim Tahillari Aras. Projesi 1983/84 Yili Gelisme Raporu, Erzurum.

Donald, C.M. 1968. The breeding of crop ideotypes. Euphytica 17: 385-403.

Dregne, H.E. and Willis, W.O. 1983. Dryland Agriculture. ASA, CSSA, SSSA, No. 23 in the Series of Agronomy, Madison, Wisconsin, USA.

Durutan, N., Guler, M., Pala, M. ve Karaca, M. 1982. Nadas-Tahil Ekim Nobeti Sisteminde Bugdayda Ekim Donemi Urun Kayiplari. Hasat Oncesi, Hasat ve Hasat Sonrasi Urun Kayiplari Semineri, 13-17 Aralik, Ankara.

Durutan N., Yilmaz, B., Kiziltan, M. 1987. Small grains and food legumes production improvement in Turkey. Pages 66-80 *in* Winter Cereals and Food Legumes in Mountain-

ous Areas. (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds). Proceedings of workshop, 6-10 July, Ankara. ICARDA-136 En, Aleppo, Syria.
FAO 1978. Report on the agro-ecological zones project, Vol. 1. Methodology and results for Africa. World Soil Resources Report 48/1. Rome, Italy.
FAO 1979. Report on the agro-ecological zones project, Vol. 2, Results for South West Asia, World Soil Resources Report 48/2. Rome.
FAO 1986. Production Yearbook, Rome, Italy.
Frederick, J.R. and Marshall, H.G. 1985. Grain yield and yield components of soft red winter wheat as affected by management practices. Agronomy Journal 77:495-499.
French, R.J. and Schultz, F.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. 1. The relation between yield, water use and climate. Australian Journal of Agricultural Research 35:743-764.
Gecit, H.H., Gurbuz, B., Ozcan, S. 1987. Ekmeklik bugdayda ekim sikliginin birim alan degerleri uzerine etkileri. Turkiye tahil simpozyumu, TUBITAK, 6-9 Ekim, Bursa, Turkey.
Guler, M. 1975. Yield and other agronomic characters of winter wheat cultivars as affected by five seeding rates and three different environmental conditions. M.Sc thesis, Oregon State University, USA.
Guler, M., Unver, I., Pehlivanturk, A., Izgin, C.N., Pala, M. 1977. Orta Anadoluda 1970-76 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari: Ekim Zamani Bugday Cesidi x Tohum Miktari, pp. 41-64, ORZA Yayin No 77-2, Agronomi Rapor No 1, Ankara, Turkey.
Guler, M., Unver, I., Pala, M., Durutan, N. and Karaca, M. 1979. The fallow system and cereal production in the dryland areas of Turkey. 5th Cereal Workshop, May 5-9, Algiers, Algeria.
Guler, M., Pala, M., Durutan, N., Karaca, M., Avcin, A., ve Avci, M. 1981. Nadas alani sinirlarinin belirlenmesinde yararlanilabilecek olcutler. Kuru Tarim Bolgelerinde Nadas Alanlarindan Yararlanma Simpozyumu, TUBITAK Yayin No. 593, 28-30 Eylul, Ankara.
Hall, A.E., Cannell, G.H, and Lawton, H.W. 1979. Agriculture in semi-arid environments. Ecological studies 34. Springer-Verlag, Berlin, Germany.
Hogras, A.M. 1986. Effect of seeding methods on yield and yield components of some wheat cultivars 1982. Field Crops Abstracts, Vol: 39 (7):4766.
ICARDA-CP, 1986. Pages 79-90 *in* Annual Report, Cereal Improvement Program, ICARDA, Aleppo, Syria.
ICARDA-FRMP 1987, 1988. Annual Reports, Farm Resource Management Program, ICARDA, Aleppo, Syria.
Joseph, K.D.S.M., Alley, M.M., Braun, D.E. and Gravelle, W.D. 1985. Row spacing and seeding rate effects on yield and yield components of soft red winter wheat. Agronomy Journal 77: 211-214.
Kalayci, M., Sonmez, S., ve Aydin, M. 1985. Bati gecit bolgesinde bugday tarimi sorunlari ve oneriler. Zirai Arastirma Enstitusu, Eskisehir, Turkey.
Karaca, M., Guler, M., Unver, I., Pala, M. and Durutan, N. 1980. The effect of seeding rates on yield and yield components of Bolal 2973, Haymana 79 (*T. aestivum*) and Cakmak 79 (*T. durum*). Turkish Journal of Agricultural Research Vol. 2, No. 1, 22-30.

Kassam, A.H. 1981. Climate, soil and land resources in North Africa and West Asia. Plant and Soil 58:1-29.
Keatinge, J.D.H., and Cooper, P.J.M. 1984. Physiological and moisture-use studies on growth and development of winter-sown chickpeas. Pages 141-157 *in* Proceedings of the Workshop on Ascochyta Blight and Winter Sowing of Chickpeas, ICARDA, 4-7 May 1981, Aleppo, Syria, (Singh, K.B. and Saxena, M.C., eds). Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, The Netherlands.
Keatinge, J.D.H., Dennett, M.D. and Rodgers, J. 1986. The influence of precipitation regime on the crop management of dry areas in northern Syria. Field Crops Research 13:239-249.
Meigs, P. 1964. Classification and occurrence of Mediterranean type dry climates. *In* Land Use in Semi Arid Mediterranean Climates. Arid Zone Research 26, UNESCO, Paris.
Mizrak, G. 1983. Turkiye Iklim Bolgeleri ve Haritasi. Orta Anadolu bolge Zirai Arastirma Enstitusu Teknik Yayin No 2, Genel Yayin No 52, Ankara, Turkey.
Nachit, M. 1988. ICARDA Cereal Improvement Program Annual Report. Aleppo, Syria.
ORZA (Orta Anadolu Bolge Zirai Arastirma Enstitusu) 1983, 1985, 1986. Annual Reports, Ankara, Turkey.
OSU (Oregon State University) 1979. Dryland agriculture in winter precipitation regions of the world-status of the technical art. Office of International Agriculture, USA.
Pala, M. 1982. A study on the effects of the depths and implements of summer tillage on changes in soil moisture and temperature (Turkish). Faculty of Agriculture. Ph.D. thesis, Ankara, Turkey.
Pala, M. and Mazid, A. 1988. Pages 77-93 *in* ICARDA-FRMP Annual Report. Aleppo, Syria.
Pala, M. and Nordblom, T. 1986. Pages 106-118 *in* ICARDA-FRMP Annual Report, Aleppo, Syria.
Pala, M., Guler, M., Unver, I., Durutan, N., Karaca, M. 1980. The effect of spring tillage at the fallow period on wheat yield in central Anatolia. Turkish Journal of Agricultural Research, Vol 2, No. 2:78-89.
Photiades, I. and Hadjichristodoulou, A. 1984. Sowing date, sowing depth, seed rate and row spacing of wheat and barley under dryland conditions. Field Crops Research, 9:151-162.
Puckridge, D.W., and Donald, C.M. 1967. Competition among wheat plants sown at a wide range of densities. Australian Journal of Agricultural Research 18:193-211.
Saxena, M.C. 1980. Recent advances in chickpea agronomy. Pages 96-98 *in* Proceedings of the International Workshop on Chickpea Improvement, 28 Feb-2 Mar 1979. Hyderabad, ICRISAT, Patancheru, India.
Saxena, M.C. 1981. Agronomy of lentils. Pages 111-129 *in* Lentils (Webb, C. and Hawtin, G., eds). CAB/ICARDA, Wallingford, UK.
Saxena, M.C. 1987. Agronomy of chickpea. Pages 207-232 *in* The Chickpea (Saxena, M.C. and Singh, K.B., eds). CAB/ICARDA, Wallingford, UK.
Saxena, N.P., Kapoor, S.N. and Bisht, D.S. 1983. Emergence of chickpea seedlings in sub-optimal moisture. International Chickpea Newsletter 9:12-14.
Silim, S.N., Saxena, M.C. and Erskine, W. 1991 Effect of sowing date on the growth and yield of lentil in a rainfed Mediterranean environment.Experimental Agriculture (accepted).
Silim, S.N., Saxena, M.C. and Erskine, W. 1990 Seeding density and row spacing for lentil in rainfed Mediterranean environments. Agronomy Journal 82: 927-930.

Singh, T., Sharma, H.C. and Singh, H. 1979. Response of durum and aestivum varieties of wheat to planting pattern. Pages 9-13 *in* Haryana Agricultural University Journal of Research Vol IX, No. 1.
Singh, K.B. 1981. Yield potential of tall chickpeas at increased plant density. International Chickpea Newsletter, 4:10-11.
Stern, R.D., Dennett, M.D. and Dale, I.C. 1982. Analysing daily rainfall measurements to give agronomically useful results. II. A modelling approach. Exp. Agric. 18: 237-253.
Tosun, O. and Yurur, N. 1981. Serin iklim tahillari ders notu. A.U. Ziraat Fak. Teksir No. 72, 217s, Ankara, Turkey.
Tully, D., and Rassam, A. 1985. Wheat production practices in northwest Syria. Pages 43-56 *in* ICARDA-Farming Systems Program Annual Report, Aleppo, Syria.
UNESCO/FAO 1963. Bio-climatic map of Mediterranean zone. Arid Zone Research 21. Paris, France.
Unver, I. 1978. A study on the effect of time, depth and implements of tillage at fallow on the change in soil moisture and temperature. A.U. Faculty of Agriculture PhD thesis, Ankara, Turkey (in Turkish).
Yesilsoy, M.S. 1974. The influence of tillage practices on moisture conservation and the wheat yield in Central Anatolia. 2nd Regional Wheat Workshop, May 6-11, Ankara, Turkey.

Crop Architecture and Water Use Efficiency in Mediterranean Environments

E. ACEVEDO, HAZEL C. HARRIS AND P.J.M. COOPER

ICARDA, P.O. Box 5466, Aleppo, Syria.

Introduction

In the rainfed farming systems of West Asia and North Africa, the limited and variable seasonal moisture supply almost always defines the upper boundaries of crop production potential, although certain strategies are possible which increase the amount of water available to a crop. Traditionally fallowing the land in the preceding year has been used by farmers to store additional water for a subsequent crop, but 'fallowing efficiency' is low and variable (see Harris *et al.* 1991) In addition, recent increases in human and livestock numbers and the resultant greater pressures on land resources are causing the abandonment of this practice throughout the region.

Other traditional strategies which include the practice of water harvesting (see Rees *et al.* 1990) and supplemental irrigation (Perrier and Salkini 1989) are also being re-evaluated by recent research, and will undoubtedly contribute to improved yields and enhanced water use efficiency if they are successfully adopted by farmers.

In spite of these alternative strategies, it is almost certain that in the foreseeable future the bulk of the region's non-irrigated production will continue to rely upon seasonal rainfall alone for its crop water supply. In evaluating potential production innovations under such moisture limited conditions, agronomists assess crop performance in terms of water use efficiency (WUE) where

$$\text{WUE} = \frac{\text{Yield (or total biomass) per unit area}}{\text{Water used to produce yield (biomass)}} \qquad (1)$$

and is usually expressed in units of kg/ha/mm. (Bolton 1981; Cooper *et al.* 1987).

Gregory (1991) shows that analysis of equations relating to crop growth and water use allows the formulation of a more explicit form of equation (1), hence

$$\text{WUE} = \frac{k}{(1+Es/T)(VPD)} \qquad (2)$$

where k = a crop specific coefficient
Es = seasonal moisture loss due to evaporation from the soil surface under the crop
T = seasonal moisture loss through crop transpiration

VPD = seasonal average vapour pressure deficit
(weighted only for periods of transpiration)

Equation (2) illustrates two important principles for improving the water use efficiency of rainfed production. Firstly, any innovation which reduces the ratio of soil evaporative loss (Es) to transpiration (T) will improve WUE. Since the rate of soil evaporation is related directly to the amount of radiant energy received at the soil surface, and hence inversely to that intercepted by the crop canopy, any strategy which enhances the rate of crop establishment and canopy expansion will reduce Es. Similarly, the same strategy will increase the energy intercepted by the canopy and thus increase T. Combined, these will lessen the Es/T ratio and improve WUE.

Secondly, equation (2) shows that WUE is inversely related to the vapour pressure deficit (VPD) experienced by the crop during periods of transpiration (see also Tanner and Sinclair 1983). Vapour pressure deficits show a marked seasonal variation in Mediterranean climates, with low values during the cool wet winters and early spring rising rapidly in the late spring and summer. Hence any innovation which increases the amount of dry matter production during periods when VPDs are low will also result in an increase in WUE.

With these principles in mind, and within the context of crop establishment, it becomes clear that timely sowing, vigorous early crop growth and rapid canopy closure are likely to be key processes in the improvement of crop water use efficiency and the setting of high production potentials.

In this paper we report results from several seasons' research at two contrasting locations (Tel Hadya and Breda) in northern Syria which was designed with two main objectives:

- to assess techniques for improving the establishment of barley crops in dry rainfed Mediterranean environments; and,
- to assess the extent to which modifications in the crop architecture of barley could influence dry matter production, grain yield and water use efficiency.

Barley was chosen as the test crop, not only because of its importance as a feed crop within the region, but also because it is grown in the drier rainfed environments where improvements in water use efficiency are most crucial.

The Experiment

The bulk of the results reported and discussed in this paper were obtained from a single trial conducted across two locations for three seasons (see next section). Factors judged to have an important influence on crop establishment, crop architecture and canopy expansion were row spacing, planting date, planting depth and crop cultivar. Planting depth and cultivar were known to be associated factors from previous research which had established a clear relationship between cultivar differences in coleoptile length, planting depth and plant emergence (Table 1).

Three two row barley cultivars differing in coleoptile length, namely Wadi Hassa (5.68 cm), Harmal (4.75 cm) and WI2269 (3.65 cm), as determined in a germination chamber, were

Table 1. The percentage of coleoptiles emerged as a function of sowing depth and cultivar in an experiment conducted in a germination chamber.

Sowing Depth (cm)	Cultivar Long Coleoptile (%)	Short Coleoptile (%)
2.5	100.0	100.0
5.0	87.4 a	59.7 b
7.5	46.7 a	30.8 b
10.0	31.1 a	10.0 b
Mean	66.3 a	50.1 b

Within a row, numbers followed by a different letter differ at $p < 0.05$.

planted at 10, 20 and 40 cm row spacing, at 3, 7 and 10 cm planting depths on three planting dates (early, medium and late). The experimental design consisted of a single replication of a 3^4 factorial with nine blocks. The three-factor interactions were partially confounded.

Before planting, the soil was fertilized with 40 kg and 20 kg N/ha in the form of ammonium sulphate at Tel Hadya and Breda, respectively, and with 60 kg P_2O_5/ha as triple superphosphate at both sites. The fertilizers were broadcast and incorporated into the soil with the last harrowing operation before sowing. Additional nitrogen was topdressed at mid-tillering at both sites, again 40 kg N/ha at Tel Hadya and 20 kg N/ha at Breda.

The sowing rate was adjusted, according to the 1000-grain weight and germination percentage of each cultivar, to a rate equivalent to 250 viable seeds per m². In the early and medium planting dates the seed was drilled with a plot planter. Late planting was done by hand to achieve more precision in the placement of the seed at the desired depth according to the treatment. Immediately after planting Preforan was used as a pre-emergence herbicide at a rate of 2.5 l/ha. Weed control was complemented with bromoxynol + MCPA applied at mid-tillering at a rate of 1 l/ha of commercial product. Powdery mildew was prevented by spraying once with Bayleton (0.5 g/l).

The plots were 1.2 m wide and 2.5 m long, with 12, 6 or 3 rows according to the row spacing treatment. At harvest, border rows were discarded and an area of 1 m2 was harvested from the center of the plots.

Planting and emergence dates varied according to the site and season (Table 2). Due to a delay in the onset of rain, the early planting at Tel Hadya in the first (1985/86) season received 4.5 cm of irrigation on December 3, 1985.

The parameters of crop growth recorded are shown in Table 3. In this paper we report data on five of these. The remainder are being used in other studies which aim to quantify the

Table 2. Planting and emergence dates for barley sown at Tel Hadya and Breda, northern Syria, in three seasons.

Planting Treatment	Planting Date		Emergence Date	
	Tel Hadya	Breda	Tel Hadya	Breda
1985/86				
Early	October 25	October 27	December 12	January 1
Medium	December 9	January 9	January 7	January 26
Late	January 17	January 27	February 2	February 10
1986/87				
Early	October 28	October 23	November 11	November 11
Medium	December 12	December 16	December 30	January 4
Late	January 15	February 11	January 30	February 5
1987/88				
Medium	November 24	November 11	December 6	November 22

Table 3. Parameters of crop growth recorded in an experiment designed to test the influence of factors of management on crop establishment and water use efficiency.

Parameter	Code	Stage of Observation	Units
Plants m^{-2}	PNO[1]	Zadoks Scale 11-12	number
Sub-Crown internode length	SCIL[1]	Zadoks Scale 22-23	cm
Tillers m^{-2}	TNO	Stem elongation	number
Ground cover	GC[1]	Sequential	score[2]
Growth habit	GH	Tillering	score
Leaf curling	ROLL	Tillering	score
Pre-dawn Water potential	PSI	Heading	M Pa
Plant height	PLHT	Grain filling	cm
Peduncle length	PLNG	Grain filling	cm
Spike length	SPLNG	Grain filling	cm
Heads m^{-2}	HNO	Maturity	number
Biological yield	BIOY[1]	Maturity	$g\ m^{-2}$
Head weight	HWT	Maturity	$g\ m^{-2}$
Grain yield	GWT[1]	Maturity	$g\ m^{-2}$
Straw weight	STWT	Calculated	$g\ m^{-2}$
Harvest index	HI	Calculated	-

1. Data reported in this paper.
2. Scale of 0-10

association between plant morphological and physiological characters and drought tolerance (Acevedo and Naji 1987; Acevedo *et al.* 1987).

Additional plots, 4.8 m x 10 m, sown with a single cultivar (Wadi Hassa) at a depth of 10 cm and row spacings of 10, 20, 30 and 40 cm, were used to measure evapotranspiration. Two neutron probe access tubes were installed in each plot to a depth of 2 m, and readings were taken at approximately 10-day intervals.

Sites and Seasons. The two sites at which the experiment was conducted are the main ICARDA research station, Tel Hadya, and a permanent sub-station in a contrasting environment, Breda.

Tel Hadya (35° 55' N, 36° 55' E) has a long term mean seasonal rainfall total of about 330 mm. The soil is classified as a Vertic (calcic) Luvisol, with variable profile depth. The trials were located on fields with >1.5 m depth of soil. Breda (35° 55' N, 37° 10' E) is situated approximately 35 km east of Tel Hadya and expects a long term seasonal rainfall total of 280 mm. The soil is classified as a Calcic Xerosol with a soil profile depth >1.5 m. Detailed profile descriptions and soil analyses for both sites are reported elsewhere (Cooper *et al.* 1981).

The climate at both sites is typical of the Mediterranean type, but the influence of continentality results in colder winters than are experienced nearer the coast or in much of North Africa. A monthly summary of major climatic variables for the three years is presented in Table 4.

Results and Discussion

The main factor influencing crop establishment was site (Table 5). This can be related to both the rainfall and soil type. Rainfall distribution was similar between sites, but smaller quantities per rain event at Breda led to less assured establishment. Also, the soil at Breda contains about 40% of silt which causes it to slake and form a surface crust with successive rain events. Crusting, in turn, may impede emergence of seedlings especially when there is drying of the surface between intermittent rain events.

Emergence of the cultivars in the field conformed to the pattern expected from controlled environment work (Table 1; Table 5); that is, it was reduced by decreasing length of sub-crown internode. The effect reached statistical significance ($p < 0.05$) at Breda. This result was probably not a simple response to the genetically determined internode length, but an interaction between internode length and the depth of sowing. At Breda, but not at Tel Hadya, deeper planting (> 7cm) increased the plant population (Table 5). Therefore reliable seedling establishment from germinated grains depended on there being a sufficient depth of wet soil for a secure water supply to the developing seedling. A longer sub-crown internode then allowed plants to emerge from a greater depth.

Early planting also favoured establishment at the drier site (Table 5), and there was a significant interaction ($p< 0.01$) between planting date and planting depth. Deep sowing was most critical with the early planting date when evaporation rates are greatest and cause rapid drying of the soil surface following a rain event. The decline in plant population with delayed time of planting is more complex. The formation of a surface crust, coupled with a reduced rate of growth of seedlings before emergence as soil temperature declined during December and January, led to the loss of almost 50% of viable seed planted at the latest date.

Table 4. Monthly means (or totals) of selected climatic variables at Tel Hadya and Breda Research Stations, northwest Syria (1985/86, 1986/87, 1987/88).

Variable	Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
Tel Hadya										
Rainfall (mm)	85/86	23	15	54	72	76	26	23	28	317
	86/87	32	33	47	89	63	64	13	3	344
	87/88	71	46	74	85	97	93	29	3	498
Mean Temp. (°C)	85/86	17.5	14.7	7.7	7.7	9.9	12.1	17.2	18.9	
	86/87	20.5	10.8	6.8	7.8	9.9	8.2	14.4	20.4	
	87/88	18.5	11.9	8.9	6.5	8.4	10.5	15.4	21.3	
Class A Pan Evap. (mm/day)	85/86	5.3	2.9	1.8	1.4	2.4	4.1	6.2	8.5	
	86/87	5.5	2.4	1.9	1.6	2.7	2.7	5.3	8.7	
	87/88	6.4	2.5	1.4	1.3	2.0	3.1	4.6	9.4	
Breda										
Rainfall (mm)	85/86	17	4	37	58	58	19	15	10	218
	86/87	23	25	33	67	32	47	17	0	244
	87/88	68	36	41	86	82	66	19	10	408
Mean Temp. (°C)	85/86	15.8	14.3	6.4	5.9	8.2	11.1	17.5	19.4	
	86/87	19.5	9.1	5.8	7.5	9.9	8.1	14.7	20.6	
	87/88	18.5	11.4	8.0	6.2	7.9	10.7	16.2	22.3	
Class A Pan Evap. (mm/day)	85/86	6.1	3.0	1.7	1.3	2.5	4.9	6.5	9.1	
	86/87	6.9	2.5	1.8	1.6	3.4	3.2	6.6	1.2	
	87/88	6.4	2.3	1.4	1.3	1.9	2.8	4.6	9.4	

In contrast, at the wetter site, Tel Hadya, which has a well structured soil, virtually 100% of viable seeds established plants at the later plantings (Table 5). Plant number was reduced ($p < 0.05$) only in the early planting when the soil water content was less assured.

In all plantings, plant populations were unaffected by row spacing.

The risk associated with establishment from early planting is one reason given for the use by farmers of the region of sowing methods that result in a variable planting depth. The data presented indicate that this is a rational practice. However, farmers use heavy seeding rates. With controlled planting depth it should be possible to reduce the quantity of seed planted by adjusting the depth according to conditions at planting time.

Wide row spacing caused a marked reduction in ground cover that persisted throughout the season at both sites. This effect, and its influence on yield and water use efficiency in the wet season of 1987/88 are illustrated in Figure 1 and Table 6. The reduction in ground

Table 5. Mean crop establishment (plants/m^2, % viable seeds) in four environments in response to cultivar, sowing date and sowing depth.

	Tel Hadya		Breda	
	PNO	%	PNO	%
Cultivar[1]				
Wadi Hassa (L)	211 a	84	79 bc	72
Harmal (M)	197 ab	79	160 cd	64
WI 2269 (S)	186 abc	74	140 d	56
Sowing Date[2]				
Early	209 a	72	209 a	72
Medium	243 b	97	174 b	70
Late	245 b	98	130 c	52
Sowing Depth[2]				
3 cm	234 a	94	149 b	60
7 cm	245 a	98	178 a	71
10 cm	218 a	87	186 a	74

1. Values followed by the same letter are not significantly different.
2. Within columns, values followed by the same letter are not significantly different.

cover was greatest early in the season at Breda, when it amounted to 50% two to three months after planting (Fig.1). Seasonal biomass production at 40 cm row spacing was reduced, relative to 10 cm spacing, by almost 30% at Tel Hadya and just over 30% at Breda. However, total evapotranspiration for the season did not differ between the wide and narrow row spacings, so that the water use efficiency of total biomass production was reduced by wide spacing by about the same proportions as the biomass (Table 6); that is, around 30% at both sites.

Similar effects of row spacing were recorded in the first two drier seasons (Table 7), although the relative yield reduction was less. The response differed between the sites, and narrow spacing was relatively more advantageous under drier conditions at Breda. Delayed planting reduced yield of both total biomass and grain (Table 7). Again the effect was most severe at the drier site where late planted crops gave less than half the yield of early planted ones.

The combined influence of planting date, row spacing and site in the first two drier seasons, expressed as rainfall use efficiency of grain production (kg/ha/mm total seasonal rain), is shown in Table 8. The absence of interactions amongst the factors indicates that the effects were consistent throughout. Efficiency was 25 to 50 percent less at Breda than at Tel Hadya no doubt due to the effect of reduced ground cover (Table 6) on the Es/T ratio. This effect is also reflected in the reduced efficiency at row spacings greater than 10 cm in all plantings except the late one at Tel Hadya.

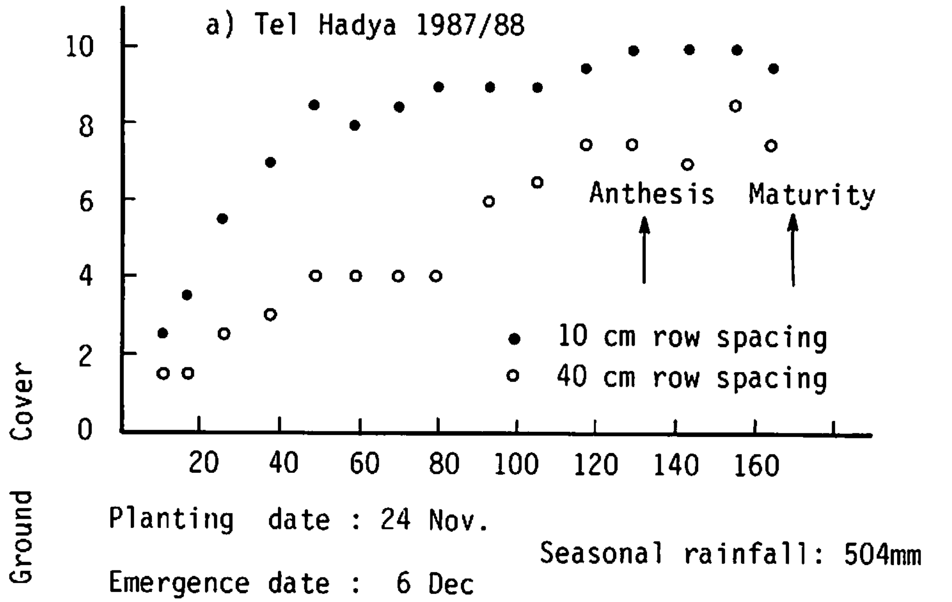


Fig. 1 Relative ground cover (scale 1-10) during the growing season of barley cultivars at two row spacings (10 cm and 40 cm) and two sites, Tel Hadya (a) and Breda (b) in northwest Syria.

Table 6. Seasonal values (1987/88) for mean ground cover, above ground biomass (g/m^2), actual evapotranspiration (mm) and water use efficiency ($g/m^2/mm$) at two sites in northwest Syria. The data are for barley planted at 10 and 30 cm row spacing at the same sowing rate (250 viable seeds / m^2) and the ratios between the 30 and 10 cm row spacings are also shown.

	Tel Hadya			Breda		
Variable	10 cm	30 cm	30/10	10 cm	30 cm	30/10
Mean Ground Cover (0-10)	7.0	5.8	82.8	7.3	5.2	71.2
Dry Weight (DW) (g/m^2)	1934	1401	72.4	1079	720	66.7
ETa (mm)[1]	391	379	96.9	291	291	100.0
DW/ETa (WUE) ($g/m^2/mm$)	4.9	3.6	73.5	3.7	2.5	67.6

1. Actual evapotranspiration from soil water balance.

Table 7. Mean relative above ground biomass and grain yield (percentage) of all cultivars as influenced by row spacing and planting date in four environments in 1985/86 and 1986/87.

	Tel Hadya		Breda	
	Biomass	Grain	Biomass	Grain
Row Spacing				
10 cm	100 (989)	100 (420)	100 (377)	100 (170)
20 cm	87	87	87	83
40 cm	89	89	79	77
Planting Date				
Early	100(1114)	100 (483)	100 (421)	100 (191)
Medium	79	75	90	88
Late	67	63	48	44

Figures in parentheses are g/m^2.

Table 8. Rainfall use efficiency (kg/ha/mm) of mean grain production for all cultivars as influenced by planting dates, site and row spacing.

Site	Row Spacing	Planting Date Early	 Medium	 Late
Tel Hadya	10 cm	16.9 (100)	11.2 (66)	9.3 (55)
	20 cm	12.7 (75)	10.3 (61)	9.6 (57)
	40 cm	13.5 (80)	10.9 (64)	9.1 (54)
Breda	10 cm	9.3 (55)	8.6 (51)	4.0 (24)
	20 cm	7.6 (45)	7.2 (43)	3.4 (20)
	40 cm	7.7 (46)	6.0 (36)	3.3 (20)

Figures in parentheses are percentage values with respect to Tel Hadya, 10 cm, early planting.
Planting Date x Site x Row Spacing interaction and Planting Date x Row Spacing interaction not statistically significant.

Early planting led to the most efficient use of rainfall at both sites. The proportional decline in rainfall use efficiency with delayed planting was similar at both sites.

As would be expected in an environment where rainfall varies considerably from one season to another and from one place to another, there was an interaction ($p < 0.01$) in rainfall use efficiency among site, planting date and season (Fig.2). Early planted crops were the most efficient at Breda in the first year and at Tel Hadya in the second. However, the most important point is that in both environments there was no disadvantage of early planting relative to the medium date, indicating that the practice probably has a low risk in northern Syria. If adopted it should allow advantage to be taken of those seasons when the rain starts early in order to make the best use of the limited rainfall of the region.

When the data were averaged across sites, seasons and cultivars, rainfall use efficiency was clearly shown to be increased by narrow row spacing, the effect being most important with early planting (Figs 3 and 4). The cost in grain yield of a delay in planting date, and thus a reduction in rainfall use efficiency, is illustrated in Figure 5. For the sequence of seasons in which this experiment was carried out this cost amounted to 22 kg grain/ha/day at Tel Hadya and 9 kg/ha/day at Breda.

Conclusions

The results presented illustrate the importance of early ground cover in environments where crops are almost entirely dependent on the rain which falls during the growing season. Management practices that reduced the input of solar radiation to the soil surface reduced unproductive water loss through soil evaporation. In the Syrian environment, early and more complete establishment allowed ground cover development before low temperatures slowed the rate of growth, and ensured that soil evaporation was minimized during the period of peak rainfall in December, January and February. At the same time there was an increase in interception of energy by the crop during the early part of the season (Fig.1) and the timing

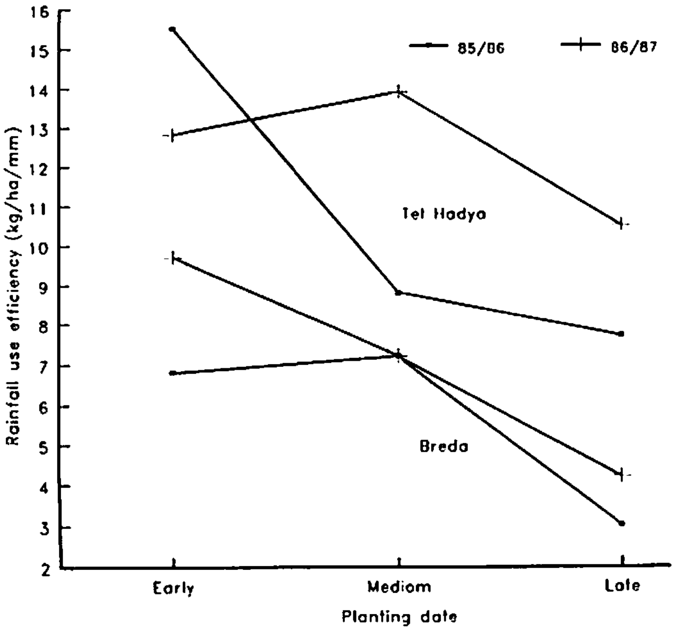


Fig. 2 **The influence of planting date on the efficiency of use of rainfall for grain production (kg/ha/mm) of barley cultivars at Tel Hadya and Breda, 1985/86 and 1986/87.**

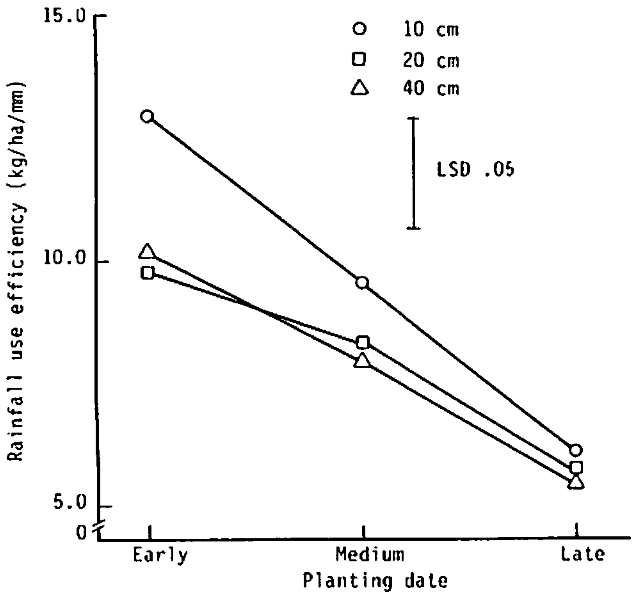


Fig. 3 **Mean rainfall use efficiency (kg/mm/ha) of barley cultivars as influenced by the interaction between row spacing and sowing date in the environment of northwest Syria.**

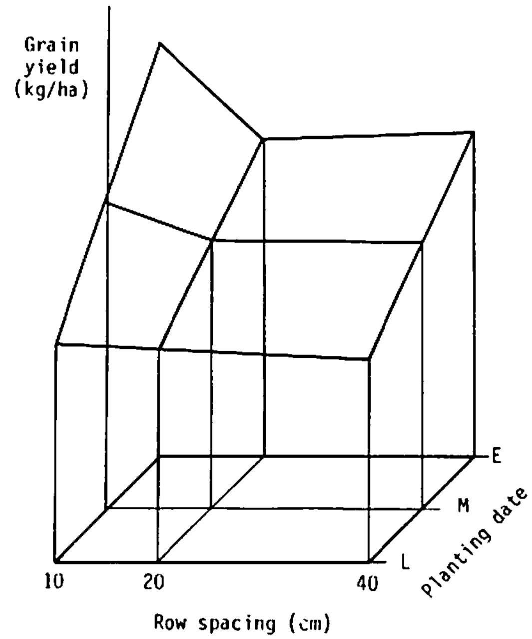


Fig. 4 The response to row spacing and planting date of the mean grain yield of barley cultivars at Tel Hadya and Breda, 1985/86 and 1986/87.

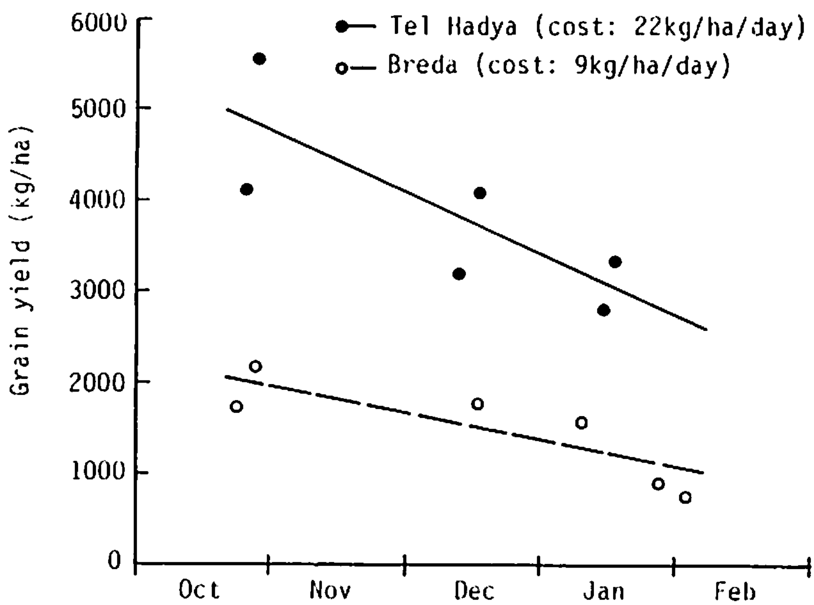


Fig. 5 The effect of delayed sowing date on the mean grain yield of barley cultivars grown in two seasons at Tel Hadya and Breda.

of biomass production was shifted towards those times of the year when vapour pressure deficits were least. In this way the size of the Es/T ratio was minimized, transpiration efficiency was increased and maximum rainfall use efficiency was achieved.

These experimental results clearly illustrate the application of the principles of water use efficiency which we discussed at the outset of this paper to the management of crops in two environments. The strategies used are simple ones that can be implemented relatively easily - deeper planting, improved crop architecture and timeliness of operations.

While the actual results, the most appropriate time of planting in particular, may be unique to the West Asian lowland regions represented by northwest Syria, these strategies are undoubtedly applicable to other places. For a given set of environmental conditions rainfall use efficiency will be maximized by a combination of these management factors, tailored to the weather patterns of the environment. Research to determine the most efficient combination of the factors should begin with an analysis of the environment of the type illustrated by Gregory (1991). The objective will be to reduce the risk of crop failure, and to maximize the yield of either biomass or grain, depending on the production goal.

References

Acevedo, E. and Naji, I. 1988. Genotype characterization. Pages 117-126 *in* Cereal Improvement Program Annual Report for 1987. ICARDA, Aleppo Syria.

Acevedo, E., Naji, I. and Diekmann, J. 1988. Barley management for dry areas. Pages 127-129 *in* Cereal Improvement Program Annual Report for 1987. ICARDA, Aleppo, Syria.

Bolton, F.E. 1981. Optimizing the use of water and nitrogen through soil and crop management. Plant and Soil 58; 231-248.

Cooper, P. J. M., Allan, A. Y., Harmsen, K., Keatinge, J. D. H., Nygaard, D., Saxena, M. and Islam, R. 1981. Soil, water and nutrient research. 1979-80. ICARDA Project Report No. 3. Aleppo, Syria.

Cooper, P. J. M., Gregory, P. J., Tully, D. and Harris, H. C. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23; 113-158.

Gregory, P. J. 1991. This Volume.

Harris, Hazel C., Osman, A. and Jones, M. J. 1991. This Volume.

Perrier, E.R. and Salkini, A.B. 1989. Scheduling of supplemental irrigation on spring wheat using water balance methods. Pages 448-460 *in* Irrigation, Theory and Practice (Rydzewski, J.R. and Ward, C.F., eds). Pentech Press, London, England.

Rees, D.J., Nagy, J.G., Keatinge, J.D.H., Rehman, F., Samiullah, A., Sabir, G.F., and Raza, S.H. 1990. Barley production under suboptimal conditions in upland Baluchistan: agronomic and socio-economic considerations. *In* proceedings of the workshop, The Agrometeorology of Rainfed Barley-based Farming Systems, Tunis, March 6-10 1989. ICARDA/WMO (In preparation).

Tanner, C. B. and Sinclair, T. R. 1983. Efficient water use in crop production: research or re-search? Pages 1-27 *in* Limitations to Efficient Water Use in Crop Production (Taylor, H. M., Jordan, W. R. and Sinclair, T. R., eds). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisc., USA.on the production goal.

Winter Sowing of Chickpea - A Case Study

S.N. SILIM* and M.C. SAXENA

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

Abstract

The productivity of chickpea, the fifth most important grain legume in the world, is low in Mediterranean areas because traditionally farmers have had to avoid cold and disease stresses and used to wait until spring to sow the crop, when it has then had to face the different stresses of heat and drought. Now that ascochyta blight-resistant and cold-tolerant varieties are available, however, it is possible to sow chickpea in winter so that early growth has the advantage of cooler, wetter conditions. The following paper describes the experiments carried out by ICARDA at Tel Hadya in Syria to determine how agronomic practices should be adapted if the planting date for chickpea is advanced from spring to winter. The trials, from 1978 to 1987, studied the date of sowing, choice of cultivar, plant density and sowing method most appropriate for winter-sown chickpea. There were also experiments with supplementary irrigation, as winter sowing allows chickpea cultivation in drier areas where moisture stress is common. Results suggest that the best sowing date is between December 15 and 31, the most suitable cultivars are early maturing, and precision seeders and drills are better than broadcasting.

Introduction

Chickpea is the fifth most important grain legume in the world after soybean, groundnut, dry bean and dry pea (FAO 1988). Its productivity in West Asia, North Africa and South Europe is low because the traditional varieties are susceptible to ascochyta blight and cold so have to be sown in spring (Hawtin and Singh 1984). Although the productivity of any crop species depends on its genetic potential, it is the environment that determines the expression of this potential. In the Mediterranean environment where rainfall occurs exclusively in winter, the spring-planted crop is largely raised on residual moisture and as the season progresses, the crop is exposed to increasing moisture deficit and unfavourable photoperiod and temperatures (Saxena 1984). The work reported here deals with the management of agronomic factors for improving the productivity of Kabuli chickpea in Mediterranean environments.

Date of Sowing

In West Asia and North Africa (WANA) where chickpea depends on winter rainfall, date of sowing has a profound influence on crop performance because it determines the kind of

---

* Current address: ICRISAT, Patancheru AP, India.

environmental conditions to which the various phenological stages of the crop are exposed (Saxena 1987). In the spring-sown crop, raised on conserved soil moisture, increasing soil moisture deficit and rising temperatures cut short the vegetative and reproductive growth of chickpea, thus resulting in low yield (Saxena 1980). The yield increases when the sowing is advanced from spring to winter because the vegetative and early reproductive phase of development occur under cool temperatures and assured moisture conditions (Saxena 1984).

In order to obtain information on the effect of advancing sowing date from the traditional spring sowing, experiments were conducted at the ICARDA site at Tel Hadya, northern Syria, from 1978 to 1987. Initially, when chickpea lines resistant to ascochyta blight were not available, experiments had to be carried out using agronomically superior land races under fungicidal protection (Saxena 1984). In later years, lines resistant to ascochyta blight became available and were used. The results of the 1980/81, 1984/85 and 1986/87 seasons are presented in Fig. 1.

The 1980/81 season had a mild winter with 371.5 mm total rainfall, of which over 66% was received between October and February. The highest grain yield was from the November 20 sowing followed by the December 20 sowing, and thereafter each delay in sowing resulted in significant reduction in yield. The December 20, January 20, February 20 and March 20 sowings attained respectively 99%, 73%, 65% and 35% of the yield of the November 20 sowing. The 1984/85 season was characterized by a severe late frost with rainfall similar to the 1980/81 season (ICARDA 1986). The grain yields during the season were low and the greatest yields were obtained from the January 6 and February 6 sowings. The December 6 sowing and those later than February 6 gave significantly low yields (Fig. 1). During the 1986/87 season, the weather in the April-June period was mild (Abdelnour 1988), permitting an extension of a favourable thermal regime late into the growing season. The grain yields were high (Fig. 1). The highest yield was from the December 2 sowing and delay in sowing resulted in reduction in yield. The seed yield differences between the December 2, January 11 and February 3 sowings were small and non-significant.

The study confirmed previous results that winter sowing improved the productivity of chickpea as compared to spring sowing (Saxena 1980, 1984, 1987; Hawtin and Singh 1984). It also showed, however, that the best time to recommend sowing in winter is determined by the average weather conditions during the growing season. In the seasons with mild winters, as in 1980/81, the highest yield is obtained from late autumn/early winter sowing but when frost occurs in spring, the earlier sown chickpeas which are at an advanced stage of development are adversely affected, as shown by yield reduction in the first sowing date in 1984/85 (Fig. 1). Of course, the frequency of occurrences of late frost in lowland areas is rather low (Smith and Harris 1981). The 1986/87 season had favourable thermal regimes in spring and winter (Abdelnour 1988) resulting in high seed yield in general and its maintenance up to the early spring sowing (Fig. 1). The variability in seed yield from the November - early December sowings over the years of study and the low yield from spring sowings suggests that the most appropriate time for sowing chickpea in lowland conditions in the Mediterranean basin is in the second half of December.

The major factors responsible for improved seed yield of winter sown chickpea included the more favourable thermal regime during the vegetative and part of the reproductive phase, which allowed the plants to develop a large vegetative frame that intercepted more radiation (Saxena 1984), and more reproductive nodes which in turn ensured production of more pods and seeds (Tables 1 and 2). These combined with better plant establishment

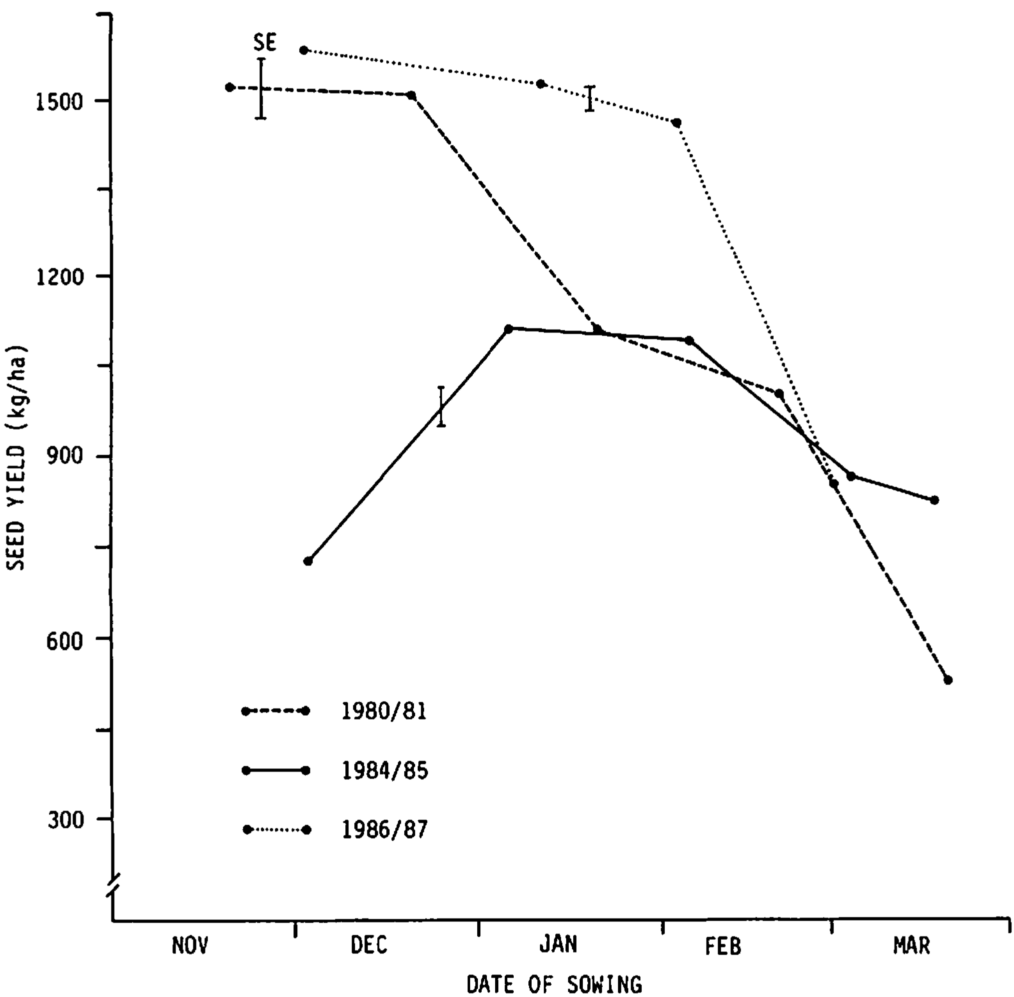


Fig. 1 The effect of sowing date on the mean seed yield (kg/ha) of chickpea, Tel Hadya, N.W. Syria, 1980-87.

Table 1. The effect of date of sowing on some of the yield components of chickpea. Tel Hadya, 1986/87.

Date of Sowing	*Biological yield* (kg/ha)	(g/plant)	Population /m²	Pods/ plant	Seeds/ plant	Seeds/ m²	100 seed wt (g)	Harvest Index
12 Dec 1986	3303	14.7	27.4	20.2	26.8	734	36.5	0.49
11 Jan 1987	3080	14.7	26.8	19.9	26.8	718	34.8	0.46
3 Feb 1987	3107	12.3	28.8	16.9	17.9	516	38.6	0.48
1 Mar 1987	1818	10.7	20.8	13.8	14.5	302	34.7	0.48
LSD (5%)	334	2.26	4.13	2.9	3.0	89.3	NS	NS
SE	105	0.71	1.29	0.92	0.94	27.9	1.28	0.02
CV%	14.8	21.1	20.4	21.4	19.9	17.8	14.2	7.6

Table 2. Correlations between seed yield (kg/ha) and some of the components of yield for chickpea sown at different dates at Tel Hadya in 1986/87.

	Biological yield (kg/ha)	Biological yield (g/plant)	Population $/m^2$	Pods/plant	Seeds/plant	Seeds/m^2	100 seed wt (g)	Harvest Index
Seed yield (kg/ha)	0.945	0.814	0.687	0.723	0.743	0.840	0.055	-0.097
Biological yield (kg/ha)		0.839	0.677	0.687	0.610	0.720	0.191	-0.380
Biological yield g/plant			0.425	0.702	0.778	0.739	0.815	-0.278
Population/m^2				0.310	0.305	0.523	0.111	-0.186
Pods/plant					0.971	0.959	-0.360	0.204
Seeds/plant						0.968	-0.321	0.185
Seeds/m^2							-0.265	0.111
100 seed wt (g)								0.191
Harvest index								

resulted in improved crop yield with improved water use efficiency, the latter based on total seasonal precipitation (Table 3). Development of an early ground cover in winter sowing helps in reducing evaporation and a larger proportion of total water-use is converted into transpiration. With total water-use thus remaining the same, and higher yields, the water-use efficiency increases (Keatinge and Cooper 1983).

Choice of Cultivar

The environment of the lowland zone of WANA has been described in detail (Harris 1979; Kassam 1981; Smith and Harris 1981), and the importance of targetting the crop to the environment has been emphasized by Acevedo and Ceccarelli (1988). Since not much work has been reported on the relationship between choice of chickpea cultivar and environment, experiments were conducted at Tel Hadya, in northern Syria, and Terbol, in Lebanon, to test the performance of promising chickpea lines at different sowing dates (ICARDA-FLIP 1987). Results for the 1985/86 season at Terbol and the 1986/87 season at Tel Hadya are presented for ILC 482 and ILC 3279 (Fig. 2). ILC 482 is an early maturing cultivar whereas ILC 3279 is a late maturing one. In each year, ILC 482 outyielded ILC 3279 and up to early

Table 3. Biological and grain yields (kg/ha) and water (rainfall) use efficiency (WUE) for chickpea sown at different dates at Tel Hadya, North Syria, 1986/87.

	Dates of Sowing			
	12/12/1986	1/1/1987	3/2/1987	1/3/1987
Biological yield (kg/ha)	3303	3080	3107	1818
WUE (kg biological yield/ mm water/ha)	9.24	8.60	8.68	5.08
Grain yield (kg/ha)	1588	1525	1459	845
WUE (kg seed yield/mm water/ha)	4.44	4.26	4.08	2.36
Total precipitation (mm) in 1986/87 season	358			

February sowing it maintained high seed yield (Fig. 2). In ILC 3279 each delay in sowing resulted in yield reduction. Total biological yields of ILC 482 and ILC 3279 were similar (Table 4), but the harvest index differed. ILC 482 had a higher harvest index which was not influenced by date of sowing. On the other hand, ILC 3279 had a relatively lower harvest index

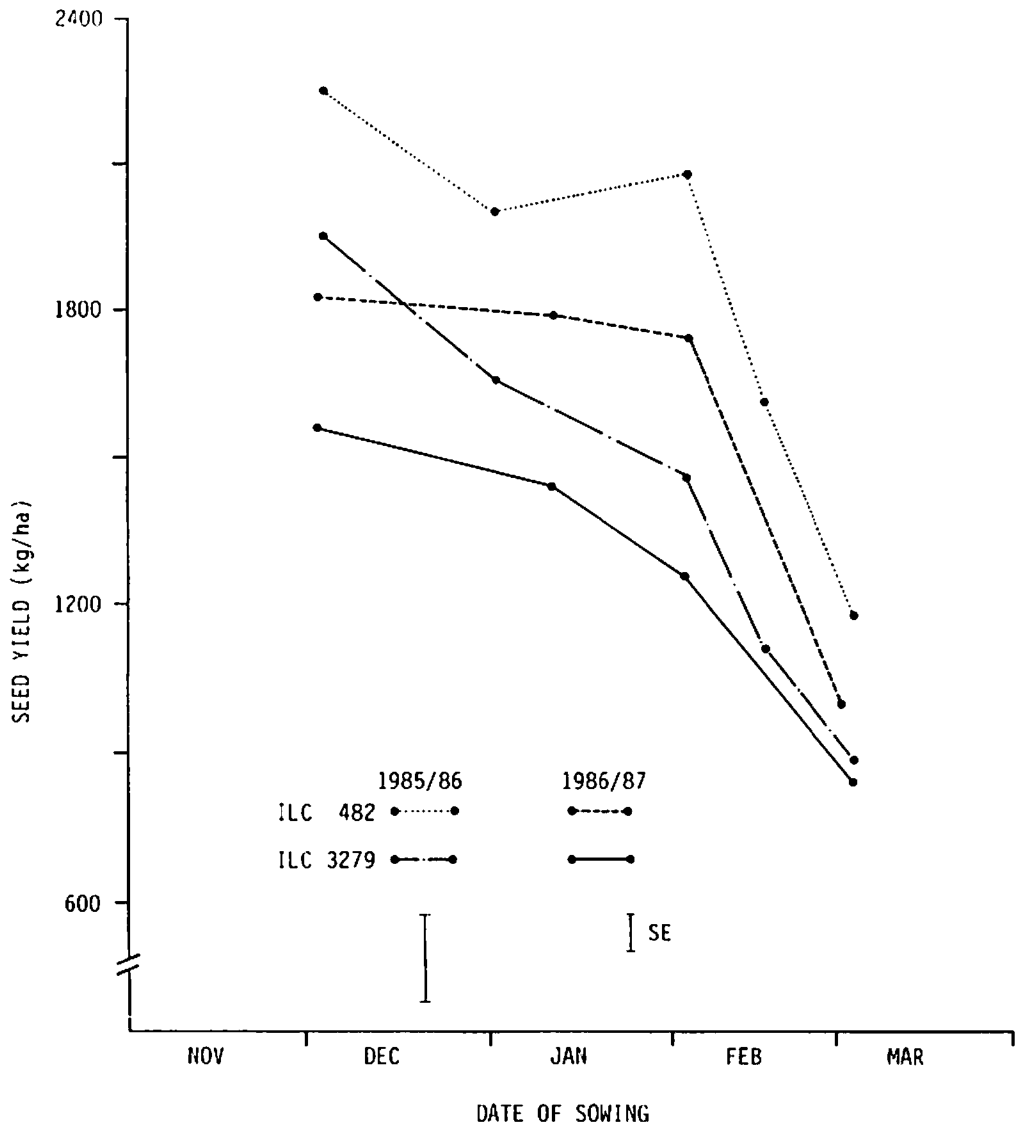


Fig. 2 Seed yield (kg/ha) of ILC 482 and ILC 3279 sown at different dates, Terbol, Lebanon, 1985/86 and Tel Hadya, N.W. Syria, 1986/87.

which was reduced by each delay in sowing date (Table 4). A combination of fast early growth during cool winter months and a more rapid crop development were reported as among the major determinants in the improvement of productivity of barley in northern Syria (Cooper *et al.* 1987). This lends support to the explanation that ILC 482's greater early vigour, faster phenological development, and better partitioning of the assimilate produced to the reproductive parts (Fig. 3) most probably account for its better yield performance. Such early maturing cultivars seem better suited to the particular environment of WANA because the more favourable weather conditions occur early in the growing season.

Plant Density and Sowing Method

A survey of chickpea fields in Syria revealed that stand was less than 20 plants/m^2, and poor plant stand was one of the major causes of low yields (Saxena 1980, 1987). A study was conducted at Tel Hadya and other locations in Syria and Lebanon to determine optimum levels of seeding density. Densities tested varied between 16.6 to 50 seeds sown/m^2. Total precipitation at Tel Hadya during the 1979/80, 1981/82 and 1987/88 growing seasons was 428 mm, 338 mm and 504 mm, respectively. The results show that despite variation in rainfall,

Table 4. Biological yield (kg/ha) and harvest index for ILC 482 and ILC 3279 sown at different dates in Tel Hadya during 1986/87 seson

Date of sowing	Biological yield (kg/ha)			Harvest index		
	ILC 482	ILC 3279		ILC 482		ILC 3279
2.12.1986	3458	3068		0.56		0.47
11. 1.1987	3134	3236		0.57		0.45
3. 2.1987	3078	3140		0.57		0.41
1. 3.1987	1782	1939		0.56		0.41
	Sowing (S) date	Variety (V)	SxV	S	V	SxV
LSD (5%)	334	NS	NS	NS	.026	.053
CV(%)	14.8	8.6		7.6	7.6	

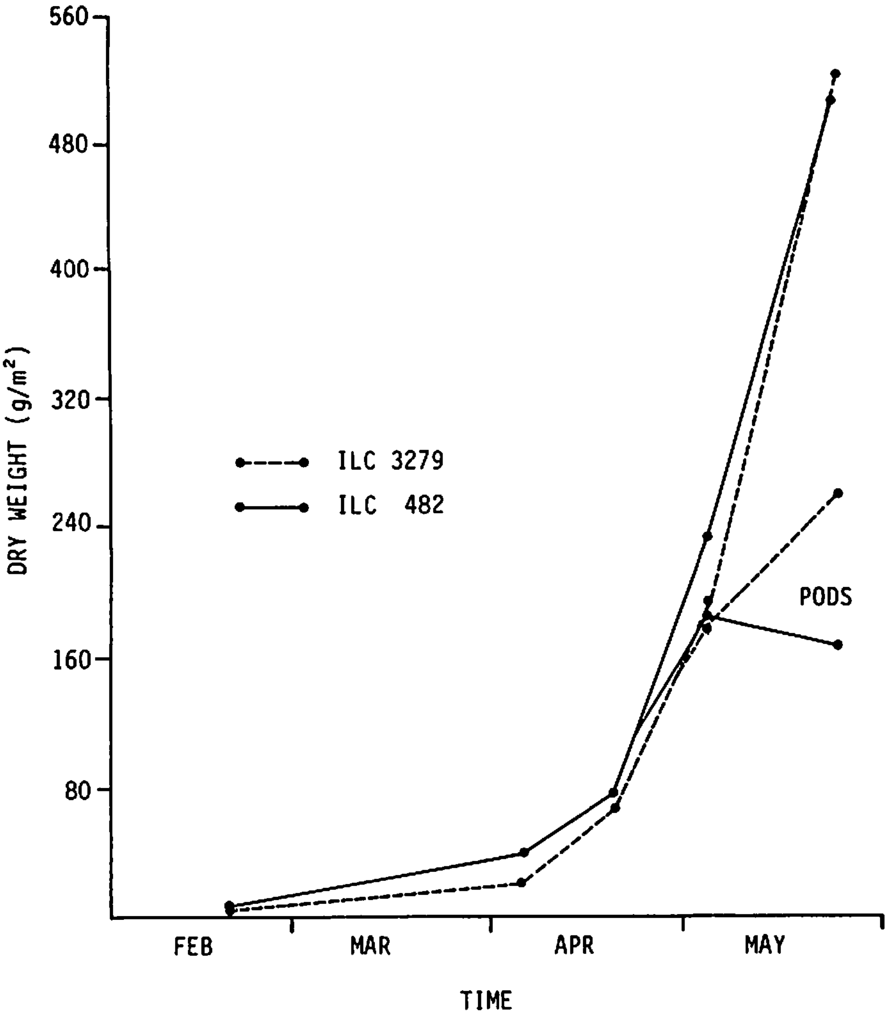


Fig. 3 Total dry weight (g/m²) and dry matter distribution (g/m²) to the pods in ILC 482 and ILC 3279 sown in Dec 1986/87, Tel Hadya, N.W. Syria.

seed yields of winter sown chickpea increased with increasing seeding density to the highest level tested (Fig. 4). As seen in Table 5, however, the required density may not always be achieved. One probable reason is reduced emergence. Different seeding machines were tested at ICARDA's main research station in northern Syria, using the same seeding density, to study their effect on the emergence and yield of chickpea. The results show that plant stand and seed yields were better with the precision seeder and the cereal drill than hand sowing (Table 6).

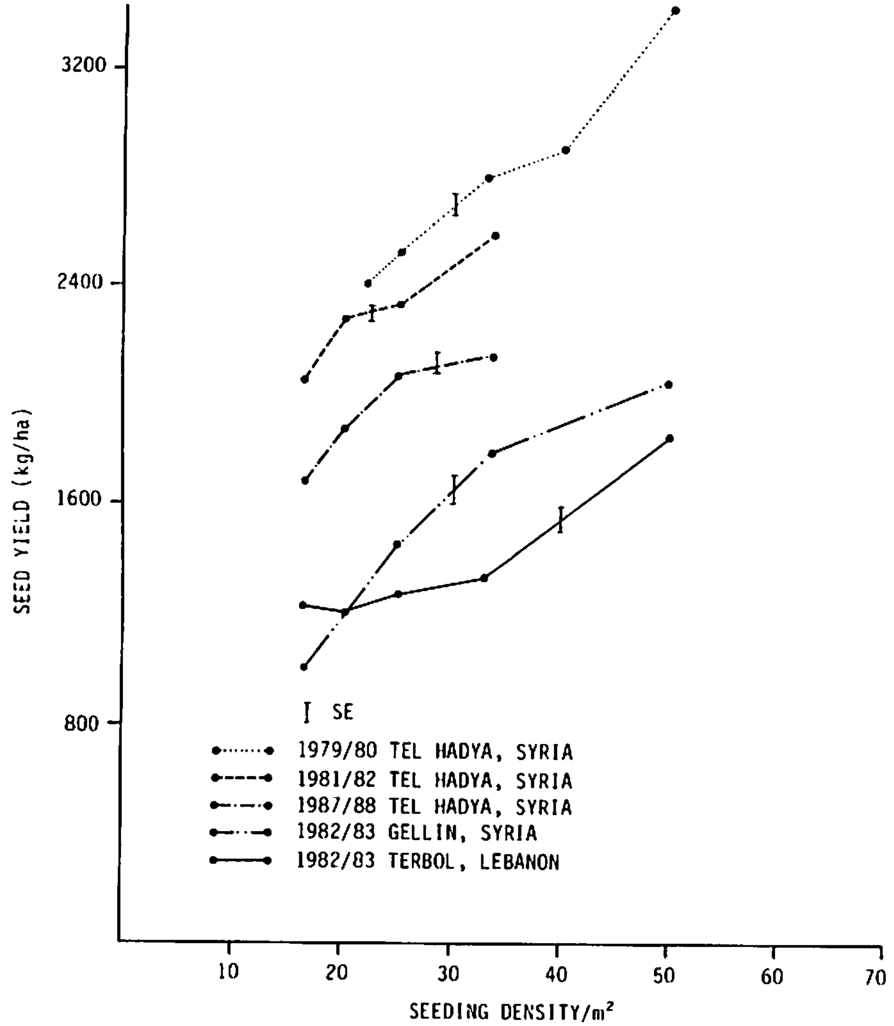


Fig. 4 The effect of seeding density on seed yield (kg/ha) of winter sown chickpea in selected locations in Syria and Lebanon.

Table 5. The relationship between seeding density/m² and the population/m² achieved in winter sown chickpea, Tel Hadya, 1987/88.

	Density/m²				
Seeding (number of seeds sown)	22.2	25.0	33.3	40.0	50.0
Population achieved at harvest	19.0	18.9	27.3	33.2	36.9

Table 6. The effect of different methods of planting on seed and biological yields (kg/ha), harvest index and plants/m² at harvest of spring sown chickpea (ILC 482), at Tel Hadya in 1984/85.

Treatment	Yield (kg/ha) Seed	Yield (kg/ha) Biological	Harvest Index	Plant population/m² Target	Plant population/m² Achieved	Plant population/m² %achieved
Hand planting 45 cm rows	637	1316	0.48	40	16	40
Cereal drill 22.5 cm rows	717	1455	0.49	40	24	60
Precision seeder with 45 cm rows	853	1600	0.54	40	28	70
LSD (5%)	87	151	0.024		2.8	
SE (±)	27.1	151	0.024		2.8	
CV (%)	7.5	6.6	3.0		8.1	

Supplemental Irrigation

Chickpeas are generally grown under rainfed conditions in the Mediterranean basin in areas where seasonal precipitation is more than 400 mm. Winter sowing permits expansion of chickpea cultivation into areas drier than the traditional areas. However, both spring- sown chickpeas in traditional areas and winter - sown chickpea in areas with <400 mm rainfall would experience moisture stress in the later part of the crop growth (Cooper *et al.* 1987). Also, there could be periods of extended drought at different stages in the growing season even in areas where total seasonal precipitation may be >400 mm. In some of these areas, however, supplemental irrigation is possible because of availability of wells or canal water and farmers may apply this to chickpea if it is responsive. Studies conducted elsewhere have shown that the flowering and pod filling stages are most sensitive to water stress (Palled *et al.* 1985; Saxena 1987). At Tel Hadya, the effects of supplemental irrigation, one each at flowering and pod filling stages, were examined for both winter-sown and spring-sown chickpea, and variation among promising cultivars for their response was examined. The data presented in Table 7 are for ILC 482 and ILC 3279 sown in winter. In the rainfed treatment, seed yields in both cultivars were similar, with water use efficiencies (kg/mm/ha) of 6.08 for

Table 7. Yields (kg/ha), harvest index and water use efficiency of winter-sown chickpea cultivars ILC 482 and ILC 3279, rainfed only or with supplementary irrigation. Tel Hadya, 1986/87

	Rainfed (358 mm)		With supp. irrigation (+190mm)		Increase due to supp. irrigation	
	ILC 482	ILC 3279	ILC 482	ILC 3279	ILC 482	ILC 3279
Seed yield (kg/ha)	2175	2159	3774	2663	1599	504
Straw yield (kg/ha)	1991	2320	4140	5014	2149	2694
Biological yield (kg/ha)	4166	4479	7914	7677	3748	3198
Harvest index	0.52	0.48	0.48	0.38	0.43	0.16
WUE* Seed yield	6.08	6.03	6.89	4.86	8.42	2.66
Straw yield	5.56	6.48	7.55	9.15	11.31	14.18
Biological yield	11.64	12.51	14.44	14.00	19.73	16.83

* WUE - Water use efficiency (kg yield/mm water/ha).

ILC 482 and 6.03 for ILC 3279. However, when supplemental irrigation was given, ILC 482 produced significantly higher seed yield than ILC 3279. The respective water use efficiencies in the irrigated treatments were 6.89 and 4.86. The seed yield increase with the 190 mm of supplemental irrigation was 1599 kg/ha for ILC 482 and 504 kg/ha for ILC 3279 with respective efficiency of water applied as supplemental irrigation to be 8.42 and 2.66. Since biological yields in the two cultivars in the irrigated treatment did not vary significantly, the lower seed yield in ILC 3279 compared to ILC 482 was, therefore, due to low harvest index (Table 7). The results imply that chickpea cultivars with better early vigour and early maturity appear to benefit more from supplemental irrigation than the late maturing cultivars.

References

Abdelnour, Mireille, 1988. Meteorological reports for ICARDA Experimental Stations in Syria: 1986/87 Season. International Center for Agricultural research in the Dry Areas (ICARDA), Aleppo, Syria.

Acevedo, E. and Ceccarelli, S. 1988. Role of physiologist - breeder in a breeding program for drought resistance conditions. *In* Symposium on Drought Resistance in Cereals - Theory and Practice, 28-30 November, 1988, Cairo, Egypt.

Cooper, P.J.M., Gregory, P.J., Tully D. and Harris, H.C., 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 113-158.

Food and Agriculture Organization (FAO) of the United Nations. 1988. FAO Production year book Vol. 41 (1987), Rome, Italy.

Harris, H.C. 1979. Some aspects of the agroclimatology of West Asia and North Africa. Pages 7-14 *in* Food Legume Improvement and Development (Hawtin, G.C. and Chancellor, G.J., eds), ICARDA, Aleppo, Syria and IDRC, Ottawa, Canada.

Hawtin, G.C. and Singh, K.B. 1984. Prospects and potential of winter sowing of chickpeas in the Mediterranean Region. Pages 7-16 *in* Ascochyta Blight and Winter Sowing of Chickpeas (Saxena M.C. and Singh, K.B., eds). Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, The Netherlands.

ICARDA (International Center for Agricultural Research in the Dry Areas). 1986. Weather report. Pages xvii - xxiv. *in* ICARDA Annual Report 1985. Aleppo, Syria.

Kassam, A.H. 1981. Climate, soil and land resources in North Africa and West Asia. Pages 1-29 *in* Soil, Water and Nitrogen in the Mediterranean - type Environments (Monteith, J. and Webb, C., eds). Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, The Netherlands.

Keatinge, J.D.G. and Cooper, P.J.M. 1983. Kabuli chickpea as a winter sown crop in Northern Syria: Moisture relations and crop productivity. Journal of Agricultural Science, Cambridge 100: 667-680.

Palled, Y.B., Chandra Shekhariah, A.M. and Rodder, C.D. 1985. Response of Bengal gram to moisture stress. Indian Journal of Agronomy 30: 104-106.

Saxena, M.C. 1980. Recent advances in chickpea agronomy. Pages 89 - 96 *in* Proceedings of the International Workshop on Chickpea Improvement, 28 Feb. - 2 March 1979, Hyderabad, India, ICRISAT, Patancheru, A.P., India.

Saxena, M.C. 1984. Agronomic studies on winter chickpeas. Pages 123-137 *in* Ascochyta Blight and Winter Sowing of Chickpeas (Saxena, M.C. and Singh, K.B., eds). Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, The Netherlands.

Saxena, M.C. 1987. Agronomy of chickpea. Pages 207-232 *in* The Chickpea (Saxena, M.C. and Singh, K.B., eds). Commonwealth Agricultural Bureaux International, Wallingford, U.K.

Smith, R.C. and Harris, H.C. 1981. Environmental resources and restraints to agricultural production in the Mediterranean - type environment. Pages 31-57 *in* Soil, Water and Nitrogen in Mediterranean - type Environments (Monteith, J. and Webb, C., eds). Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, The Netherlands.

Coleoptile length may not be the best characteristic for breeders to concentrate on, because it is not absolutely stable. It can differ with temperature, even within a variety. Also, many varieties with long coleoptiles, mostly durum wheats, tend to lodge in fertile conditions. Earliness of heading date and flowering may be better traits, because they can prolong the grain-filling period, or the flag leaf (which should be green for as long as possible, and erect), because it makes a significant contribution to the dry matter accumulated in the spike. Root development and tillering are also important; they are strongly affected by soil temperature, which is relevant to sowing date. Quick seminal root growth is desirable, and only enough tillers to form a good number of adventitious roots. Tiller survival is an important criterion: number of heads/unit area depends on this, and it is tiller survival that is affected by stress. Main tiller number is highly correlated to a yield-based stress-resistance index (Acevedo; Kun; Moussadeq).

The cropping system should be taken into account when selecting varieties: different seeding depths and different coleoptile lengths are required in a fallow system, where the seed-zone water is about 7 to 8 cm deep, from those suited to an annual cropping system where rainfall is needed for emergence. However, ICARDA experiments have found that dry planting does not adversely affect plant emergence. Pooling the data, a 0.5% decrease was observed in grain yield for every day's delay in sowing after the last week in October. Deep sowing, even in the late (Dec 15 - Jan 7) plantings did not appear to affect crop establishment when sowing depths at different planting dates are compared. Late planting significantly decreases the number of plants established per unit area of soil and delays emergence, probably due to lower temperatures. On the other hand, early sowing, 10 cm deep, using long coleoptile varieties appears to improve stand establishment, presumably due to reduced risk of a "false start" when planting is done in a dry soil. It appears that wherever possible it is preferable to have the seeds in the soil before the break of the season (Karaca; Acevedo).

There is some evidence which suggests that row spacing and plant arrangement can play an important role in WUE and yields of some crops in limited moisture conditions by reducing excessive moisture extraction so that some is left for the critical grain-filling stage (Farah). This is true under conditions of high vapour pressure deficit of the atmosphere (spring sown crops in Mediterranean environments) and crops grown on stored soil moisture. In the case of autumn sown cereals growing on actual rainfall and with a high probability of terminal drought, early ground cover and narrow spacing of the plants is beneficial. It increases radiation interception when it is limiting and it also increases the transpiration component of ET. Since the crop at this time is small ET crop is also low and WUE tends to increase. It is worth keeping in mind the equation $WUE = k/(e_o\text{-}e)$ where K is a crop coefficient (approximately constant) and $(e_o\text{-}e)$ the vapour pressure deficit of the atmosphere. In autumn sown cereals some authors have postulated that there may be an optimum ground cover. So far the beneficial effects of an increased ground cover during winter in Mediterranean environments with terminal drought is the only experimental evidence available (Acevedo).

Poor emergence of crops seems to be common in the region. In Victoria, Australia, where there is a similar problem, surveys have shown that the seed harvested and sown by farmers often has poor germination because of damaged, immature or diseased seed. An extension program was started to improve timing of harvest and setting of harvesters, and encourage the use of the results of simple germination tests to adjust seeding rates (Amor). Data from Bangladesh showed that emergence increased to more than 90% with the use of Furadan, and emerged plants were more vigorous (Hobbs)

Varieties which are not sensitive to day length would be useful in areas with heavy soils which cannot be prepared early. Farmers have to wait for enough rain before they can plough. Varieties with low sensitivity to photoperiod are available from ICARDA and CIMMYT, as are varieties with various vernalization requirements.

Selection of genotypes for dry environments involves more than just the morphological traits dealt with in Dr. Acevedo's paper. Some morphological traits have a physiological origin (e.g. leaf-rolling, plant colour, growth vigour). The physiological responses to stress mentioned, decrease in relative turgidity and nitrate reductase activity, for example, are not necessarily indicative of stress resistance, and they are difficult to screen for in large numbers of genotypes. Furthermore, they are "instantaneous plant reactions" and do not necessarily reveal the stress history of the plant. Some "integrative" physiological parameters such as C-13 discrimination (indicative of transpiration efficiency) hold a better promise for this purpose (Yilmaz; Acevedo).

Early crop cover increases yields and WUE in Northwest Syria and Central Anatolia because of the high potential for water loss through soil evaporation in the soils in those areas, but these findings are less likely to apply on the yermosols of Baluchistan or any other place where potential rates of soil evaporation are lower (Rees). The information presented in terms of early planting and increased early ground cover, based on theory and experimental data, would be valid for any environment in which the crop is autumn planted and:

a) radiation and temperature during winter limit photosynthesis and growth
b) the crop is growing essentially on current rainfall.

The severity of terminal drought may indicate an optimum (as opposed to a maximum possible) ground cover in very dry environments.

If the crop is growing on residual soil moisture, i.e. summer rainfall for autumn grown crops, different principles apply (Acevedo).

Fertilizer Management

Fertilizer Use, Crop Growth, Water Use and Water Use Efficiency in Mediterranean Rainfed Farming Systems [1]

PETER J.M. COOPER

FRMP, ICARDA, P.O. Box 5466, Aleppo, Syria

Abstract

Farmers of West Asia and North Africa today face the same agro-ecological constraints to crop production that have shaped the evolution of the diverse farming systems within the region. Variable and often chronic deficiency of rainfall coupled with widespread nitrogen and phosphorus deficiencies are major factors contributing to the uncertainty of crop production. Past and on-going research has demonstrated the major role that fertilizer has to play in helping farmers and national agencies offset large predicted food and feed deficits. This paper discusses how balanced fertilizer dressings can dramatically increase the efficiency of water use by plants and summarizes some of the major environmental factors which will interact with and affect the economics of fertilizer responses. The paper concludes with a discussion of some priority areas of fertilizer research for the future.

Introduction

Dryland agriculture in West Asia and North Africa (WANA) today is constrained by the same problematic soil and climatic conditions that farmers have faced for centuries: similar crops are grown and cropping systems followed, and livestock production practices are much the same (White 1963, 1970; Watson 1974). Socio-economic conditions, however, have changed radically, at both farm and national level, and the traditional rainfed agricultural systems cannot cope with the increased food and feed demands arising from growing populations, rural migration and agricultural policies favouring industrial crops (Table 1).

There are three main ways in which agriculture can change to meet such demands: by bringing more land under cultivation; by increasing cropping intensity; and by higher productivity. In WANA only 7% of the required increase in production can come from the first (FAO 1987) -- already fragile marginal lands are being degraded at an unacceptable rate; the second option (fallow replacement, for example) could provide 20%; the remaining 73% must come from the third, higher yields per crop.

This is now possible, with new agricultural technology. Farmers should be able to increase their yields by controlling pests and diseases, improving soil fertility, using modern tillage methods and equipment, and growing new crop varieties. However, in this rainfed region, the background of limited, variable and often deficient rainfall, combined with large seasonal changes in air temperatures will always provide a major element of uncertainty and

1. Much of the material and discussion presented in this paper has already been published by IFDC/ICARDA in an article by Cooper, Jones, Harris and Matar (1989).

Table 1. Production, food and feed demands and deficits for selected agricultural commodities in the WANA region in 1981/85 and projected for 2000 (all figures in million metric tons)[a]

Commodities	1981/85 Production	1983 Demand	Deficit	2000 Production	2000 Demand	Deficit
Wheat	47.9b	69.1	21.2	71.5b	105.4	33.9
Rice	9.6b	11.0	1.4	15.4b	18.4	3.0
Maize	8.5b	18.2	9.7	14.2b	25.2	11.0
Barley	14.3b	19.3	5.0	26.1b	37.4	11.3
Pulses	4.3b	4.1	+0.2	5.9b	5.7	+0.2
Meat	5.6c	6.9	1.3	11.4c	12.9	1.5
Milk	29.0c	35.5	6.5	48.4c	59.8	11.4
Veg. oils	2.2c	4.7	2.5	3.2c	8.9	5.7

a. *Source:* Somel, K. (1988). (Somel based his estimates on data files for the 1987 FAO study *Agriculture: Toward 2000).*

b. Production figure from Somel (1988), p. 131.

c. Production figure is difference between demand and deficit estimates from Somel (1988), p. 125.

variability in actual crop production, and thus affect the profitability and stability of performance of new technologies (see Harris 1991).

Fertilizer has a proven potential to make a substantial and economic contribution to increased productivity. The soils of the region are diverse, and 21 of the major soil groups recognized in the FAO/Unesco soil map of the world occur. However, just seven of those groups account for 86% of the 125 million hectares of rainfed agricultural land receiving between 200 and 600 mm mean seasonal rainfall (Table 2). The potential of lithosols and regosols for arable farming is naturally low, and most are used for marginal grazing. Among the other five groups, many of the same fertility problems tend to recur.

Table 2. Major soil groups in regions of West Asia and North Africa receiving between 200-600 mm seasonal rainfall

	Area (10^6 ha)*		
Soil group	N. Africa	W. Asia	Total
Vertisols	1.2	4.1	5.3
Xerosols	5.6	22.0	27.6
Cambisols	7.0	10.2	17.2
Luvisols	3.8	7.7	11.5
Yermosols	3.1	6.3	9.4
Lithosols	5.4	20.6	26.0
Regosols	2.4	7.9	10.3

* Area data from: Kassam (1981)

Calcareous soils, formed from limestone residuum, predominate, and calcium carbonate plays an important role because of its direct effect on soil pH. High pH decreases the availability of micro nutrients such as iron, manganese, copper and zinc. However, responses to micronutrients are less pronounced in rainfed agriculture and, so far, have been less frequently reported than in the more intensive and higher yield potential irrigated systems (Haddad *et al.* 1979; El-Fauly 1983).

Calcium carbonate also has an important effect on the availability of phosphorus through the formation of insoluble or slowly soluble forms of calcium phosphate. In general, available phosphate levels are low to very low in cultivated soils to which fertilizer is never applied. Crop responses to applied phosphate are widespread (Harmsen 1984; SMAAR/ICARDA 1985, 1986, 1987).

Organic matter levels and organic nitrogen levels are also low, and nitrogen deficiency widespread. Responses to nitrogen fertilizers are therefore also common (van Keulen *et al.* 1977; Vlek *et al.* 1981; Anderson 1985).

Because of these widespread deficiencies in nitrogen and phosphorus, much research has been undertaken within the region by national and international agencies. Resulting from this research, fertilizer recommendations have been formulated and extended to farmers. During the last fifteen years there has been a dramatic increase in fertilizer use (Table 3), but this has been largely restricted to irrigated agriculture and the higher potential rainfed areas.

Table 3. Fertilizer use in countries of West Asia and North Africa (kg/ha of arable land and permanent crop)

	Nitrogen (N)		Phosphate (P_2O_5)		Area of arable land and Permanent crops [1] (1000 ha)	
	1975	1985	1975	1985		
Algeria	5.3	12.9	8.5	17.8	7610	(4)
Cyprus	17.3	23.4	13.1	16.0	432	(2)
Iraq	4.7	22.0	1.3	9.4	5450	(32)
Jordan	4.9	25.6	8.0	7.6	418	(9)
Lebanon	20.9	39.7	14.9	39.7	300	(29)
Libya	7.3	9.8	9.4	16.3	2127	(11)
Morocco	8.2	16.2	8.7	13.1	8401	(6)
Sudan	7.8	7.4	-	0.1	12478	(14)
Syria	8.8	24.2	4.0	15.2	5623	(11)
Tunisia	4.8	9.1	5.3	9.6	4923	(4)
Turkey	17.4	35.1	14.0	17.3	27541	(8)
Yemen AR	2.5	11.1	1.0	0.9	1351	(18)
Yemen PDR	6.5	13.8	0.4	-	167	(37)
AVERAGE	8.9	19.2	6.8	12.5		(14)
Bahrain	11.5	95.0	-	75.0	2	(50)
Egypt	146.9	257.6	29.4	79.7	2486	(99)
Kuwait	-	233.3	-	200.0	3	(35)
Oman	6.9	48.9	2.3	27.7	47	(89)
Qatar	100.0	130.0	-	15.0	4	-
Saudi Arabia	5.2	143.8	2.1	121.1	1175	(38)
UAE	72.7	164.7	9.1	47.1	17	(37)
AVERAGE	49.0	153.3	6.1	80.8		(58)

[1] Figures in parentheses indicate % of arable land and permanent crops under irrigation

Source: World Bank Development Report 1988. FAO Fertilizer Year Book 1986.

Coupled with this increased use of fertilizer, several countries within the region have also substantially increased their production capacities of nitrogen and phosphate fertilizer, both for domestic consumption and export allocation (Table 4). This is an encouraging picture, but there is no doubt that if the predicted food and feed deficits are to be met in the future, there must be further rapid advances in fertilizer research, production, marketing, extension and farmer adoption.

Table 4. Fertilizer production (1000 MT of plant nutrients) in countries of West Asia and North Africa

	Nitrogen (N)		Phosphate (P_2O_5)	
	1975	1987	1975	1987
Algeria	78.7	112.5	61.8	53.8
Cyprus	0	0	0	0
Iraq	33.6	64.7	0	164.7*
Jordan	0	99.2*	1.4	253.4*
Lebanon	0	0	127.6	0
Libya	0	239.9*	0	0
Morocco	10.5	59.1	148.8	466.5*
Sudan	0	0	0	0
Syria	12.5	104.1	0	79.0
Tunisia	0	160.9*	184.8	701.5*
Turkey	189.0	692.5	344.2	532.2*
Yemen AR	0	0	0	0
Yemen PDR	0	0	0	0
Bahrain	0	0	0	0
Egypt	100.2	601.9	95.0	128.1
Kuwait	27.6	338.9*	0	0
Oman	0	0	0	0
Qatar	55.4	343.6*	0	0
Saudi Arabia	80.6	435.6*	0	0
UAE	0	211.6*	0	0

* indicates major exports of these nutrients.

Source: FAO Fertilizer Year Book 1975 and 1987.

In the subsequent sections of this paper I will briefly discuss the mechanisms by which fertilizer can improve crop water use and water use efficiency in rainfed crop production, and the agro-ecological constraints of the Mediterranean region which affect responses to fertilizer. I will end by outlining key areas of fertilizer research which I consider to be of high priority for the future.

Water use efficiency and fertilizer use

As has been illustrated by Gregory (1991) the water use efficiency of dry matter production can be expressed as:

$$WUE = \frac{k}{VPD\ (1+Es/T)} \quad (kg/ha/mm) \qquad (1)$$

where k is a crop constant
VPD is the mean seasonal vapour pressure deficit
Es is the seasonal total amount of water lost by evaporation from the soil underneath the crop, and
T is the seasonal total amount of water transpired by the crop.

It is widely observed that balanced fertilizer applications (N and P) give substantial increases in dry matter production and grain yield from essentially the same quantity of available water (Table 5), meaning that water is used much more efficiently when nutrient deficiencies are corrected.

This is largely due to more rapid growth and canopy development during the winter period. More solar energy is intercepted by the crop and less reaches the soil surface. As a result soil evaporation (Es) is reduced and crop transpiration (T) is increased (Fig. 1). In other words, fertilizer reduces the ratio Es:T, leading to greater WUE (Equation 1).

A notable effect of phosphate deficiency is retarded plant development. When P is applied to deficient soils, it speeds up crop development and can result in maturity being reached up to two weeks earlier (Shepherd *et al.* 1987). In an environment where VPD increases steadily through the spring and early summer months, earlier maturity means that crops will experience lower mean VPD over the growing season. This further improves WUE (Equation 1).

Fertilizer also enhances root growth (Cooper *et al.* 1987) and so may increase crops' ability to extract moisture during the spring and early summer months when they depend entirely on what is stored in the soil (Fig. 2). The extent to which such enhanced extraction is possible will depend on the amount and distribution of seasonal rainfall.

Table 5. Effect of fertilizer (N + P) on barley yield and water use efficiency at Breda, Syria

	80/81		81/82		82/83		83/84	
Seasonal rainfall, mm	299		324		284		207	
Fertilizer	0	NP	0	NP	0	NP	0	NP
Total dry matter, t/ha	3.84	7.54	4.54	6.13	2.01	3.40	1.37	2.09
Crop evapotranspiration, mm	234	225	231	231	224	235	171	174
Water-use efficiency, kg DM/ha/mm	16.4	33.5	19.7	26.5	9.0	14.5	7.8	12.0

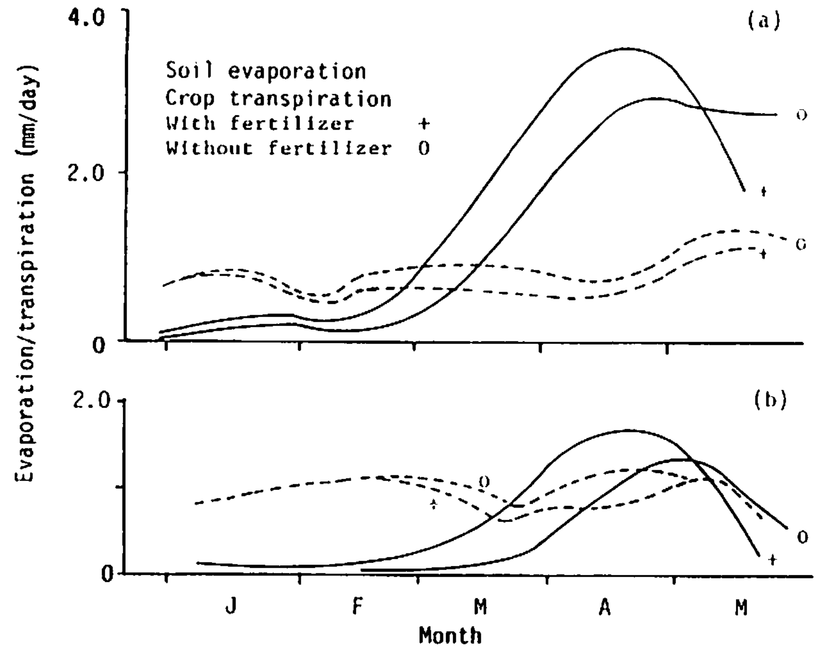


Fig. 1 Seasonal pattern of evaporation from soil and crop transpiration under barley (cv. Beecher) in the presence (+) and absence (o) of fertilizer at (a) Jindiress and (b) Breda in N.W. Syria, 1983.

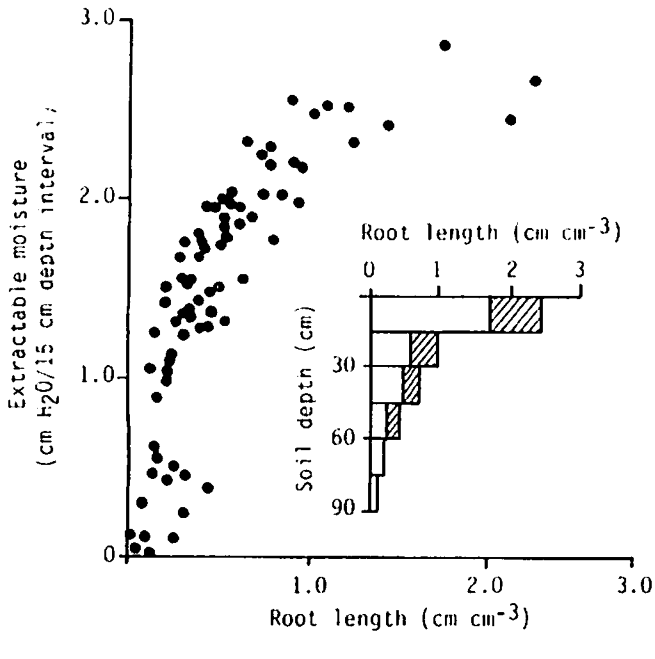
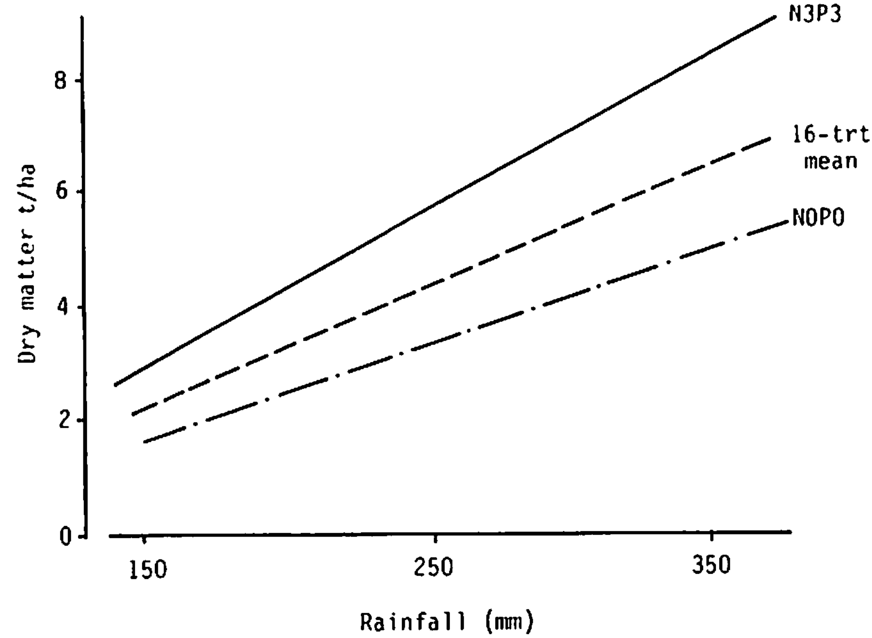


Fig. 2 The relationship between root length density of barley and plant extractable soil moisture in discrete soil layers. Inset figure illustrates the fertilizer-induced increase (shaded area) in root length density.

Fertilizer responses, rainfall variability and risk

In environments with variable rainfall, we must accept the fact that fertilizer use will increase year to year variability in crop production. The fact is, the more successful one is at controlling other factors limiting production, such as poor nutrient supply, the more dependent production becomes, albeit at a higher level, on uncontrollable factors such as rainfall (Fig. 3). This uncertainty of production from season to season, which cannot be predicted, is one of the major problems faced by farmers in semi-arid environments. It undoubtedly is the main reason why their attitude to the introduction of new management practices tends to be



For the regressions of each treatment:

	r² values (%)				Slope Coefficient			
	P0	P1	P2	P3	P0	P1	P2	P3
N0	39.3	38.9	35.5	29.2	16.6	17.2	17.2	18.0
N1	41.1	47.5	49.3	46.1	18.1	22.0	24.0	20.4
N2	48.6	50.2	51.8	64.2	20.7	22.5	21.5	26.1
N3	49.8	51.7	59.6	64.1	21.6	23.9	24.9	27.8

Fig. 3 Regressions of barley dry matter response on seasonal rainfall under different fertilizer regimes from 32 on-farm trials in Syria (SMAAR/ICARDA 1985, 1986).

conservative. Costs, such as that for phosphate fertilizer, must be incurred before it is known whether the season will be good or bad, and from that viewpoint there may be some risk of financial loss associated with fertilizer use. However, the data derived from on-farm fertilizer trials in the arid zones of Syria (Fig. 4), show that there is always a yield response to balanced fertilizer application even in very dry years, and indicate that the risk may be lower than anticipated by farmers. The residual effects of fertilizer, discussed in a later section, further improve the prospects for a good financial return and reduced risk.

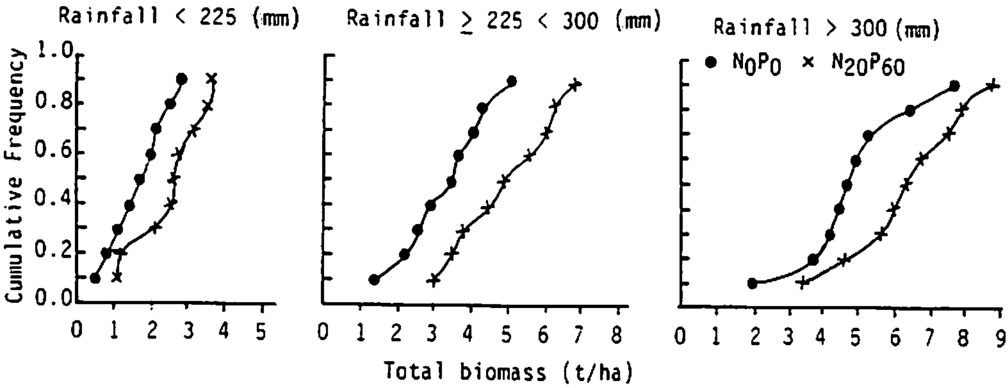


Fig. 4 **Cumulative frequency distribution of total biomass of barley as affected by balanced fertilizer applications and rainfall amounts. Data derived from 75 on-farm trials (SMAAR/ICARDA 1985, 1986, 1987, 1988).**

Rainfall-soil fertility interactions with fertilizer responses

As crop growth potential increases with increasing rainfall up to a crop specific optimum level, so do responses to balanced fertilizer applications (Fig. 3). These responses interact with the level of available nutrients in the soil, differently for nitrogen and phosphate fertilizer. Figures 5 and 6 are derived from data from over 50 on-farm trials conducted in cooperation with the Syrian Soils Directorate (SMAAR/ICARDA 1985, 1986, 1987). Figure 5a illustrates that beyond a certain amount of rainfall, which is soil fertility dependent, the increase in yield due to 60 kg P_2O_5/ha starts to level off and subsequently decline. With nitrogen however, this is not observed (Fig. 5b). These differences become more apparent if the same data are expressed, not as absolute increases in yield, but as percentage increases in yield over the control (Fig. 6a and 6b).

These results confirm the wider observation that, in WANA, responses to nitrogen are more important in wet years and locations, while in dry years and locations, responses to phosphate are dominant. This is largely due to the very different mobilities of phosphate and nitrate in the soil.

Crop rotation and fertilizer responses

Nitrogen fertilizer responses of cereal crops are particularly influenced by the type and performance of the preceding crop. Wheat is commonly preceded by legumes (lentils,

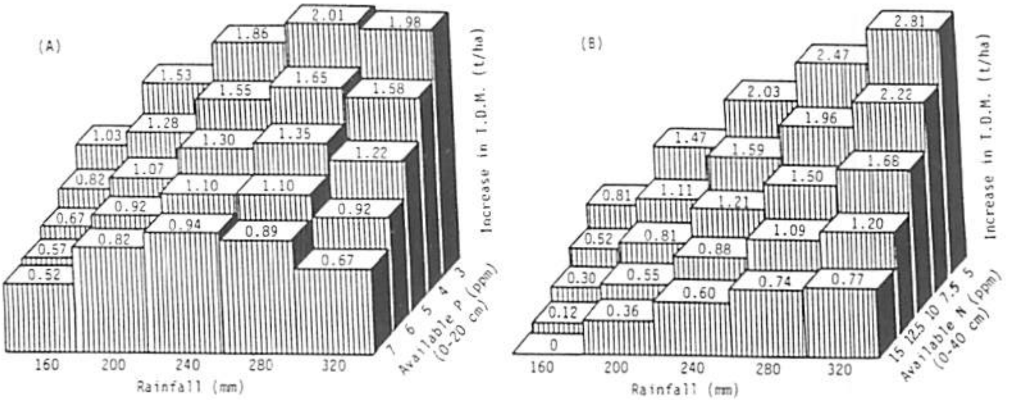


Fig. 5 The effect of rainfall and available soil nutrients on the increase in total dry matter production (TDM) resulting from (a) 60 kg P_2O_5/ha and (b) 40 kg N/ha.

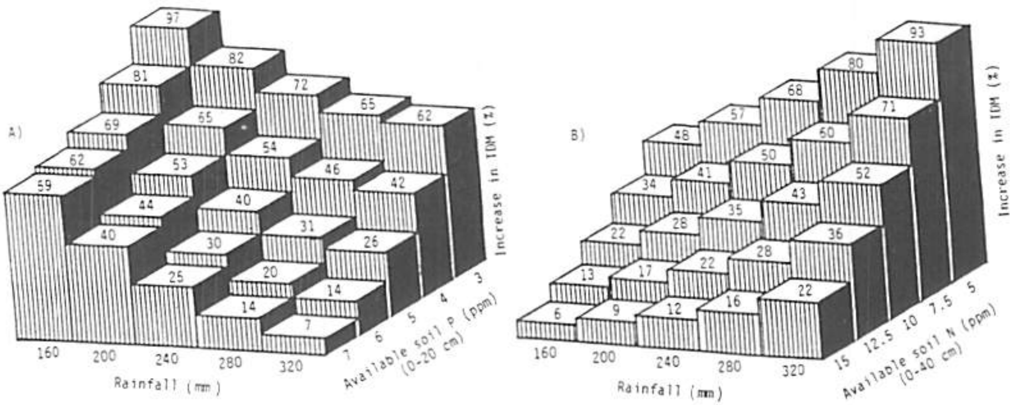


Fig. 6 The effect of rainfall and available soil nutrients on the percent increase in total dry matter production (TDM) resulting from (a) 60 kg P_2O_5/ha and (b) 40 kg N/ha.

chickpea or faba bean) or by summer crops such as maize, water melons or sesame, or a weedy fallow. Barley is most usually preceded by a fallow (which may be clean or weedy) or increasingly is grown as a continuous crop.

Mineralization of organic nitrogen occurs during fallows. How much of the mineralized nitrogen is available for a subsequent cereal crop depends partly on the uptake by weeds during the fallow or by a summer crop grown on stored moisture. In many parts of the region, fallow has been replaced with food or forage legumes. The amount of mineralized nitrogen available to a following cereal crop then depends on how successful the legume is in meeting its nitrogen requirements through biological nitrogen fixation. In general, subsequent availability follows the sequence:

Clean fallow > Faba bean > Summer crop > Lentil
> Chickpea > Weedy fallow > Cereal

In addition, the amount of available moisture remaining after the preceding crop will also vary, and (as illustrated before) this too will affect nitrogen responses.

The consequences of the preceding crop on nitrogen responses of wheat and barley in Syria are illustrated in Figs 7 and 8.

Weed control and fertilizer responses

Weeds can present serious problems for farmers in WANA, particularly in areas receiving more than 350 mm of rainfall. Herbicides are being rapidly adopted for use on cereal crops (wheat) by farmers in many countries, but weeds in legume crops still pose problems. Farmers still rely on late sowing and subsequent hand weeding. Late sowing allows weeds which germinate with the early rains to be killed by the pre-sowing tillage. However, late sowing also reduces yield potential, and hand weeding is still usually necessary and is expensive. As a result, legumes are becoming less and less attractive to farmers in economic terms. When farmers fail to control weeds, fertilizer responses of legumes are substantially reduced (Table 6).

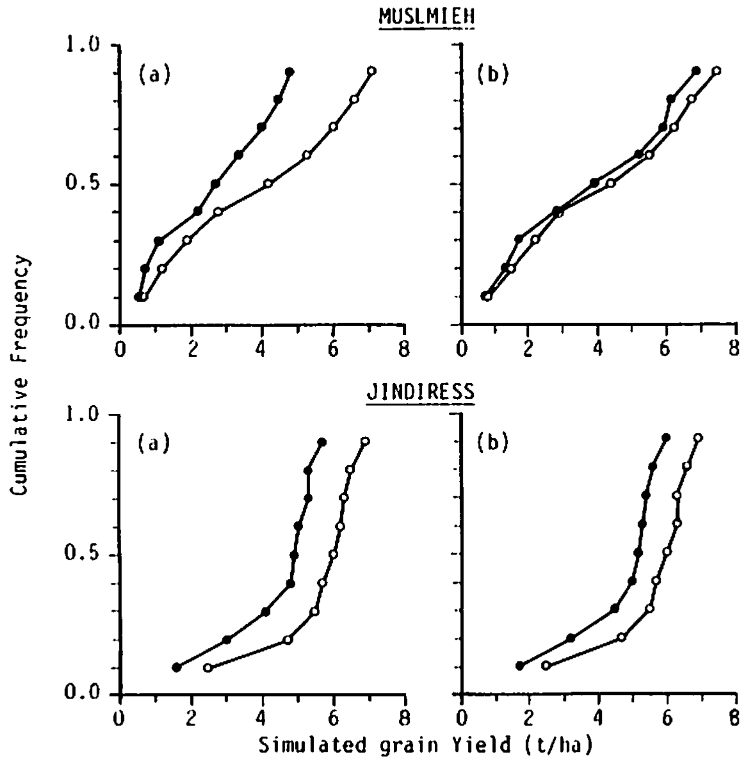
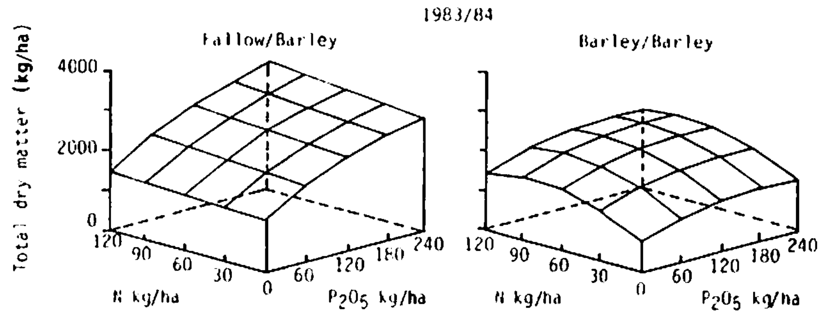
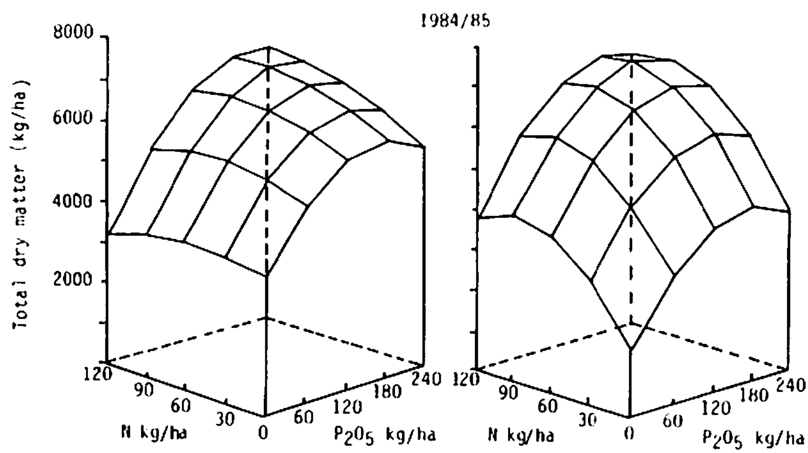


Fig. 7 Simulated wheat yields (Ceres-N Wheat Growth Model) in two crop rotations at (a) Muslmieh and (b) Jindiress, N.W. Syria. Open circles, zero N; solid circles, 80 kg N/ha.

Weed infestation can also seriously affect the economics of fertilizer use on wheat. In the worst cases weeds respond so vigorously to both N and P that wheat yields may be reduced below those obtained when no fertilizer is applied. In both cereal and legume fields, where weeds are known to be a problem, weed control and fertilizer use must be recommended as a package.



	Constant	P	N	NP	N^2	P^2	R^2
F/B	1353	10.0 ***	1.4 ns	0.009 ns	-0.002 ns	-0.020 ***	0.85
B/B	755	5.5 **	18.9 ***	0.003 ns	-0.115 ***	-0.015 **	0.68



	Constant	P	N	NP	N^2	P^2	R^2
F/B	3320	29.6 ***	11.5 ns	0.06 **	-0.11 ns	-0.09 ***	0.81
B/B	1615	30.5 ***	54.0 ***	0.03 ns	-0.31 ***	-0.09 ***	0.79

Fig. 8 The effect of crop rotation and year on the response surface of total dry matter production of barley to N and P fertilizer at Breda, N.W. Syria. Inset tables give respective regression equations with levels of significance, *** $p < 0.01$, ** $p < 0.05$, ns not significant.

Table 6. Effect of hand weeding and fertilizer (60 kg/ha P_2O_5 and 20 kg/ha N) on water use, dry matter production and water use efficiency (WUE) of weeds and lentils. Conventional tillage was used and the crops grown in NW Syria

Fertilizer	Weed Control	E+T[1] (mm)	Dry matter (kg/ha)		WUE (kg/ha/mm)	
			Lentil	Weeds	Lentil	Weed+Lentil
+	-	270	1128	1084	4.2	8.2
+	+	237	2038	37	8.6	8.8
-	-	255	667	685	2.6	5.3
-	+	218	751	72	3.4	3.8

1 (E+T) is crop evapotranspiration

Phosphate application, immobilization and residual effects

As soon as phosphate fertilizer is incorporated into calcareous soils, a process of immobilization begins, with the phosphate being transformed into less available or unavailable forms. The rate at which this reaction proceeds varies with soil chemical properties and rainfall amount and distribution (Fig. 9). However, it may well be two to three years before the

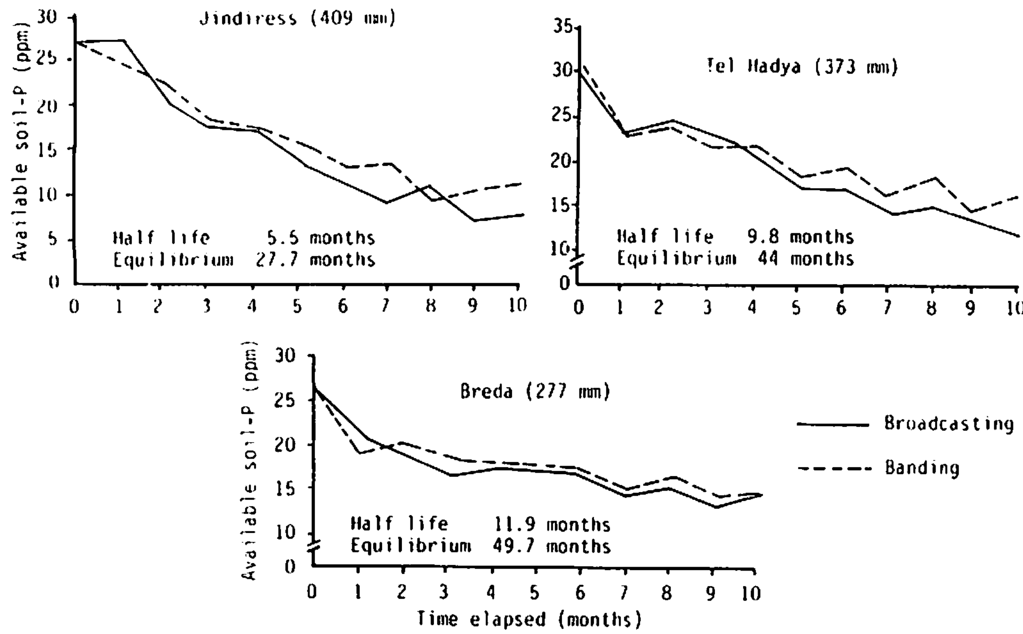


Fig. 9 **Effect of banding and broadcasting phosphate fertilizer (80 kg P_2O_5/ha) on its availability with time at three locations in N.W. Syria.**

availability of phosphate in the soil falls back to its original pre-fertilization level, and residual crop responses to phosphate fertilizer may sometimes be observed in the second and even the third year after application. This is illustrated in by the data in Table 7 which shows the responses of a range of food and forage legumes to either 100 kg/ha P_2O_5 applied to a preceding wheat crop or 100 kg/ha P_2O_5 drilled with the legume. Mean responses to residual and applied-P are similar, and it is noteworthy that they were substantially greater in the drier year of 1986/87 (see also Figs 5 and 6).

In addition regular applications of phosphate fertilizer by farmers gradually increases the available phosphate status of their soils. Figure 10 illustrates the effect of 20 years use of phosphate fertilizer on the P-status of wheat fields in Syria compared with barley fields which have remained unfertilized. Phosphate build-up modifies the response to and economics of subsequent applications. To avoid wasteful use of fertilizer, the concept of maintenance fertilization needs to be introduced and the size of the optimum maintenance dressings determined.

Methods of application of fertilizer to annual crops

The commonest method of applying both nitrogen and phosphate fertilizer is broadcasting. Currently, little precision placement of fertilizer occurs in West Asia and North Africa.

Phosphate fertilizer is applied either several weeks before sowing and incorporated into the soil through tillage, or it is broadcast at the time of sowing and incorporated with the seed. Due to its immobility in calcareous soils, precision placement of phosphate with the seed results in more immediate availability to the growing roots and hence gives greater responses (Cooper *et al.* 1989). Drills which can sow seed and place phosphate fertilizer need not be expensive and would be economically attractive. Such machines are already used in some countries either by custom operators or private ownership.

Table 7. The main responses (kg/ha) of total dry matter in five legume species to 100 kg P_2O_5/ha of residual or applied phosphorus at Tel Hadya, Syria

	Pea	Chickpea	Faba bean	Lentil	Vetch	Mean
			1986/87 (Rainfall 358 mm)			
Residual-P	1072	969	683	983	738	889
Applied-P	1292	352	553	570	1459	845
Mean	1182	660	618	776	1098	
			1987/88 (Rainfall 504 mm)			
Residual-P	1604	16	381	290	42	466
Applied-P	1244	156	0	656	56	422
Mean	1424	86	190	473	49	

Source: Matar 1989

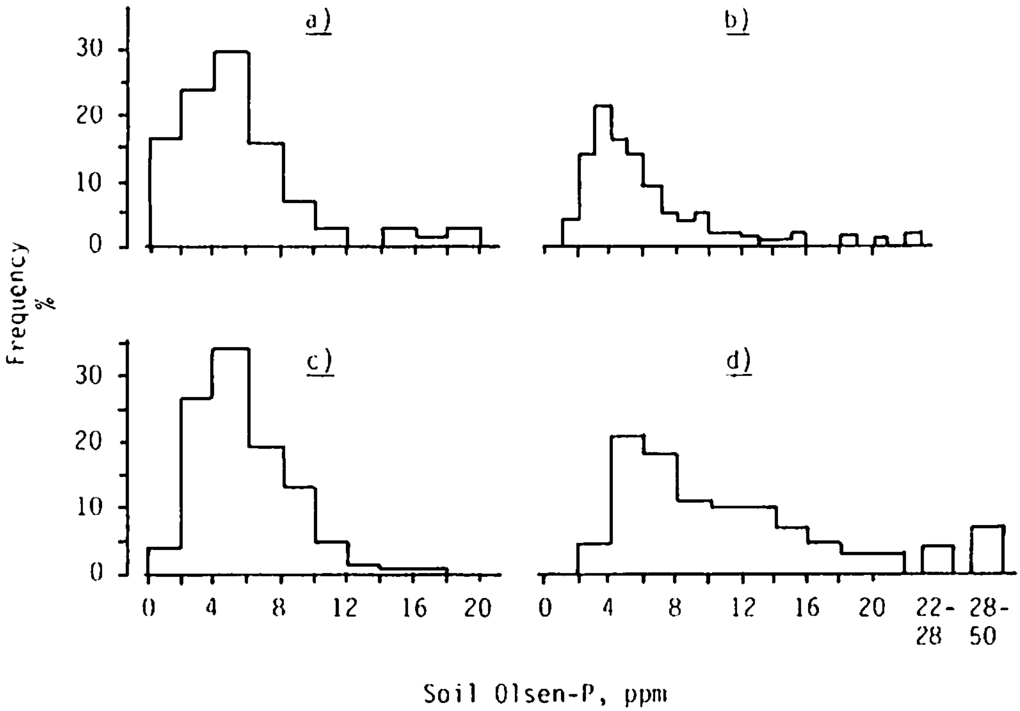


Fig. 10 Distribution of topsoil Olsen-P values in Syria: (a) barley and wheat fields, 1969; (b) barley fields, 1982; (c) barley fields, 1987; and (d) wheat fields, 1987.

The bulk of nitrogen fertilizer is topdressed on winter cereals at tillering. Some farmers may also apply a "starter" dose of nitrogen at seeding time. In many instances, farmers are aware of the interaction between rainfall amounts and nitrogen responses, and modify their top dressings accordingly (Table 8).

Table 8. Fertilization rates used by wheat growers in Syria according to rainfall

	Phosphate (kg/ha)			Nitrogen (kg/ha)		
	Mean	SD	Sample number	Mean	SD	Sample number
Rainfall						
Wet	91	42	29	162	124	55
Average	83	38	29	118	63	55
Dry	67	44	29	74	54	55

Source: Tully and Rassam (1986)

Priority Areas for Research

Characterization of environment: fertilizer response interactions through on-farm research

In this paper, certain environmental variables and their effect on fertilizer responses have been discussed. These include soil fertility, rainfall and crop rotation. If national agencies wish to use a limited supply of domestically produced (or imported) fertilizer in an economically efficient manner, then fertilizer recommendations which take such factors into account must be developed. Because these factors vary across "space" and "time", they can be quantified only by selecting research locations which sample the natural variability. It seems unlikely that existing networks of research stations adequately represent the "spatial" variability of the physical and chemical characteristics of soils or contrasting crop rotations. In addition, the variability of rainfall amount and distribution can be sampled at a single location only by many years repeated research.

To overcome the limitations of on-station fertilizer research, it is a high priority for national research programs to develop the capabilities and facilities for conducting on-farm research. In doing so, the additional opportunity for including the farmer as a partner in research is created. In target areas where farmers have little or no experience of fertilizer use, such a partnership is invaluable both in aiding technology transfer and impact assessment, and in identifying possible constraints to adoption which the farmers may face. These issues are being discussed in some detail later in this workshop.

Dynamic fertilizer recommendations

Even within a single field, let alone a fertilizer recommendation domain, environmental and soil conditions are not static. Both within a given season, and over longer periods, they change, and fertilizer recommendations must change with them if economic responses are to be maintained.

Phosphate application to calcareous soils over several years results in a steady increase in the level of plant available-P, and thus original phosphate recommendations become inappropriate. Research is needed to quantify the dynamics of phosphorus in calcareous soils and to describe the effects of previous fertilizer application on the level of available-P in the soil. Once the available P has risen to a level at which responses are no longer expected, "maintenance dressings" are needed to keep it at that level. Such dynamics are a function of the physical and chemical properties of the soil and the rainfall and temperature conditions. Currently, they are poorly understood and form an important priority area for research.

In contrast to phosphorus, there is little evidence of residual effects of nitrogen fertilizer, but the within-season dynamics of fertilizer nitrogen and the nitrogen requirements of the crop are strongly affected by rainfall. Most of the nitrogen fertilizer applied to wheat and barley by farmers is top-dressed, and since a large part of the season's rain will have fallen before top-dressing, the potential exists for more precise and flexible N-fertilizer recommendations. Crop growth simulation models can indicate the development and growth of the crop and the amount of moisture stored in the soil prior to top-dressing. Analyses of long term climatic records can predict the probabilities of receiving different amounts of rainfall thereafter and "best-bet" nitrogen top-dressing requirements can be determined.

Such models could be applied by national planners to follow the development of cereal yield potential as the season progresses. District-specific and year-specific recommendations could be formulated in a timely fashion and made available to farmers through extension agents, radio and television. Such models already exist for wheat and barley, but they have not been widely validated or used in the region. Initial research and testing has, however, shown them to be reliable predictors and sensitive to environmental changes (Harris and Godwin 1989). Wider testing and use of such models is another high priority area of research.

National allocation of fertilizer

In most countries of WANA, central planners are faced with the problem of how to allocate supplies of domestically produced fertilizer among competing crops in contrasting production environments. In some countries in which fertilizer production levels are high, the option of exporting fertilizer has to be balanced against domestic use. In other countries where deficits in domestic fertilizer production exist, the option of importing fertilizer must also be considered. Nordblom and Al-Ashram (1989) describe a framework which can be used to consider multiple crop and recommendation domain-specific yield responses to N and P fertilizer while balancing marginal production values against exporting and importing options. The allocation framework takes the form of a linear programming model which provides the best economic solutions rather than yield maximizing ones *per se*. Initial testing has demonstrated great potential for such an approach, but the authors point out that several areas of research still remain before the model can become fully effective.

1. The response coefficients for all main crops in all main fertilizer recommendation domains are needed before valid planning can take place with such a model.
2. Estimates of yield responses to fertilizer are almost always derived from researcher-managed trials and are typically higher than those obtained by farmers. For valid planning, these yield gaps must be quantified and incorporated into the model.
3. The framework used is currently static: it assumes fixed response functions which represent expected responses prior to the onset of the season. It is important to test the value of expanding the model by providing alternative season-dependent response functions which allow for contrasting weather patterns, and decisions on mid-season applications.

The data requirements for such a model are formidable, and in many countries a substantial amount of research will be required to produce such a data set. However, the same data are needed on a decentralized basis to derive environment-specific extension recommendations. Given the potential value of this approach for planners and the impact that the effective use of such a model could have on agricultural production, we consider the further development and testing of this model also to be a high priority area for research.

References

Anderson, W.K. 1985. Grain yield responses of barley and durum wheat to split nitrogen applications under rainfed conditions in a Mediterranean environment. Field Crops Research 12:191-202.

Cooper, P.J.M., Gregory, P.J., Keatinge, J.D.H. and Brown, S.C. 1987. Effects of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. 2. Soil water dynamics and crop water use. Field Crops Research 16:67-84.

Cooper, P.J.M., Jones, M., Harris, H., and Matar, A. 1989. Agro-ecological constraints to crop production in West Asia and North Africa, and their impact on fertilizer use. Presented at Workshop on Fertilizer Sector Development and Agricultural Production in selected countries of the Mediterranean, Middle East and North Africa. IFDC, Muscle Shoals, AL, USA, May 1988. Paper Series IFDC-P-9.

El-Fauly, M.M. 1983. Micronutrients in arid and semi arid areas: levels in soils and plants and the need for fertilizers with reference to Egypt. Pages 163-174 *in* Proceedings of the 17th Colloquim of the International Potash Institute, Rabat, Morocco, May 1983.

Gregory, P.J. 1991. Concepts of water use efficiency. (This Volume).

FAO 1975, 1986, 1988. Fertilizer Year Books, Rome, Italy.

FAO 1987. Agriculture: Toward 2000 (revised version 1987). Food and Agriculture Organization of the United Nations, C87/27. Rome, July 1987.

Haddad, G.A., Chaudhry, F.M., Haque, I., and Khan, G.A. 1979. Effect of micronutrient fertilization on various legumes and cereals in the Kufra Oasis. Pages 303-308 *in* Proceedings of 3rd Symposium of C.I.E.C. on Water and Fertilizer Use for Food Production in Arid and Semi-arid Zones (Eeltze, E., ed.) Gottingen, Federal Republic of Germany.

Harmsen, K. 1984. Dryland barley production in Northwest Syria. I. Soil conditions. Pages 12-41 *in* Proceedings of Soils Directorate/ICARDA WOrkshop on Fertilizer Use in Dry Areas, March 1984, Aleppo, Syria.

Harris, H. 1991. Implications of climatic variability. (This Volume).

Harris, H., and Godwin, D. 1989. Crop growth simulation models. Pages 95-105 *in* Farm Resource Management Program Annual Report, 1988. ICARDA-142 En. ICARDA, Aleppo, Syria.

Kassam, A.H. 1981. Climate, soil and land resources in North Africa and West Asia. Plant and Soil 58:23-28.

Matar, A. 1989. Phosphorus requirements of food and forage legumes: residual and applied fertilizer effects. Pages 55-59 *in* Farm Resource Management Program Annual Report, ICARDA-142 En. ICARDA, Aleppo, Syria.

Nordblom, T., and Al Ashram, M. 1989. An economic framework for centralized fertilizer allocation to crops in contrasting production zones. Pages 117-132 *in* Farm Resource Management Program Annual Report 1988. ICARDA-142 En. ICARDA, Aleppo, Syria.

Shepherd, K.D., Cooper, P.J.M., Allan, A.Y., Drennan, D.S.H. and Keatinge, J.D.H. 1987. Growth, water use and yield of barley in Mediterranean-type environments. Journal of agricultural Science, Cambridge 108: 365-378.

Somel, K. 1988. Food and agriculture in West Asia and North Africa: Projections to 2000. Pages 121-143 *in* Farm Resource Management Program Annual Report, 1987.ICARDA, Aleppo, Syria.

SMAAR/ICARDA 1985, 1986, 1987, 1988. Collaborative research project annual reports on fertilizer use on barley in N. Syria. Syrian Arab Republic, Ministry of Agriculture and Agrarian Reform, Soils Directorate and ICARDA, Aleppo, Syria.

Tully, D., and Rassam, A. 1986. Wheat production practices in N.W. Syria. Pages 43-56 *in*

ICARDA Annual Report 1985, ICARDA, Aleppo, Syria.
van Keulen, H. 1977. On the role of nitrogen in semi-arid regions. Stikstof No. 20:23-28.
Vlek, P.L.G., Fillery, I.R.P., and Burford, J.R. 1981. Accessions, transformation and loss of nitrogen in soils of the arid region. Plant and Soil 58:133-176.
Watson, A. 1984. The Arab agricultural revolution and its diffusion. 700-1100. Journal of Economic History 34, No. 1.
White, H. 1963. Roman Agriculture in North Africa. Nigeria Geographical Journal 6:39-49.
White, H. 1970. Fallowing, crop rotation and crop yields in Roman times. Agricultural History 44:281-290.

The Impact of N and P Fertilizers on Root Growth, Total Yield, and Water Use Efficiency of Rainfed Cereals in Tunisia

M. MECHERGUI[1], A. GHARBI[2] AND S. LAZAAR[1]

1 INAT, 43 Avenue Charles Nicolle, 1002 Tunis Belvedere, Tunisia
2 Ecole Superieure d'Agriculture, 7199 le Kef, Tunisia

Abstract

N and P fertilizers were applied to two cereal crops, barley and bread wheat, to study their effect on root growth, total yield and water use efficiency in a semi-arid region. The experimental design was a split plot and treatments consisted of applying combined rates of nitrogen and phosphorus. The soil moisture was monitored throughout the period between tillering and maturity using a neutron probe.

Results indicated that nitrogen supply increased root length densities, total yield and water use efficiency of the species studied, while phosphorus enhanced root growth and increased total yield and water use efficiency of both crops. Application of combined rates of N and P resulted in a greater increase of such plant parameters in most of the treatments.

Introduction

In the semi-arid region of Tunisia cereal crop production is often limited by water stress caused when evaporative demand exceeds the rate at which plant roots can extract soil water. In such areas, where soil water is the most limiting factor, crop yields have been shown to correlate well with the level of the annual rainfall.

In these regions, cereal producers usually apply 100 kg of triple superphosphate at sowing and 100 kg of ammonium nitrate as a split dressing, regardless of the levels of N and P in the soil. In drier years usually only half of the recommended nitrogen rate is used.

Research in dry areas has often been concentrated on the study of factors that enhance the water use efficiency of cereal crops, and within this context, studies on root production and crop water use are important. Mantel (1966) reported that the absolute root weight of kikuyugrass was considerably increased by adding nitrogen. Moore and Rhoades (1966) found a highly significant correlation between the root weight and total soil nitrogen. Brown *et al.* (1987) showed that N and P fertilization significantly increased the total root length of barley at the beginning of stem extension. Data of Kopke *et al.* (1980) revealed that cereal root length densities up to 6 $cm.cm^{-3}$ are very common in surface soil and up to 1 $cm.cm^{-3}$ are common at the 50-100 cm soil depth interval. Kopke *et al.* (1982) reported that under field conditions cereals root to a depth slightly exceeding one meter.

The water-production function, which relates yield to the amount of evapotranspiration of the crop was shown to be linear (Stewart and Hegan 1973; Bauder *et al.* 1978) although it was found concave - upward curvilinear by Turk *et al.* (1980). Kallsen *et al.* (1984) reported that the water-production function varies significantly among soil nitrogen fertility levels and found that nitrogen affected water use efficiency expressed in terms of weight of cereal grain per mm of crop evapotranspiration.

Power (1985) observed that nitrogen supply increased water-use efficiency of cereals from between 3 and 9 kg of grain/mm to between 13 and 23 kg of grain/mm of crop evapotranspiration. He also found that water use was generally about 20 mm greater for N-fertilized than for unfertilized grass. Brown *et al.* (1987) and Cooper *et al.* (1987) reported that N and P fertilizers increased both the shoot and root weight of barley and resulted in large increases in water-use efficiency. Such increases were shown to be largely due to increased transpiration efficiency and to a reduction in soil evaporative loss through greater soil shading by the crop canopy (Power 1985; Cooper *et al.* 1987).

The present paper reports on the effect of N and P fertilization on root growth, plant response, and on water-use-efficiency of barley and bread wheat grown in the semi-arid Mediterranean environment of Tunisia.

Material and Methods

This study was undertaken on a vertic xerochrept. The soil was fine textured (40% clay), alkaline (pH 8) with an organic matter content of about 2.5%. The initial N, P, and K levels were 1200 ppm, 18 ppm, and 1.08 me/100 g respectively. The trial was located at Lorbeus in the north western part of Tunisia. The climate is Mediterranean, typified by dry summers and cool, wet winters. The mean annual rainfall is about 460 mm varying from year to year between 200 and 700 mm. The monthly rainfall and evapotranspiration during the trial season are presented in Figure 1.

The experimental design was a factorial N^3 P^3 conducted in a split plot where fertilizer treatments form the main factor and cereal species the secondary factor. The plot size was 25 m^2 (10m x2.5 m). Fertilizer treatments consisted of adding three rates of ammonium nitrate (0, 33, and 50 kg N/ha) in combination with three rates of triple super-phosphate (0, 27 and 45 kg P_2O_5/ha) to two cereal species, barley (Tej) and bread wheat (Florence x Aurore). Phosphate fertilizer was broadcasted and incorporated in the soil prior to sowing, whereas nitrate fertilizer was applied at emergence and tillering stages of growth.

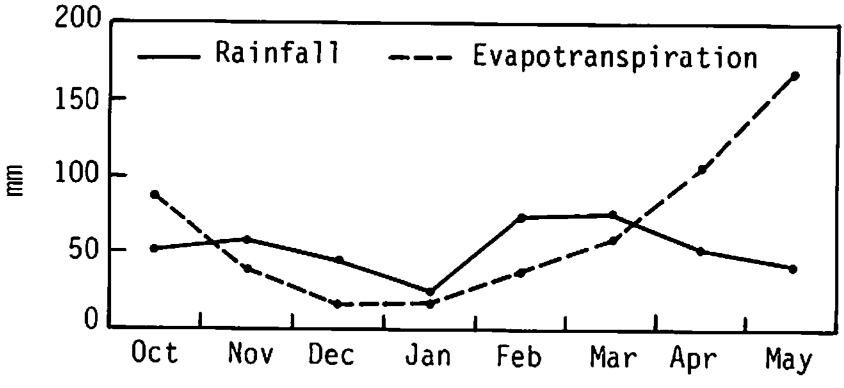


Fig. 1 Distribution of monthly rainfall and evapotranspiration.

Soil moisture was monitored by a neutron probe through access tubes placed in the center of each plot to a depth of 0.95 m. A pronounced hard pan at 0.95 cm was known to restrict both water penetration and root growth. Moisture was recorded throughout the period between tillering and maturity. The overall change in soil moisture (M) for each plot was computed. The total rainfall (R) for the same period was 172 mm. The amount of crop evapotranspiration (E_t) was derived from the following equation: $E_t = R - \Delta M$.

Drainage and surface run-off were assumed to be very low and were not included in the calculation.

At heading stage plant roots were carefully excavated from the soil in each plot using a soil sampling auger according to the method described by Schuurmann *et al.* (1971). Root samples were carefully washed with distilled water in order to separate the roots from soil material after placing them in a sodium solution. Root lengths were measured according to the procedure described by Tennant (1975).

At harvest, grain and straw yields in each plot were recorded, and water use efficiency expressed as weight of dry matter produced per mm of crop evapotranspiration was calculated for each treatment. All data were statistically analyzed. The means were separated according to the LSD method.

Results and Discussions

Root growth

As recorded in Table 1 the rooting system of barley and bread wheat is mainly concentrated in the 0-20 cm layer. The application of N fertilizer increased root length of both species in the 0-20 cm layer as well as in the underlying 20-40 cm, when compared to the control ($P<0.05$). Root length of both crops and at both depths increased following the addition of incremental rates of nitrogen fertilizer (Table 1).

The application of 27 kg $P_2 0_5$/ha significantly enhanced root growth of barley and bread wheat and resulted in a greater root length than that in unfertilized plots ($P<0.05$). The further supply of 45 kg $P0_5$/ha showed no significant effect on the root length density of bread wheat or barley. The greatest effect of fertilizer on root growth was however achieved when moderate rates of N and P were added together.

Water use by crops

There were small, but significant increases in crop evapotranspiration when N and P fertilizers were added to both wheat and barley ($P<0.05$), compared with unfertilized crops (Table 2). Such results are in line with previous findings (Cooper *et al.* 1987). Addition of incremental amounts of N or P alone led to greater amounts of crop evapotranspiration. Application of combined rates of N and P enhanced crop evapotranspiration by barley, but appeared to have less impact on bread wheat.

The observed increase in crop evapotranspiration seems to be in line with observed increases in root growth resulting from fertilization. Other results (Cooper *et al.* 1987) have shown clear relationships between root length density and the amount of water extracted from given soil depth intervals.

Table 1. Root length density (cm/cm³) in 0-20 and 20-40 cm soil depth intervals of wheat and barley grown at Lorbeus, N.W. Tunisia, 1986/87

kg P_2O_5/ha	kg N/ha					
	0		33.5		50	
	Barley					
	0-20	20-40	0-20	20-40	0-20	20-40
0	0.77	0.13	0.94	0.17	1.05	0.24
27	1.01	0.19	1.18	0.28	1.24	0.20
45	1.13	0.24	1.29	0.27	1.30	0.28
	Bread wheat					
0	0.82	0.22	0.91	0.30	1.13	0.35
27	1.13	0.24	1.30	0.33	1.18	0.37
45	1.13	0.28	1.30	0.35	1.30	0.39

Table 2. Biological yield (Y;t/ha), evapotranspiration, (ET;mm) and water use efficiency (WUE;kg/ha/mm) of wheat and barley as affected by N and P fertilizers, Lorbeus, N.W. Tunisia, 1986/87

kg P_2O_5/ha	kg/N ha								
	0			33.5			50		
	Y	ET	WUE	Y	ET	WUE	Y	ET	WUE
	Barley								
0	4.5	186	24.2	5.6	190	29.5	6.6	193	34.2
17	5.7	193	29.5	6.8	194	35.0	5.7	197	28.9
45	6.2	191	32.5	6.5	192	33.8	6.7	197	34.0
	Bread wheat								
0	4.6	204	22.5	5.0	213	23.4	6.8	225	30.2
17	5.7	213	26.7	5.9	197	29.9	4.7	199	23.6
45	6.3	225	28.0	6.6	208	31.7	7.2	210	34.3

Biological yield

Biological yield data (grain plus straw) are presented in Table 2. Since crop evpotranspiration was only recorded between tillering and maturity, and because we wished to relate dry matter production to crop water use efficiency, the values of biological yield presented are in fact "total dry matter at maturity minus dry matter at tillering". The supply of both nitrogen and phosphorus resulted in a greater dry matter yield of both crops ($P < 0.05$).

Dry matter yield rose significantly with incremental rates of nitrogen as well as with incremental rates of phosphorus. The application of combined rates of N and P gave the greatest amounts of dry matter.

Water use efficiency

Water use efficiency, expressed as the amount of shoot dry matter per mm of crop evapotranspiration, rose following the addition of either N or P fertilizer. WUE increased with increasing rates of either N or P. The application of combined rates of N and P resulted in the greatest water use efficiency of both species. These results agree well with those of previous research, and emphasize the important role fertilizer has to play in improving cereal production in the water limited rainfed systems of Tunisia.

Acknowledgement

The authors are very grateful to Dr Selmi Ali, Professor at Institut National Agronomique de Tunis and Director of the Farming System Research Project for his encouragement and financial support through the MIAC-USAID project.

References

Bauder, J. W., Bauer, A., Ramirez, J.M. and Cassel, D.K. 1978. Alfalfa water use and production on dryland and irrigated loam. Agronomy Journal 70: 95-99.

Brown, S.C., Keatinge, J.D.H., Gregory, P.J. and Cooper P.J.M. 1987. Effects of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. 1. Root and shoot growth. Field Crops Research 16: 53-66.

Cooper, P.J.M., Gregory, P.J., Keatinge, J.D.H. and Brown S.C. 1987. Effects of fertilizer, variety, and location on barley production under rainfed conditions in northern Syria. 2. Soil water dynamics and crop water use. Field Crops Research 16:67-84.

Ellis, F.B., and Barnes, B.T. 1980. Growth and development of root systems of winter cereals grown after different tillage methods including direct drilling. Plant and Soil 55:283-295.

Gregory, P.J., Biscoe, P.V., and Hunter, B. 1978. Water relations of winter wheat. I. Growth of the root system. Journal of agricultural Science, Cambridge 91:91-102.

Kallsen, G.E., Sammis, T.W. and Gregory, E.J. 1984. Nitrogen and yield as related to water use of spring barley. Agronomy Journal 76:59-64.

Kopke, U., Bohm, W. and Jachmann, Th. 1982. Rooting patterns of three winter wheat cultivars in a field and greenhouse experiment. Zeitschrift fuer Acker Pflanzenbau. 151:42-48.

Mantell, A. 1966. Effect of irrigation frequency and nitrogen fertilization on growth and water use of kikuyugrass lawn (Pennisetum clandestinum Hochst). Agronomy Journal 58:559-561.

Moore, A.W. and Rhoades, H.F. 1966. Soil conditions and root distribution in two wet meadows of the Nebraska sandhills. Agronomy Journal 58:563-566.

Negeswara Rao, R.C., Sardar Singh, Sivakumar, M.V.K., Srivastava, K.L., and Williams, J.H. 1985. Effect of water deficit at different growth phases of peanut. I. Yield responses. Agronomy Journal 77:782-786.

Power, J.F. 1985. Nitrogen- and water-use efficiency of several cool-season grasses receiving ammonium nitrate for 9 years. Agronomy Journal 77:189-192.

Schuurmann, J.J. and Goedn Waagen, M.A.J. 1971. Methods for the Examination of Root Systems and Roots. PUDOC Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.

Stewart, J.I. and Hagan, R.M. 1973. Functions to predict effects of crop water deficits. Journal of Irrigation and Drainage Division, American Society of Civil Engineers 99:421-439.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. Journal of Ecology 63:995-1001.

Turk, K.J., Hall, A.E. and Asbell, C.W. 1980. Drought adaptation of cowpea. I. Influence of drought on seed yield. Agronomy Journal 72:413-420.

Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas of Syria

ELIAS JABBOUR and MAZEN NAJI

Soils Directorate, Ministry of Agriculture and Land Reform, Damascus, Syria

Introduction

Dryland agriculture in Syria is practised on six million hectares receiving over 250 mm annual rainfall, extending eastward from the Mediterranean coastal plain to near the Syrian desert. A two-year rotation is almost universally practised, with wheat as the main crop, mostly in rotation with fallow but sometimes with lentil, chickpea, vetches and summer crops such as water melon and sunflower. Traditionally farmers assumed that fallowing was an effective means of conserving water, controlling weeds and maintaining soil fertility, and indeed the fallow system has shown its merits in many parts of the world, but the improvements in the fertilizer industry and in soil management and conservation have lessened its value. Barley occupies a large area of the rainfed agricultural zone which receives 200-250 mm average annual precipitation. A barley-fallow rotation is dominant; however, more and more farmers are growing barley after barley.

Soils of the dryland farming area differ in depth, texture, topography and productivity, depending upon the soil-forming factors. The determination of the fertilizer needs of the various crops grown in the different soils is of paramount importance in increasing agricultural production and improving the water use efficiency (WUE) in rainfed areas. An ambitious program of field tests was initiated in Syria in the early sixties to investigate the fertility of the soils of the wheat-based system, and their fertilizer needs. The barley area remained neglected, however, and no fertilizer trials were conducted in this area until the early eighties, when it was clearly proved that application of mineral fertilizers had improved the rainwater use efficiency even in dry years.

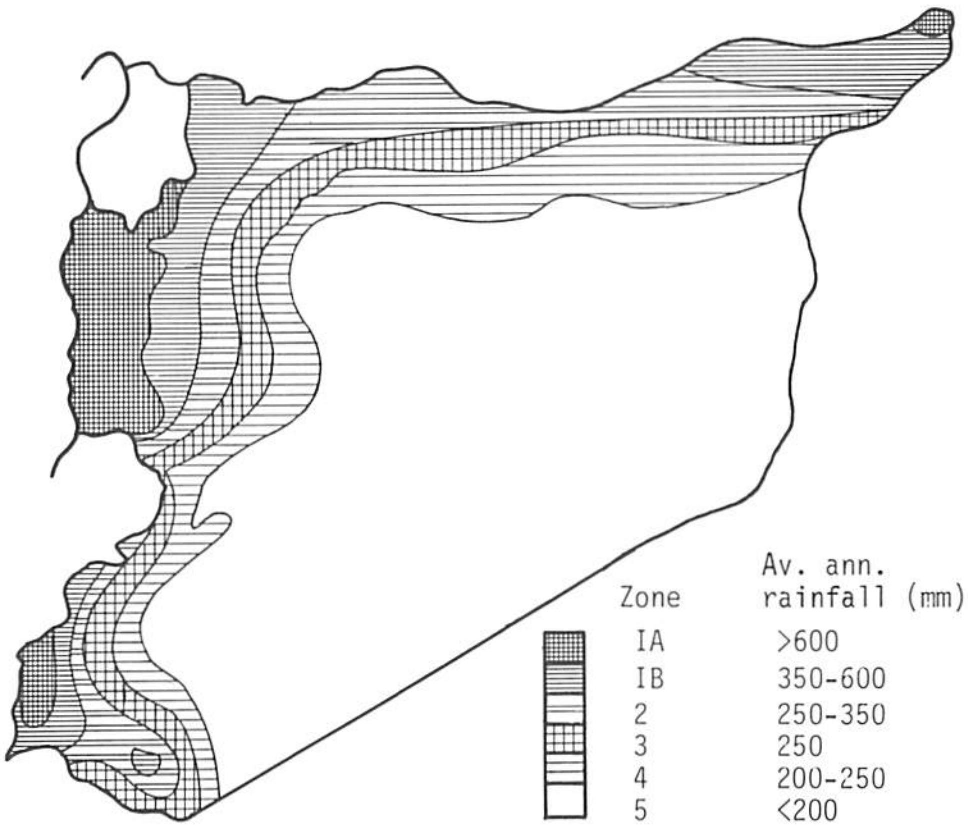
Climatic Zones of Syria

Rainfall is the main climatic factor limiting plant growth in Syria. Rainfall distribution and reliability are mainly affected by the Atlantic cyclones passing eastward along the Mediterranean.

Generally precipitation decreases from the west and north towards the east and south-east (Fig. 1). Breaks between the western mountain chains allow the penetration of relatively higher quantities of precipitation to the interior. The rainfall season usually begins in September over the coastal and north-eastern areas, and in October over the rest of the country.

The mean annual precipitation in Syria varies from as little as 100 mm to a maximum 1600 mm.

The Syrian steppe is quite extensive and represents the area receiving less than 200 mm rainfall. The land is used for natural grazing and pastures. It is a good source of feed for



Source: Annual Agricultural Statistical Abstract. (SMAAR)

Fig. 1 Average total precipitation in Syria.

sheep during a large part of the year. The average rainfall here ranges from less than 100 mm in the south-east, to about 200 mm.

The area with mean annual rainfall of 200-400 mm is relatively large. It includes the area of the barley-based system, with less than 250 mm, and of the wheat-based system with more than 250 mm. That area includes the greatest parts of Hauran, and the Jabal el Arab, Hama, Aleppo and Idlib plains. It is the main rainfed agricultural area in Syria.

Annual rainfall averages 400-600 mm in the Golan heights, and a strip to the east of the coastal mountains that includes El-Ghab, Afreen and a part of the Idlib and Aleppo region. The Qamishli area in the north-east corner of Syria receives similar rainfall. The amount of precipitation increases sharply in the coastal area to 850-860 mm over the plain, and in the mountains it increases gradually with elevation to reach a maximum of 1500 to 1600 mm.

Dryland agriculture is practised in three main regions: Djeizireh, Houran and Sweida.

Djeizireh is the largest rainfed area, with annual rainfall of 250-500 mm. The soil parent materials are of lagoonal Miocene origin covered with a relatively thin gravelly sedimentary layer of the Quaternary. The lagoonal Miocene sediments are formed either from gypsum, or gypsum anhydride, or limestone. The Miocene sediments comprise embedded layers of silt and clay in sandstones. Soils in the Djeizireh range in texture from a dark brown clay in the wet region to yellowish brown and silty soils in the drier area with a calcium carbonate content ranging from 13 to 30%.

In the late sixties fertility tests were carried out on 23 types of soils, chosen from various sites representing the main soil groups of the Djeizireh. Wheat was used as an indicator plant. The results showed that most soils responded markedly to nitrogen and to a lesser extent to phosphorus. None of the soils responded to potash. Soil chemical tests showed a low level of N, 0.08 to 0.15 %, a medium to low level of $NaHCO_3$ - extractable P, 2 and 10 ppm, while exchangeable potassium was very high in most soils, ranging from 390 to 800 ppm.

The soils of Houran are derived basically from a basalt parent material dating from the lower Quaternary. They are clay to clay loams, deep, cracking deeply in summer, calcareous with 8 to 15 % of calcium carbonate in the top layers with lime concretions in the lower horizons. Rainfall ranges between 200 and 350 mm. Chemical analyses have shown that the soils of Houran are very rich in exchangeable K, 450 to 800 ppm, but very poor in total nitrogen (0.04 to 0.13 %) and available phosphorus (2-5 ppm). Fertility tests demonstrated a strong response to nitrogen and phosphorus for most Houran soils with no response to potash fertilization.

Soils of Sweida are older, derived from an old Neogene basalt, located in a more humid climate (400 to 450 mm annual rainfall) and at a higher altitude than the Houran Plain. The soils of Sweida are brown to dark brown in colour, heavy to medium textured, strong, lime free in their surface horizon and of a neutral pH. The soils are more leached than the Houran soils, with less exchangeable K, but contain more nitrogen and available P. The fertility tests showed medium to strong response to N fertilization, poor to medium response to P and none to potash.

Most soils of the Homs-Hama inland plains are derived from calcareous limestones, except in some localized spots with basalts as the parent material. The dominant climate is semi-arid to semi-humid, with 300 to 450 mm of annual rainfall. Soils derived from the hard limestones are red to reddish brown (calcareous Rhodoxeralf), of clay to clay loam texture. Soils derived from the soft limestones are lighter in colour and usually of higher lime content and of lighter texture. The calcium carbonate in the soils is between 0 and 45%.

Laboratory analyses of soils, following the dry farming system in the area, showed a low level of total N and of available P with medium to high level of exchangeable K. The fertility pot tests demonstrated a large response to N fertilization, but a medium response to P.

A good part of the inland plains, the Orontes Valley, was put under irrigation, and chemical fertilizers have been used extensively by farmers in the last twenty years.

History of Fertilizer Research in Syria

Since the early sixties, fertilizer experiments have been carried out in the field by the staff of the Ministry of Agriculture of Syria, in cooperation with experts from the Food and Agriculture Organization of the United Nations (FAO) and the World Hunger Campaign. Demonstration field trials showing the benefit of fertilization in raising crop yields were carried out, followed later by well-designed experiments for the determination of types and amounts of each fertilizer needed for the crops grown in the various ecological conditions of Syria.

Initially, a fertilizer demonstration trial, consisting of four to five different treatments, the control, N, NP, NK and NPK, were carried out annually on hundreds of field plots throughout the country. The program was a success. Field days drew the attention of the farmers to the beneficial effects of fertilizers. The demonstration program lasted until early 1967, when more detailed information on the type, rate and method of fertilizer application was needed for each crop. Following this, factorial experiments with N, P and sometimes K fertilizers, three to four levels each and with three to four replications were carried out in order to estimate the most economic use of fertilizers for optimum yields.

Wheat and small grains

During the late sixties and early seventies fertilizer experiments on wheat, lentils, vetches, and other small grains were carried out on many soils of the rainfed area, including the Houran Plain, the Djeizireh area, and the plains of Homs, Aleppo and Hama (Loizides 1979). The main results of these experiments can be summarized as follows:

1. There was no effect of potash fertilization on yield of wheat or any other small grain crop grown in the rainfed area.
2. All soils responded to N fertilizers, and rates of 40 to 50 kg N/ha were found very satisfactory for wheat grown in the Houran or the inland plains of Homs and Hama. Higher rates of N fertilization were found to depress yields in dry years.
3. Few experiments were carried out to study the effect of source and split applications of N on yield. Single application of N before sowing, mixed with P, was equally as effective as two or more split applications. Ammonium sulphate (21%) was used in the early experiments, and then replaced by ammonium nitrate produced by the Fertilizer Complex Factory in Homs.
4. The effect of P fertilizers was not consistent. It depended on climatic conditions and the past fertilization history of the soils.
5. Further combined studies on the effectiveness of P fertilization were found necessary to evaluate the residual effect of P on crop yields, the effect of climatic conditions on P responses and the correlation of soil tests for available P to responses to phosphorus application.

Research on Response of Wheat and Legumes to Phosphate Fertilization under Changing Rainfall Conditions

The response of wheat and lentil to phosphate fertilization was quite variable and inconsistent from one year to the next. The data from two long-term phosphate experiments, conducted in the Houran plain of Syria, were used to study the relationships between response to phosphate and rainfall distribution (Matar 1976a and b, 1977; Loizides 1979).

It was found that the relative response of either wheat or lentils to the additions of P fertilizers was largely dependent on rainfall distribution. Negative linear correlation coefficients were observed between the relative responses of lentil or wheat to P application and amount of rainfall. In general the greater response to P fertilization was observed in the dry and less productive years.

Crop rotations in relation to soil moisture and fertilizer requirements

A number of crop rotation experiments carried out in Syria show that the yields of wheat or barley after a leguminous forage are not inferior and may be superior to those after fallow (Loizides 1979). Loizides concluded that in a Mediterranean climate fallow does not result in any significant increase in the amount of water available to the next crop. At sowing and at the onset of rapid growth in March, the crop has to rely entirely on rain. The water content of the root zone to a depth of 80-90 cm or more is the same irrespective of whether the land was cropped or under fallow during the preceding cropping season. However, more detailed studies at ICARDA later demonstrated that good storage of rainwater could take place under fallow in rainy years.

Cooperative program with ICARDA on fertilization of barley and wheat

Since 1984/85 an extensive multidisciplinary program of field research was initiated with ICARDA to study the biological and economic response of barley and wheat to nitrogen and phosphorus fertilization. The response to fertilization was related to rainfall, soil fertility status, previous crop, soil subgroup and other factors. Water use efficiency proved to be greatly improved by fertilizer application.

A series of technical reports have been published on the response of barley to fertilization (SD/ICARDA 1984/85, 85/86, 86/87 and 1987/88). A four-year report is in progress. It was demonstrated that fertilization of barley is quite economic and highly significant even under low rainfall conditions (Fig. 2). The response of barley to fertilization was found related to rainfall conditions, soil testing and previous crops. However, a yield gap was observed between the farmer-managed trials and the researcher-managed trials.

In the barley-based system, the most limiting nutrient was found to be phosphorus.

Cooperative research on fertilization of wheat in farmers' fields has demonstrated that the main nutrient needed was nitrogen and that little response to P was observed. Apparently the regular application of phosphate by farmers during the last twenty years had led to a fertility build-up in available-P. The response to N application was found related to rainfall, previous crop and soil mineral N content at sowing. A two-year report on fertilization of wheat is in progress.

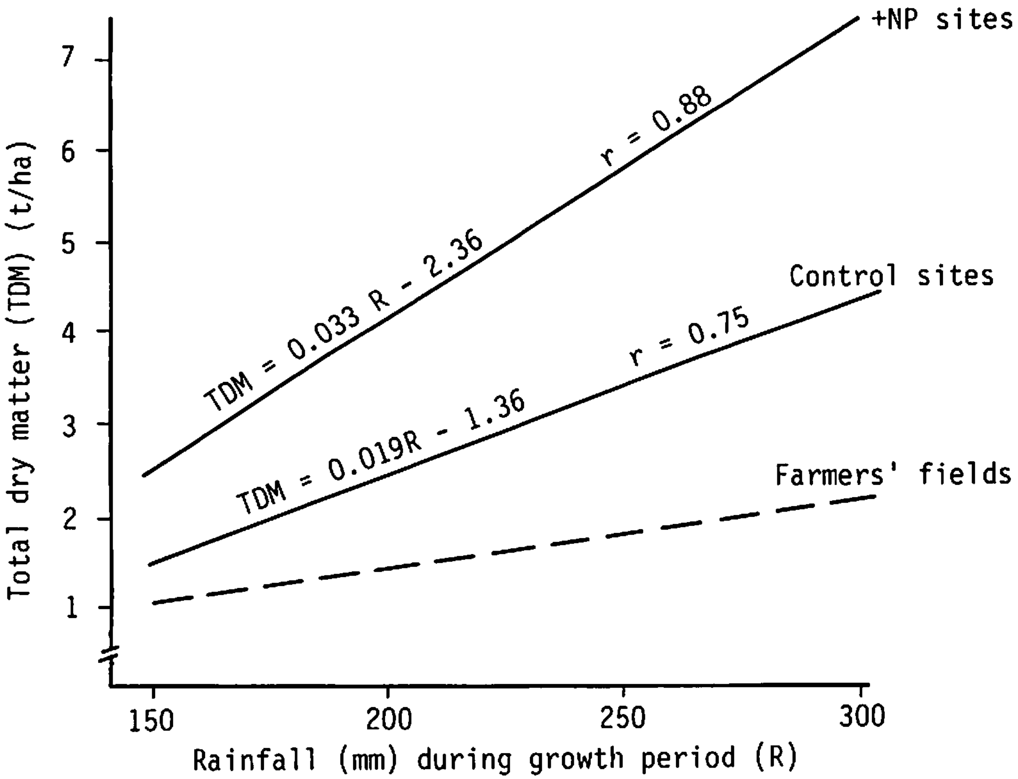


Fig. 2 **Pooled effect of P and N fertilizers in 22 barley trials as compared to farmers' fields throughout the barley area of Syria 1985/86.**

Progress in the consumption of fertilizers

Many fertilizer experiments were conducted in the eighties by the Soils Directorate in various zones under rainfed agriculture that included wheat, summer crops, and chickpea (El Hajj 1985). In cooperation with the Soils Directorate the extension service conducted a massive program of demonstrations, which led to an increased consumption of fertilizers per hectare by farmers; and the difference between optimum dressing of fertilizers per hectare and the actual consumption is becoming less and less (see Table 1). The actual consumption of nitrogen and phosphorus fertilizers has steadily increased by sixfold in the last twenty years (see Fig. 3).

The application of the fertilizers necessary for soils poor in nutrients will lead eventually to a significant and progressive increase in rainwater use efficiency.

The recommended rates of fertilizers for crops under rainfed agriculture

Fertilizer requirements have been calculated, from the large number of field experiments conducted on various crops in the different agro-ecological zones of rainfed areas. Several parameters were considered when recommending fertilizer rates: climatic zoning (Zone 1,

Table 1. Development of actual mineral fertilizers consumption (kg/ha) on arable land in Syria, 1955-1985

Period	N	P_2O_5	K_2O	Total
1955-60	1.29	.48	0.045	1.81
1961-70	3.36	1.25	0.139	4.75
1971-80	12.27	5.80	0.446	18.52
1980/81	20.49	11.32	0.889	32.70
1981/82	21.34	12.86	1.32	35.55
1982/83	24.63	13.75	1.47	45.96
1983/84	28.12	16.37	1.47	45.96
1984/85	32.54	19.06	1.45	53.05
1985/86	44.75	26.32	1.94	73.01
1986/87	41.15	24.52	1.74	67.41
Optimum dressing	64	52	19	135

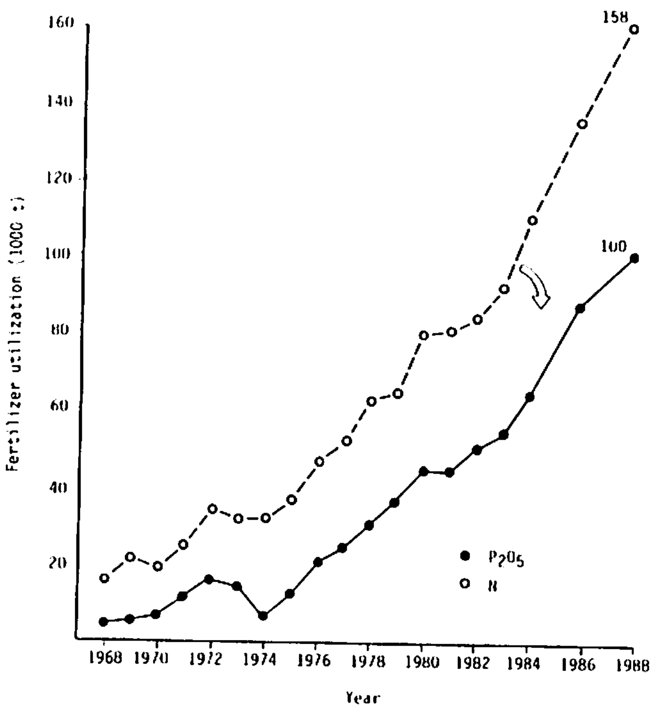


Fig. 3 N and P fertilizer use (1000t) in Syria 1968-86.

Zone 2 and Zone 3), the potential productivity of varieties used (high yielding varieties against local varieties), the availability of fertilizer, and prices (Jabbour 1988).

The recommended rates of fertilizers for rainfed crops have been grouped in Table 2.

Table 2. Recommended rates of fertilizers (kg/ha) for various rainfed crops in Syria

	Climatic Zones*					
	Zone 1		Zone 2		Zone 3	
Type of Crops	N	P_2O_5	N	P_2O_5	N	P_2O_5
Wheat (HYV)**	100	80	80	60	-	-
Wheat (local)	80	60	60	60	40	40
Barley	50	40	40	40	20	20
Legumes	30	50	20	40	20	30
Fruit trees (olive, pistachio, almond)	100	60-100	100	60-100	-	-

* Zone 1: more than 350 mm mean annual rainfall.
Zone 2: 250-350 mm mean annual rainfall with more than 250 mm in 2/3 of years.
Zone 3: more than 250 mm mean annual rainfall with more than 250 mm in 1/2 of years.
** HYV: High yielding variety.

Future Research needs

Examples of the interactions between fertilizer responses and environmental factors, especially rainfall, have been cited above. Other variables such as the fertility level of the soil, rotations, and soil types, depth, and slope should not be underestimated. In the future the effect of these variables on response to fertilization must be quantified, through well-designed and carefully-located on-farm trials. The cooperation with ICARDA on the research program of fertilization of barley has been very useful in training our research workers in well organized on-farm trials, and in the concurrent farm surveys which give us practical ideas on the actual methods of soil and crop management used by farmers, the equipment available and farmers' reactions to fertilizer use.

The use of fertilizer in Syria has been increasing steadily, and farmers are wanting to use more fertilizers (especially in the wheat systems or irrigated areas) than recommended by the extension service. The cumulative effect of repeated fertilization, especially with phosphate, was very significant, and the response to P application has decreased. The Soils Directorate in Syria is implementing a substantial program of soil testing under rainfed agriculture. So far soil testing has been largely in collaboration with ICARDA scientists, but in future, it will be extended through our departments in the provinces to all important rainfed and irrigated crops. A more complete understanding of relationships between fertilizer response and soil and environmental conditions will lead to better fertilizer recommendations and better fertilizer use efficiency.

References

El Hajj, K. 1985. Fertilizer use in the Syrian Arab Republic. Present status and future development. Soils Directorate, Ministry of Agriculture and Land Reform (in Arabic), Douma, Syria.

Jabbour, E. 1988. Land and fertilizer use in Syria. Presented at the Workshop on Fertilizer Sector Development and Agricultural Production in Selected Countries of the Mediterranean, Middle East and North Africa, May 1-14, 1988, Muscle Shoals, Alabama, USA.

Loizides, P. 1979. Crop rotations under rainfed conditions in a Mediterranean climate in relation to soil moisture and fertilizer requirements. pages 23-38 *in* Proceedings of Regional Seminar on Rainfed Agriculture in the Near East and North Africa. Amman, Jordan, 5-10 May 1979. FAO, Rome 1980.

Matar, A.E. 1975a. Direct and cumulative effects of phosphorus in calcareous soils under dry farming agriculture of southern Syria. Page 24 *in* Soil Science P-4, Arab Centre for Studies of Arid Zones and Dry Lands (ACSAD), Damascus, Syria.

Matar, A.E. 1975b. Correlation between $NaHCO_3$-extractable P in soils and yields of wheat and lentil grains under dry farming conditions. Page 16 *in* Soil Science P-2, Arab Centre for Studies of Arid Zones and Dry Lands (ACSAD), Damascus, Syria.

Matar, A.E. 1977. Yields and response of cereal crops to phosphorus fertilization under changing rainfall conditions. Agronomy Journal 69: 879-881.

Matar, A.E. 1979. Fertilization studies under rainfed agriculture of Syria. pages 71-82 *in* Proceedings of Regional Seminar on Rainfed Agriculture in the Near East and North Africa. Amman, Jordan, 5-10 May 1979. FAO, Rome 1980.

SD/ICARDA. Collaborative research project report on fertilization use on barley in northern Syria. 1984/85, Report 1; 1985/86, Report 2; 1986/87, Report 3; 1987/88, Report 4, ICARDA, Aleppo, Syria.

The Effect of Nitrogen Fertilizer on Winter Wheat in the Western Transitional Zone of Turkey

M. KALAYCI, S. SIIRT, M. AYDIN and V. OZKAN

Transitional Zone Research Institute, Eskisehir, Turkey

Introduction

Extensive research has been carried out on fertility management of wheat in the winter wheat growing areas of Turkey, but since only those experiments related to nitrogen were also studied for water relations, we will confine this paper strictly to nitrogen fertility in relation to precipitation.

We will discuss the actual data obtained from experiments conducted in the Western Transitional Zone of Turkey, and the conclusions drawn. First, however, we want to clarify what we mean by nitrogen use efficiency and water use efficiency.

Nitrogen use efficiency (NUE) consists of at least two different sorts of efficiency which might or might not be similar for a given cultivar. First of these is the efficiency of a crop in taking up nitrogen from the soil, which can be called uptake efficiency, and the other is the crop's ability to convert it to a harvestable product. Since wheat is cultivated mostly for grain in Turkey, for an agronomist with practical considerations, "conversion efficiency" can be defined as the ability of a wheat crop to convert nitrogen into grain yield. However, a physiologist might say that it is the efficiency of conversion to dry matter, leaving the rest of the process to be studied within the context of harvest index.

There is still another differentiation to be made between nitrogen use efficiency and fertilizer use efficiency: nitrogen use efficiency should include the total amount of nitrogen available to the crop, both fertilizer and native soil-N.

Similar definitions can be made for water use efficiency (WUE) and precipitation use efficiency (PUE).

In this paper we shall compare nitrogen fertilizer use efficiencies and precipitation use efficiencies of four different wheat cultivars grown in the Western Transitional Zone. We shall also try to show the effect of nitrogen fertilizer on the precipitation use efficiencies of the different cultivars.

Experimental Area

The Western Transitional Zone is located between the Central Plateau and the Western Coastal Plains. It has slightly higher rainfall and, in the southern provinces, slightly warmer temperatures than the Central Plateau. Eskisehir is the only province in the region where bread wheat predominates. Of the other provinces, the northern two produce bread wheat, though durums are much more usual; the farmers of the southern provinces nearly always grow durums.

Another important characteristic of the region is the great variation in precipitation from year to year and from location to location. According to the long-term averages, total annual precipitation ranges from less than 300 mm in some counties of Eskisehir, to over 600 mm in others in the lakes area in the south.

Experiments Conducted

Starting in 1979, experiments were carried out for nine years to study the effect of nitrogen fertilizer on wheat yields. Two bread wheat varieties (Gerek 79 and Bolal 2973) and two durums (Cakmak 79 and Kunduru 1149) were used in the experiments. The total number of trials was 28, of which 19 were conducted on farmers' fields, 4 on the experimental field of the main station in Eskisehir, and 5 at the Hamidiye substation 40 km east of the main station.

The first and the most important objective of these experiments was to develop practical recommendations for the farmers in the region. But as time went on, observations and experimental results showed that a more detailed examination was necessary in order to account for some unexpected results. Two main problems encountered after the first three years were as follows:

1. There was a great difference between the results we obtained from on-farm trials and on-station trials. Though we obtained higher yields on the deep fertile alluvial soils of the main station, nitrogen responses were much lower compared to the on-farm trials. At this point, we decided that these trials could not be evaluated together unless we had soil nitrogen analysis values.
2. Even among the on-farm trials there was a huge variation among results. Yield levels varied greatly depending on the environmental conditions and these affected the responses to nitrogen.

For these reasons, from 1984 onwards we started analyzing our experimental area soils for stored moisture and inorganic nitrogen in the 120 cm profile at sowing time. In this paper, we will not discuss our attempts to develop multiple regression equations relating nitrogen fertilizer, soil inorganic nitrogen, stored moisture, and precipitation to yield level. We will confine our account to the effects of nitrogen fertilizer and precipitation, and only the results of 15 on-farm trials, for which we have reliable meteorological data, will be discussed.

Experimental Results

The effect of precipitation on grain yield

The total seasonal precipitation (from October through June) ranged from 306 mm to 538 mm during these experiments. First we calculated the simple correlation coefficients between total seasonal precipitation, precipitation of each individual month and all possible combinations of them and grain yields of the cultivars used. For all four cultivars, the highest correlation coefficients were obtained with the total precipitation received in October + November + April + May, which can be called the Active Growing Period (AGP) as cold temperatures limit cereal growth throughout December, January, February and March in this environment.

Not all these calculations will be given here, and we will focus our discussion on the results of linear regression analyses of yields against total seasonal and active growing period precipitation. The coefficients of determination for the cultivars are listed in Table 1. The linear regression equations for the cultivars are given below where y is grain yield in kg/da and x is AGP precipitation in mm (Table 2 and Fig. 1).

Table 1. Coefficients of determination for the relation between wheat grain yield and precipitation

Precipitation	Linear Correlation Coefficients			
	Gerek 79	Bolal 2973	Cakmak 79	Kunduru 1149
Total seasonal	0.111	0.141	0.128	0.103
Active G. Period	0.439	0.358	0.380	0.245

Table 2. Linear regression equations for grain yield over AGP precipitation

Cultivar	Regression Equation
Gerek 79	$Y = 119.9 + 1.330\,x$
Bolal 2973	$Y = 150.6 + 1.042\,x$
Cakmak 79	$Y = 144.4 + 1.094\,x$
Kunduru 1149	$Y = 177.9 + 0.633\,x$

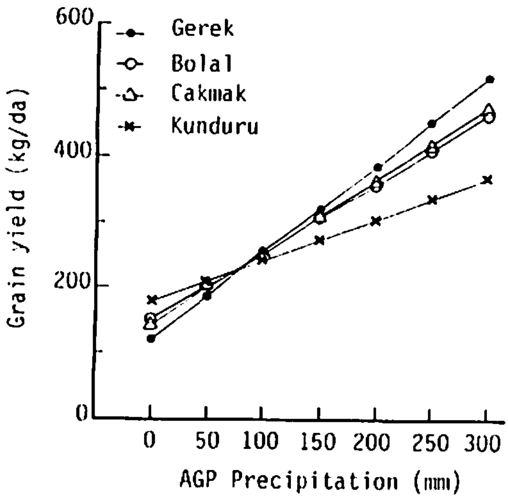


Fig. 1 Effect of AGP precipitation (mm) on grain yield (kg/da) of four wheat cultivars.

AGP precipitation gave higher correlations with grain yields for all cultivars, so in subsequent sections, the precipitation use efficiency (PUE) was calculated for this portion of precipitation only.

Among the three varieties (Gerek, Bolal and Cakmak) with similar yield levels, Gerek 79 was the one with the highest PUE (1.330) and the lowest intercept value (119.9). This low intercept value might seem to be different than expected because this variety has been proven to have the highest yield stability of all winter wheat cultivars grown in the region. We have to be very careful in interpreting these results because we never had zero precipitation during this period. The minimum obtained was 97 mm: it can be misleading to make estimations on values beyond the limits of actual data. For this reason, we prefer to say simply that Gerek 79 gave the highest PUE value. Kunduru 1149, a tall durum variety, already known to have the lowest yield potential among these varieties, also gave the lowest PUE value (0.633) and the lowest coefficient of determination, as would be expected.

The effect of nitrogen on PUE

The relationships between wheat grain yield and AGP precipitation were calculated for the four rates of nitrogen and are presented in Tables 3a and b and Fig. 2. The slopes of the regression equations represent the PUE. Yields increased linearly with increasing AGP precipitation in all four varieties and at all four nitrogen rates, but higher PUE values were observed with increasing nitrogen fertilizer. There appeared to be little difference in the rate of PUE with increasing nitrogen fertilizer between the four varieties.

Table 3a. Yields (kg/da) and NUE values of the four varieties

	GEREK 79		BOLAL 2973		CAKMAK 79		KUNDURU 1149	
N(kg/da)	Yield	NUE	Yield	NUE	Yield	NUE	Yield	NUE
0	227.0		219.8		236.2		198.5	
1	248.2	21.2	240.1	20.3	250.8	14.6	215.3	16.8
2	267.6	19.4	258.5	18.4	264.4	13.6	230.5	15.2
3	285.0	17.4	274.9	16.4	277.0	12.6	244.2	13.7
4	300.5	15.5	289.5	14.6	288.7	11.7	256.3	12.1
5	314.1	13.6	302.1	12.6	299.4	10.7	266.8	10.5
6	325.8	11.7	312.8	10.7	309.1	9.7	275.8	9.0
7	335.6	9.8	321.6	8.8	317.9	8.8	283.2	7.4
8	343.5	7.9	328.5	6.9	325.8	7.9	289.0	5.8
9	349.5	6.0	333.5	5.0	332.7	6.9	293.3	4.3
10	353.5	4.0	336.5	3.0	338.6	5.9	296.0	2.7
11	355.7	2.2	337.7	1.2	343.5	4.9	297.1	1.1
12	355.9	0.2	336.9	-0.8	347.5	4.0	296.7	-0.4
13	354.3	-1.6	334.2	-2.7	350.6	3.1	294.7	-2.0
14	350.7	-3.6	329.6	-4.6	352.6	2.0	291.1	-3.6
15	345.2	-5.5	323.1	-6.5	353.8	1.2	286.0	-5.1

Table 3b. Regression equations of wheat grain yield (Y) on Active Growing Period precipitation (X), for different levels of nitrogen (kg/da)

N	Regression equations Gerek	Bolal	Cakmak	Kunduru
3	Y = 148.1 + 0.869x	Y = 154.6 + 0.764x	Y = 164.7 + 0.716x	Y = 188.9 + 0.347x
6	Y = 140.4 + 1.183x	Y = 181.4 + 0.838x	Y = 150.5 + 1.000x	Y = 194.9 + 0.527x
9	Y = 103.5 + 1.560x	Y = 140.2 + 1.225x	Y = 138.3 + 1.244x	Y = 175.8 + 0.733x
12	Y = 87.9 + 1.709x	Y = 126.1 + 1.341x	Y = 124.1 + 1.417x	Y = 151.8 + 0.925x

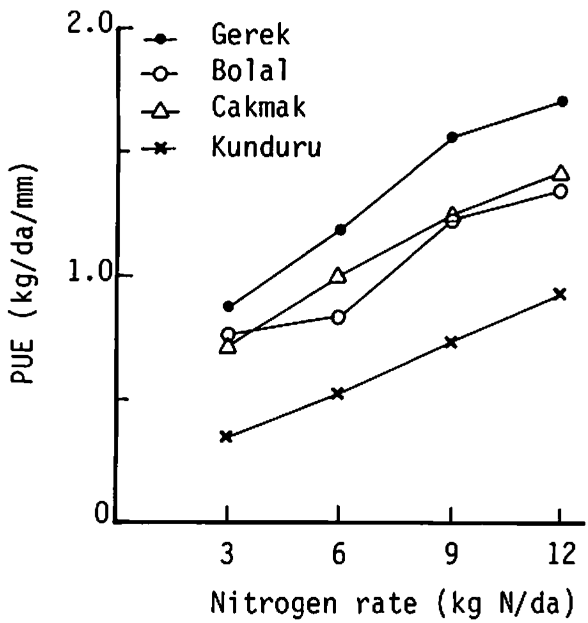


Fig. 2 **Effect of nitrogen rate (kg/da) on PUE values (kg/da/mm) of four wheat cultivars.**

The effect of nitrogen on grain yields

Except in a few trials, nitrogen fertilization greatly increased wheat yields, but the optimum levels of nitrogen were different from trial to trial (Table 4a). The regression equations for the mean response of the varieties across all 15 locations are given below (Table 4b) and the regression curves are shown in Fig. 3. The effect of nitrogen on yield showed a quadratic relation for all cultivars.

It is clear from the b1 and b2 values of the equations that the two bread wheat varieties gave a faster response to nitrogen than the durums. We think, at this point, we need to define what a nitrogen responsive variety is. Is it one with higher NUE or one which responds to

Table 4a. Grain yields (kg/da) of four cultivars at 15 sites at four N rates.

Fert. Cult.*	N3	N6	N9	N12	N3	N6	N9	N12	N3	N6	N9	N12
	TEFENNI 1979/80				ALTINTAS 1980/81				CIVRIL 1981/82			
G	299	323	384	397	199	273	332	346	266	317	332	342
B	364	399	417	462	206	277	299	289	213	299	337	338
C	307	329	374	395	240	323	377	405	257	276	315	333
K	270	300	354	359	226	299	342	309	238	290	289	270
	ALTINTAS 1981/82				AFYON 1983/84				ISPARTA 1983/84			
G	297	365	434	470	388	491	517	520	383	440	476	497
B	286	351	394	375	336	367	439	414	335	356	415	458
C	251	323	404	440	344	400	412	438	392	428	466	489
K	200	300	311	365	263	297	302	350	287	294	329	341
	ASLANAPA 1 1984/85				ASLANAPA 2 1984/85				ALPU 1985/86			
G	190	229	228	199	228	254	267	281	232	253	256	263
B	189	217	227	206	239	289	281	294	222	232	236	231
C	189	204	210	216	215	244	246	261	238	252	262	270
K	209	241	235	234	177	164	178	187	181	201	203	200
	CAL 1985/86				SEYITGAZI 1985/86				AFYON 1986/87			
G	394	459	500	522	357	392	381	365	317	310	295	305
B	369	423	448	443	341	365	367	363	325	330	297	324
C	364	434	479	498	387	399	429	421	283	264	264	261
K	345	389	422	426	312	339	341	335	254	290	263	299
	CIVRIL 1986/87				SOGUTONU 1986/87				YALVAC 1986/87			
G	290	289	297	291	97	107	99	112	335	395	435	433
B	245	254	263	270	106	116	125	122	345	424	449	466
C	259	264	260	260	135	125	127	129	300	351	385	390
K	264	270	274	276	150	146	157	152	275	348	367	357

* G = Gerek 79; B = Bolal 2973; C = Cakmak 79; K = Kunduru 1149

Table 4b. Quadratic regression equations showing the effect of nitrogen fertilizer (X) on wheat yield (Y) (kg/da)

Cultivar	Regression equation
Gerek 79	$Y = 227.0 + 22.192\,x - 0.954\,x^2$
Bolal 2973	$Y = 219.8 + 21.243\,x - 0.957\,x^2$
Cakmak 79	$Y = 236.2 + 15.037\,x - 0.480\,x^2$
Kunduru 1149	$Y = 198.5 + 17.579\,x - 0.783\,x^2$

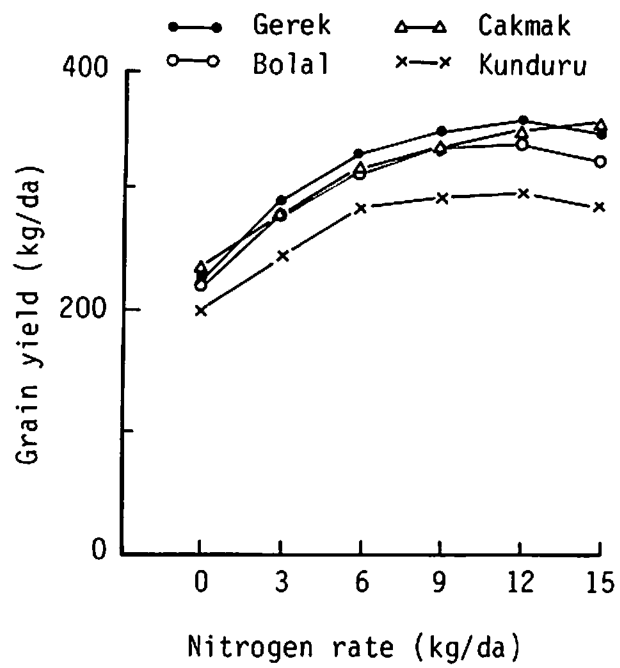


Fig. 3 Effect of nitrogen rate on wheat yield (kg/da).

higher rates of nitrogen? These two properties seem to act in reverse directions. It seems possible to achieve optimum yields at lower nitrogen rates with a nitrogen-use-efficient variety. Again, yield potentials of varieties are also important in making such comparisons.

Another question is whether varietal differences in NUE remain the same at all nitrogen levels. The answer given by our data is that they do not. This is clearly demonstrated in Fig. 4 which shows the effect of nitrogen levels on NUEs of the different cultivars. As would be expected from the quadratic relationships illustrated in Fig. 3, NUE values fall with increasing N fertilizer rates. Initially, the bread wheat varieties gave higher efficiency values, but as yield levels approached optimals, Cakmak 79 was the most efficient variety. This might have resulted from the higher potential yield of this semi-dwarf durum. In these rainfed trials yields were influenced not only by genetic potentials of the cultivars, but also, and to a greater degree, by environmental conditions. However, the genetic potentials of these cultivars, known from other experiments, seem to have an influence on their nitrogen responses. For instance, Cakmak 79 is unique among these varieties in that it is also grown under irrigated conditions, giving more than 700 kg/da yield in some cases, and this may be related to its greater NUE at high levels of N application.

However, in situations where rainfall is both limiting and erratic, and where farmers are often poor, we obviously need varieties with the optimum nitrogen use efficiencies (Gerek 79 in our example) provided that they give acceptable yields.

The economic optimum nitrogen rates, optimum yields and maximum nitrogen rates (where the slopes turn down) are given in Table 5.

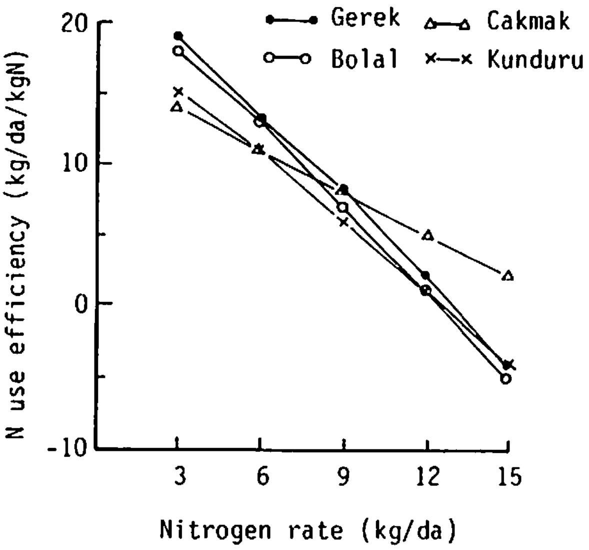


Fig. 4 Effect of N on NUE (kg/da/kg N).

Table 5. Optimum and maximum nitrogen rates and wheat yields (kg/da)

Variety	Opt. N	Opt. Yld.	Max. N
Gerek	9.0	349.5	11.4
Bolal	8.7	332.1	10.7
Cakmak	10.6	341.6	15.0
Kunduru	9.1	293.6	10.8

Unfortunately we cannot recommend these nitrogen rates to the farmers of the region nor are they acceptable to the farmers, because these trials, though set in farmer fields, were not actually so-called "adaptive research". Except for land preparation, everything was done by ourselves, according to whatever we considered to be optimum. The yield levels were therefore rather higher than those of the farmers, and clearly the optimum nitrogen rates will be highly yield-dependent. For this reason, some means to adjust these optimals to farmer yield levels are required.

Conclusions

1. Among all the cultivars used in the experiment, the variety with the lowest yielding ability (Kunduru 1149) gave both the lowest PUE and the lowest NUE values. Hence, in making such comparisons, yield levels should also be considered.

2. The cultivar with the highest PUE (Gerek 79) also gave the highest NUE at low to medium levels of nitrogen application.
3. Nitrogen fertilizer increased PUEs of all cultivars. It seems probable that this increased water use efficiency was largely due to the more rapid development of ground cover and reduction of soil evaporative losses as described by Gregory (1991) and Cooper (1991) in these proceedings. The study of the effect of nitrogen on actual water uptake and water use efficiency by plants could well be considered in the future.
4. Nitrogen use efficiencies were higher for the two bread wheat varieties used in the experiment, but these two varieties might not be representative of all the bread wheat cultivars grown in the region. These efficiency differences might be related to yield potentials and growth habits (influencing their water and nitrogen use regimes) rather than the genotypes themselves.
5. For rainfed areas with erratic rainfall patterns, varietal development programs should consider both water and nitrogen use efficiencies. Varieties with low efficiencies but responsive to higher rates of nitrogen should be reserved for irrigated or, at least, for areas with sufficient rainfall. Varieties with the reverse characteristics are more appropriate for dryland areas.

References

Cooper, P.J.M. 1991. Fertilizer use, crop growth, water use and WUE in Mediterranean rainfed farming systems. (This volume).

Gregory, P.J. 1991. Concepts of WUE. (This volume).

Water Harvesting and Nitrogen Fertilizer Application as a Means of Increasing Crop Water Use Efficiencies in Suboptimal Conditions in Upland Baluchistan

D.J. REES[1], M. ISLAM[2], A. SAMIULLAH[2], Z. QURESHI[2], S. MEHMOOD[2], F. REHMAN[2], J.D.H. KEATINGE[1], H. RAZA[2], and B.R. KHAN[2]

[1] *ICARDA, P.O. Box 362, Quetta, Pakistan*
[2] *Arid Zone Research Institute, Brewery Road, Quetta, Pakistan*

Abstract

The results of a wheat variety/fertilizer trial and a water harvesting trial conducted in upland Baluchistan over several years are reviewed. The local wheat variety was found to be more cold-tolerant than the "improved" variety recommended for this area. Phosphate fertilizer gave little increase in productivity, perhaps due to high rates of fixation on the highly calcareous soils (20-35% lime) of Baluchistan. The addition of nitrogen fertilizer was economic only in the "wet" year of 1986/87. Examination of the data and limited soil water information suggested that economic responses to nitrogen can be expected only if crop water availability is in the order of 300 mm, a situation likely in only 5 to 25% of years under rainfed conditions in upland Baluchistan.

A simple form of water harvesting, consisting of clearing and compacting the upper part of gently sloping valley-bottom fields to form a catchment area, gave considerable increases in water availability and crop yields in both a "wet" and an extremely dry year. These results suggest that appreciable increases in productivity in upland Baluchistan should be possible, with a combination of water harvesting and nitrogen fertilizer use.

Introduction

The climate of upland Baluchistan (27°N to 32°N, 66°E to 70°E) has been classified as continental semi-arid Mediterranean (Rafiq 1976) with annual precipitation varying from 200 to 350 mm. Cereals, in particular wheat, are grown by most dryland farmers as dual-purpose crops, with the grain being used for human consumption and the straw for animal feed. Yield expectations are low, ranging from only 100 to 800 kg/ha (Rees *et al.* 1988). Agricultural inputs in dryland cropping are minimal: most ploughing and planting is carried out with draft animal power; the farmers' own unimproved seed is used; neither fertilizer nor herbicides are applied; and most threshing and winnowing is carried out by hand or draft animal power.

This paper reviews key results of a multi-locational trial designed to evaluate the response of dryland wheat to the addition of fertilizer and to weeding; and of a water harvesting trial designed to evaluate the possibility of improving productivity of land that does not normally receive additional run-on water. Further details can be found in ICARDA (1987, 1988).

Fertilizer Responses

A wheat variety/fertilizer trial was planted at several locations in upland Baluchistan from 1985/86 to 1987/88 with the following treatments: i) local/"improved" wheat variety (Zarghoon); ii) with/without 40 kg N/ha (10 kg/ha NH_4NO_3 in the seedbed and 30 kg/ha top-dressed at tillering); iii) with/without 60 kg P_2O_5/ha (triple superphosphate); iv) with/without 60 kg K_2SO_4/ha; v) with/without weeding (manually three times).

Annual rainfall totals varied with site from 138 to 206 mm in 1985/86, 254 to 780 mm in 1986/87, and 32 to 147 mm in 1987/88. Table 1 summarizes some of the trial characteristics. Soil water at planting to 1 m depth varied from 26 to 133 mm depending upon pre-planting rainfall and/or irrigation, and rainfall during crop growth varied from 32 to 221. Kjeldahl nitrogen assays of the top 30 cm were generally quite low, ranging from 257 to 603

Table 1. Trial characteristics and response of the local variety of wheat to the addition of fertilizer

Trial	Soil water[1] (mm)	Growing season rain (mm)	Kjeld. N (ppm)	Olsen P (ppm)	Final total dry wt (kg/ha)	Response to fertilizer % N	Response to fertilizer % P
			1985/86				
1	40	130	299	3	244	-28	+8
2	66	151	356	4	196	+21	+25
3	34	137	320	4	700	+4	+15
4	80	184	418	7	886	-27	+12
5	52	143	386	4	256	-4	+2
			1986/87				
6	116	162	366	6	1336	+34	-2
7	53	194	581	8	1365	+3	+6
8	53	194	581	8	1590	+34	-10
9	111	221	459	6	2248	+27	-5
10	111	221	459	6	2204	+16	+9
			1987/88				
11	133	32	257	3	474	+24	+10
12	87	51	427	9	502	+6	+13
13	41	107	447	8	181	-7	-6
14	45	147	576	10	276	+49	+28
15	26	102	603	8	133	-10	+2
Mean	70	145	436	6	839	+9	+7

[1] Soil water to 1 m depth at planting.

ppm (average 436 ppm); while Olsen phosphate assays were low to medium, ranging from 3 to 10 ppm (average 6 ppm). The trial mean above-ground yields (straw + grain) averaged 456 kg/ha in 1985/86, 1749 kg/ha in 1986/87, and 313 kg/ha in 1988. The average response of both varieties to the addition of nitrogen and phosphate fertilizers did not show any consistent pattern with the soil nitrogen or phosphate status; the only clear pattern was that responses to nitrogen were all positive and nearly all large in the "wet" year of 1986/87.

Table 2 presents the main effects averaged over each year. In 1985/86 the "improved" variety produced more straw than the local, but in 1986/87 both straw and grain production of the "improved" variety were greatly reduced when compared to the local. Observations indicated that the "improved" variety suffered severe cold damage during the winter period in this season (in 1985/86 and 1987/88 the crops did not emerge until spring and so cold stress was not a factor). Nitrogen fertilizer had little effect except in 1986/87, whilst addition of

Table 2. Wheat yields (kg/ha) averaged over sites for each year

Season:	1985/86		1986/87		1987/88	
	Total [1]	Grain	Total	Grain	Total	Grain
Local cv.	456	135	1748	497	313	43
"Improved " cv.	539	134	1127	350	299	52
	*		***	***		*
Without N	494	140	1297	389	299	53
With N	502	129	1578	458	313	51
				***	***	
Without P	459	114	1429	417	311	54
With P	536	154	1446	430	301	50
	*	*				
Without K	533	139	1457	439	317	52
With K	461	129	1418	408	295	52
	*					
Weeding	510	129	1401	427	300	51
No weeding	486	140	1473	419	312	54
Site mean	498	134	1438	423	306	52
S.E.	22.6	12.3	52.0	18.9	15.1	7.2

[1] Total above-ground dry weight at maturity.

* Treatment pairs marked with *, **, or *** differ significantly at p < 5, 1, or 0.1 %, respectively.

phosphate fertilizer resulted in some increase in grain yield in 1985/86, but not in subsequent years. Potassium fertilizer and weeding also had little measurable effect. The poor performance of the "improved" variety under cold stress suggests that it is not suitable for dryland production in upland Baluchistan and so further analyses are restricted to the local variety alone.

Figure 1 illustrates a variety x treatment versus environment analysis in which soil water at planting plus rainfall during crop growth are used as an environmental index. The linear correlation of 0.886 between total above-ground dry weight at maturity (Y) of the local variety, and this water availability index (WI) indicates that the index closely reflects crop growth in this semi-arid environment. The slope of the line, 9.19 kg/ha/mm, gives a measure of the water use efficiency (WUE) of the crop, in reasonable agreement with other data, (e.g. Cooper *et al.* 1987). Similar analyses were performed on the data with and without nitrogen or phosphate fertilizer:

-N: y = 8.09(WI-115)	+N: y = 10.28(WI-123)
-P_2O_5: y = 9.18(WI-121)	+P_2O_5: y = 9.19(WI-118)

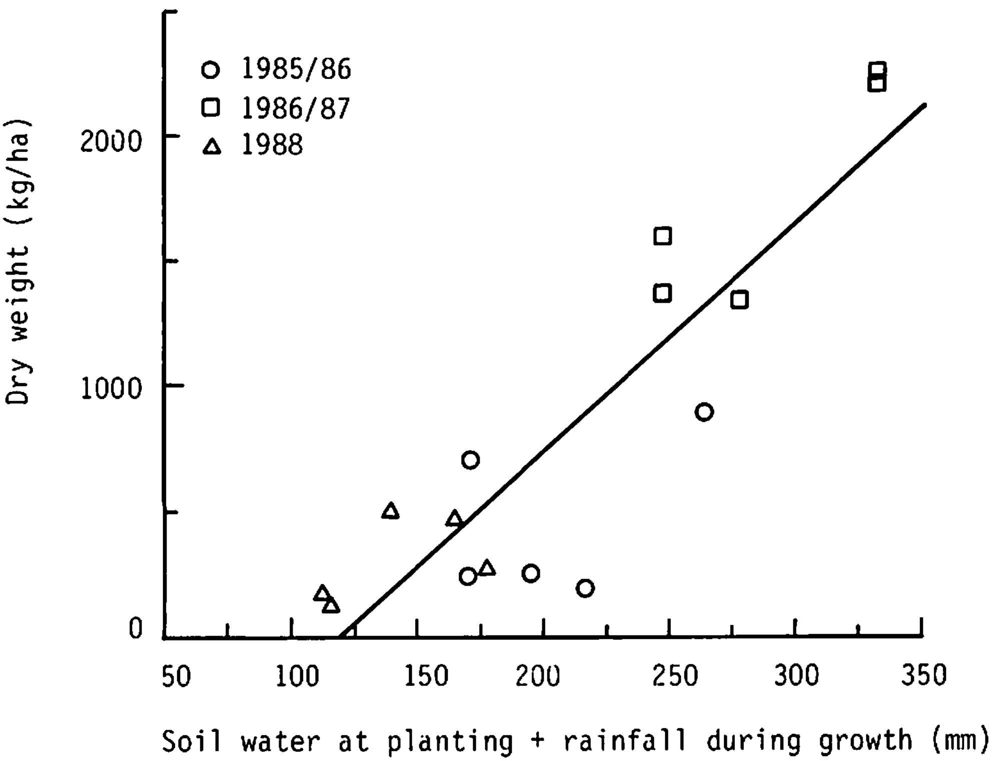


Fig. 1 Total dry weight (kg/ha) of local wheat variety at maturity versus water availability (mm).

Addition of nitrogen fertilizer increased crop WUE overall by 24%, but phosphate fertilizer had little effect. This lack of response to phosphate is surprising in view of the Olsen phosphate assays, but is perhaps attributable to high rates of phosphate fixation in these calcareous soils, which are 20-35% lime (ICARDA 1987; 1988). Nevertheless, marked responses to phosphate have been reported in similar soils in Syria, even at locations receiving as little as 180 mm of rainfall (Cooper *et al.* 1987). The lack of response observed in this research deserves further study.

Crop prices varied at about 2 R/kg for grain and 0.5 R/kg for straw (April 1989: 20 R = 1 USD). The nitrogen fertilizer "farm-gate" price was 262 R/ha. In 1986/87 the marginal rate of return for nitrogen application was positive in four of the five trials, ranging from 40 to 100% (ICARDA 1987). Linear regression equations between grain and straw production and the water availability index can be used with these prices to find the water availability at which application of nitrogen fertilizer is likely to be economic:

$$2 \times 3.18(WI-134) + 0.5 \times 7.10(WI-118) - 2 \times 2.52(WI-127) - 0.5 \times 5.57\,(WI-109)$$
$$= 262 \Rightarrow WI = 283\text{mm}$$

In other words, nitrogen fertilizer application is unlikely to be economically feasible unless water availability is 283 mm or greater, in upland Baluchistan. This corresponds roughly to an annual rainfall of 295 mm, which has a probability of occurrence of 5 to 25% throughout most of upland Baluchistan (Kidd *et al.* 1988). Median rainfalls for most of upland Baluchistan are in the range of 180 to 240 mm, indicating that an additional 40 to 60% of water supply would be required before fertilizer application is likely to be economic.

Water Harvesting

In 1986 an experimental water harvesting trial was established on a slightly sloping (0.75°) valley bottom with silty clay loam soil. Two more trials were set up in 1987. Water catchment areas were created by ploughing the upper portions of the field to remove weeds, then compacting and pulverizing the soil with a heavy wooden plank mounted on a three-point hitch behind the tractor. Strong soil crusts resulted after rain, creating a relatively impermeable soil surface. Three treatments were imposed: control plots; 1:1 ratio of catchment:crop area; and a 2:1 catchment:crop area (ICARDA 1987). When rainfall was greater than about 20 mm in three days, runoff water from the catchment areas collected in the bunded crop areas.

Figure 2 shows soil water profiles sampled at three different positions (2 m from the bund; center of the cropped area; 2 m from the catchment area) within the cropped areas (each data point is the mean of 12 samples) on 21 March 1988, after 78 mm rain had fallen in five showers. At each position soil water content was significantly increased ($p<0.1\%$) by the water harvesting treatments. The figures suggest that at the positions 2 m from the bund and in the center of the cropped areas the water harvesting treatments increased soil water content to below 1 m depth. Averaged to 1 m depth only, the data indicate an additional water receipt of 43 mm in the 1:1 treatment (55% runoff efficiency), and 67 mm in the 2:1 treatment (43% runoff efficiency).

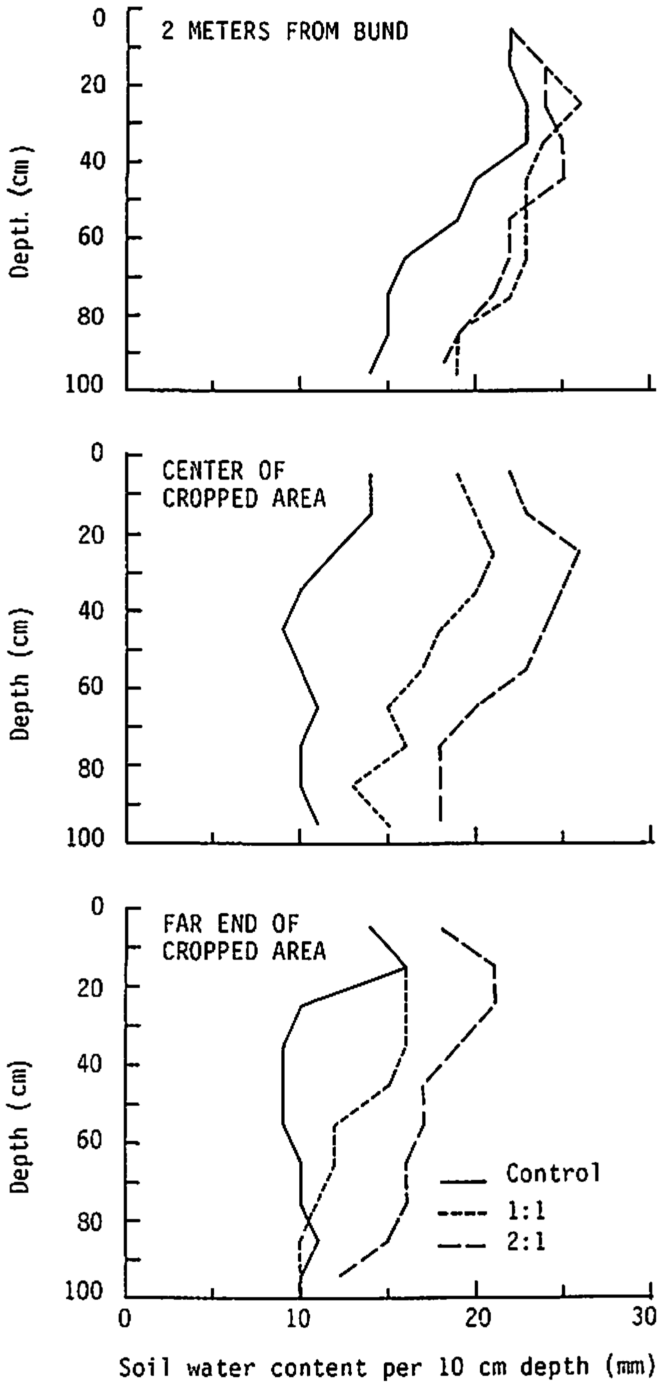


Fig. 2 **Soil water content (mm) of cropped soil at different positions in the water harvesting trial at Dasht, March 21 1988.**

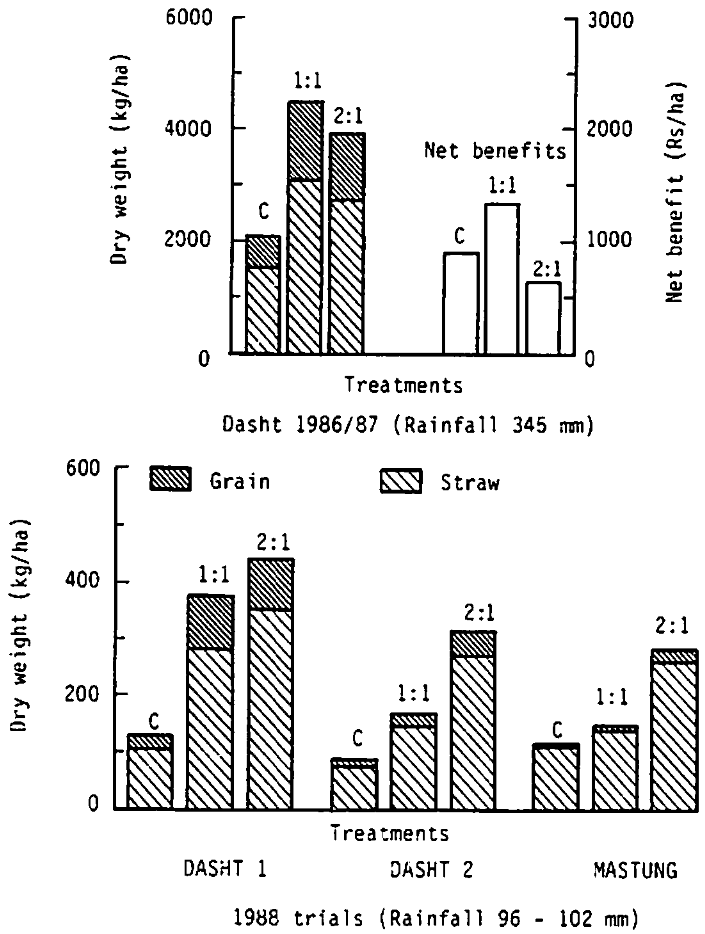


Fig. 3 Final yields (DM kg/ha) of grain and straw and net benefits of the water harvesting trials.

Figure 3 summarizes the final yield data of the 1986/87 and 1987/88 trials. In 1986/87 345 mm were received during crop growth and yields were high for Baluchistan even in the control treatment. Water harvesting more than doubled yields in the 1:1 treatment, resulting in a 50% increase in net benefits. Note that the yield increase was less in the 2:1 treatment, and not enough to make up for the loss of land taken up by the catchment area, resulting in a decrease in net benefits. Observations indicated that this was because too much water had been received, resulting in considerable waterlogging damage to the crop. This problem could be reduced by including drainage structures in the bunds (which would however entail additional investment costs), or by growing more flood-tolerant crops, such as barley. In 1988 rainfall was only 96 to 102 mm and net benefits were negative in all cases. Even so, water harvesting still resulted in considerable yield increases and losses were less. At Dasht site 1 seed yields were more than the seeding rate in the water harvesting plots, so at least the seed could be retained for the following year.

Discussion

The data presented here indicate that application of nitrogen fertilizer was economically viable only in the "good" rainfall year of 1986/87, and not in the "normal" or "poor" years of 1985/86 and 1987/88. Phosphate fertilizer had little effect in the calcareous soils of upland Baluchistan. Together with limited soil water information the data indicate that nitrogen fertilizer increased crop WUE overall from 8.1 to 10.3 kg/ha/mm, suggesting that a water availability to the crop of about 300 mm or more is required before application of nitrogen fertilizer is likely to be economical. Under rainfed conditions this is likely in only 5 to 25% of years in upland Baluchistan, depending upon location.

The simple water harvesting technology described here, aimed at improving productivity of the rainfed soils of Baluchistan, more than doubled yields in both a "wet" and an extremely dry year, with approximate runoff efficiencies in the order of 50%. The technology could be improved considerably by including drainage structures, but only at increased initial cost. The 1:1 treatment on silty clay loam soils gave considerable yield increases and seems to be a reasonable initial compromise between waterlogging problems in wet years, and failure to harvest sufficient water in very dry years. Other ratios of crop to catchment would be required on other textual soil types; a computer model of runoff (developed by E. Perrier, ICARDA) suggests that the 1:1 ratio should be satisfactory for silty loams under Baluchistan rainfall conditions, but would have to be increased to 3:1 for sandy loams (Perrier 1989; Rees 1989). These two series of experiments indicate considerable promise of increased crop productivity in upland Baluchistan, but only with water harvesting techniques increasing water availability to the crop to the point where economic yield increases in response to nitrogen fertilizer can be expected in most years.

References

Cooper, P.J.M., Gregory, P.J., Tully, D. and Harris, H.C. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture *23*: 113-158.

ICARDA 1987. High-elevation research in Pakistan: The MART/AZRI project. Annual report for 1986. Research Report *110 En*, ICARDA, Aleppo, Syria.

ICARDA 1988. High-elevation research in Pakistan: The MART/AZRI project. Annual report for 1987. Research Report *127 En*, ICARDA, Aleppo, Syria.

ICARDA 1989. Small ruminant production and its sustained improved in upland Baluchistan. Annual report for 1988. Research Report *138*, ICARDA, Aleppo, Syria.

Kidd, C.H.R., Rees, D.J., Keatinge, J.D.H., Rehman, F., Samiullah, A. and Raza, S.H. 1988. Meteorological data analysis of Baluchistan. The MART/AZRI Research Report 19, ICARDA, Quetta, Pakistan.

Perrier, E.R. 1989. Probability analysis with water balance calculations for water harvesting farming. Pages 152-173 *in* Highlight proceedings and recommendations of the water harvesting, soil and water conservation workshop, Quetta and Islamabad 1988. (In press.)

Rafiq, M. 1976. Crop ecological zones of nine countries of the Near East region. FAO, Rome, Italy.

Rees, D.J. 1989. Catchment water harvesting design for upland Baluchistan. Pages 133-151 *in* Highlight proceedings and recommendations of the water harvesting, soil and water conservation workshop, Quetta and Islamabad 1988. (In press.)

Rees, D.J., Nagy, J.G., Raza, S.H., Mahmood, K., Chowdry, B.A. and Keatinge, J.D.H. 1988. The dryland arable farming system of upland Baluchistan: A case study. Pages 81-98 *in* Winter Cereals and Food Legumes in Mountainous Areas (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds), Research Report *136 En*, ICARDA, Aleppo, Syria.

Fertilizer Management on Wheat in Chile's Secano Interior: an On-Farm Research Case Study

P. del CANTO SELGADO[1] and M.A. McMAHON[2]

[1]*Agricultural Research Institute, Quilamapu Experiment Station, Chillan, Chile*
[2]*Wheat Program, CIMMYT, Mexico*[*]

Abstract

Research and technology transfer was badly needed in Secano Interior because an important proportion (20%) of Chile's rainfed bread wheat is grown there, but with very low yields. In 1981, therefore, an on-farm research project was developed by the Instituto de Investigaciones Agropecuarias (INIA) and the Centro Internacional de Maiz y Trigo (CIMMYT) to try to close the gap between actual and potential wheat yields, through research based on farmer surveys and a strategy for transferring the resulting new technology to the farmers. A series of trials were carried out to determine actual and potential yield, the best wheat varieties, the most effective fertilizer and optimum rates and timing of application, and weed control. A package was developed, and the new fertilizer recommendations adapted to take account of the farmers' economic circumstances.

Introduction

Secano Interior, located between 33° and 37° south (Fig. 1) is one of the most important rainfed wheat-producing areas in Chile. About 20% of the total area sown with bread wheat in Chile is in this area. The average yield is low (500-700 kg/ha). The present study was carried out in the south sector where 158 000 ha are suitable for wheat cultivation (Del Canto and McMahon 1986; McMahon and Del Canto 1987).

Climate

Secano Interior has a Mediterranean-type climate with an annual mean rainfall of 650 mm (Cauquenes), of which 75-80% occurs between May and August (autumn-winter). Occasionally rains are important in spring (September to November), when wheat is heading. Annual pan evaporation is 1880 mm, highest in Summer (December to April), when wheat has been harvested. The mean maximum temperature of the warmest month (January) is 30°C, and the mean minimum temperature of the coldest month (July) is 5°C. Frosts are not important (Fig. 2).

Soils

Soils are derived from metamorphic and granitic rocks with sandy clay loam surface horizons

[*] Current address: World Bank, Washington, USA.

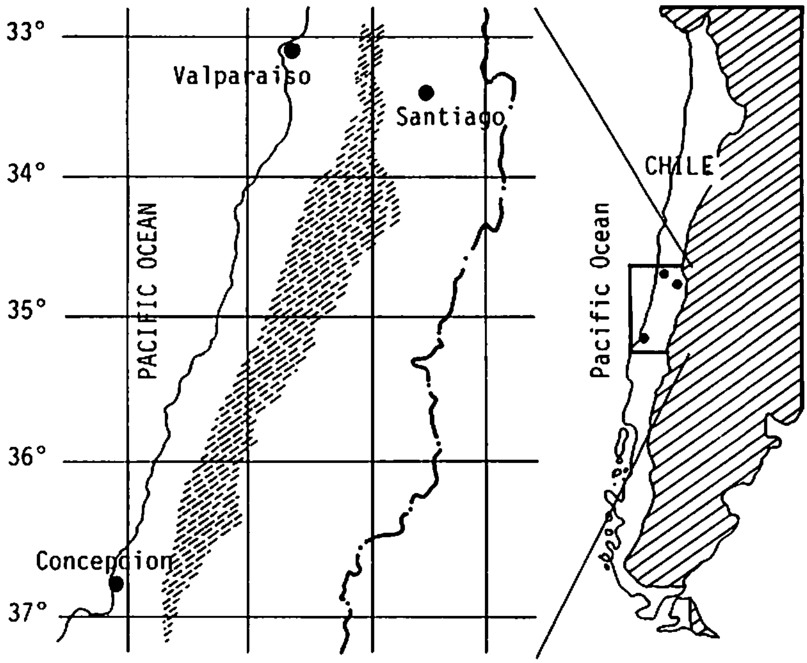


Fig. 1 **Secano Interior, Chile.**

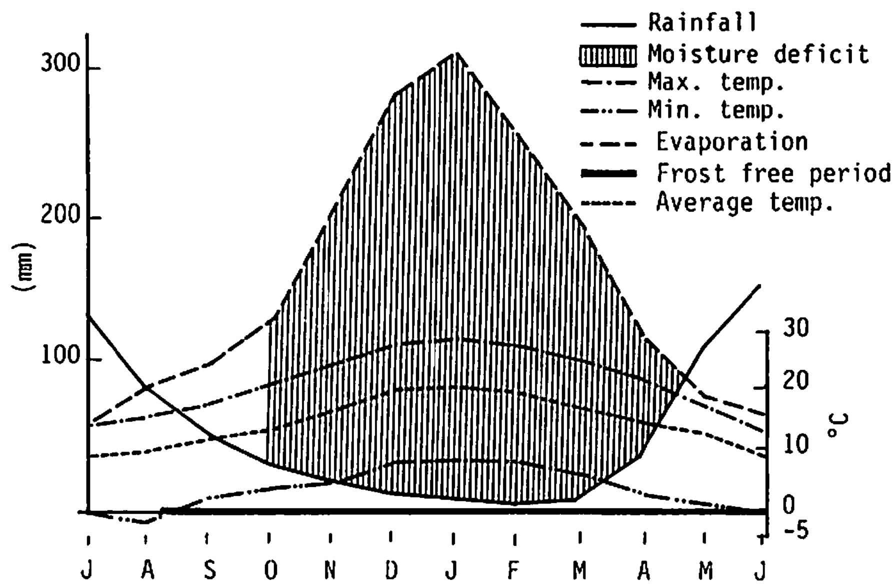


Fig. 2 **Climodiagram (25 years of data from Cauquenes, Chile).**

and sandy clay subsoils. Intensive cultivation with wheat and grain legumes, and inadequate soil management practices, have resulted in a highly eroded area with very low fertility (Acuna *et al.* 1983). Some general chemical characteristics are presented in Fig. 3.

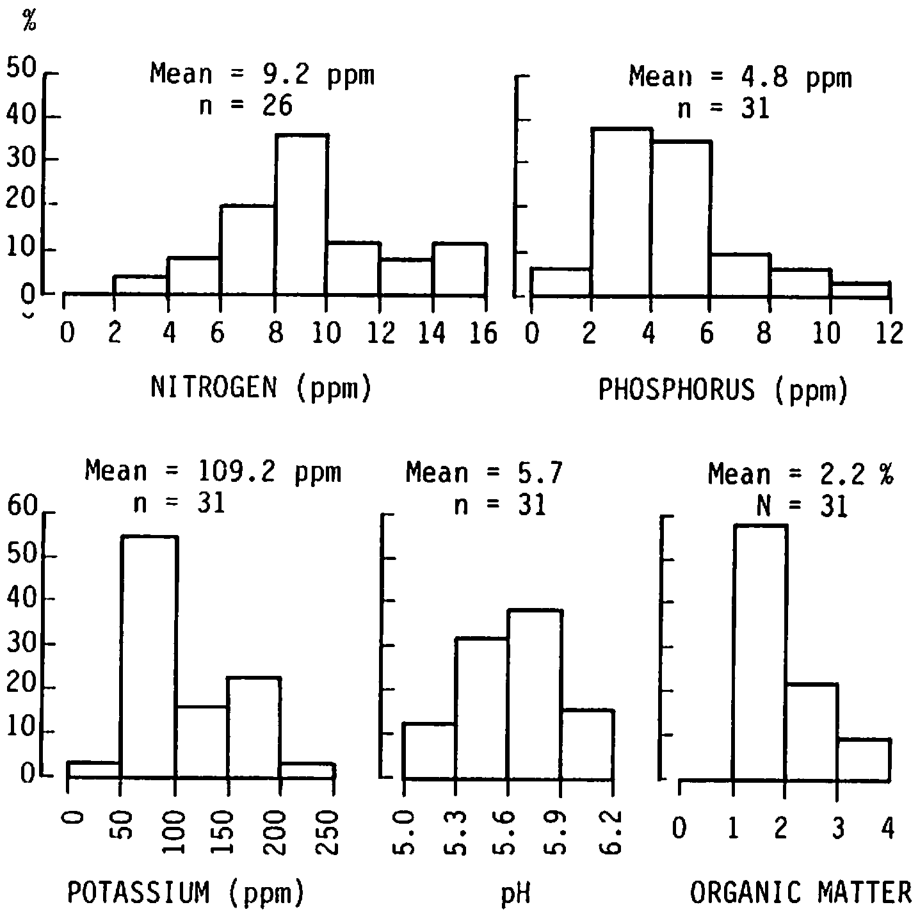


Fig. 3 Chemical properties of soil from Secano Interior.

Cropping systems

The principal cropping system consists of a three-course bare fallow-wheat-natural pasture rotation, but both food legumes (chickpea and lentil) and forage legumes (chickling) are often included. In these systems wheat yield is low, 500-700 kg/ha, and is related to the available soil moisture at heading. Usually, small farmers in the Secano Interior produce wheat under a sharecropping system in fields of three hectares or less, and all power is supplied by horses or oxen. The wheat is consumed by the small farmer's family, who need, on average, about 2000 kg/year/family (Del Canto and McMahon 1986).

On-farm Research Results

As there was obviously a need for research and technology transfer in the Secano Interior, a project was developed by the Instituto de Investigaciones Agropecuarias (INIA) in cooperation with the Centro Internacional de Maiz y Trigo (CIMMYT) program, starting in 1981, with the following objectives:

- To determine the wheat yield potential
- To determine the gap between actual and potential yields
- To determine the contribution of each technological factor to potential yield
- To set priorities within the technological package and to determine the interactions involved
- To determine the technological package for transfer to the farmer.

The on-farm research was developed according to Perrin *et al.* (1976); Zandstra *et al.* (1981) and our own experiences (Del Canto and McMahon 1986).

This cooperative program started with a preliminary farm survey to gather information about wheat production in Secano Interior. 93% of the farmers interviewed used traditional varieties (released in the 1940s) that mature when the available soil moisture becomes scarce. The genetic yield capacity of the varieties was low, and did not respond to high levels of nitrogen fertilizer. For this reason 53% of the farmers did not apply nitrogen, and the remainder applied it only at tillering at low rates (less than 20 kg/ha). Phosphorus and other fertilizers were not used in this area. Weed control was absent but was not important because weed populations were small. The most important weeds were broadleaves such as *Raphanus* spp.; *Anthemis* spp.; *Rumex* spp. and *Vicia* spp. (Del Canto and McMahon 1986).

Based on the farmer survey, in 1982 the studies were focused on comparing the response of the farmers' old variety with the INIA improved variety to nitrogen plus phosphorus fertilization. The results indicated that in farmer conditions the new early variety "Lucero-INIA", released in 1979 (Kohli 1986), yielded 220% over the old variety "Milquinientos" (released in 1939) when 120 kg/ha of nitrogen and 60 kg/ha of P_2O_5 were applied (Fig. 4). Without fertilizers the yield difference was 114%: this was probably due to genetic potential for higher water use efficiency (Figs 4 and 5).

To change the farmers' old varieties was the obvious conclusion after this second year of work, and a strategy of technological transfer was developed. In 1983, we selected several farmers to continue the work based on these results. Fertilizers were recommended for INIA improved varieties in doses of $N:P_2O_5 = 100:50$ kg/ha. It also became necessary to use herbicides against broadleaved weeds (MCPA plus Dicamba) because when fertilizer was applied competition for water by weeds increased. With these new management practices the farmers' wheat yield potential reached 5900 kg/ha with "Lucero-INIA" (Del Canto and McMahon 1986).

In 1984 more detailed fertilizer research was begun to characterize the response of improved varieties to fertilizers. This was very important because in Secano Interior not all farmers can easily afford nitrogen and phosphate fertilizers. According to the results of N-P trials, using an incomplete factorial experiment, the effect of nitrogen on the yield of new

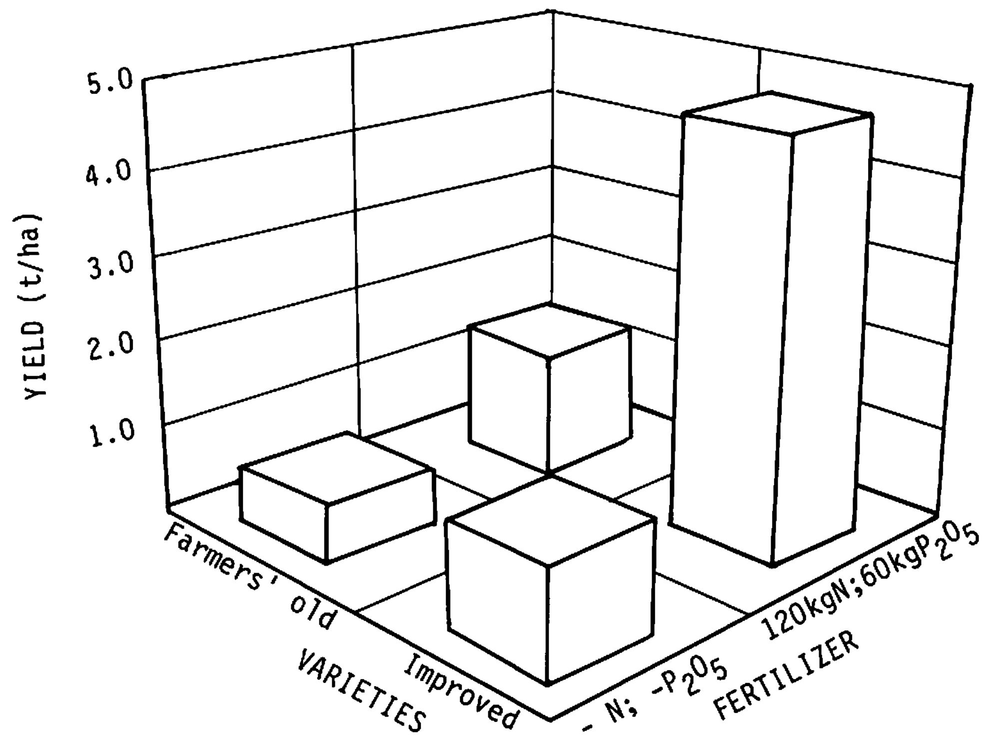


Fig. 4 Effect of N and P fertilizer on yield (t/ha) of improved wheat, San Nicolas, Chile, 1982/83.

improved varieties was considerable; there was little effect of phosphorus on its own, but a positive NxP interaction was found (Fig. 6).

At this point, it was necessary to determine the best nitrogen fertilizer and the best date of application. Rodriguez *et al.* (1987) found that Chilean sodium nitrate (16% N) or urea (45% N), have the same effect on wheat yield when applied regardless of time of application (Fig. 7). Thus the choice between the two fertilizers was based on the cost of the nitrogen unit.

The new wheat technology (improved early varieties, balanced fertilization with nitrogen and phosphorus, and broadleaved weed control) was adopted by large farmers as a package, but small farmers, normally sharecroppers, could only afford to apply around 20 kg/ha of nitrogen. In contrast to this, the existing fertilizers recommendation in Chile is based on soil tests according to previous calibration trials, and with the determination of optimum economic rates ($N:P_2O_5$ = 100:50 to 120:75 kg/ha in Secano Interior). Clearly, this is not satisfactory when the farmers cannot afford to buy fertilizers. The recommendations therefore needed to be changed, using a method proposed by Perrin *et al.* (1976) based on net benefit curves. As an example Fig. 8 shows the results of an N:P trial in Sanzal and Fig. 9 shows the net benefit curve. The fertilizers recommendation based on soil tests has been changed,

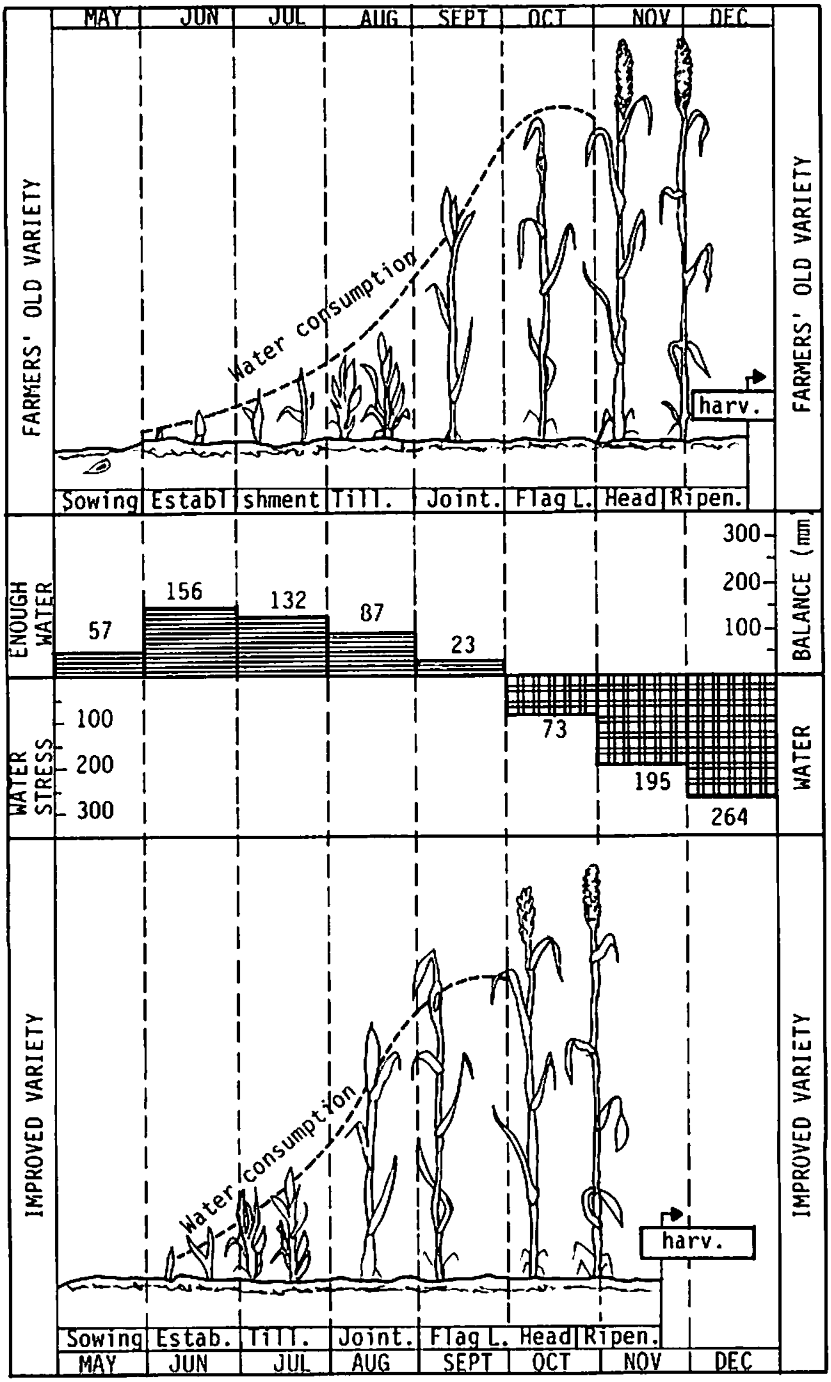


Fig. 5 **Comparison of developmental stages of traditional and improved wheat varieties in relation to water balance in Secano Interior.**

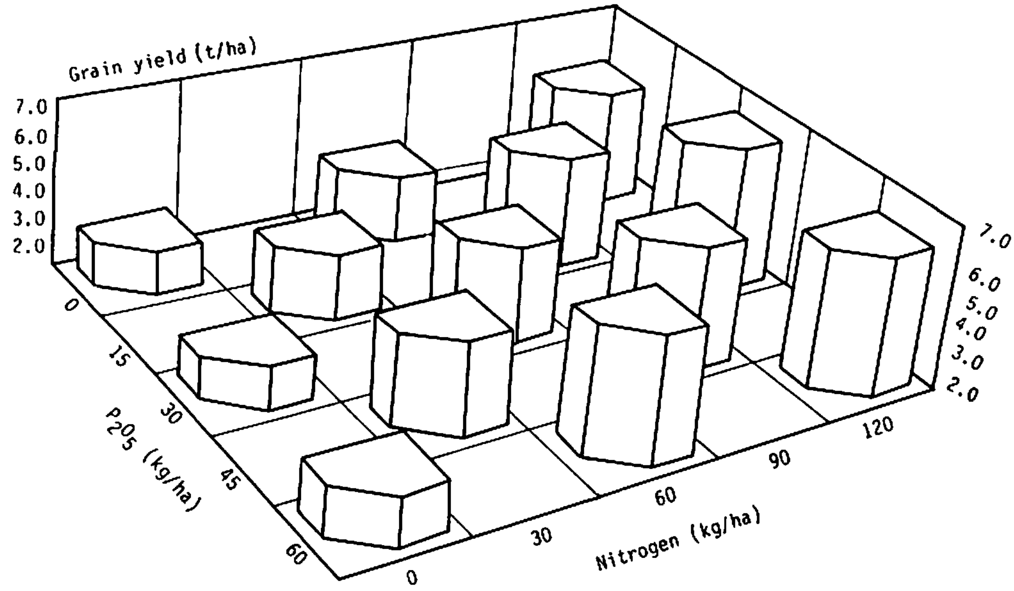


Fig. 6 Effect of N and P on yield (t/ha) of improved wheat variety, San Nicolas, Chile, 1984/85.

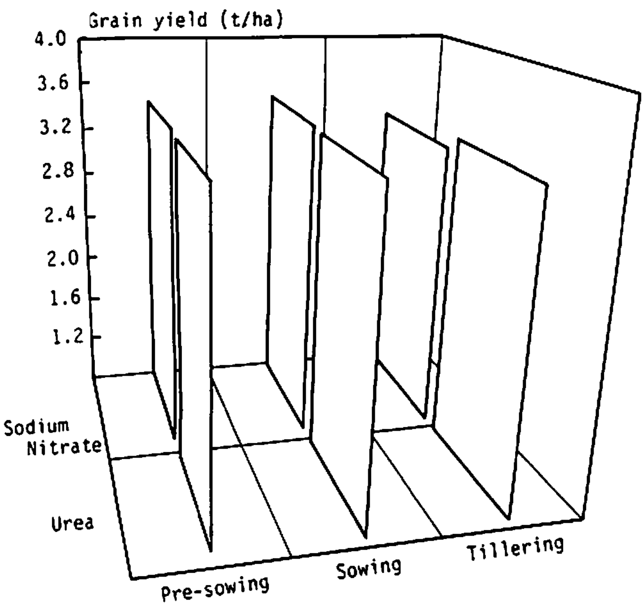


Fig. 7 Comparison of sodium nitrate and urea fertilizers in relation to date of application.

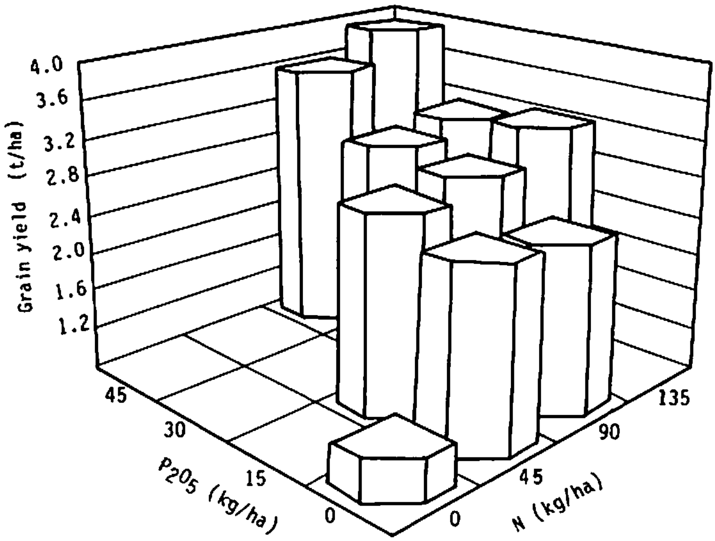


Fig. 8 Effect of N and P on yield (t/ha) of improved wheat variety, Sauzal, Chile, 1987/88.

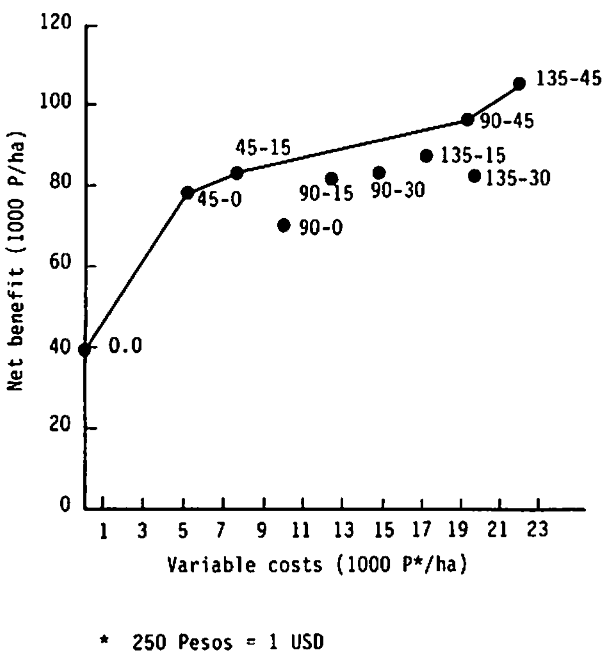


Fig. 9 Net benefit curve for fertilizer trial, Sauzal, Chile, 1987/88.

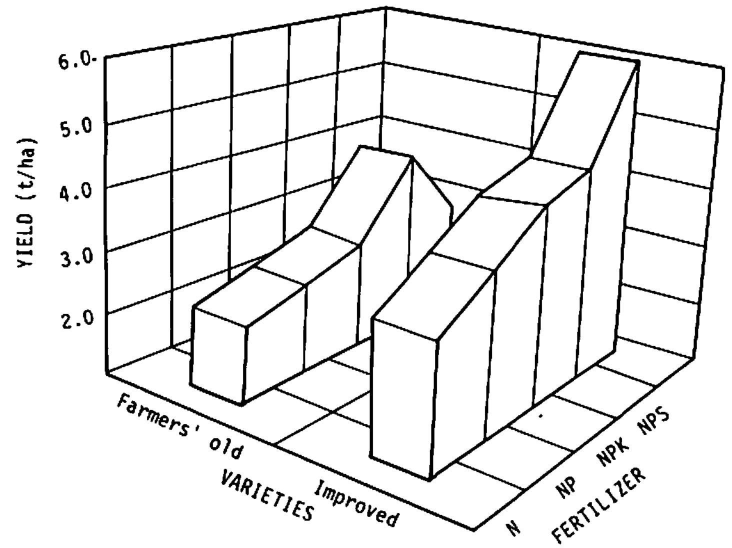


Fig. 10 Effect of four different fertilizers on wheat yield (t/ha) of traditional and improved varieties, Cauquenes, Chile, 1987/88.

and is now related to how much money the farmer can afford to spend on fertilizers. There are five alternative N:P_2O_5 combinations: 45:0; 45:15; 60:20; 90:30 and 135:45 kg/ha.

In 1987 research was started to find out why there was not the expected response to nitrogen and phosphorus in certain types of soils. The results indicate that it could be due to sulphur deficiency in early improved varieties of wheat (Fig. 10). Current research is focusing on the best way to solve this problem.

References

Acuna, P. Hernan, Avendano, R., Julia and Ovalle, M., Carlos, 1983. Caracterizacion y variabilidad de la pradera natural del Secano Interior de la zona Mediterranea subhumeda. Agricultura Tecnica (Chile) 43(1):27-38.

Del Canto S., Pedro and McMahon, M.A. 1986. Dryland wheat production in Chile's Secano Interior. International Wheat Conference, May 2-9, Rabat, Morocco.

Kohli, M.M. 1986. Variedades de trigo del cono sur de Sudamerica. Nombres; progenitores; genealogia y origen. CIMMYT, Progama de Trigo del Cono Sur, CIMMYT, Mexico DF.

McMahon, M.A. and Del Canto, S. Pedro. 1987. Rotation of wheat and *Medicago* spp. in Chile's Secano Interior. Pages 59-65 *in* CIMMYT Research Highlights 1986. CIMMYT, Mexico DF.

Perrin, R.K., Winkelman, D.L., Moscardi, E.R. and Anderson, J.R. 1976. From agronomic data to farmer recommendations: an economic training manual. Information Bulletin 27. CIMMYT, Mexico DF.

Rodriguez, S. Nicasio, Chavarria, R. Jorge, and Belmar, N. Ciro. 1987. Fertilizacion nitrogenada en trigo en la region centro sur: Comparacion de la eficiencia del salitre sodico y urea en la produccion del trigo. Investigacion y Progreso Agropecuario, Quilamapu, Chile, 33:28-32.

Zandstra, H.G., Price, E.C., Litsinger, J.A. and Morris, R.A. 1981. A methodology for on-farm cropping systems research. International Rice Research Institute (IRRI), Los Banos, Philippines.

It is clear that fertilizer recommendations need finer tuning to environmental conditions, especially amount and distribution of rainfall, taking into account the different behaviour of nitrogen and phosphate. P seems to be more effective in drier areas and years, whereas N has more effect in more favourable conditions (Pala; Yurtsever; Kacemi).

In WANA farmers avoid the risk of applying too much N for a dry year by only applying small 'starter doses' (or none at all) at seeding, and the rest is top-dressed at tillering in spring, when the bulk of the rains have fallen. In other words, they adjust N fertilizer rates to match the potential of the season. In the calcareous soils of this region water-soluble P is largely immobile, and uptake by plants depends on root contact and moist soil. In wet years the native P is more available because the soil is more often wet and the roots more extensive and active, so applied P has less effect. ICARDA's limited studies show that approximately half the applied P becomes fixed during the crop growth cycle (Cooper). It may still be economic to apply fertilizer in a dry season because dry years are years of shortage, and prices for barley increase markedly. In addition, the residual effect of fertilizers, particularly phosphate, following dry years has to be considered in these very deficient soils (Reeves).

Cereals after clean fallow will usually give the highest yields, because of some water storage, N-accumulation and pest and disease control, but replacing fallow with food or forage legumes, or a summer crop such as water melon or maize, almost always gives greater total production and greater economic returns over the two years. The exception to this is if clean fallow is replaced by continuous cereal (Farah; Cooper).

Weed Control

Effect of Weeds on Water Use of Rainfed Crops

AMOR, R.L.

*Department of Agriculture and Rural Affairs, Victorian Crops Research Institute, Horsham, Victoria 3400, Australia**

Abstract

Control of weeds increases the amount of water available for crop production. In the interval between crops, the growth of weeds reduces accumulation of soil water in both fallows and non-fallow systems. The effect of various control practices are described. Factors influencing in-crop competition for water are discussed and the value of integrated weed control stressed.

Introduction

Weeds compete with crops for water, resulting in lower water use by the crop and therefore lower yields. In this paper, the main factors influencing the competition between crops and weeds are discussed as well as the practices which will minimise the use of water by weeds. As indicated by Cooper and Gregory (1987), the main effect of weed control is to increase the water supply available to the crop, although it also interacts with factors such as early sowing, which affects transpiration efficiency, and mulching, which reduces soil evaporation.

Water use by weeds in the interval between crops

Weeds in annual cropping systems

In annual cropping systems in semi-arid areas there is generally a period of about 4 months between crops, and weeds in stubble are often grazed. In the Great Plains of USA ungrazed weeds can use up to 5 mm water/ha/day resulting in a 0.7 to 1.3 t/ha loss in the potential yield of the next wheat crop, and in Victoria, Australia, they used 88 mm/ha over a five month period (Greb *et al.* 1979; Cooke *et al.* 1985). In some years crops, particularly shallow rooted ones, do not utilise all the stored water, which is then available for the subsequent crop.

Apart from grazing stubble to suppress weeds, other options include cultivation, the use of herbicides, and various combinations of these control methods. In New South Wales, Australia, weed control in this period increased the water stored in the soil by 16 mm; if wheat stubble was also retained 55 mm more water was stored which increased the potential yield by 0.7 t/ha (Cornish and Lymberg 1986).

Weeds in fallow-cereal systems
(9-12 months or more)

* Present address: 176 Wellington Parade, East Melbourne, Victoria 3002, Australia

The use of long cultivated fallows, for about 9-12 months, has generally resulted in improved yields, fewer crop failures and more stable farm incomes. The main reasons for this have been the control of weeds resulting in moisture conservation, accumulation of mineral nitrogen and reduction in the carryover of crop diseases. However, responses to long fallowing on sandy soils previously ascribed to water conservation are now attributed mainly to disease control, as most of the water stored by long fallows moves below the root depth of wheat crops. Retention of stubble on long fallows usually increases the amount of stored water (Schultz 1980). This applies mainly to fine textured soils as the sandier soils retain less moisture and generally produce less than 2 t/ha of stubble.

Grazing is an inexpensive means of suppressing weeds on fallows and increases the economic returns from livestock. However, an initial cultivation followed by grazing with sheep improved wheat yields in Victoria by only 65%, whereas cultivated fallows improved yields by 137% (Rooney *et al.* 1966).

In the Central Great Plains in the USA, 38 mm more moisture was stored in the soil in chemical fallows than in cultivated fallows, and wheat yields were 0.49 t/ha higher (Greb and Zimdahl 1980). A similar result was found on clay soils in Victoria, i.e., 29 mm more moisture and 0.7 t/ha higher yields respectively (O'Leary and Incerti 1988). Fallows can be started off with "knockdown" herbicides (e.g., glyphosate) and maintained over the summer with residual herbicides (e.g, atrazine and chlorsulfuron). It is important that rates are adjusted so that there are no harmful effects on the subsequent crop, particularly in dry years. An integration of various methods of controlling weeds on fallows is desirable, as this is often more acceptable to the farmer and is consistent with environmental concerns about minimising soil erosion and the use of pesticides.

In-crop water use by weeds

Intra and inter species competition occurs between crops and weeds for water, light and nutrients, the former being the main limiting factor in semi-arid areas. There is a tendency for the crop-weed association to maximise the combined dry matter produced, each species developing at the expense of the other. Weed control in Morocco increased wheat yields by 19%-53% and WUE by 19%-48% (Tanji *et al.* 1987), and weed-free millet crops in the Central Great Plains of USA had 17% higher yields and 15% higher WUE than weedy crops (Anderson and Greb 1987).

Factors influencing the competition between crops and weeds include soil type, climate/weather, spatial diseases and insect pests, crop factors (genotype, density, plant arrangement, time of sowing, depth of sowing, response to nutrition, stage of development, potential yield) and weed factors (genotype, weed seed bank, density and biomass, period during which weeds are present, and response to control measures). Although less widespread than annuals, perennial weeds are often very competitive and difficult to control because of their extensive root systems.

Indirect methods of weed control include manipulating crop genotype, density, spatial arrangement, time of sowing, depth of sowing and nutrition. Direct methods include cultivation, physical removal, chemical control and biological control. Pavlychenko and Harrington (1934) reported that barley was the most competitive crop which they evaluated, others, in descending order, being rye, wheat, oats and flax. Food legumes have slow initial growth and as a group, are less competitive than cereals. Knott and Halila (1988) reported that the average loss due to weeds in the yield of food legumes in India, Syria and Tunisia was 53% (range 20%-82%), and they also presented differences in losses between crop types.

Numerous studies have shown that the effect of weeds on the growth and yield of crops can be reduced by increasing the crop density. However, this approach is more advantageous in areas of ample rainfall than in semi-arid areas. In the latter, crops sown at high seeding rates can produce so much biomass early in the year that there may be insufficient moisture to finish crop development.

The first plants to occupy an area generally have an advantage over late-comers and, therefore, the planting arrangement of a crop can influence its ability to compete with weeds. Medd (1987) concluded that, within the limits of normal crop densities, plants that are uniformly spaced are better able to compete with weeds than those planted in widely spaced rows.

In any area there is usually an optimum time and depth of sowing. Crops are usually planted in a moist seedbed, which can give the crop a competitive advantage over weed seeds in an often drier soil surface. Delaying the time of sowing to allow early germination of weeds to be controlled by cultivation will reduce the weed competition experienced by the crop. However this advantage has to be weighed against any yield penalty from delaying sowing after the optimum time.

Crop growth and the ability to compete with weeds can be manipulated by modifying the nutrient supply. Some weeds such as *Lactuca serriola* compete mainly with weeds in unthrifty crops grown on soils of low fertility, and raising the soil fertility by the use of legumes or applied nitrogen will reduce the effect of such weeds (Amor 1986). On the other hand, others such as wild oat respond to nitrogen fertilizer and are not selectively suppressed unless the nitrogen is banded beneath the crop seed (Reinertsen *et al.* 1984).

Weeds can be removed by cultivating between rows or by shallow cultivation after sowing and before the crop has emerged. More commonly, weeds are controlled by herbicides or hand weeding. Hepworth *et al.* (1975) reported increases of up to 33% in wheat yields in Turkey due to chemical control. In rainfed crops there have so far been few cases of successful biological control, one exception being control of *Chondrilla juncea* in Australia by the introduced rust *Puccinia chondrillina* (Delfosse and Cullen 1982).

In a Mediterranean-type environment, French and Schultz (1984) found that more than 70% of the total water use by wheat crops occurred by anthesis, and considered that the amount of rainfall before anthesis is the main determinant of crop yield. If this is so, weeds will have the greatest effect on crop water use efficiency by their influence on pre-anthesis growth. When *Bromus tectorum* emerged within one week of wheat it depressed yield by 20%-32%, but did not affect yield when it emerged two weeks or more after the wheat (Wicks 1966). Root systems of wheat plants grown under weed competition are smaller than those grown in the absence of weeds and clearly root development is a major factor in competition in dry environments (Pavlychenko 1937).

There is generally a linear relationship between weed biomass and loss in crop biomass and yield, although the relationship will depend on the relative timing of the peak growth of the components. For practical reasons, Poole and Gill (1987) and others argue for the use of weed densities in crop-weed competition models. They have shown that it is possible to obtain robust relationships between weed densities and wheat yield for *Avena* *fatua, Bromus diandrus* and *Dordeum leporinum*, but in the case of *Lolium rigidum*, the results are more variable, and appear to be related to the amount of rainfall in the early germination and establishment phase. Although there is considerable debate on the theory and practice of economic thresholds for weeds, it has been possible to produce tables for deciding whether or not to spray some weeds based on the relationships between yield loss, weed density, weed-free yield and the price of wheat (Poole and Gill 1987). Similar decisions about handling the common field problems of weeds with extended periods of germination and the effect of weed control on crops in the following year have yet to be resolved.

Integrated weed control

Weed problems are dynamic, as they change with changes in farming systems. In minimising the competition between the current weeds and crops for water, it is important that an integrated approach to control is adopted. Rather than relying on only one method, several possible alternatives should be used in a systematic manner, thus increasing the chance of developing economic and sustainable farming systems. Components of integrated weed control systems may include preventing problems from developing (e.g., by using clean seed), crop competition, crop rotation, grazing, cultivation, hand weeding, chemical control, biological control and considerations of economics and farmer attitudes. Because of the long term nature of research on integrated weed control, the cost-effectiveness of field experiments is improved if they are utilized by various inter-disciplinary specialists. Adoption can be promoted by demonstrations and the use of farmer success stories.

References

Amor, R.L. 1986. Incidence and growth of pickly lettuce (*Lactuca serriola* L.) in dryland crops in the Victorian Wimmera. Plant Protection Quarterly 1: 148-151.

Anderson, R.L. and Greb, B.W. 1987. Residual herbicides for weed control in proso millet (*Panicum miliaceum* L.). Crop Protection 6(1): 61-63.

Cooke, J.W., Willatt, S.T. and Ford, G.W. 1985. Water use by weeds growing in stubble. Page 374 *in* Proceedings of 3rd Australian Agronomy Conference, Hobart.

Cooper, P.J.M. and Gregory, P.J. (1987). Soil water management in the rainfed farming systems of the Mediterranean region. Soil Use and Management 3(2): 57-62.

Cornish, P.S. and Lymberg, J.R. 1986. Effects of stubble retention and weed growth on water conservation over summer. Pages 39-40 *in* Proceedings of Conference on Recent Advances in Weed and Crop Residue Management (Pratley, J.E. and Cornish, P.S., eds). Southern Conservation Farming Group Occasional Publication No. 2, Wagga Wagga, New South Wales.

Delfosse, E.C. and Cullen, J.M. 1982. Biological control of weeds of Mediterranean origin. A progress report. Australian Weeds 1: 25-30.

French, R.J. and Schultz, J.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. 1. The relation between yield, water use and climate. Australian Journal of Agricultural Research 35: 743-764.

Greb, B.W., Smika, D.E. and Welsh, J.R. 1979. Technology and wheat yields in the Central Great Plains: Experiment station advances. Journal of Soil and Water Conservation 34: 264-268.

Greb, B.W. and Zimdahl, R.L. 1980. Ecofallow comes of age in the Central Great Plains. Journal of Soil and Water Conservation 35: 230-233.

Hepworth, H.M., Zinn, T.G. and Anderson, W.L. 1975. Improved techniques for dryland mean more wheat from fallow farming. 2nd ed. USAID, Oregon State University Team, Ankara, Turkey.

Knott, C.M. and Halila, H.M. 19889. Weeds in food legumes: problems, effects and control. Pages 535-548 *in* World crops: Cool season food legumes (Summerfield, R.J., ed.), Kluwer Academic Publishers, Dordreeth, The Netherlands.

Medd, R.W. 1987. Weed management on arable lands. *In* Tillage. New directions in Australian agriculture (Cornish, P.S. and Pratley, J.E., eds), Inkata Press, Melbourne, Australia.

O'Leary, G.J. and Incerti, M. 1988. The effect of stubble retention and nitrogen application on wheat yield in the Victoria Wimmera: a progress report. *In* Proceedings of Workshop on Tillage Systems, Rotations, Nitrogen and Cereal Root Diseases, Adelaide, Australia, 24 March 1988.

Pavlychenko, T.K. 1937. Quantitative study of the entire root systems of weed and crop plants under field conditions. Ecology 18: 62-79.

Pavlychenko, T.K. and Harrington, J.B. 1984. Competitive efficiency of weeds and cereal crops. Canadian Journal of Research 10: 77-94.

Poole, M.L. and Gill, G.S. 1987. Competition between crops and weeds in Southern Australia. Plant Protection Quarterly 2: 86-96.

Reinertsen, M.R., Cochran, V.L. and Morrow, L.A. 1984. Response of spring wheat to N fertilizer placement, row spacing and wild oat herbicides in no-till system. Agronomy Journal 76: 753-756.

Ronney, D.R., Sims, H.J. and Touhey, C.L. 1966. Cultivation trials in the Wimmera. Journal of the Department of Agriculture, Victoria 64: 403-410.

Schultz, J.E. 1980. Moisture conservation practices in dryland agriculture. Pages 440-470 *in* Proceedings of International Congress on Dryland Farming, Adelaide.

Tanji, A., Karrou, M. and El Mourid, M. 1987. Effect of weeds on yield and water-use efficiency of wheat under semi-arid conditions of Morocco. Rachis 6: 36-39.

Wicks, G.A. 1966. Downy brome competition in winter wheat. Page 22 *in* Proceedings of the North Central Weed Control Conference, Oklahoma City, USA.

The Current Status of Weed Control in Algeria

A. ZEGHIDA[1], M. ZAIR[2] and A. HAMADACHE[3]

[1]*ITGC, El-Khroub, 25100 Constantine, Algeria*
[2]*ITGC, Tiaret, Algeria*
[3]*ITGC, El-Harrach, Algeria*

Abstract

Intensification of a cropping system relies on the understanding of the major limiting factors to production. Weeds are one of the major constraints limiting yields. Many trials have been conducted to show the effect of weed control on yields. Most of these trials, whether using chemicals, soil cultivation, or other cultural practices, have shown their effectiveness. Substantial increases in production have been evident in the last few years. However, to reach self-sufficiency in cereals and food legumes, much of the effort should now be concentrated on extension, advantageous production prices, and state support of production factors such as fertilizers, herbicides, seeds, and equipment.

Introduction

Cereal production in Algeria varies from 0.8 million tonnes in dry years, to 3 million tonnes in favourable weather conditions. The area cropped to cereal covers three million hectares, and receives an average annual rainfall of 250 mm in the south to 800 mm in the north. Tables 1 and 2 show, however, that the actual production level does not meet the high demand of the rapidly increasing population (Ministry of Agriculture 1973/74-1985/86; CIMMYT 1983, 1985; Benbelkacem 1987; Maatougui 1987).

For food legumes, despite the efforts to increase the area cultivated, the gap between national needs and production is becoming more and more serious (Tables 2 and 3). The area allocated to food legume crops is about 140 thousand hectares (Ministry of Agriculture 1973/74-1985/86; CIMMYT 1983, 1985; ITGC 1983; Maatougui 1987; Hamadache 1988).

Acceptable production levels, for both crops, could be guaranteed by applying a package of basic cultural practices, including

Table 1. Area (1000 ha), production (1000 t) and yield (t/ha) of wheat, 1975-1987

	1975	1977	1979	1981	1983	1985	1987
Area	2664	2216	2724	2692	2090	2967	2482
Production	1919	980	1476	1786	1233	3004	2069
Yield	0.72	0.44	0.54	0.66	0.59	1.01	0.83

Source: Ministry of Agriculture (1973/74 - 1985/86)

Table 2. Wheat and food legumes consumption per capita (kg) and imports (1000 t)

	Wheat [1]		Food legumes [2]	
	Consumption	Imports	Consumption	Imports
1979-81	194	2194	6.1	960
1982-84	173	2967	-	-

Sources: 1. CIMMYT (1983, 1985)
2. ITGC (1983)

Table 3. Area (1000 ha), production (1000 t) and yield (t/ha) of food legumes, 1975-85

	1975	1977	1979	1981	1983	1985	1987
Area	77	80	105	106	99	132	140
Production	278	226	235	258	201	456	634
Yield	0.36	0.28	0.22	0.24	0.20	0.34	0.45

Source: Ministry of Agriculture (1973/74 - 1985/86)

- Use of adapted and high yielding varieties
- Seeding at the optimum date and rate
- Use of adequate fertilizer rates
- Development of intensive chemical weed control
- Study and application of a well adapted cropping system
- Encouraging price policies and provision of credit facilities to farmers.

This paper deals with weed control, which accounts for more than 25% of the losses in potential production of cereals, and probably over 40% in food legumes (ITGC 1976, 1977a, 1977b; Hamadache 1988).

Sources of Weed Infestation

Fallow More than 30% of the arable land is kept fallow in the rotation system every year. This practice should have rainwater storage and weed control as primary objectives. However, the main constraints to these two goals are the presence of livestock on most farms and the low forage production, so that the fallow is not tilled early but grazed. Tillage starts very late when most weeds have already set and dropped seeds.

Forage crops The country is very deficient in forage crops, and many sheep holders rely on fallow for animal grazing. Also, most of the forage crops are not well managed. Cutting for haymaking occurs very late. Most weeds set and drop seeds before cutting.

Herbicide misuse Only one-eighth of the total area cropped to cereals and dry legumes is treated (400 thousand out of 3 million hectares). The remaining untreated area provides a large area for weed multiplication. Besides that, only a few herbicides are used. Some of them are specific to wild oats only and some others, such as 2,4-D, which has been used for over 30 years, contributed to the development of grassy weeds such as wild oat, phalaris, rye grass and brome grass. It is evident that a short- and medium-term program of research should concentrate on these major sources of weed infestation.

Major Weeds of Cereal and Food Legume Crops

Grassy Weeds (Monocotyledons)

- *Avena spp.* There are no specific zones of wild oat distribution; it is the most prevalent and the most competitive weed in cereal crops, probably the species that contributes most to loss in production, because it bears large numbers of strongly persistent seeds. Its prevalence is being enhanced by deep ploughing, practised by most Algerian farmers.

- *Bromus spp.* Its presence used to be restricted to some areas in the high plateaux, but with the exchange of uncleaned cereal seeds between different parts of Algeria, the total absence of measures for weed control, and the lack of chemicals specific to it, brome grass has rapidly spread in the main cereal zones. The only way to deal with it is deep cultivation of the soil, and the delay of seeding so that the first germinating generations are destroyed.

However, while this practice reduces brome grass, it increases wild oats. There is a choice to make: it is probably wiser to deal with wild oats than with brome grass at present, because there are many chemicals for wild oat control and none for brome grass.

- *Lolium and Phalaris spp.* The area of distribution is confined to the wet zones. They are not as important as wild oat and brome, but care should be taken when dealing with them. They might become a serious weed problem if no action is taken to limit their spreading infestation.

Broadleaf weeds (Dicotyledons)

Several species are important in both cereal and legume crops. The species which are causing the most severe yield losses are:

- *Cruciferae.* prevalent in both crops
- *Umbelliferae* . do not develop well in cereal crops but grow very well in dry legume crops
- *Compositae.* very important in both crops
- *Papaveraceae* . together with the mustards, cover most of the cropping area
- *Rubiaceae.* more important in dry legumes
- *Polygonaceae* . infest both crops
- *Liliaceae* sp. very important in both crops but they seem to infest dry legumes more because of the wide spacing and short height of the crop. The same is true for *Rubiaceae* .

The other genera, such as legumes, *Veronica* spp., *Ranunculus* spp., are secondary in terms of competition and numbers. Their prevalence is hidden by the above species, which are the first to appear in the crops, and grow taller than the crop itself (CIMMYT 1976; CIMMYT 1983, 1985; Hamadache 1988).

Weed Control Research

Much of the effort to control weeds on cereals and legumes has been grouped into the following topics:

- Weed control by cultural practices
- Chemical weed control

Weed control with cultural practices

Crop rotation In the crop rotation system as practised in most cropping areas of Algeria, weed infestation depends on the volume of weed seeds produced in the previous crop. Trials conducted at Tiaret, Algeria, in 1986 showed that the differences in weed infestation are a consequence of the methods used to manage the previous crop, and the weed seed stock remaining in the soil (Table 4). Table 5 shows the effect of weed population on yield components and yield of wheat. For grassy weeds, the number of kernels/spike and 1000 kernel weight were significantly affected, while broadleaf weed competition had an effect on

Table 4. Weed distribution in wheat after winter fallow, spring fallow, forage and food legumes

	Weed infestation level*			
	Winter fallow	Spring fallow	Forage	Food legume
Main weed species:				
- Wild oats	2	3	3	3
- Brome grass	2	3	1	3
- Phalaris spp.	2	2	3	2
- Rye grass	1	3	0	0
- Umbelliferae	2	3	2	3
- Cruciferae	2	3	3	2
- Papaveraceae	3	3	3	3
- Fumariaceae	2	2	2	3
- Leguminosae	2	2	1	2

* 0 = no weeds; 1 = 1 to 15 plants/m2; 2 = 16 to 25 plants/m2;
3 = over 25 plants/m2
Source: ITGC Annual Reports (1986, 1987, 1988)

Table 5. Weed population effect on wheat yield components

Weed type	Infestation level*	Spikes/m^2	Kernels/ spike	1000 kernel weight (g)	Yield (t/ha)
	Wheat yield components				
Monocotyledons	0	296	22	48	3.12
	1	294	20	46	2.70
	2	294	17	43	2.14
	3	290	16	42	1.94
Dicotyledons	1	292	19	45	2.49
	2	290	18	43	2.24
	3	285	18	42	2.15
LSD at 0.05		6.4	2.8	2.6	0.61

* See Table 4.
Source: ITGC Annual Reports, 1986, 1987, 1988.

the number of spikes/m^2 and 1000 kernel weight. Wheat yield was significantly reduced when the grassy weed population reached 15 plants/m^2 and no yield decrease was noticed with a broadleaf weed population of up to 25 plants/m^2 (ITGC 1986-88). When both weed types are present the effect on wheat is greater. Table 6 shows the effect of the different rotations on the level of weed infestation and wheat yield.

Soil cultivation Soil cultivation before seeding allows the elimination of one generation of germinating weeds and permits a weed-free seedbed. This practice allows an even and vigorous crop emergence and a crop able to compete better with later emerging weeds (CIMMYT 1976; ITGC 1976, 1977a; Hamadache 1988).

Table 6. Effect of crop rotation on wheat yield (t/ha)

Previous crop	Level of weed infestation *	Weed type	Yield
Fallow	1	Monocotyledons	2.68
Forage	2	Monocot. and Dicot.	2.09
Lentil	2	Monocot. and Dicot.	1.81
Wheat	3	Monocot. and Dicot.	1.37

* See Table 4
Source: ITGC Annual Reports, 1986, 1987, 1988

The results of a trial conducted at El-Khroub, Constantine (Algeria) in 1976 are shown in Table 7. Correct seedbed preparation increased yield by 1.69 t/ha and reduced the wild oat population by 7152 seeds/m^2, which meant that 1.8 t/ha of wild oat seeds were eliminated from the field.

However, soil cultivation effects on the weed population must be completed by chemicals to control late-emerging weeds. The practice of additional cultivation before seeding is only used when delaying seeding to allow weeds to germinate after rainfall, at the cost of yield. However, the usual practice is to sow on a dry seedbed. In most cases reliance on chemicals is more appropriate, to gain the advantage of early sowing for increased production through higher water use efficiency.

Table 7. The effect of additional cultivation on wild oats

Factors	Unweeded seedbed	Weed-free seedbed
Wild oat head/m^2	152	33
Wild oat seed/m^2	8200	1056
Wild oat seed production (t/ha)	2.05	0.26
Wheat yield (t/ha)	2.11	3.80

Source: CIMMYT (1976)

Chemical weed control

Cereals

The chemicals tested for weed control efficiency on wheat in Algeria from 1970 to 1980 were as follows:

1) *Tribunil:* High control of broadleaf weeds and moderate effect on wild oats, rye grass and *Phalaris spp.*
2) *Printan 22*: Efficient on broadleaf weeds, and fair control of wild oat, rye grass, and *Phalaris spp.*
3) *Dosanex + Tok WP-50:* 65 to 75% control of broadleaf weeds and grassy weeds
4) *Suffix:* Highly efficient on wild oats only
5) *2,4-D:* Very efficient on broadleaf weeds only
6) *Dicuran + Tok WP-50:* 80 to 90% control of rye grass and broadleaf weeds, respectively
7) *Dicuran + Certol*: 60 to 70% control of wild oat, rye grass, *Phalaris spp.* and broadleaf weeds
8) *Dicuran:* 40 to 60% effectiveness on wild oat, rye grass, *Phalaris spp.* and broadleaf weeds.
9) *Suffix + 2,4.-D*: 70 and 90% effectiveness on wild oat and broadleaf weeds, respectively

10) *Buctril M:* Specific to broadleaf weeds only
11) *D. M. 68*: Very effective on broadleaf weeds
12) *Oxytril M.*: Specific to broadleaf weeds
13) *Quinorexone sp.*: Effective on broadleaf weeds only
14) *Diclofop Methyl*: Effective on wild oats and rye grass
15) *Diclofop Methyl + Bromoxynil:* Wild oats and broadleaf weeds
16) *Suffix + MCPA*: Wild oat and broadleaf weeds control
17) *Avenge*: Specific to wild oat control in cereals.

In heavily infested areas, herbicides significantly increased yields. The yield increase due to herbicide utilization varies from 0.2 t/ha to 0.9 t/ha in the central part of Algeria and from 0.24 t/ha to 0.87 t/ha in the east (CIMMYT 1976; ITGC 1976, 1977a, 1977b).

The combination of cultivation for a weed-free seedbed and the application of herbicides for later emerging weeds gave a yield increase of 1.69 t/ha (Table 7) (CIMMYT 1976).

However, most farmers rely much more on chemicals to control weeds because of a lack of suitable equipment for fallow management and correct seedbed preparation. In this case crop and weed germination happen at the same time, so competition begins earlier. No pre-plant or pre-emergence herbicides are used on cereals. The chemicals actually available and widely used by farmers are as follows:

- Suffix: benzoylprop-ethyl: for wild oat control
- Suffix + MCPA: wild oat and broadleaf weed control
- 2,4-D: for broadleaf weed control
- *Diclofop methyl*: for wild oat and rye grass control
- *Diclofop methyl + bromoxynil:* for wild oat and broadleaf weed control
- *Metoxuron*: Dosanex: for wild oat and broadleaf weed control.

All of these chemicals are applied after the weeds emerge, and all of them, except diclofop methyl, are applied at tillering and shooting stages. We consider that yield has already been affected, to some extent, by early weed competition. A better control can be obtained by the combination of early and late herbicide applications because of the high weed infestation in most fields.

During the last three years, intensive extension and farmer training have had a great impact on wheat production. More forage crops are being grown, so fallow can be tilled earlier. After 1983, the application of appropriate practices such as fallow management, weed control, fertilization, optimum date and rate of seeding, had a great effect on production, as shown in Table 1.

Food Legumes

For food legumes weed control relies mainly on chemicals, applied pre-plant and pre-emergence. They do not last long enough to control late emerging weeds. Most of the weeds specific to food legume crops are not controlled by the few herbicides available (Table 8). The only herbicide widely available to farmers is Treflan. However, most of the weeds infesting food legumes, which generally germinate late in the season, are not susceptible to it. Weeds make mechanical harvesting very difficult and yield losses serious. Although there is a substantial increase in food legume area, yields are still very low (Table 2).

Table 8. Weeds resistant to Treflan

Broadleaf weeds

Cruciferae

- *Raphanus raphanistrum*
- *Rapistrum rugosum*
- *Diplotaxis virgata*
- *Neslia paniculata*
- *Conringia orientalis*
- *Capsella bursa-pastoris*
- *Coronopus squamatus*

Leguminosae

- *Melilotus* spp.
- *Vicia* spp.
- *Lathyrus ochrus*
- *Coronilla scorpioides*
- *Medicago* spp.

Umbelliferae

- *Daucus carota*
- *Ammi majus*
- *Scandix pecten veneris*
- *Bifora testiculata*
- *Ridolfia segetum*
- *Bipleurum lancifolium*

Rubiaceae

- *Calium* spp.

Polygonaceae

- *Polygonum aviculare*

Compositae

- *Calendula arvensis*
- *Armenis praecox*
- *Senecio vulgaris*
- *Carduus pycnocephalus*
- *Scolymus maculatus*
- *Sonchus oleraceus*

Papaveraceae

- *Papaver rhoeas*

Grassy weeds

- *Avena* spp.
- *Lolium* spp.
- *Bromus* spp.
- *Phalaris* spp.

On-going Research on Weed Control

Cereals

Two topics are being investigated.

1. Fallow management at different times of the year to show the effect of tillage on weed control, water use efficiency, and wheat yield. This research is conducted on a large field scale, using different soil tillage and cultivation implements, i.e.

   - Mouldboard plough
   - Disc plough
   - Chisel
   - Tined implements (ducksfoot cultivator)

2. Herbicide screening. Pre-emergence and post-emergence herbicides are being tested, i.e.

Herbicide	*Time of application*
- Isoxaben	Pre-emergence of wheat and weeds
- Imazamethabenz	Post-emergence: from 3-leaf to tillering stage of wheat
- Sulfmethmeton methyl	Post-emergence: from 3-leaf to tillering stage of wheat
- L.flampro.isoprodil + MCPA	Shooting stage
- Diclofop-methyl + bromoxynil	4-leaf to tillering stage of wheat

Food legumes

The main problem of weed control in food legumes is the late emerging weeds. The only herbicides (Treflan) available are applied before the crop emerges, and their persistence is limited.

New pre-emergence and post-emergence herbicides are being tested for their effectiveness on food legume weeds, in chickpea and lentils, in a joint program with INPV. These chemicals are as follows:

- Setoxydine	Post-emergence
- Terbutryn	Pre-emergence
- Fluazifop-butyl	Post-emergence
- Carbetamide	Post-emergence
- Pyridate	Post-emergence
- Prophyzamide	Pre- or post-emergence
- Pendimethaline + Neburon	Pre-emergence
- Methobromuran	Pre-emergence
- Prometryne	Pre-emergence
- Diclofop-methyl	Post-emergence

The results of a chickpea international weed control trial conducted at El-Khroub Agricultural Research Station, during the 1986/87 season, showed that pre-emergence application of terbutryn (Igran) at a rate of 3 kg a.i./ha provided the highest yield (1568 kg/ha) which was an increase of about 62% over a weedy check (968 kg/ha) (ICARDA/FLIP 1989).

Conclusion

Production of cereals and especially food legumes has not increased to its potential level. This is due mainly to the inappropriate application of the different cultural practices, lack of incentive, inadequate extension, not enough effective equipment, and low production prices. Research, extension, development and incentives offer great potential for the increase of yield in both types of crop.

Since the weed problem is not confined to particular areas, but is a general and serious problem to crop production everywhere, it is essential to think of weeds as a main yield-reducing factor. Therefore weed control must be intensified by all means to reduce weed intensity and infestation. At present, chemicals offer the best possibility because of their competitive prices, low investment, ease of application, and instant effect which encourages farmers. Weed control should not remain optional, but should become obligatory. However, integrated weed control, which combines use of chemicals with soil and crop management practices should be considered as the key element for this, when possible unavailability of chemicals and also the dangers of environmental pollution are taken into account.

The government is contributing towards increasing yields and production through production prices and by making the major inputs available to farmers.

References

Benbelkacem, A. 1987. Pages 142-147 *in* Proceedings of an international symposium on Winter Cereals and Food Legumes in Mountainous Areas. 6-10 July 1987, Ankara, Turkey. (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds). ICARDA-136 En, Aleppo, Syria.

CIMMYT 1976. Algeria. Pages 142-165 *in* Report on Wheat Improvement. CIMMYT, Lisboa, Mexico.

CIMMYT 1983, 1985. World wheat facts and trends. Report 2: 1983, Report 3: 1985. CIMMYT, Lisboa, Mexico.

Direction de la production vegetale Ministere de l'Agriculture. Evolutions des Grandes Cultures. Campagnes 1973/74 a 1985/86, Algiers, Algeria.

Hamadache, A. 1988. Les methodes de lutte contre les mauvaises herbes des cereales d'hiver. Station Experimental de l'ITGC Oued Smar - Alger, Algeria.

ICARDA-FLIP 1989. Food Legume Improvement Program, International Nursery Report No. 11, Food Legume Nurseries 1986/87, ICARDA, Aleppo, Syria.

ITGC 1976, 1977a. Annual reports, Section Experimentation. Station Experimentale de l'ITGC du Khroub - Constantine, Algeria.

ITGC 1977b. Revue Cerealiculture No. 2, Alger, Algeria.
ITGC 1982, 1983. Station Experimentale de l'ITGC du Khroub. Seminaire Regionale sur la mecanisation des legumes secs. El-Khroub, Constantine, Algeria.
ITGC 1986, 1987, 1988. Annual reports 1986, 1987, 1988 Station Experimental le l'ITGC de Tiaret, Algeria.
Maatougui, M.E.H. 1987. Country report *in* ICARDA International Workshop on Genetic Resources of Cool Season Pasture, Forage and Food Legumes for Cool Semi-arid Temperate Environments. June 19-24, 1987, Cairo, Egypt.
OAIC 1987-89. Cereal and food legume cooperative (list of prices), Algeria.

On-going Research in Weed Control in Afghanistan

G.M. BAHRAM, N. HARIQ, M.M. MOHAMMAD AYUB

Agricultural Research Institute, Ministry of Agriculture and Land Reform, Kabul, Afghanistan

Abstract

Afghanistan's economy is based on agriculture, which contributes more than 68% to the GNP. However, crop management practices are generally very poor and crop yields pretty low. Numerous research programs on various aspects of crop management have been carried out. Weed control is a major problem, but there has been no study determining the costs of weeds in Afghanistan. Manual and mechanical weed control methods have been widely employed. Herbicides are not widely used but have been introduced to farmers. Comparative efficiency of hedonal and tribunil for controlling weeds in winter wheats has been studied in three agroecological regions in Afghanistan. Herbicides increased wheat grain yield 1.3-21.3, 3.4-29.3 and 18.8-98.6% over the weedy check at Kabul, Herat and Baghlan, respectively. Further it was found that herbicidal efficiency was as good as repeated hand weeding at controlling weeds, and also seems to be economic.

Introduction

Afghanistan is a land-locked country, mostly covered by high mountains, rangeland and desert plains, characterized by arid and semi-arid climatic conditions. Out of a total geographical area of 62.23 million hectares the cultivable area is limited to 8.0 million hectares. Of this, only 4.9 million hectares are cultivated, with irrigation facilities for 2.586 million hectares. Forests cover 1.97 million hectares, of which 1.3 million hectares are evergreen. The better quality rangeland covers about 9 million hectares and provides pasture for 1.1 million milking cows, 3.0 million goats, 5.5 million karakul sheep and 14.7 million ordinary sheep.

The country has a population of about 17 million with a growth rate of 2.51%: 28% of the labor force is engaged in agriculture. Although improved varieties of various crops are being adopted by some farmers, due to traditional methods of cultivation the yields are low. Some farmers are reluctant to use improved varieties, while those who are willing cannot obtain the seed, and crop management practices are generally very poor (Bahram 1982).

Research Programs in Afghanistan

The Agricultural Research Institute of Afghanistan, the Faculty of Agriculture, Kabul University and the Faculty of Agriculture, Rushan University carry out numerous research programs on various aspects of crop management, including weed control. Although we are expanding our efforts to improve methods of weed control, we retain an interest in exploiting possible benefits of weeds. Unfortunately there has been no study on determining the costs of weeds in Afghanistan, but it is evident that the losses caused by weeds are more than the losses caused by any other category of agricultural pests. As in the other developing countries, the losses in reduced crop yields and quality and the cost of weed control in Afghanistan demand greater attention, particularly from the research organizations, towards concentrating efforts on weed control. For comparison, according to an ICARDA study in 1977/78, effective weed control could increase cereal yield by 20% or more and legume yield by about 40% (ICARDA 1980). In on-farm trials conducted by ICARDA in Northern Syria in 1984/85, weed control gave a 27% mean yield increase in wheat (average of 18 sites) (ICARDA-FSP 1985) and similarly in 1985/86, weed control provided an 18% mean yield increase in wheat (average of 15 sites) and about a 25% increase in lentil and chickpea yields (average of 18 sites) (ICARDA-FSP 1986).

Weed Control Measures in Afghanistan

Weed control is a major problem of crop management. Ploughing, hoeing, hand pulling, burning, flooding and crop rotations have been widely employed as the more important means of weed control. In some parts of the country ashes and salt have also been used for this purpose. Herbicides are not widely used but have been introduced to the farmers. Weed control methods, each of which has its special impact on different weeds, depending on their habitat, play a major role in retaining water for crop use. Rain, snow, hail, dew, fog and irrigation provide necessary water for plant use. This water is not only lost by percolation, runoff, evaporation and transpiration, but is also used up by weeds. Afghanistan is facing serious problems in relation to water supply, and weed control is crucial for boosting water use efficiency in crop management practices. The competition of weeds with crops in using water, sunlight and soil nutrients, and even the secretion of poison by some weeds, greatly jeopardize crop yield and quality. The most common weeds identified in crop fields are listed in Table 1.

Weed control methods of a preventive, biological, managerial, physical and chemical nature are to be fully introduced to the farmers, although the Afghan farmers already, directly or indirectly, utilize to some extent some of these methods on their farms, all specific to certain weeds yet complementing each other (ARI 1987).

The significance of weed control in water use efficiency in rainfed areas

In Afghanistan water supply for crop use is a major problem and it is a limiting factor on yield and quality. The unequal distribution of rainfall and shortage of irrigation water is a determining factor in the utilization of water by crops for reproduction and survival. Manipulation of water supplies plays an important role in controlling weeds and also make weeds more susceptible to other control measures.

Weeds constitute a serious problem in many crop growing areas, particularly in the regions of Kabul, (high, cooler, 300 mm rainfall) Herat, Baghlan (lower, dry and cold, 250-300 mm rainfall) and Kunduz (lower, warmer, 400-500 mm rainfall). Hand weeding is not only difficult, time-consuming and laborious but also at times is not possible, because most weeds come out in greatest numbers during the spring, coinciding with the rainy season and the spring-sowings. Even if the farmer wants to do the weeding, he does not have the time and resources. Consequently, weeding remains a neglected problem.

Table 1. Common weeds identified in our research on field crops

Common name	Scientific name	Life cycle
Canada Thistle*	*Cirsium arvense* (L.) Scop.	Perennial
Russian Knapweed*	*Centaurea repens*	Perennial
Hoary Cress*	*Cardaria draba*	Perennial
Shepherd's purse*	*Capsella Bursa-pastoris*	Annual
Field bindweed*	*Convolvulus arvensis*	Perennial
Sow Thistle	*Sonchus arvense*	Perennial
Quick grass	*Agropyron repens*	Perennial
Lambsquarters	*Chenopodium album*	Annual
Wild lettuce	*Lactuca scariola*	Annual
Dandelion	*Taraxacum officinale*	Annual
Wild Mustard	*Brassica kaber*	Annual
Wild oat	*Avena fatua*	Annual
Mallow	*Malva neglecta*	Annual
Purslane	*Portulaca oleracea*	Annual
Buckhorn plantain	*Plantago lanceolata*	Annual
Pigweed	*Amaranthus retroflexus*	Annual
Knotweed	*Polygonum* spp.	Perennial
Wild sunflower	*Helianthus annuus*	Perennial
Downy Brome	*Bromus tectorum*	Annual
Puncture-vine	*Tribulus terrestris* L.	Annual
Japanese honeysuckle	*Lonicera japonica*	Annual
Woollyloco	*Astragalus mollissimus*	Perennial
Rose clover	*Trifolium hirtum*	Annual
Alsike clover	*Trifolium hybridum*	Perennial
Kochia or Mexican Burning Bush	*Kochia scoparia*	Perennial
Bermuda grass	*Cynodon dactylon*	Perennial
Alfalfa	*Medicago sativa*	Perennial
Common sow thistle	*Sonchus oleraceus*	Annual
Black Medic or Yellow trefoil	*Medicago lupulina*	Annual
Nutsedge, purple	*Cyperus rotundus* L.	Perennial
Nutsedge, Yellow	*Cyperus esculentus* L.	Perennial
Camelthorn, Alhagi	*Alhagi camelorum*	Perennial
Wild carrot	*Daucus carota*	Biennial
Jimson weed	*Datura stramonium* L.	Annual

* Most common

Comparative efficiency of Hedonal and Tribunil for controlling weeds in winter wheats

The objective of this study was to compare the annual weed control efficiency of *tribunil* (methabenzthiazuron) (70% w.p., 1-benzothiazol-2 yl-1,3-dimethylurea) and *hedonal* (2,4-D) (30% w.p. 2,4-dichlorophenoxyacetic acid) herbicides at Kabul, Baghlan and Herat in *autumn*-planted wheat. The treatments consisted of four levels of tribunil (0.7, 1.4, 2.1 and 2.8 kg a.i./ha), three levels of hedonal (0.8, 1.6 and 2.4 kg a.i./ha), three levels of hedonal (0.4, 0.8 and 1.2 kg a.i./ha coupled with 3% urea) and two checks (handweed once in spring and unweeded except at Baghlan where it was kept completely free of weeds by weeding at 15- day intervals). There were 12 treatments which were tested in a randomized block design with four replications. Fertilizer dose was kept uniform.

The data presented in Table 2 reveal that use of weedicides increased wheat grain productivity over a weedy check by 1.3 to 21.3% at Kabul, 3.4 to 29.3% at Herat, and 18.8 to 98.6% at Baghlan. Further, it was noticeable that herbicides were as good at controlling

Table 2. Grain yield of wheat as influenced by different weed control techniques in various agro-climatic regions (grain t/ha)

	Rate (kg a.i./ha)	Kabul	Inc. over weedy check (%)	Herat	Inc. over weedy check (%)	Baghlan	Inc. over weedy check (%)
Tribunil	0.7	3.44	7.5	4.33	-8.1	2.90	36.1
Tribunil	1.4	3.88	21.3	3.58	-24.0	3.13	46.9
Tribunil	2.1	3.10	-3.1	3.74	-20.5	3.28	53.9
Tribunil	2.8	3.24	1.3	2.94	-37.6	2.53	18.8
Hedonal	0.8	3.49	9.1	5.10	8.3	3.15	47.9
Hedonal	1.6	3.51	9.7	4.87	3.4	4.23	98.6
Hedonal	2.4	3.79	18.4	5.93	25.9	3.03	42.3
Hedonal (+3% urea)	0.4	3.77	17.8	5.07	7.6	3.18	49.3
Hedonal (+3% urea)	0.8	3.69	15.3	6.09	29.3	3.45	61.9
Hedonal (+3% urea)	1.2	3.66	14.4	5.40	14.6	2.55	19.7
Weed-free check		3.91	22.2	5.41	14.8	3.88	82.2
Unweeded check		3.20		4.71		2.13	
SE (+)		0.15		0.22		0.30	
LSD (0.05)		0.43		0.65		0.87	
CV (%)		8		10		20	
Variety		Bezostaia		Bezostaia		Kalyan sona	

weeds as repeated hand-weeding. Repeated weeding at 15-day intervals at Baghlan proved, in general, far superior to weedicides, but it would cost the farmer much more.

Tribunil, on the whole, provided no satisfactory weed control since it was only as good as the unweeded check. This could be due to tip-burning caused by this herbicide at all the locations to varying degrees, depending upon the degree of aridity. This explanation is strengthened by the results achieved at Baghlan in the wettest area, where use of tribunil at 2.1 kg a.i./ha controlled weeds effectively and also improved the grain yield. Use of 2,4-D alone at 2.4 kg a.i./ha or 0.4 to 0.8 kg a.i./ha coupled with 3% urea proved equally effective in controlling weeds and increasing the grain yield of wheat. However, the latter appeared more economical for commercial use.

References

ARI (Agricultural Research Institute of Afghanistan), 1987. Annual Report. Kabul, Afghanistan.

Bahram, G.M. 1982. "Science and Technology for Sound Rural Development in Afghanistan". Academy of Sciences of the Republic of Afghanistan.

ICARDA, 1980. Pages 19-32 *in* Weed Control Research in Northern Syria 1978-79. Farming Systems Research Program Research Project 5. ICARDA, Aleppo, Syria.

ICARDA-FSP, 1985. Pages 56-57 *in* ICARDA Annual Report 1985, Aleppo, Syria.

ICARDA-FSP, 1986. Pages 87-96; 106-118 *in* Farming Systems Program Annual Report, Aleppo, Syria.

Effect of Various Components of the Management Package on Weed Control in Dryland Agriculture

N. DURUTAN, M. GULER, M. KARACA, K. MEYVECI, A. AVCIN and H. EYUBOGLU

Field Crops Research Institute (TARM), P.K. 226, Ankara, Turkey

Abstract

Water supply is the major yield-limiting factor in dryland areas and must be more efficiently used if increased crop production is to be achieved. Correct tillage and moisture conservation practices will increase soil moisture and reduce losses from evaporation and transpiration, and correct crop management practices will make the best use of water stored in the soil and precipitation. Research is in progress in Central Anatolia to determine the cultural practices best suited for such an environment. Weed control is one of the most important components of a management package because weeds compete with crops for the limited water. Weeds can be controlled through proper seedbed preparation, tillage and seeding methods, which affect stand establishment and thus ability to compete, and through crop rotations. Fertilization and selection of crop varieties also have an effect on weed growth and density. The management of fallow and its possible reduction by 33 to 50% is also important in relation to weed control and water use efficiency (WUE).

Introduction

The Central Anatolian Plateau is one of the largest dryland areas in the Mediterranean Basin. More than 50% of the total area is occupied by dryland wheat and barley grown as winter crops in rotation with either fallow or some alternative crops (Fig. 1).

Although a fallow - small grains rotation has been the primary cropping pattern for centuries, this has been changed remarkably in recent years. With the implementation of the project "Utilization of Fallow Areas", fallow was replaced by certain crops, mainly by legumes like lentil, chickpea and vetch in the higher rainfall areas. Reduction of fallow areas has become very popular among the farmers, and fallow practice has been gradually abandoned, not only in the project areas but in many other locations as well (Durutan *et al.* 1990). However, cropping intensity not only depends on annual precipitation but also on economic factors and government policy.

The climate

Central Anatolia carries the common climatic characteristics of the dryland areas as characterized by Oram (1980):

1. low total rainfall with at least one pronounced dry season (sometimes two) so that lack of moisture puts a ceiling on year-round cropping even though it may be adequate for one crop (Fig. 2);

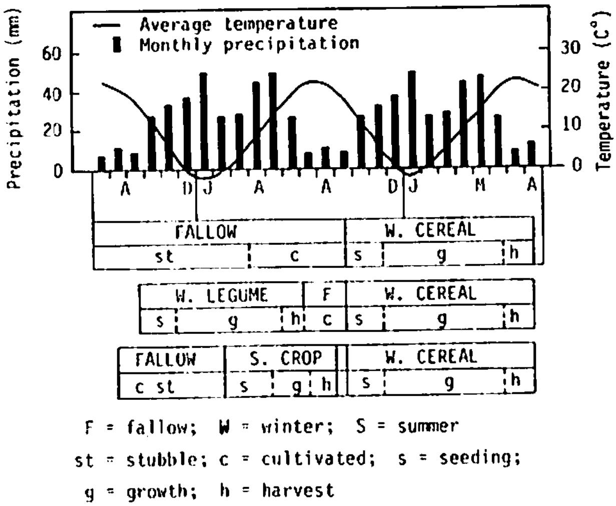


Fig. 1 Monthly average temperature and total precipitation and a schematic time base for common cropping systems in the Central Anatolian Plateau.

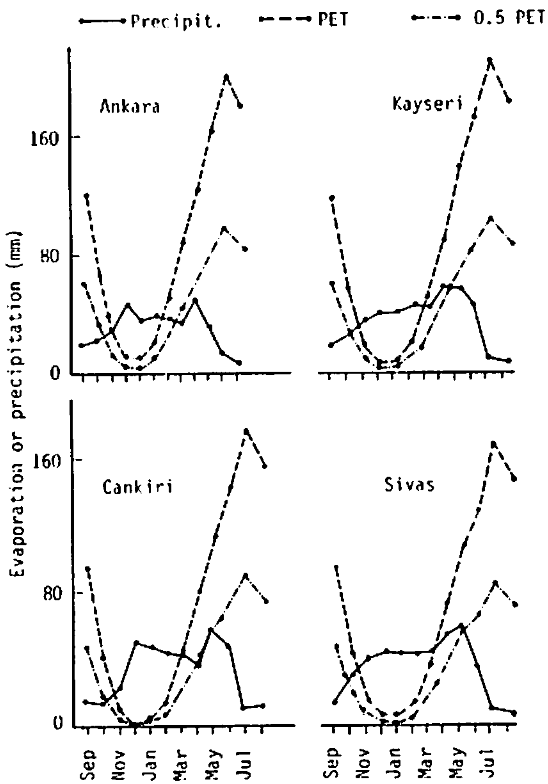


Fig. 2 Agroclimatic characteristics of four representative dryland locations in the Central Anatolian Plateau.

2. highly variable and unreliable precipitation during the rainy season with large year-to-year differences in total rainfall and its distribution, and from month to month within seasons (Figs 3 and 4);
3. increasing unreliability and variability with decreasing annual rainfall;
4. potential evapotranspiration exceeding precipitation for at least 7 months of the year (Fig. 2);
5. very high intensity rainstorms leading to high runoff and erosion.

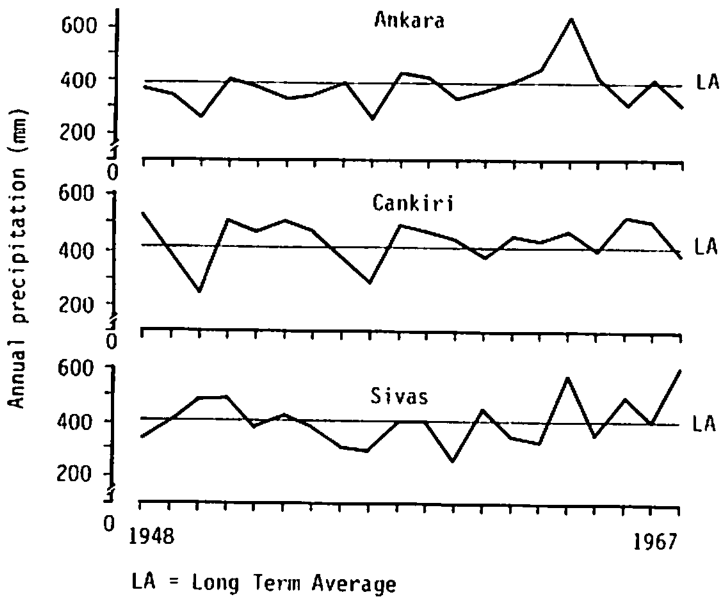


Fig. 3 Year-to-year differences in total precipitation in three different locations in the Central Anatolian Plateau.

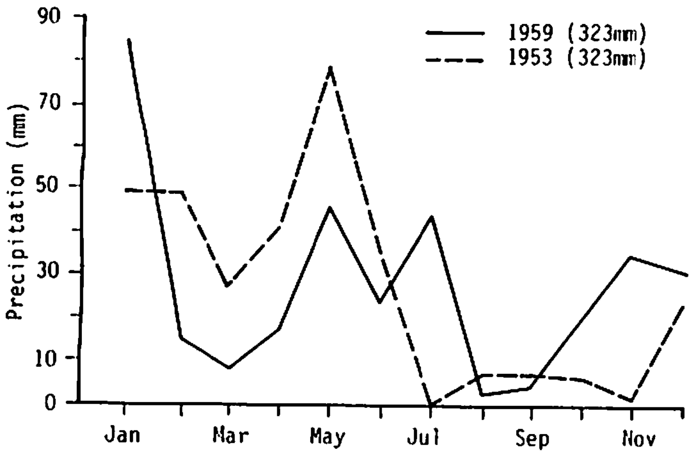


Fig. 4 Variability in monthly precipitation in two years with identical totals in Ankara.

The area is included in the "semiarid" bioclimatic zone (0.20 < P/PET < 0.50) according to the climatic aridity index established by the United Nations Conference on Desertification (UNESCO 1977). The area is also classified as "semiarid" in terms of growing period by the FAO classification (FAO 1978): it has a normal growing period that includes a humid period (Fig. 1).

The rainfall distribution pattern occurring in Central Anatolia is the winter rainfall type which is also known as "Mediterranean" (Steiner *et al.* 1988; Durutan *et al.* 1990). Most of the precipitation occurs in 7-8 relatively cool months (Fig. 5). These wet months are followed by hot and dry summer months.

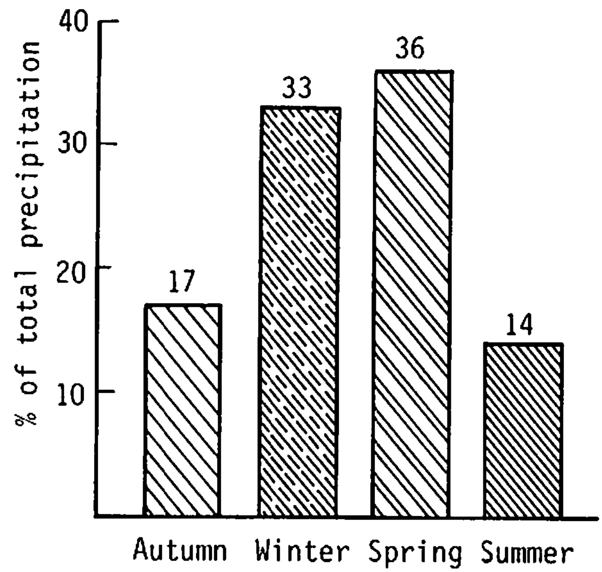


Fig. 5 Rainfall distribution pattern in the Central Anatolian Plateau.

Due to cold temperatures, low radiation and high relative humidity during winter months, the crop transpiration and soil evaporation rates are very low. Consequently, precipitation in excess of crop evapotranspiration is accumulated in the soil profile (Fig. 2). The stored moisture contributes to the water requirements of the crops in the rest of the crop cycle.

As the season proceeds the warmer temperatures coupled with higher radiation and lower relative humidity result in high rates of evaporative demand. During this period, particularly after May, the rainfall diminishes and is no more than half the potential evapotranspiration, except in the transitional zones.

The soils

Soils of the Central Plateau belong to the Great Brown Soil Group. Fifty six percent of the central drylands have clay and clay loam soils. Approximately 40% are loam. Most soils present limitations in water conservation since the depth is around a meter over the calcareous parent material. These soils have low water intake rate with very slow downward movement into the subsoil, but when evaporation takes place at the soil surface considerable upward movement occurs. Generally the soils are poor in organic matter and phosphorus, but most are rich in lime and potassium (Durutan *et al.* 1986).

Weed control and water use efficiency

It is clear that the major yield limiting factor on the Plateau is the water supply. Therefore economic and stable production can only be achieved through more efficient use of the limited soil moisture.

Bolton (1981) identifies two things that must be done in order to do this: 1) increase the amount of water stored in the soil, and reduce losses due to evapotranspiration and 2) make maximum use of stored water and subsequent precipitation by management of cropping practices geared to the prevalent climatic conditions. The former is related to tillage and moisture conservation practices, and the latter is concerned with crop management practices specifically tailored to fit the available and expected moisture supply to achieve maximum economic crop production.

Although limited, variable, and unpredictable precipitation restricts the yield potential in dryland areas, it is possible to increase the actual yield through application of a proper management package. Weed control is an important component of such a package because it is one of the most effective means of increasing the amount of water available to the crops and so, of increasing water use efficiency. According to Bolton (1983), other improved cultural practices without adequate weed control will generally lead to disappointing yield results.

During the fallow period, efforts should be directed towards preventing the use of limited soil moisture by the weeds and conserving it for crop use. Therefore to obtain maximum water storage for the subsequent crop, land must be kept free of weeds.

In the crop year, scarcity of moisture creates severe competition. In order to minimize the negative effect of such competition, an effective weed control program should be followed, particularly in the early stages of the crop cycle.

The success of the program depends on combining herbicides with various agronomic practices that suit the local conditions of dryland areas. The most dependable results in weed control as well as other areas of pest control are currently achieved by combining various complementary methods into a management system. This basic concept underlines effective weed control practice. However, the choice of methods and techniques of agricultural weed control may vary with region, crop, the nature of weed infestation and the level of agricultural mechanization.

Almost every component of the management package influences weed growth. In other words, if used properly, every element of the package contributes to weed control to a certain degree. Therefore, when efforts are directed towards the particular goal of each element, the side-effect of the operation on weeds should also be taken into consideration.

In various research projects conducted by the Field Crop Improvement Center (TARM) in the Central Anatolian Plateau data on weeds have been collected.

Soil Management

Fallow - wheat system

To determine the proper fallow tillage system for the Plateau, TARM tested various soil tillage systems in terms of infiltration rate, moisture conservation, weed density and wheat yields (Durutan 1982; Karaca *et al.* 1988). The results (Fig. 6) indicated that a soil mulch system provided significantly higher yields due to higher infiltration rate, increased soil water storage and fewer grassy weeds (*Bromus tectorum* L.).

The lowest weed density occurred with a soil mulch system, as shown in Fig. 6. The regression equation indicated that every 100 culm increase in *Bromus tectorum* density would result in a 0.29 t/ha yield decrease. Because of the dual benefit of the system for increasing soil water supply and for reducing weed problems, the soil mulch system is recommended to farmers.

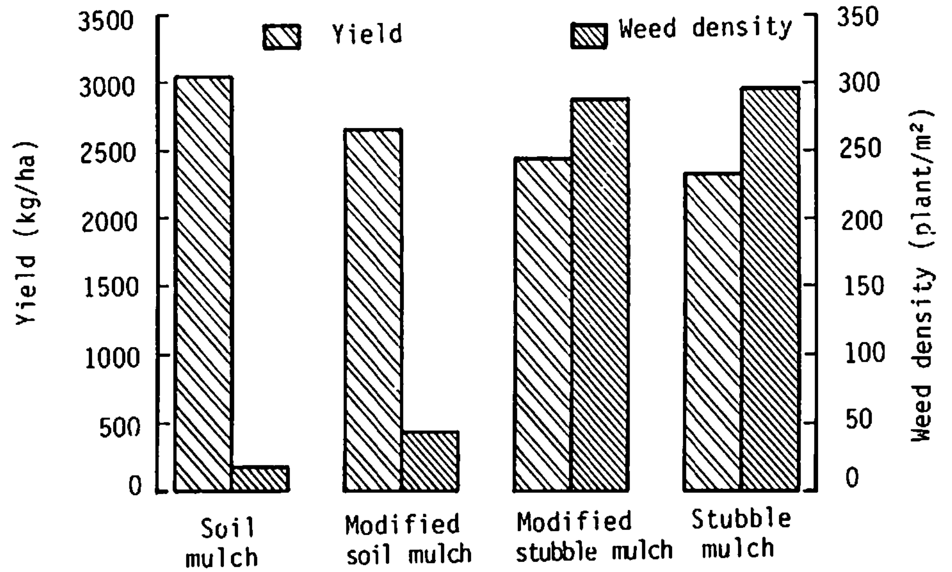


Fig. 6 Effect of fallow tillage systems on wheat yield (kg/ha) (1976-80) and grassy weed density (plant/m^2) (1979/80).

It requires timely tillage operations at critical times. For instance, the first tillage should be performed in early spring as soon as the best possible soil conditions occur and before weeds and volunteer wheat have attained much growth. From the point of view of weed control timeliness has a major effect. Tillage delayed until late spring increases the weed density and markedly reduces the stored soil water. This results in increased weed density in the crop year as well (Pala *et al.* 1980). The data obtained by TARM from the initial tillage time experiment are given in Fig. 7.

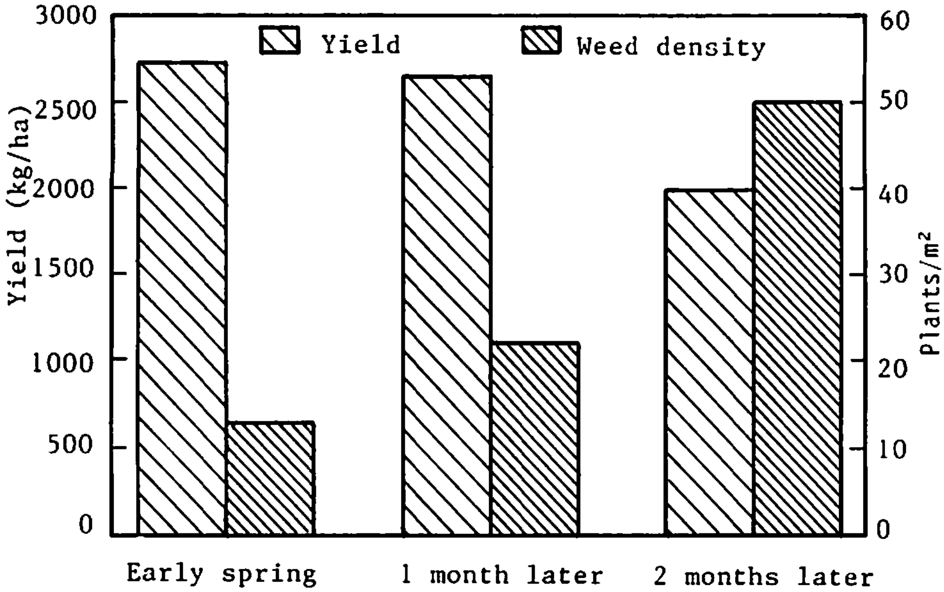


Fig. 7 Effect of time of initial tillage on wheat yield (kg/ha) and weed density (plant/m^2), 1977/78.

During the summer the water supply is very limited due to hot dry weather, so weed control becomes more critical. The soil mulch system requires two or three tillage operations in the dry period to keep the land free of weeds and to maintain a loose soil mulch layer providing thermal insulation with significant resistance to liquid and vapor flow. Research data obtained on the Plateau indicated that significant yield increases were obtained with summer tillages over no summer tillage (Durutan *et al*, 1989). The shallow cultivations with sweep reduce transpiration losses, prevent weeds from producing viable seeds and contribute to seed-zone soil water (Fig. 8).

Annual cropping system

Two of the important problems in annually cropped dryland areas are seedbed preparation and seeding methods in the rotation. Observations on the Plateau indicated that success of the rotation largely depends on these two factors. Therefore, TARM established two research projects aimed at determining the proper methods for spring lentil-wheat and winter vetch-wheat systems. The data obtained up to now have shown that there were significant differences among the methods tested in terms of WUE, yield, and weed control.

Results indicated that weed growth is closely related to the tillage and seeding method used. Ploughing significantly lowered the weed growth in lentil compared to sweep. When a mouldboard was used in the previous autumn the weed growth was 22% less compared to ploughing in spring (Fig. 9). Ploughing in autumn and drilling in spring significantly increased the water use efficiency and yield of lentil.

Weediness, regardless of the methods used, caused significant decreases in water use efficiency and yield of lentil (Fig. 10).

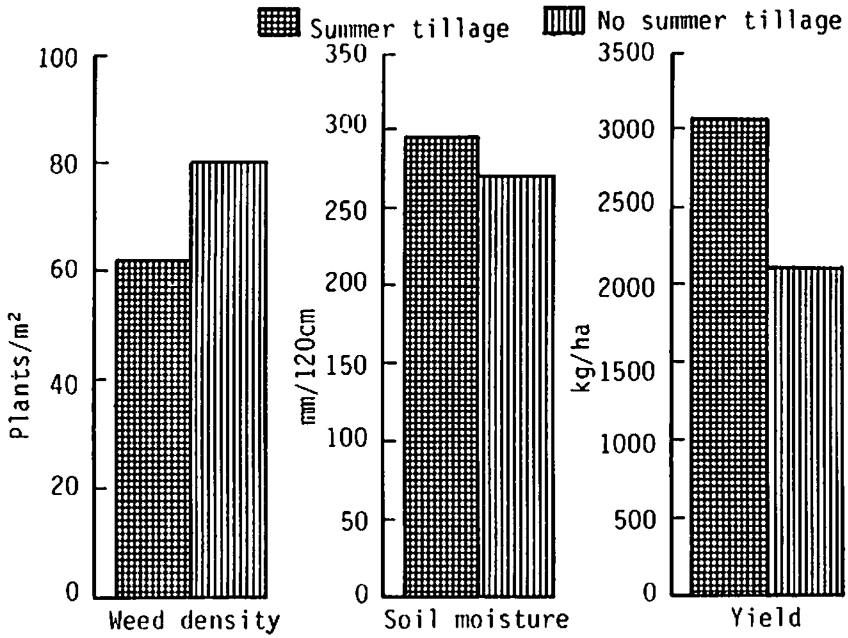


Fig. 8 Effect of summer tillage on weed density (plant/m^2), soil moisture at seeding time (mm/120 cm) and wheat yield (kg/ha), 1980/81.

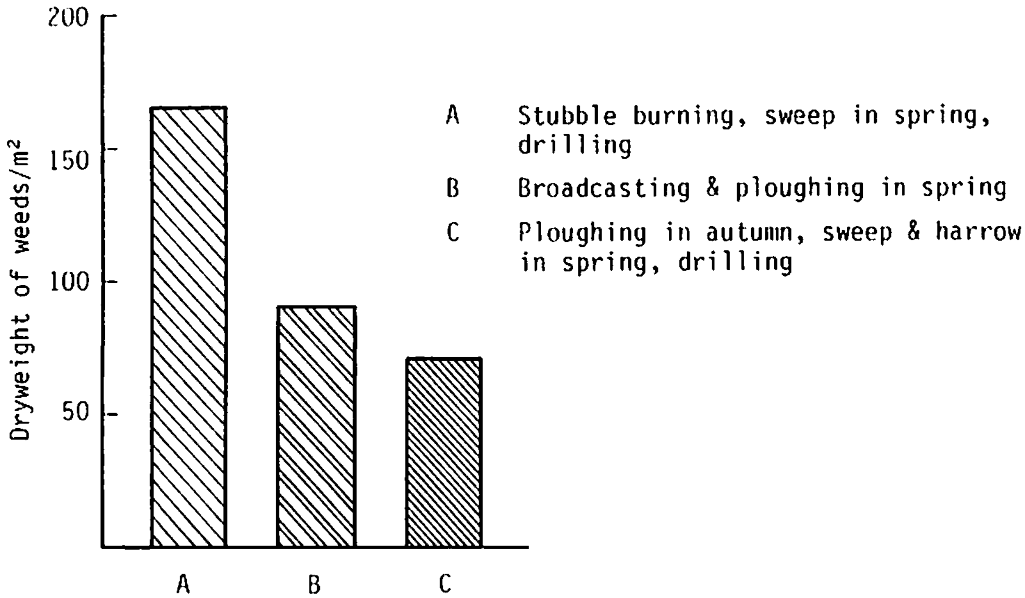


Fig. 9 Effect of seedbed preparation and seeding methods on weed growth in spring lentil, 1984-87.

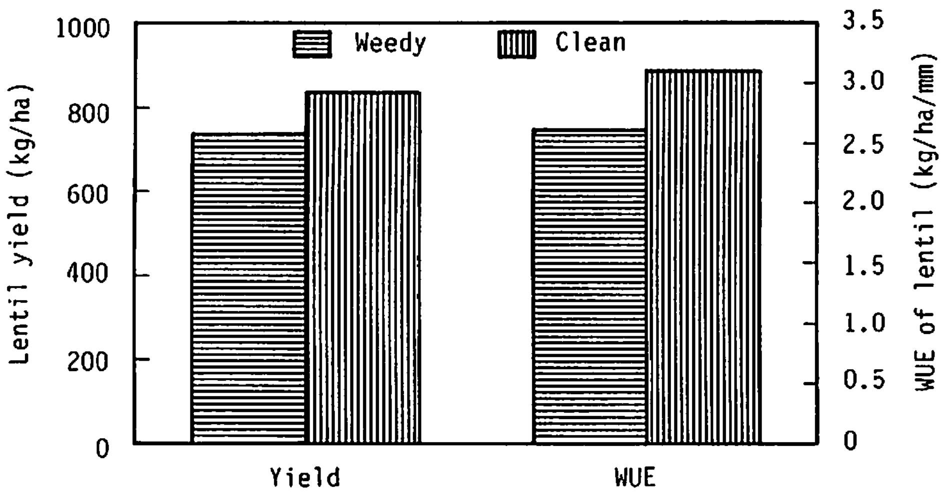


Fig. 10 Effect of weediness on WUE and yield of spring lentil, 1984-87.

Lack of weed control in lentil not only decreased the lentil yield, but significantly lowered the subsequent wheat yield as well (Fig. 11). The wheat crop following weedy lentil started the season at a disadvantage in terms of soil moisture level at the seedbed zone, and since viable seed development, mainly of annual broadleaved weed species, had not been suppressed in the previous year the weed density increased remarkably in the wheat year, resulting in significant yield losses.

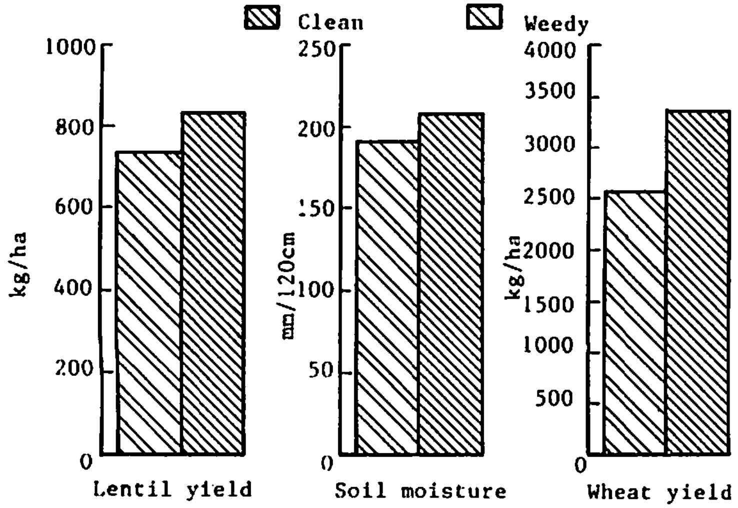


Fig. 11 Effect of weediness of lentil on lentil yield (kg/ha), soil moisture after lentil harvest (mm/120 mm) and subsequent wheat yield (kg/ha), 1984-87.

Management in the Crop Year

Cropland represents a plant community of the crop in association with weeds. In this environment weeds compete with each other and with the crop plants. A principle of plant competition is that the first plants to occupy an area have an advantage over latecomers. This is important in practical weed control, where cropping practices are always directed at the establishment of the crop ahead of the weeds (National Research Council 1968). During the growth cycle efforts should be directed towards maintaining the crop in a dominant or superior competitive position. Therefore, every component of the package of practices should be carefully determined and performed.

Variety

It is well known that improved varieties have contributed remarkably to the yield increase in the dryland areas over the years. When improved management and improved varieties are incorporated in the production system maximum benefits are obtained. This is the key factor in increasing the WUE in dryland areas.

Varieties not only differ in their yield potential but in their competitive ability as well. In general the competitive ability of traditional/local varieties is relatively higher than of improved ones. Under either poor fertility or poor farming conditions plants tend to give sparse stands and the ecological niches are quickly occupied by weeds. Even when weed control is poor local tall varieties can still survive by overshadowing most weeds.

In addition, these varieties are characterized by rapid growth that enables them to be better competitors.

In several studies carried out by TARM the common wheat varieties of the Central Plateau were compared in terms of competitive ability. The results indicated that bread wheat varieties were more competitive than durum wheat varieties. Height and tillering capacity were the main characteristics defining competitive ability (Table 1). Under weedy conditions the greatest number of weeds occurred in the shortest durum wheat variety, Cakmak 79.

This evidence strengthens the argument that introduction of new varieties with higher yield potential but less competitive ability has little value unless weeds are controlled. In relatively poor farming areas of the Central Plateau, farmers are encouraged to use all means of weed control if they are to grow improved short varieties.

Table 1. Effect of some agronomic characteristics on crop competition, 1979/80 (Durutan 1982)

Variety	Av. height (cm)	Tillering capacity (tiller/plant)	Weed density (plant/m^2)
Bolal 2973 (bread wheat)	90	1.76	13
Gerek 79 (bread wheat)	89	1.70	20
Haymana 79 (bread wheat)	91	1.63	28
Cakmak 79 (durum wheat)	79	1.23	40

Stand establishment

In dryland cereal-producing areas with a winter precipitation pattern, the optimum time of stand establishment may have a considerable effect on water use efficiency (in relation to economic yield) by ensuring that the crop growth is adjusted to the available soil moisture (Bolton 1981).

A crop that is seeded in a clean, moist seedbed germinates and emerges quickly, gaining the advantage of being early. The subsequent growth before the onset of cold weather depends on the establishment of a uniform, vigorous ground cover from the beginning. Therefore, through fallow tillage and/or seedbed preparation an optimum habitat for rapid crop emergence should be provided. Then, the optimum planting date that suits the local ecological conditions should be determined.

Studies carried out on the Central Plateau indicated that advancing the planting date from early November to early October gave winter wheat seedlings a quick start. Well developed roots enabled the crop to compete with weeds in early growth stages (ORZA 1978).

A uniform, vigorous stand is established by using optimum seeding rates. Many studies conducted in different dryland regions of the world have shown that optimum rate of seeding is closely related to the local ecological conditions.

Seeding rate studies conducted on the Central Plateau indicated that in the case of seeding with very low rates, the additional space can be taken up by the weeds, and weeds and volunteer crop plants compete strongly with planted crops, mainly for moisture, causing remarkable yield losses. Data on seeding rate experiments have shown that varieties with higher competitive ability were not as severely affected by lower densities as relatively poor competitors (Fig. 12). For instance, dryweight of weeds attained at the lowest seeding density (225 seeds/m^2) in Cakmak 79, was the highest (160 g/m^2) among the varieties tested. Therefore, as the number of crop plants per unit area increased, the weeds were less of a problem, providing the most remarkable dryweight reduction (57%) at the optimum seeding density (450 seed/m^2). Bolal 2973, the tall bread wheat variety, competed more satisfactorily with the weeds even at sparse stands like 225 seeds/m^2. Higher densities did not lower the weed growth as remarkably as Cakmak 79. The dryweight reduction of weeds at the optimum seeding rate was 27%.

Fertilization

One way to minimize the competition or interference effect of weeds on crops is proper fertilization. In a greenhouse study the effect of nutrients on the competitive ability of the crop was investigated. As expected, the dryweight of wheat was decreased under weedy conditions. However, the rate of decrease was significantly higher in nutrient-deficient crop plants (Table 2) (Durutan 1982).

A balanced nutrient supply not only increases the water use efficiency of the crop directly, but indirectly affects it through increasing its ability to compete with weeds. Similar results were obtained from on-farm trials conducted in northern Syria during 1984/85 and 1985/86 (ICARDA-FSP 1985, 1986). Results from 18 locations in 1984/85 showed that mean yield reduction under weedy conditions was 32% in unfertilized plots whilst it was 18% in fertilized ones as compared with fertilized + weed free plots. In the 1985/86 cropping season,

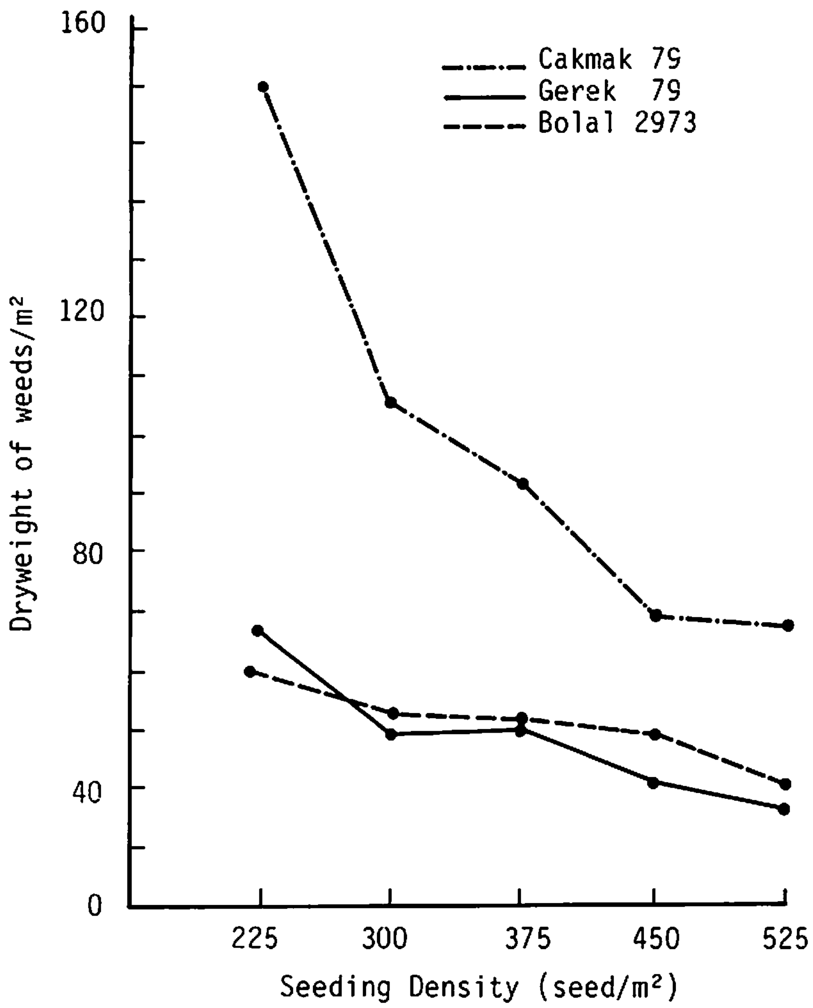


Fig. 12 **Effect of seeding density (seed/m^2) on weed growth (DM weeds/m^2) in some wheat varieties of the Central Plateau, 1980-82.**

Table 2. Effect of fertilization on dry-weight of wheat under weedy conditions

	Decrease in dry weight of wheat (%)
Fertilized	2.7
Unfertilized	14.3

the results from six locations showed the same trend but of different magnitude, with yield reduction of 27% and 8%, respectively.

Cropping sequence

Crop rotation is the best cultural method of weed control available because the different planting times and periods tend to keep the weed population down. Data obtained from the Central Plateau indicated that continuous wheat created the most serious grassy weed problem (Fig. 13) since the competing plants are most alike in vegetative habits and demands upon resources. In the absence of an effective herbicide the grassy weed population increases tremendously, resulting in serious crop failure. Tilled fallow represents on extreme condition of soil disturbance for the weeds. Although over time weeds develop some adaptations that permit them to survive, timely tillages during fallow period are sufficient to ensure adequate weed control, as shown in Fig. 13. In the two-year cropping sequence, winter and/or summer crops were alternated with wheat, and weed levels in the subsequent wheat did not build up.

Herbicide application in the crop year

The rate of yield increase caused by herbicide spraying in the crop year depends on the weed density and growth. Studies carried out on the Central Plateau showed that the yield increase by herbicide treatment varied greatly among the years in the same area. In a three-year period the yield increases were 14, 26 and 9% (TARM 1985-88).

Data obtained from the same studies indicated that the WUE value of sprayed wheat was significantly higher than of wheat left weedy.

Successful weed control programs should integrate mechanical, cultural and chemical methods. In this way limited water supply in dryland areas can be used efficiently.

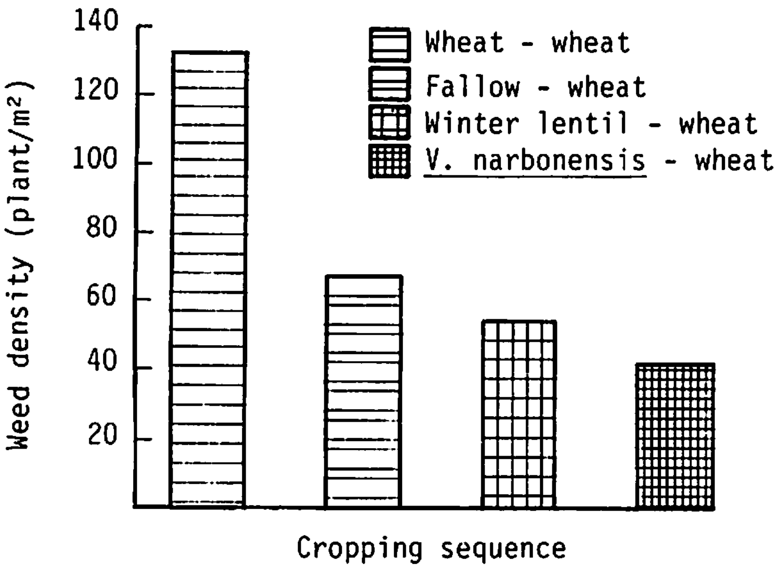


Fig. 13 Effect of cropping sequence on the grassy weed density (plant/m^2) in wheat.

References

Bolton, F.E. 1981. Optimizing the use of water and nitrogen through soil and crop management. Plant and Soil 58: 231-248.

Bolton, F.E. 1983. Cropping Practices: Pacific Northwest. Pages 57-72 *in* Dryland Agriculture, Agronomy monograph 23. Dregne, H.E. and Willis, W.O, eds). USA-CSSA-SSSA, Madison, WI, USA.

Durutan, N. 1982. Orta Anadolu Bugday Ekim Alanlarinda Brom (*Bromus tectorum* L.)'un yayilisi, Biyoekolojisi ve Mucadele Olanaklarinin Arastirilmasi Doktora Tezi, A.U. Ziraat Fakultesi, Ankara, Turkey.

Durutan, N., Pala, M., Karaca, M. and Yesilsoy, M.S. 1989. Soil management, water conservation and crop production in the dryland regions of Turkey. Page 60 - 77 *in* Soil, Water and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region. (Whitman, C.E., Parr, J.F., Papendick, R.I. and Meyer, R.E., eds) Proceedings of Workshop on Soil, Water and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region, Amman, Jordan, Jan. 1986. USDA, Washington.

Durutan, N., Meyveci, K., Karaca, M., Avci, M. and Eyuboglu, H. 1990. Annual cropping under dryland conditions in Turkey. Pages 239-255 *in* Proceedings of Workshop on the Role of Legumes in the Farming Systems of Mediterranean Areas, Tunis, Tunisia, June 20-24, 1988. (Osman, A.E., Ibrahim, M.H. and Jones, M.A. eds). Kluwer Academic Press, Dordrecht, The Netherlands.

FAO 1978. Report on the agro-ecological zones project: Methodology and results for Africa. World Soil Resource Report 481. FAO, Rome, Italy.

ICARDA-FSP, 1985. Pages 56-57 *in* ICARDA Annual Report, Aleppo, Syria.

ICARDA-FSP, 1986. Pages 87-96 *in* Farming Systems Program Annual Report, Aleppo, Syria.

Karaca, M., Guler, M., Durutan, N., Pala, M. and Unver, I. 1988. Effect of fallow tillage systems on wheat yields in Central Anatolia, Turkey. Pages 131 - 133 *in* Challanges in Dryland Agriculture. A Global Perspective. Proceedings of International Conference on Dryland Agriculture, Texas, USA, August 1988.

National Reserch Council 1968. Committee on Plant and Animal Pests. Principles of Plant and Animal Pest Control. Vol. 2. Weed Control. National Academy of Science, Washington, DC, USA.

Oram, P. 1980. What are the world resources and constraints for dryland agriculture? Pages 17-78 *in* Proceedings of the International Congress on Dryland Farming. South Australia Department of Agriculture, Adelaide, Australia.

ORZA 1978. Orta Anadolu'da 1970-76 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari. ORZA, Ankara, Turkey.

Pala, M., Guler, M., Unver, I., Durutan, N. and Karaca, N. 1980. Orta Anadolu'da nadas donemi ilkbahar toprak isleme zamaninin bugday verimine etkisi. Tarimsal Arastirma Dergisi, cilt 2: (2) S: 78-88.

Steiner, J.L., Day, J.C., Papendick, R.I., Meyer, R.E. and Bertrand, A.R. 1988. Improving and Sustaining Productivity. Pages 79-122 *in* Dryland Regions of Developing Countries. Advances in Soil Science, Vol. 8. Springer - Verlag, New York Inc., USA.

TARM 1985-88. Annual Reports (in Turkish), Ankara, Turkey.

UNESCO 1977. World Map of Desertification. United Nations Conference on Desertification Report A/Conf. 74/2. United Nations, New York, USA.

The extent of the effect of weeds upon crop yield relative to other factors varies. It would appear that high weed density is particularly significant for crops that are short, as the improved high-yielding varieties tend to be, because they cannot compete with taller weeds. Weed control seems to be one of the two most important components of a management package to increase yields, together with nitrogen fertility (Guler; Zeghida). Weeds are not necessarily a disadvantage, however. It is well-known that in North Africa weedy fallows provide much-needed grazing for livestock, and any program for fallow replacement must take account of this. It should be recognized that within a weedy fallow, regarded as forage, there are many species that may rightly be considered as "weeds" because they have little or no feed value. This is a reason for trying to replace weedy fallow with a medic (or some other) pasture system, as in Algeria. In the dry areas of the high plateaux there, they are aiming to replace fallow with annual medics, or dual-purpose barley where medics do not do well. In the wetter areas (>450 mm) fallow will be completely replaced with intensive forage crops and food legumes (Jones; Zeghida).

Another possible advantage of weeds in fallow is that they might play a role in keeping mineralized nitrogen within the upper layers of soil thus making it available to subsequent crops, although there is little evidence for this. Some research comparing the effects of weedy and clean fallow on protein content of wheat grain found that weedy fallow in fact reduced the protein by 2% (Gregory; Pala).

When chemical weed control is compared with hand weeding, depending on the crops and weeds involved, selective herbicides can be as effective as hand weeding, and certainly less time- and labour-consuming. Which method to use will depend on the availability and cost of the two methods (Khaldi; Amor).

The timing of weed control measures is critical but often difficult to determine, especially with variable management practices. If the farmer waits for the first weeds to emerge, so that they can be ploughed in at the same time as the seeding operation, the crop does not benefit from the first rains and growth will be delayed, thus increasing the risk of drought stress at seed-filling stage (Farah). There can be no hard and fast rules: such decisions are highly location and year specific.

In some areas of the Central Plateau in Anatolia farmers tend to burn the stubble in a continuous cropping system, expecting some benefit in weed control, but if the weeds have already set seed the burning does not have much effect; the flames pass over the seeds so quickly that they are not damaged. However, there is some evidence in the literature that non-dormant seeds could become dormant after exposure to high soil temperature (Papastylianou; Durutan).

In the TARM breeding studies the lines were screened under weed-free conditions, but recently weedy treatments have been introduced. Farmers do not adopt any HYV if it cannot compete with weeds under poor farming conditions. Perhaps such varieties should only be recommended where herbicides are to be used (Reeves; Durutan).

A soil mulch system gradually decreases weed density over the years (Jones; Durutan).

Crop Rotations

The Management of Crop Rotations for Greater WUE under Rainfed Conditions

HAZEL C. HARRIS, A.E. OSMAN, P.J.M. COOPER and M.J. JONES

ICARDA, P.O. Box 5466, Aleppo, Syria

Introduction

Throughout history, West Asia and North Africa have been exporters of agricultural products. Gibbon (1981) comments that during the Roman period, and again under Arab domination, the systems were probably the most highly organized and productive in the world. Colonization over several centuries is blamed for a decline in their efficiency and productivity as existing social systems and traditions governing land management were disrupted.

Since independence, land tenure has changed either towards large-scale, highly mechanised state farms or to small owner-operated units under agrarian reform (eg. Farming Systems Program 1979). This has further reduced coherence of tribal structures that used to be cornerstones of earlier land management laws. New laws have been introduced but people in rural areas do not necessarily conform to them. Currently, examples of mismanagement of land abound throughout the Mediterranean region, and there is serious degradation of both soil and vegetation in arable and pastoral areas.

Two major factors can be associated with the deterioration of the systems; mechanization and population pressure. In traditional systems, the extent and intensity of tillage undoubtedly was limited by the power available from draught animals. Now, with the widespread introduction of tractors, land which has perhaps never been cultivated is being cropped annually; steep hillsides and vast areas in 150 to 250 mm rainfall zones are being ploughed with results that are potentially, and often actually, disastrous in the promotion of soil erosion.

Burgeoning rural populations and a shortage of arable land (van Schoonhoven 1990) are also forcing the expansion of cropping to unsuitable areas. Added to this is the increased demand of larger and more affluent urban populations for food, and especially for animal products. Not only are human populations expanding, but as a result, populations of livestock, primarily small ruminants, are also increasing. This has led to severe overgrazing and degradation of natural vegetation.

If current gaps between food production and requirements (van Schoonhoven 1991) are to be narrowed, the farming systems of the region must be restructured to be stable and highly productive once again.

Rotations with fallow

Farmers in the Mediterranean region employ both short and long fallows to store water in the soil for subsequent use by crops. In a short fallow, which lasts for about nine months from the end of one winter crop in May or June to the following March or April, land is kept weed free during the winter rainfall period and the water stored is used to grow spring sown crops. Long fallows extend from the end of one winter cropping season through the next and are about fourteen to sixteen months long.

Short fallows

This system is confined to wetter regions (> ca 350 mm annual rainfall) as enough water has to be stored in the soil to carry the summer crops throughout their growth cycle. The crops vary with the rainfall zone within a country, and from country to country, presumably according to market demands arising from social habits and government policies. In wetter areas they include chickpea (*Cicer arietinum*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), cotton (*Gossypium* spp.), sunflower (*Helianthus annuus*), tobacco (*Nicotiana tabacum*), sesame (*Sesamum indicum*), and numerous vegetable species. In drier areas, in Syria at least, cucurbits (*Cucurbit* spp) predominate but short season crops such as cumin (*Cuminum cyminum*) are also found. There is flexibility in the choice of crop depending on seasonal conditions. Eighty percent or more of the rain for the season has normally been received by the time they are sown in March or April. The quantity of water available is known and farmers choose crops according to their water requirements. In dry years, when there is insufficient stored water for a successful crop they will not be sown.

Summer crops can follow a cereal or a food legume, depending on the environment and the cropping sequence, which may be dictated by conditions or tradition. Intuitively they provide a management option in which the work load is spread through the year and thus they may make it more possible for a farmer to rely on family labour rather than having to hire labour which may be in short supply and costly at peak work periods. Summer crops also would provide a more uniform cash flow than winter cropping alone, and have the advantage over a long fallow that a crop is grown almost every year.

Long fallows

Long fallows are extensively used in both North America and Australia to store soil water and hence to increase the yield of cereals per unit of sown area. In the Mediterranean region they are most common in drier zones (<300 mm), where barley-fallow rotations appear to have a long tradition. In West Asia, most appear to be kept free of weeds, although in part this may arise from naturally sparse weed populations due to the poor nutrient status of soils in barley growing areas. In North Africa weedy fallows provide grazing for livestock. They may be grazed throughout the year, or ploughed in the early spring, after much of the weed has been grazed, and then kept weed-free over the summer. We know of no local data on the soil water storage under the latter form of management. Studies begun in Tunisia two years ago have unfortunately encountered severe drought and have yet to yield information (H. Mellouli, personal communication). Early work cited by Sims (1977) in a review of the history of fallowing in Australia showed that a substantially greater amount (65 to 110 mm) of water was stored under clean fallows than weedy ones, but it is not clear whether the weedy fallows were grazed or not.

Water Use Efficiency of Fallows

In our experience long fallows in this region do not store water efficiently. On the Anatolian Plateau of Turkey, with relatively mild evaporative conditions in summer, fallow efficiencies of from 23 to 31% were reported by Durutan *et al.* (1989). However, soil depth of >90 cm is required for fallow to increase yields of cereals (Guler and Karaca 1988). In the six years from 1983/84 to 1987/88 at a dry site, Breda in northern Syria (annual rainfall 280 mm), 25 to 55% of the seasonal rain was stored by bare fallows at the time of peak soil profile recharge but this was reduced to less than 10% by the end of the following summer.

In the same period crop water use was monitored where barley fertilized with 60 kg P_2O_5/ha and 20 kg N/ha was grown either every year, or in rotation with fallow. When the water use efficiency was calculated on the basis of the water used during crop growth it was greater for crops grown after fallow than for those grown year after year on the same land (Table 1). However, it needs to be remembered that a crop is grown only every second year in fallow-barley systems and there is unproductive water loss from the fallow every other year. When water use efficiency was calculated on a two year basis and the water 'used' by fallows was included in the estimation of WUE for fallow-barley, continuous barley was shown to be the more efficient crop sequence (Table 1).

At our main station, Tel Hadya, the seasonal rainfall average is 330 mm and there is normally a greater depth of wet soil at the end of the rainy season than at Breda. The proportion of rainfall stored by the end of summer in the years 1986/87 to 1988/89 ranged from 8% in a dry year to 37% in a wet one. The water use efficiency for grain production of wheat after fallow was lower than for wheat after either chickpea or medic (*Medicago* spp) pasture in two of the three years (Table 2). It was only when a severe drought followed an exceptionally wet season that the rotation with fallow was the most efficient. In this case

Table 1. The rainfall and the total above-ground biomass (kg/ha) and water use efficiency (kg/ha/mm) of barley systems when the crop was grown continuously or in rotation with fallow at Breda, northern Syria.

Year	Rain (mm)	Total Biomass (kg/ha)	WUE (kg/ha/mm)	Total Biomass (kg/ha)	WUE (1) (kg/ha/mm)	WUE (2) (kg/ha/mm)
		Continuous Barley			**Barley-Fallow**	
83/84	207	2125	11.5	1715	17.2	9.0
84/85	277	4310	17.4	2380	19.4	11.0
85/86	218	2085	12.5	2735	26.3	15.6
86/87	245	2255	10.4	1700	14.3	7.7
87/88	415	4095	13.0	4390	26.4	15.3
Mean	272	2974	13.0	2584	20.7	11.9

WUE(1) Calculated from water used during crop growth

WUE(2) Includes water loss from fallow

Table 2. The rainfall and the water use (mm) and water use efficiency (kg/ha/mm) of grain production of wheat (cv. Cham I) at two levels of nitrogen fertilizer application (0 and 90 kg/ha) in three rotations at Tel Hadya, northern Syria from 1986/87 to 1988/89.

Year	Rain (mm)	N (kg/ha)	W-F WU (mm)	W-F WUE (1)	W-C WU (mm)	W-C WUE (1)	W-M WU (mm)	W-M WUE (1)
86/87	333	0	337	3.0	308	3.7	307	3.3
		90	336	3.6	322	4.6	329	3.8
87/88	485	0	461	3.9	414	4.8	419	5.7
		90	535	5.8	453	8.4	460	8.3
88/89	238	0	350	2.7	193	1.8	178	2.0
		90	379	3.9	178	2.5	184	1.4

(1) Units of kg/ha/mm
W-F = Wheat-Fallow; W-C = Wheat-Chickpea; W-M = Wheat-Medic.

170mm of water had been stored in the fallow, and this greatly reduced the amount of water stress experienced by the crop in the drought year, allowing it to fill grain relatively efficiently.

Summer cropping cannot be expected to lead to efficient water use as the crops are grown during the period of the year when the vapour pressure deficit is at its greatest and hence transpiration efficiency is at its least (Gregory 1991). Maize and sorghum have the C_4 photosynthetic pathway and may be more efficient than the others mentioned which are all C_3 species. Nevertheless, this system should be more efficient than the long fallow as summer-growing crops will make use of water that would otherwise be lost through evaporation from the soil. For example, one study (ICARDA 1984) showed that soil evaporation from a bare fallow (88mm) was 60% of the water used by a crop of water melon (145mm) over the same period. The efficiency of the short fallow system will vary with: the rainfall zone, being greater under higher than lower rainfall; soil type, being greater on self-mulching vertisols and grumosols than on coarse textured soils; soil depth, being greater on deep than shallower soils because evaporation occurs mainly from the top 60 cm of the profile; the crop species, depending on ground cover and photosynthetic pathway; and, weed and tillage management (see other sections in this volume).

Nutrients and Fallow

Accumulation of nutrients, especially nitrogen, through mineralization of organic matter is a second factor contributing to an increase in yield of cereals following fallow. In Australia there was debate for many years as to which was the more important consequence of fallow, more water or more nitrogen. Not surprisingly, it was finally concluded that there is a strong interaction between the two, and rainfall regimes where one or the other contributes more were defined for parts of southern Australia (Sims 1977).

Studies in long term rotation trials show that a cereal-fallow rotation leads to a decline in the organic matter content of soils and thus to a depletion of the quantity of nitrogen mineralized during fallow (Sims 1977; Clarke and Russell 1977). The rate of loss may be exacerbated when frequent tillages are used as part of fallow management. The decline in organic matter concentration with fallowing is exponential, however, and it is possible that an equilibrium point is reached where there is little further depletion. This is possibly the case in soils of the Mediterranean region which have been farmed for many centuries.

Clarke and Russell (1977, p 287) condemn "exploitative practices, such as fallowing and frequent cultivation" as leading to systems which are unstable in the long term due to the decline in soil organic matter. The use of fertilizers, and or the incorporation into rotations of phases which restore organic matter are necessary to maintain productivity. It is not clear whether reduced or zero tillage in the fallow phase will slow the rate of loss, as experimental findings on the quantity of nitrogen mineralized under various tillage treatments are quite ambiguous (Robson and Taylor 1987). Undoubtedly the rate is influenced by such factors as the rainfall and temperature regimes and soil texture, and responses are likely to be site and season specific.

The loss of organic matter leads to deterioration not only of the chemical status of the soil but also its physical condition. The soils of the dry zones where fallows are found in Mediterranean barley-based systems generally contain little organic matter, and have poor structure, and receive no nutrients. The continuation of these systems is under threat unless management of the soil is improved through the use of fertilizers and the incorporation in rotations of phases that contribute organic matter.

Crop Sanitation and Fallow

Other beneficial effects of fallow are control of nematodes, insects, diseases and weeds. Its role in weed control is considered elsewhere in this workshop (Amor 1991), but the others deserve mention. The incidence of soil borne diseases can be reduced by fallowing, although the importance of fallow in this respect is dependent on general environmental conditions. In this region of hot dry summers, this alone may be enough to restrict the populations of some pathogenic soil fungi and nematodes which do not survive in warm, dry soils. When organisms do survive, the absence of host plant material for a season can contribute to their control (Robson 1990). In Syria, there is an increase in infestation of crops by insect pests where continuous cereal growing has been practised. In recent years there has been a spread of ground pearls (*Porphyrophora tritici*) which attack barley. Crops are most affected where barley follows barley, and the effect is most severe in crops stressed for water or nutrients. On Tel Hadya research station in the wet year of 1987/88 in plots where both wheat and barley are grown continuously, larvae of the wheat ground beetle, *Zabrus tenebroides*, caused severe damage. Adjacent plots where cereal is rotated with fallow or other crops were untouched. Reports of similar infestations on farmers' fields were widespread.

Soil Management and Fallow

Soil erosion by wind and water seems to be escalating in the Mediterranean region. The pressure of increasing rural populations and shortage of arable areas is forcing cultivation of land of marginal suitability (too steep, too dry, poor and/or shallow soil). Fallowing generally leaves the soil surface unprotected against the forces that cause erosion. Where it is practised on steep land, or on soils with slow water infiltration rates it will undoubtedly promote erosion. The retention of stubble is used to reduce erosion and increase the efficiency of water storage in cropping systems of other dryland regions (eg. Fischer 1987; Papendick 1989; Bolton 1991). However, this practice cannot yet be applied in much of the Mediterranean region where the value of stubble for grazing currently rules out its use for soil protection. Until the availability of feed for livestock, including the amount of stubble, can be increased through improved management this is likely to remain so.

Nonetheless, in a number of places around the Mediterranean, wheat stubble is now being burned. This suggests that recent gains in productivity are already generating a surplus of stubble in some areas and seasons, and that, in the future, opportunities to use stubble for better management of soil may well exist. We consider that it is timely to begin research on ways to manage stubble within the constraints, both environmental and mechanical, of local systems.

The major reason for which fallow is recommended appears to be to increase the grain yield per unit area of sown cereal crops. This may be a rational strategy for North America and Australia where production is export oriented: world markets are very limited for the few alternative crops suited to dryland cereal production areas. However, where alternative crops have a local market, a better objective is the maximization of production per unit of rainfall and per unit area of land. This is unlikely to be achieved through the use of fallow.

Rotations with Legumes

There is a very long tradition of the rotation of cereal and legume crops in lowland areas of the Mediterranean region with annual rainfall of more than 300 to 400 mm. Two course rotations of cereals with chickpea or lentil (*Lens culinaris*) are common in West Asia, whilst in North Africa faba bean (*Vicia faba*) is the main legume. Alternatively, the rotation may be a three course one in which cereals, legumes and summer crops follow one another, often in that sequence. Largely because of disease problems in the legumes during the humid part of the year and their frost susceptibility, they have been sown in the spring, with the consequences to water use efficiency noted above. Recent availability of cultivars of chickpea suited to winter sowing has significantly increased the yield potential (Saxena and Singh 1987). Early planting of chickpea and lentil improves yield through greater water use efficiency (Table 3), as much of the biomass can be produced while the vapour pressure deficit is low; vegetative cover is established more rapidly, evaporation from the soil surface is reduced and the ratio of T/Es is increased (Keatinge and Cooper 1983; Cooper *et al.* 1988; Gregory 1991). However, introduction of winter sowing has been accompanied by management problems, the most notable being more weed infestation. The benefits made possible by early sowing thus are only obtained if the practice is accompanied by a change in weed control practices. Chemical control is both possible and economic in West Asia (Pala and Mazid 1989, 1990) but has the disadvantage that it relies on pre-emergent herbicides which farmers may be reluctant to adopt. There is some increased risk of frost damage from early sowing. However, this can be quantified and areas with acceptable risk delineated. The potential for improved yield through greater water use efficiency appears to far outweigh the risk, and system modifications to enhance both the biological and economic returns from these crops are now within the reach of farmers.

Table 3. Time of planting effects on total above-ground biomass, water use and water use efficiency of chickpea and lentil at 2 locations in northern Syria. [1]

Crop and Season	Treatment	Total Biomass (kg/ha)	WU (mm)	WUE (kg/ha/mm)
Chickpea (1981/82)	Winter sown (Jindiress)	7880	422	18.7
	Spring sown (Jindiress)	3740	413	9.1
	Winter sown (Tel-Hadya)	3420	311	11.0
	Spring sown (Tel-Hadya)	1840	297	6.2
Lentil (1981/82)	Sown early (Tel-Hadya)	5249	320	16.4
	Sown late (Tel-Hadya)	3034	295	10.3
Lentil (1982/83)	Sown early at 333 pl/m^2 (Tel-Hadya)	4025	280	14.4
	Sown late at 133 pl/m^2 (Tel-Hadya)	1717	225	7.6

[1] Source: Cooper *et al* (1988). p. 821.

Faba bean requires more water than either chickpea or lentil. In North Africa it is grown in high rainfall areas, but also extensively in drier areas where it is only marginally suited. This is a response to demand because it is the major legume of the local cuisine.

Faba bean suffers from problems of disease and weed infestation, especially ascochyta blight (*Ascochyta fabae*), chocolate spot (*Botrytis fabae*) and the parasitic weed orobanche (*Orobanche crenata*), in areas where rainfall is suited to its production, although resistance to Orobanche has now been identified. Research to adapt it to more arid conditions, for example, by developing determinate types and lines with independent vascular supplies to each flower in a raceme is under way (eg. FLIP 1986; 1987; 1988). Considerably more needs to be done to improve the efficiency of the crop.

Turkey has made rapid progress in replacing fallow with food legumes. Initial promotion through Government sponsored incentive schemes led to widespread adoption by farmers and a threefold increase in area under food legumes. National production in the past two or three years has satisfied domestic demand and generated substantial export surpluses (Durutan *et al.* 1990).

The production of forage legumes, such as vetch (*Vicia* spp.) and chickling (*Lathyrus* spp.), in rotation with cereals provides a further alternative to fallow. Livestock, predominantly small ruminants, are the main product of farming systems in dry zones (<300mm rainfall), but form part of all systems. Because there is an increasing demand for livestock products, there appears to be great potential for expansion of use of forage legumes. Interest in this option throughout the Mediterranean basin is reflected in recent publications (Jaradat 1988; Osman *et al.* 1990). One of its most attractive features is that it offers flexible choices for farmers across a wide spectrum of environments. Forage crops can be grazed while green or after maturity, made into hay, or harvested at maturity for seed. In the latter case crop residues have value as animal feed and can be grazed, stored or sold.

It is possible to envisage the evolution of integrated systems of forage production and utilization. In dry areas forage legumes would be grown for feed in rotation with barley and managed according to the needs of animals in the conditions of each season. In wetter areas the main production would be of seed or hay for sale to livestock producers. This system already exists, in part. In Tunisia, for example, mixtures of vetch and oats (*Avena sativa*) grown in wetter areas (>400mm) produce hay which is marketed in the dry south of the country (Halila *et al.* 1990).

Difficulties face the further development of such a system. Mechanized harvesting methods are needed for the legumes, although recent identification of varieties with subterranean seeds offers long term prospects for self-regenerating crops of vetch and chickling (Abd El Moneim 1988; Jones 1990). Haymaking is not efficient and valuable leaf material is lost. Centralized drying facilities to process partially dried material from the farm level could be a long term solution. To be sustainable, these would need technology to use the abundant solar energy of the region for drying.

General adoption of barley-forage legume rotations is also currently inhibited by shortages of seed and fertilizer. However, Cooper and Bailey (1990) argue, from a case study of Syria, that their widespread implementation could reduce the extension of cropping into ever more marginal areas of scant rainfall and fragile soils. Requirements for sheep feed could be met from more reliable areas, allowing restoration of rapidly degrading steppeland.

A further alternative to fallow is ley farming (cereal-pasture rotation), based on annual pasture legumes. This system, developed with legumes of Mediterranean origin and widely used in Australia, has the major advantage that it requires only low inputs. Pastures, if they are properly managed, need only be sown once and thereafter are self-regenerating. Normally there is sufficient residual phosphate for the pasture from the cereal phase of the rotation, and, in Australia, the pastures not only fix enough nitrogen for their own needs but also provide much of the requirement of the following cereal.

Extensive testing of the system in the Mediterranean region has demonstrated that legume-based pastures are productive, especially when local ecotypes are selected. Adoption by farmers has been negligible, however (Osman *et al.* 1990). Reasons for this have been examined in detail elsewhere (Springborg 1986) but can be summarized as follows. The key to productive pastures is the maintenance of good seed supplies in the soil. This means that pastures must be managed to allow them to set seed. Land tenure patterns, traditional grazing rights, perception of legumes as part of the weed flora, and overstocking, all militate against the introduction of appropriate management. Acceptance of new ideas by whole communities and not just individual farmers will probably be necessary to implement the system. This is difficult to achieve and will demand imaginative research and extension methods involving communal decision-making at all stages.

Water Use Efficiency of Legume-based Rotations

The water use efficiency of total biomass production of fertilized barley-vetch rotations, in which vetch is harvested for hay at the early pod-filling stage, has been evaluated over several years. Production per hectare when half is sown to barley and half to vetch each year, is shown in Table 4. These data can be directly compared with the data for barley in Table 1 as they are

Table 4. Total biological yield (TBY) and water use efficiency (WUE) of barley-vetch rotations under three fertilizer regimes at Breda, northern Syria, from 1983/84 to 1987/88.

Year	B_{NP}-V_0 TBY (kg/ha)	B_{NP}-V_0 WUE (1)	B_{NP}-V_P TBY (kg/ha)	B_{NP}-V_P WUE (1)	B_0-V_P TBY (kg/ha)	B_0-V_P WUE (1)
83/84	1610	9.2	1945	na	1510	9.0
84/85	3830	16.2	4685	20.4	3450	15.1
85/86	3305	19.3	3590	20.4	2990	17.4
86/87	2825	13.0	3455	16.2	2470	11.4
87/88	5825	19.3	5850	19.6	4870	17.0
Mean	3480	15.4	3905	(19.2)	3060	14.1

(1) Units of kg/ha/mm
B = Barley; V = Vetch; N = 20 kg/ha elemental nitrogen;
P = 60 kg/ha P_2O_5; 0 = Zero fertilizer.

from the same trial. The barley-vetch rotations are more productive and use water more efficiently than either continuous barley or fallow-barley systems (*cf* Table 4 with Table 1). The amount of fertilizer applied, and the time of its application within the barley-vetch rotations, both influence the WUE.

From the comments on soil evaporation in the section on water use efficiency of fallows and the data of Tables 1 and 3, it follows that a rotation where a crop is grown every year will be more water efficient than one with fallow. However, in drier areas (<400-450mm) the yield of cereal crops in any one year may be less than that following fallow. Four years' data from a trial at Tel Hadya illustrate this (Table 5). The yield reduction following vetch and lentil can be ascribed to less water being available, as is evidenced by equality of yield in the wet year of 1987/88 (see Table 2 for rainfall) and data from other trials (not shown). Less wheat yield following chickpea and medic is due partly to more water use by these crops than the other legumes, and partly to other factors noted in later sections.

This does not mean, except in the extreme case of wheat after wheat, that the rotations are less productive or offer lower economic returns (Harris 1990). It means simply that water is being used for a different form of production. For example, in addition to wheat grain, the rotation with lentil produced about 2.5 t/ha/yr of seed + straw, and those with vetch or medic about 300 kg/ha/yr of animal liveweight gain.

Legume-based Rotations and Nutrition

One of the arguments for the use of legume-based rotations is that symbiotic fixation during the legume phase contributes nitrogen to the system which can be harvested by cereals. Much of the evidence for this comes from Australia where, in areas with Mediterranean-type climates, cereal production relies heavily on nitrogen from crop and pasture legumes.

Table 5 . Grain yield (kg/ha) of wheat (cv. Sham 1) in seven rotations at Tel Hadya research station, northern Syria from 1985/86 to 1988/89.

Year	Grain Yield (kg/ha)						
	W-F	W-SC	W-V	W-L	W-C	W-M	W-W
85/86	2575	2710	2130	2040	2005	1315	1380
86/87	1915	1960	1625	1650	1355	1175	1010
87/88	4105	3610	3940	3910	2940	3245	940
88/89	1845	1045	985	945	395	295	310
Mean	2610	2330	2170	2135	1675	1510	910

W = Wheat; F = Fallow; SC = Water melon; V = Vetch;
L = Lentil; C = Chickpea; M = Medic.

However, caution is needed in translating this experience to other regions (Buddenhagen 1990). While all the evidence is not yet in, current estimates are that forage legumes in West Asia fix about 50 to 75% of their nitrogen requirements (Keatinge *et al.* 1988) and food legumes approximately the amount contained in the seed they produce (Beck *et al.* 1990). These proportions are strongly influenced by agroclimatic conditions during growth. In Cyprus, however, Papastylianou (1988) has recorded substantial increases in soil nitrogen and barley yield following vetch.

Undoubtedly the amount of nitrogen that is contributed depends on management. The quantity fixed by legumes in northern Syria is directly related to total biomass (J.D.H.Keatinge, unpublished data). Improved management practices (such as those detailed throughout this meeting) that promote vigorous healthy crops, therefore, will increase the amount. When plants are harvested at maturity much of the nitrogen has been remobilized into the seed and is removed. With combine harvesting only about 30% of the total biomass (including roots) is exported and nitrogen remaining in residues is recycled in the system, whereas hand-harvesting removes all above-ground biomass and part of the roots. Beck *et al.* (1990) report N balances of from +44 to -44 kg N/ha for simulated combine harvesting, but from -10 to -70 kg N/ha for hand-harvesting. Harvest of immature plants for hay production or by grazing animals probably means that a greater proportion of the nitrogen remains in roots and that wastage of leaf material occurs, to contribute organic matter and nitrogen to the soil. Grazing animals recycle some nitrogen, but when they graze for only part of each day unknown amounts are removed to where they are housed. Studies in long term wheat-legume rotations just begun in ICARDA are designed to gain an understanding, for one environment at least, of the nitrogen balance under several forms of harvesting.

Crop Sanitation and Legume-based Rotations

The effects of crop rotation on pest and disease control are similar to those of fallow (Robson 1990). Exceptions occur when species in more than one phase are susceptible to the same organism. A problem of this nature has arisen with winter sowing of chickpea in wheat-chickpea rotations in West Asia. Both species are susceptible to root knot nematodes

(*Pratylenchus* spp.), the incidence of which has increased with winter as opposed to spring sowing. Inclusion of a summer crop in a three course rotation of wheat-chickpea-water melon does not afford control. This has contributed to reduced wheat yields in wheat-chickpea rotations (Table 5).

Soil Management in Legume-based Rotations

The presence of a crop during the rainfall season would be expected to provide some protection against erosive processes. However, before crop establishment, while crops are small, and during summer when wind erosion is the main problem, the introduction of annual legumes will have little effect on soil erosion control. Indeed, if it leads to more frequent tillage it could contribute to breakdown of soil structure and increased vulnerability to erosion.

Unquestionably, soil structure is improved by several years of continuous pasture (Clarke and Russell 1977; Hamblin 1987). This is related to a build up of organic matter and thought to depend on the formation of organic polymer bonds of various types. Persistent tillage over several years, or several tillages in one year, cause a breakdown of stable aggregates (Hamblin 1987). The degree of damage is related to soil type and is most severe where there is a high proportion of silt or fine sand in the surface layers. Disruption of soil aggregates in such soils leads to surface slaking and crust formation, reduces infiltration of water and emergence of plants, and promotes increased runoff. These effects are obvious in soils of marginal areas throughout the Mediterranean region.

The results of long-term (13 to 46 years) crop sequence trials on several soil types in southern Australia, including some soil types found in the Mediterranean region, were summarized by Clarke and Russell (1977). They generally show that wheat yields respond positively to inclusion of a pasture phase with wheat-fallow rotations. Two years of pasture are better than one. It is difficult in this work to separate the effects of soil structure and nutrients, but other work with longer pasture phases demonstrated wheat yield advantages that could not be duplicated by the addition of fertilizer. This led to the conclusion that soil physical conditions influence growth of wheat (Clarke and Russell 1977). It is not clear whether the pastures comprised annual or perennial species. Nor do any of these experiments include annual food or forage legume species.

Some of the effects of stubble retention on soil structure are similar to those of pasture, but they take longer to develop. It may be several years before they are reflected in improved cereal yields (Hamblin 1987). However, the improvements in soil structure that can be achieved may be expected to contribute to better water infiltration and storage. Research has shown that legumes can be direct drilled into stubble without loss of yield (Harris, unpublished data). These considerations add to the case for more research on stubble retention in the Mediterranean region.

The importance of maintaining and conserving soil needs no emphasis. It is the resource on which all production depends. Yet we know of no work in the Mediterranean region on the influence of crop sequence on soil stability. It is urgent that work of this nature be started.

References

Abd El Moneim, A.M. 1988. Preliminary evaluation of subterranean vetch (*Vicia sativa* var. *amphicarpa*). Pages 179-180 in Annual Report 1987, Pasture, Forage and Livestock Program, ICARDA, Aleppo, Syria.

Amor, R. 1991. This volume.

Beck, D., Wery, J. and Ayadi, A. 1990. Dinitrogen fixation and nitrogen balance in cool-season food legumes. (Submitted to Agronomy Journal)

Bolton, F. 1991. This volume.

Buddenhagen, I. 1990. Legumes in farming systems in Mediterranean climates. Pages 3-29 *in* The Role of Legumes in the Farming Systems of the Mediterranean Areas. (Osman, A.E., Ibrahim, M.H. and Jones, M.A., eds). Proceedings of the Workshop, UNDP/ ICARDA, Tunis, June 20-24, 1988. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Clarke, A.L. and Russell, J.S. 1977. Crop sequential practices. Pages 279-300 in Soil Factors *in* Crop Production in a Semi-arid Environment (Russell, J.S. and Greacen, E.L., eds). The Australian Society of Soil Science and Queensland University Press, Brisbane, Australia.

Cooper, P.J.M. and Bailey, E. 1990. Livestock in Mediterranean farming systems, a traditional buffer against uncertainty, now a threat to the agricultural resource base. Presented at the World Bank Symposium "Risk in Agriculture", Washington, DC, USA. January 9-10, 1990.

Cooper, P.J.M., Campbell, C.S. Heath, M.S. and Hebblethwaite, P.D. 1988. Factors which affect water use efficiency of food legumes, and their measurement. Pages 814-829 *in* World Crops: Cool season Food Legumes (Summerfield, R.J., ed.) Kluwer Academic Publishers, Dordrecht, The Netherlands.

Durutan, N., Pala, M., Karaca, M. and Yesilsoy, M.S. 1989. Soil management, water conservation and crop production in the dryland regions of Turkey. Pages 60-77 *in* Soil, Water, and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region. (Whitman, C.E., Parr, J.F., Papendick, R.I. and Meyer, R.E., eds). Proceedings of the Workshop at Amman, Jordan. January 18-23, 1986, USDA, Washington, DC, USA.

Durutan, N., Meyveci, K., Karaca, M., Avci, M. and Eyuboglu, H. 1990. Annual cropping under dryland areas of Turkey. Pages 808-810 *in* Challenges in Dryland Agriculture. A Global Perspective. Proceedings of the International Conference on Dryland Farming. Amarillo/Bushland, Texas, USA. August 15-19 1988. (Unger, P.W., Jordan W.R., Sneed, T.V. and Jensen, R.J., eds). Texas A&M University, College Station, Texas, USA.

Farming Systems Program 1979. Research Report No. 1. An introduction to agriculture within the Syrian economy. (Internal document). ICARDA, Aleppo, Syria.

Fischer, R.A. 1987. Responses of soil and crop water relations to tillage. Page 194-221 *in* Tillage. New Directions in Australian Agriculture (Cornish, P.S. and Pratley, J.E., eds). Australian Society of Agronomy. Inkakta Press, Melbourne and Sydney, Australia.

Gibbon, D. 1981. Rainfed farming systems in the Mediterranean region. Plant and Soil 58:59-80.

Gregory, P.J. 1991. This volume.

Guler, M. and Karaca, M. 1988. Agroclimatological criteria for determining the boundaries of fallow practice. Pages 41-49 *in* Winter Cereals and Food Legumes in Mountainous Areas (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds). ICARDA, Aleppo, Syria.

Halila, M.H., Dahmane, A.B.K. and Seklani, H. 1990. The role of legumes in the farming systems of Tunisia. Pages 115-129 *in* The Role of Legumes in the Farming Systems of the Mediterranean Areas. (Osman, A.E., Ibrahim, M.H., and Jones, M.A., eds). Proceedings of the Workshop, UNDP/ICARDA, Tunis, June 20-24, 1988. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Hamblin, A. 1987. The effect of tillage on soil physical conditions. Pages 128-170 *in* Tillage. New Directions in Australian Agriculture (Cornish, P.S. and Pratley, J.E., eds). Australian Society of Agronomy. Inkakta Press, Melbourne and Sydney, Australia.

Harris, H. 1990 Productivity of farming systems. Annual Report 1989, Farm Resource Management Program, ICARDA, Aleppo, Syria.

ICARDA 1984. (International Center for Agricultural Research in the Dry Areas). Pages 40-42 *in* Annual Report 1983. ICARDA, Aleppo, Syria.

Jaradat, A.A. 1988. Crop rotations. Pages 280-310 *in* An Assessment of Research Needs and Priorities for Rainfed Agriculture in Jordan (Jaradat, A.A., ed.). USAID, Jordan.

Jones, M.J. 1990. The role of forage legumes in rotation with cereals in Mediterranean areas. Pages 195-204 *in* The Role of Legumes in the Farming Systems of the Mediterranean Areas. (Osman, A.E., Ibrahim, M.H. and Jones, M.A., eds). Proceedings of the Workshop, UNDP/ICARDA, Tunis, June 20-24, 1988. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Keatinge, J.D.H. and Cooper, P.J.M. 1983. Kabuli chickpea as a winter-sown crop in Northern Syria: moisture relations and crop productivity. Journal of agricultural Science, Cambridge 100: 667-680.

Keatinge, J.D.H., Chapanian, N. and Saxena, M.C. 1988. Effect of improved management of legumes in a legume-cereal rotation on field estimates of crop nitrogen uptake and symbiotic nitrogen fixation in northern Syria. Journal of agricultural Science, Cambridge. 110:651-659.

Osman, A.E., Ibrahim, M.H. and Jones, M.A. (eds) 1990. The Role of Legumes in the Farming Systems of the Mediterranean Areas. Proceedings of the Workshop, UNDP/ICARDA, Tunis, June 20-24, 1988. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Papastylianou, I. 1988. The Role of Legumes in Agricultural production in Cyprus. Pages 55-63 *in* Nitrogen Fixation by Legumes in Mediterranean Agriculture (Beck, D.P. and Materon, L.A., eds) Martinus Nijhoff, Dordrecht, The Netherlands.

Pala, M. and Mazid, A. 1989. Annual Report for 1988. Farm Resource Management Program, ICARDA, Aleppo, Syria.

Pala, M. and Mazid, A. 1990. Annual Report for 1989. Farm Resource Management Program, ICARDA, Aleppo, Syria.

Papendick, R.I. 1989. Storage and retention of water during fallow. Pages 260-269 *in* Soil, Water and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region. (Whitman, C.E., Parr, J.F., Papendick, R.I. and Meyer, R.E., eds). Proceedings of the Workshop at Amman, Jordan, January 18-23, 1986. USDA, Washington, DC, USA.

Robson, A.D. 1990. The role of self-regenerating pasture in rotation with cereals in Mediterranean areas. Pages 217-236 *in* The Role of Legumes in the Farming Systems of the Mediterranean Areas (Osman, A.E., Ibrahim, M.H. and Jones, M.A., eds). Proceedings of the Workshop, UNDP/ICARDA, Tunis, June 20-24, 1988. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Robson, A.D. and Taylor, 1987. *in* Tillage. New Directions in Australian Agriculture (Cornish, P.S. and Pratley, J.E., eds). Australian Society of Agronomy. Inkata Press, Melbourne and Sydney, Australia.
Saxena, M.C. and Singh, K.B. (eds). 1987. The Chickpea. CAB International and ICARDA. CAB International, Wallingford, U.K.
Sims, H.J. 1977. Cultivation and fallowing practices. Pages 244-261 *in* Soil Factors in Crop Production in a Semi-arid Environment. (Russell, J.S. and Greacen, E.L., eds). The Australian Society of Soil Science and Queensland University Press, Brisbane, Australia.
Springborg, R. 1986. Impediments to the transfer of Australian dry land agricultural technology to the Middle East. Agriculture, Ecosystems, and Environment 17; 229-251.
van Schoonhoven, A. 1991. This volume.

Effect of Rotation Systems on Wheat Yield and Water Use Efficiency in Dryland Areas of Central Anatolia

M. KARACA, M. GULER, N. DURUTAN, K. MEYVECI, M. AVCI, H. EYUBOGLU and A. AVCIN

TARM, P.K. 226, Ulus-Ankara, Turkey

Abstract

In Central Anatolia, two-year, three-year and four-year rotation experiments are being carried out to substitute fallow with certain crops and to determine alternative cropping systems. According to the results of a two-year rotation experiment, winter-sown crops like Hungarian vetch and lentil, and the spring-sown ones like chickpea and cumin caused some yield loss in succeeding wheat compared to wheat after fallow, but the yield reduction was limited and usually less than 10%. On the other hand, it was found that WUE of wheat following these crops was increased. In the areas where annual cropping carries more risk than in the experimental area, three-year and four-year rotation systems that reduce the fallow 33 to 50% appear to be safer and more feasible.

Introduction

Cool season cereals like wheat and barley are grown in almost every region in Turkey. Most of the wheats and barleys produced in the country are winter types, primarily produced on the Central Anatolian Plateau and on its eastern and south-eastern extensions, and in Thrace. In these regions fallow-wheat and fallow-barley have been the primary cropping sequences for centuries. Fallow has been practised not only because of the limited and variable annual precipitation but also because of long tradition. This means that in many regions the land use potential has not been fulfilled.

In order to find ways to use the land more efficiently rotation studies were initiated in the Eskisehir Dryland Farming Station in the 1930s and continued for 20 years. In the two-year rotation system the best cereal yields were obtained from fallow-barley and fallow-wheat. The legumes were the best crops in terms of the effect on the succeeding wheat yield level. Among the legumes the giant vetch *(Vicia narbonensis)* was found to be the most promising crop since it is planted in winter and cut as a green forage. The yields of the spring legumes were found to be less stable than those of winter types. The fallow-wheat-giant vetch-wheat cropping sequence was the best four-year rotation system. Under limited rainfall conditions cropping depends upon water stored in the soil. Cutting the legumes as a green forage early in the spring provides more water to the succeeding wheat than growing crops for grain (Kalayci 1984).

The first attempt to introduce fallow replacement into farming systems was made in the late 1970s by a Rural Development Project in the north transitional area. Before the implementation of this project fallow-wheat or fallow-barley were the main cropping sequences. In livestock-oriented farms a rotation of wheat with spring vetch (for grain) was most commonly adopted. Food legumes like chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*) were produced on many farms for domestic use, but the yields were low. Farmers were greatly attracted to legume production as an alternative to fallow and within five years a legume (lentil, Hungarian vetch (*V. pannonica*) or chickpea) -wheat rotation system was largely adopted, so legume acreage increased and fallow areas decreased (Durutan *et al.* 1990).

The successful outcome of this project served as a base for the next extension and research project, "Utilization of Fallow Areas" (NAD). This is directed towards the utilization of fallow areas by using alternative crops. The first phase of the project was started in 1982 and completed at the end of 1986. Supported by a strong extension program, within the period 1982-86 the fallow areas decreased 35% in the project area, which is approximately 500 000 ha (Eskisehir 1987; Durutan *et al.* 1990).

More emphasis was given to research on the utilization of fallow with the initiation of this project. The boundary between fallow-cereal and annual cropping was theoretically determined by using climatic data such as precipitation, temperature and relative humidity obtained from all the meteorological stations of Turkey (Guler and Karaca 1988). Other research revealed that there was a decrease in fallow efficiency when depth of soil decreased, and fallow was not suitable for shallow soils (Yesilsoy 1984).

In a rotation experiment, conducted in Ankara (Kurt *et al.* 1988), a fallow-wheat rotation system was compared with forage legume-wheat rotation systems in which different species of forage legumes were used individually and as mixtures with cereals. There was an increase in green fodder when cereals and forage legumes were sown as mixtures. However, the yield of wheat sown after mixtures was lower than that of wheat sown after fallow. No difference was found between the yields of wheat sown after individual forage legumes and those after fallow.

In a study of the 120 cm soil profile carried out by the Field Crops Improvement Center (TARM) the nitrogen status of the two-year rotation system was determined as ammonium and nitrate nitrogen. Two-year average values showed that total inorganic nitrogen provided by legumes was at least equal to the amount accumulated by fallow at the seeding time of wheat. Two-thirds of the total inorganic nitrogen was accumulated at the upper layers of the soil profile. It decreased gradually with increasing depth (Meyveci and Munsuz 1989).

Numerous experiments are being carried out by TARM to evaluate economically optimum cultural practices. This is important not only for the second crop in the rotation but for the wheat as well. Seeding date, seed rate and row spacing, method and rate of fertilizer application, and weed control are also being studied in rotation systems. As is the case for many crops, stand establishment is very important for legumes. Seedbed preparation should be given priority in the management package since stand establishment largely depends on the seedbed properties. TARM is carrying out soil tillage experiments in winter vetch-wheat, and spring lentil-wheat rotation systems (TARM 1981-87).

Rotation Research

The objectives are summarized below:

1. To investigate the feasibility of utilizing the fallow areas.
2. To determine the most suitable crops to replace fallow.
3. To quantify the residual effects of the crops and cultural practices on the yield of succeeding wheat crops.

Experiments on two-, three- and four-year rotations are being carried out on the research farm of TARM, Haymana. The climatic characteristics of the research farm and the cropping periods within two years are given in Fig. 1.

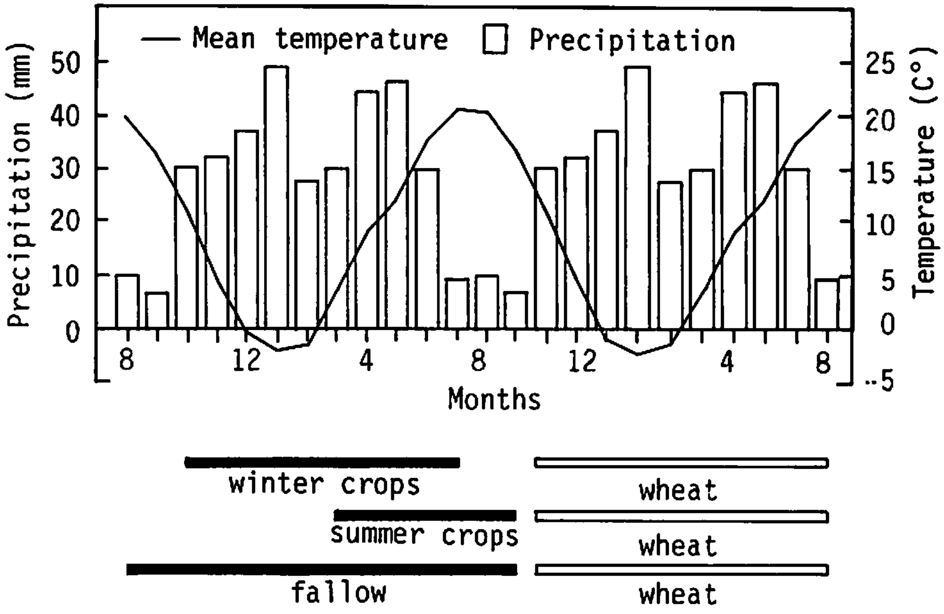


Fig. 1 Monthly average temperatures and precipitation at Haymana Research Farm, Ankara, Turkey, and the cropping periods over two years.

Precipitation in Central Anatolia normally begins in October and ends in June. Average temperature is around 0°C in winter months, beginning to rise by the end of February and continuing until August. Wheat and barley are sown in October and harvested in July. The fallow season is a 14-month period beginning after wheat harvest and ending in October of the following year. Other winter crops, mainly legumes, are sown in October and harvested in the first half of June for forage, and in July for seed. Spring crops are sown in the second half of March or later and harvested in August or September, depending on the crop.

Two-year rotation experiment

In the two-year rotation experiment wheat is being rotated with various crops such as Hungarian vetch, lentil and wheat as winter crops, and chickpea, lentil, sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*) and cumin (*Cuminum cyminum*) as spring crops.

These systems are being compared to the fallow-wheat sequence. Hungarian vetch is being harvested for green fodder. The experimental design includes both phases of the rotation so data for all crops are collected every year. Average yields for the years of the experiment are shown in Table 1.

The average (five-year) ET and WUE values given in Table 1 were calculated by using soil water data collected at the beginning of the fallow period and after the harvest of alternative crops, and the precipitation in the period beginning from fallow till harvest. Sunflower and safflower were found to be the highest moisture-consuming crops, while winter-sown legumes and cumin used the least water. Hungarian vetch, when it was cut for forage, used the soil moisture most efficiently, with wheat the next most efficient. It was found that chickpea used the soil moisture more efficiently than the other grain crops tested. WUE was lower in cumin, sunflower and safflower.

At wheat seeding time significant differences were obtained among the treatments in terms of soil moisture in the 0-120 cm soil profile. The highest amount of water was conserved by fallow, with Hungarian vetch and winter lentil next.

Water storage efficiency of most of the crops such as sunflower, spring lentil, safflower, wheat, and chickpea was negative, relative to fallow.

There were significant differences among the wheat yields obtained after different crops and fallow in six years of the experiment (Table 1). The highest wheat yield was

Table 1. Economic yield (kg/ha) and parameters of water balance and WUE in 2-course rotation systems at the Haymana Experiment Station. TARM, Ankara. Values are means for the period 1983-88

Rotation	ET for 1st crop mm	WUE of 1st crop kg/ha/mm	Soil water mm/120cm	Wheat yield kg/ha	ET for wheat mm	WUE of wheat kg/ha/mm
Sunflower - wheat	354 ab	2.0 cd	203 d	2910 d	320 cd	9.5 ab
W. lentil - wheat	310 cd	3.7 bcd	245 bc	3190 bc	358 b	9.8 a
S. lentil - wheat	346 b	2.9 cd	210 d	3040 cd	329 c	10.0 a
H. vetch - wheat	299 d	6.4 a	255 b	3300 ab	366 b	9.7 a
Safflower - wheat	369 a	2.7 cd	191 e	2500 e	309 d	8.3 b
Wheat - wheat	345 b	5.7 ab	209 d	1890 f	326 c	6.4 c
Cumin - wheat	322 c	1.7 d	235 c	3140 bc	355 b	9.3 ab
Chickpea - wheat	348 b	4.0 bc	209 d	3180 bc	326 c	10.2 a
Fallow - wheat	-	-	284 a	3410 a	399 a	8.9 ab
P	0.01	0.01	0.01	0.01	0.01	0.01
LSD (%5)	15	2.0	10	168	13	1.2
n	28	28	96	96	32	32

Values followed by the same letter are not significantly different.

P = Level at which statistical comparisons between the rotations are significant.

ET = Soil moisture in profile at seeding + precipitation in crop year - soil moisture in profile after harvest.

WUE = Yield/ET

recorded after fallow. The decrease in wheat yield was less than 10% after Hungarian vetch, winter lentil, chickpea, and cumin, and less than 15% after spring lentil and sunflower. The greatest yield reduction of wheat was in safflower-wheat (27%) and continuous wheat (45%) treatments when compared to the fallow-wheat rotation.

Total evapotranspiration (ET) by wheat was related to the stored (or residual) water following the alternative crop. As the soil profile was dried to the same level by wheat in all treatments, differences in the ET of wheat reflect the quantity of residual water in the profile at planting. Fallow significantly increased ET when compared to annual cropping (Table 1).

Significant differences were obtained among the treatments in terms of water use efficiency (WUE) of wheat (Table 1). All the annual cropping treatments except safflower and continuous wheat increased WUE of wheat by approximately 5-15% when compared to the fallow - wheat rotation. The best WUE was obtained from the chickpea-wheat rotation.

According to the data on soil water, WUE and yield obtained so far, it can be stated that there are some crops that can replace the fallow in the region: those which have high WUE value, and a limited negative effect (< 10%) on the yield level of succeeding wheat can be alternatives for fallow.

Chickpea-wheat and spring lentil-wheat are the main rotation systems used extensively in the region by the farmers. Vetch is usually used in their rotation system for grain production, and demonstrations are being carried out to show the farmers the benefit of forage production instead.

There are some problems in seedbed preparation in the short period between harvest and planting of winter crops. It is especially difficult to till the soil after the harvest of certain crops during the dry summer period. Therefore research on seedbed preparation for winter and spring legumes, and the succeeding wheat is being conducted in the annual cropping system (TARM 1981-87).

Since Hungarian vetch (cut for forage) and winter lentil leave the field earlier in the season, the soil is in a more easily worked condition for proper seedbed preparation for succeeding wheat, and this results in increased WUE of wheat. Sunflower also leads to increased WUE for wheat, although it is the second highest water consuming crop next to safflower. This might be due to the inter-row cultivation in sunflower resulting in better seedbed preparation for wheat.

Four-year rotation experiment

The aim is to find out the possibility of reducing the fallow 50% by utilizing the area in one of the two fallow years of a four-year period. In other words, to find ways of replacing the fallow-wheat-fallow-wheat system by crop-wheat-fallow-wheat in a four-year period.

Winter lentil (WL), spring lentil (SL), sunflower (Snf) and continuous wheat (W) are the crops chosen to compare with the third year's fallow (F). Again all four phases of the rotations are included in order to get data on all treatments every year. To date two phases of the rotations have been completed and the results are summarized in Table 2.

There were significant differences among the treatments in terms of soil water in the 120 cm soil profile at wheat seeding time at the end of the first year. The maximum amount of moisture was conserved by fallow, followed by winter lentil. The water storage efficiency for fallow was 24% and in the other treatments it ranged from 3 to 13%, depending on the crop.

The differences among the succeeding wheat yields were small with the exception of continuous wheat, in which the yield was reduced by 26%.

The crops that replace one of the fallows in a four-year period lower the ET for the succeeding wheat. However, all the crops except continuous wheat have increased WUE of wheat in the second year by between 8 to 24% compared to fallow.

As can be seen from Table 2, at the end of the third year, (fallow) there was no difference among the treatments in terms of soil water in the 120 cm profile at wheat seeding time. The wheat yields were not different either, regardless of the pattern three years before.

It seems possible, therefore, to reduce the fallow practice in the area by at least 50% using winter and spring lentil and sunflower in a four-year rotation system.

Table 2. Economic yield (kg/ha) and parameters of water balance and WUE, in the first two phases of 4-course rotations at the Haymana Experiment Station, Ankara, 1984-88

Year of Rotation	1st year			End of 2nd year					3rd year	4th year
1 2 3 4	Crop yield (kg/ha)	Soil water (mm/120cm)	Water storage efficiency (%)	Wheat yield (kg/ha)	Yield compared to fallow (%)	ET (mm)	WUE (kg/ha/mm)	WUE compared to fallow (%)	Soil water (mm/120cm)	Wheat yield (kg/ha)
WL -W-F-W	1400	234 b	+13	3240 a	-0.6	406	8.0	8.1	280	3200
SL -W-F-W	1300	207 c	+5	3380 a	+3.7	369	9.2	24.3	282	2940
W -W-F-W	3160	204 c	+3	2420 b	-25.8	365	6.6	-10.8	281	3160
Snf-W-F-W	910	203 c	+4	3140 a	-3.7	370	8.5	14.9	280	3080
F -W-F-W	-	283 a	+24	3260 a	-	439	7.4	-	286	3150
P		0.01		0.01					ns	ns
LSD (% 5)		11		310					11	270

For key see Table 1.

Three-year rotation experiment

The objective is to determine the possibility of reducing the fallow 33% by testing fallow, winter lentil and wheat in all different combinations in a three-year period, instead of having fallow every other year.

A three-year period has been completed in three of the fields. The average results are summarized in Table 3. To determine the need for fallow within the three-year period evaluation was made for both wheat and lentil.

The amounts of water stored during fallow in the second year were similar, regardless of the crop grown the year before (wheat or winter lentil). However, a difference was observed in fallow efficiency, which was greater in fallow after wheat than in fallow after lentil.

Approximately 50 mm less moisture was obtained after lentil at wheat seeding time and 75 mm after wheat at winter lentil seeding time compared to fallow.

There was no significant difference in wheat yields after lentil and fallow. Nor were lentil yields following wheat and fallow significantly different. Fallow practice increased ET and decreased WUE in both lentil and wheat (Table 3).

Figure 2 shows that wheat and lentil yields were not different in either of the fallow-winter lentil-wheat (F-WL-W) and winter lentil-fallow-wheat (WL-F-W) systems. Total

Table 3. Effect of three-year rotation system on yield, ET and WUE of wheat and winter lentil. 1984-88

Year of rotation			2nd year at seeding	end of year	3rd year		
1	2	3	Soil water (mm/120cm)	Water storage efficiency (%)	Yield (kg/ha)	ET (mm)	WUE (kg/ha/mm)
WL	- F	- W	295	+13	3730	407	9.2
F	- WL	- W	246	-16	3880	361	10.7
W	- F	- WL	292	+25	1230	372	3.3
F	- W	- WL	217	-26	1220	305	4.0

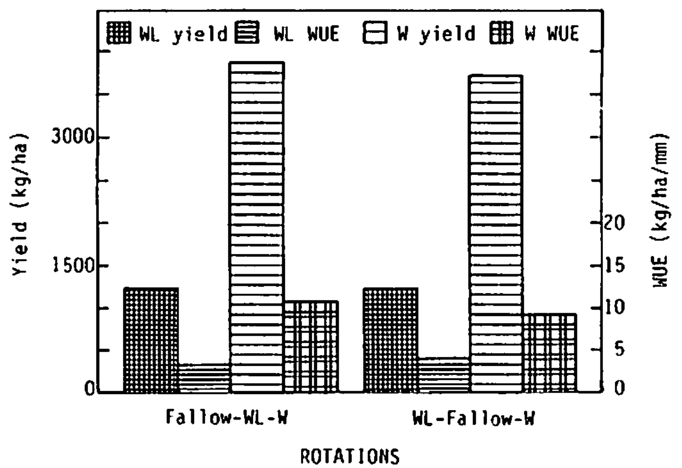


Fig. 2 Yield (kg/ha) and WUE (kg/ha/mm) of the winter lentil (WL) and wheat (W) in 3-year rotation systems at the Haymana Research Farm Ankara, Turkey.

WUE for winter lentil and wheat in the F-WL-W system was a little more than the WL-F-W system.

The results obtained from a three-year period in three fields indicated that since wheat yields following lentil were not reduced it is possible to reduce fallow by 33% easily, although when grassy weed and volunteer wheat problems in winter lentil are taken into consideration, the fallowing before lentil seems more effective. However, the results will be finalized after the completion of a few more three-year periods on the same fields, and economic analysis.

Conclusion

According to the results of a two-year rotation study, Hungarian vetch, winter lentil, chickpea and cumin, which reduced the following wheat yield not more than 10% were the most promising crops in rotation with wheat. These results are relevant for areas with similar conditions to the research site. At the research site the elevation is 1050 m, the average annual precipitation is roughly 350 mm, the monthly average temperature in the dry period below 20°C, and the soil is clay loam.

In the regions where precipitation is higher and/or the average temperature of the dry season is lower than that of the research site, and where the soils are light enough to be cultivated easily after harvest, spring lentil and sunflower fit best into the rotation with wheat.

The results indicated that there is not a significant decrease in wheat yield after winter lentil, spring lentil and sunflower compared to fallow in the four-year rotation. In the particular years considered the effect of these crops on WUE of wheat in the four-year rotation was more than in the two-year rotation, although there is no clear reason as to why this should be so.

In a continuous cropping system, grassy weeds were a special problem. In this situation, the adverse effect of weeds was cumulative in both phases of the rotation, wheat and the alternative crop. Soil preparation for winter legumes and wheat was also a problem in heavy textured soils. The risk with a two-year rotation system is possibly greater in the dry area compared to the experimental area. For these reasons, instead of a two-year rotation, a three- or four-year rotation may be more appropriate to eliminate the risk of continuous cropping by reducing the fallow 33 to 50%.

Two factors remain to be assessed in these trials. The results reported to date are for biological responses only. Clearly, adoption of these practices will depend on their economic feasibility, and final judgement on system recommendations will require an economic analysis. The second factor is the effect of intensified land use on soil physical properties. Long-term viability of the systems will require that the soil structural conditions can be maintained or improved, and that more intensive cropping does not promote soil erosion. Studies on these aspects have been started.

References

Durutan, N., Meyveci, K., Karaca, M., Avic, M. and Eyuboglu, H. 1990. Annual cropping under dryland conditions in Turkey: a case study. Pages 240-255 *in* The Role of Legumes in the Farming Systems of Mediterranean Areas. (Osman, A.E., Ibrahim, M.H. and Jones, M.A., eds), ICARDA/UNDP. Kluwer Academic Press, Dordrecht, The Netherlands.

Eskisehir Zirai Arastirma Enstitusu. 1987. NAD Projesi 1982-86 Donemi Toplu Degerlendirme Raporu, Eskisehir, Turkey.

Guler, M. and Karaca, M. 1988. Agroclimatological criteria for determining the boundaries of fallow practice. Pages 41-49 *in* Winter Cereals and Legumes in Mountainous Areas. (Srivastava, J.P., Saxena, M.C., Varma, S. and Tahir, M., eds), Proceedings of an International Symposium 6-10 July 1987, Ankara, Turkey. ICARDA-136 En. Aleppo, Syria.

Kalayci, M. 1984. Eskisehir Zirai Arastirma Enstitusu tarafindan bugune kadar yapilan nadas alanlarini azaltmaya yonelik calismalar. Kuru Tarim Bolgelerinde Nadas Alanlarindan Yararlanma Simpozyumu, 28-30 Eylul, 1981. Ankara. TUBITAK Yay. No. 593.

Kurt, O., Tan, A., ve Karagoz, A. 1988. Guzluk ve dondurma cifti ekim yontemleriyle nadasa birakilan arazilerden yem Uretimi Uzerinde arastirmalar. Sonuc Raporu ((basilmamis), TARM, Ankara, Turkey.

Meyveci, K. and Munsuz, N. 1989. Orta Anadolu Bolgesi Kosullarinda ikili ekim nobeti sisteminde toprakta nem ve inorganik azot formlarinin belirlenmesi, Turkiye Tahil Simpozyumui. TUBITAK-TOAG, 6-9 Ekim 1987. Bursa, Turkey.

TARM. 1981-87 Yetistirme Teknigi Yillik Gelisme Raporlari, Ankara, Turkey.

Yesilsoy, M.S. 1984. Nadas alanlarinin toprak ozellikleri ve bu alanlarin daha etkin kullanilma olanaklari. Kuru Tarim Bolgelerinde Nadas Alanlarindan Yararlanma Simpozyumu. 28-30 Eylul 1981, Ankara. TUBITAK Yay. No. 593.

Land and Rainfall Use Efficiency and Nitrogen Balance of Rotation Systems under Rainfed Conditions in Cyprus

I. PAPASTYLIANOU

Agricultural Research Institute, Nicosia, Cyprus

Abstract

Comparing rotation systems in two rainfed areas (250 and 350 mm) in Cyprus has shown that the vetch-barley system was more productive and had better rainfall use efficiency than the continuous barley and fallow-barley systems. The nitrogen balance (output minus input) of the vetch-barley system was 60 to 90 kg N/ha/year while for continuous cropping it was -2 to -22 kg N/ha/year. Optimum fertilization rate for the continuous barley system was 60 kg N/ha while no N fertilizer was needed for the vetch-barley system to improve productivity.

Introduction

Fallow-barley was the dominant rotation system in Cyprus up to 15 years ago. Efforts to replace fallow were reported by Littlejohn (1946), Loizides (1958) and Samios (1979). Recently a continuous barley system has been adopted, not due to agronomic evidence that it is a better system, but rather due to economic and management factors such as land shortage, mechanization, fertilizer availability and government subsidies.

The studies mentioned above showed that N fertilizer was needed for maximum cereal yield, so in 1980 a new series of rotation studies was initiated with the aim of examining the N fertilizer needs of barley in the continuous barley system as well as in fallow-barley and vetch-barley systems.

In Cyprus, as in most of the semi-arid Mediterranean environments, rainfall is the main factor limiting cereal production. In the cereal belt of Cyprus rainfall ranges between 200 to 400 mm. At the lower limits of this rainfall, its distribution is the most important factor (Hadjichristodoulou 1982). However, neither the amount nor the distribution of rainfall are predictable at the beginning of the growing season, so the rotation system and the fertilizer management should be decided on the basis of the mean of long-term studies showing the optimum management for better rainfall use efficiency.

Soil and climatic conditions in rainfed areas of Cyprus

Soils in areas where rainfed crops are grown in Cyprus are calcareous, of medium to fine texture, with low nitrogen (total soil nitrogen around 0.1%) and phosphorus (bicarbonate-extractable phosphorus 1-5 ppm), but adequate potassium (exchangeable K greater than 250 ppm).

Rainfall occurs during November through April and is rather erratic, both in amount and distribution, most of it (40%) occurring in December and January. In the cereal-growing areas, average annual rainfall is around 300 mm. Crops may suffer from water stress at any time of their growth cycle but it occurs predominantly in March-April during anthesis and grain-filling, reducing grain yields, and during sowing, resulting in late emergence and stands of low density.

Water conservation by fallowing

Fallowing aims to conserve soil water in one year, to supplement the following year's rainfall and thereby increase crop yield; but the extent and value of such conservation depends on soil factors (texture and depth), management factors (type of fallow, time and repetitions of tillage) and on rainfall itself. In particular, soil depth is critical for water storage. During the long, hot Mediterranean summer, any plant-available water in the top 30-45 cm is usually lost by evaporation; only water stored below that depth can be useful to the next crop (Loizides 1979; Cooper *et al.* 1987b). Shallow soils, therefore, have no value for moisture storage. Also, if the fallow-year rainfall is less than 200 mm, its penetration is only shallow, and no water is stored for the subsequent year, however deep the soil (Fig. 1).

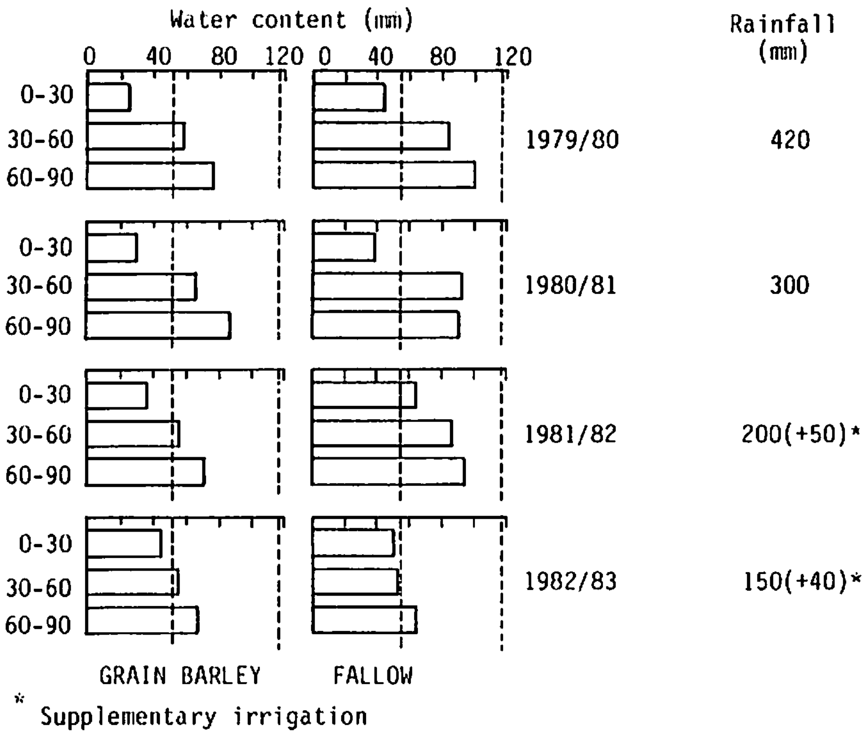


Fig. 1 Soil water profiles in late autumn of plots which grew grain barley (left) and of plots that were fallowed (right).

Even when water is stored in deep soil, its actual value to the next crop depends very much on the pattern and amount of rainfall during the cropping year. Because the growing season starts with dry topsoils, germination and early growth rely entirely on current rainfall. Crop roots reach the depth of water storage only at the end of the tillering stage. If there has been plentiful rain by then, 250 mm or more, the new wetting front will already have reached at least 70 cm depth, and water stored from the previous season will likely be of little value. Thus, previous bare-fallowing improves water availability to a crop only when a relatively dry year follows a relatively wet year. The probability of such a benefit tends to decrease as the climate becomes drier. Below a certain mean annual rainfall (depending on soil type, altitude etc), there may be little point in trying to conserve water by fallowing (Orphanos and Metochis, unpublished data).

Barley grain yield in rotations

The data presented in this report are from studies conducted at Laxia, a low rainfall area (mean 250 mm), and at Dromolaxia, near the coast, with higher rainfall (mean 350 mm). The rotations were vetch-barley, fallow-barley and continuous barley. Each phase was present every year so that since 1981 seven cycles have been completed. Barley crops received N fertilizer applied in sub-plots at 4 rates (0, 30, 60 and 90 kg N/ha). Nitrogen fertilizer was not applied on vetch or during fallowing. The 7-year mean grain yields of barley for zero and economically optimum N fertilizer rates for each rotation are presented in Table 1. At the optimum rate of fertilization barley grain yields after vetch and fallow were higher than in the continuous barley cropping system. The optimum rate of fertilization was zero fertilizer after vetch, 30 kg N/ha after fallow and 60 kg N/ha in the continuous barley system. When examining the land use efficiency it should be noted that the yields of barley, given in Table

Table 1. Grain yields of barley following vetch, fallow or barley, grown at zero and optimum rate of N fertilization, at two locations in Cyprus (Means of 7 rotation cycles)

Rotation	Fertilization (kg N/ha)	Barley grain yield (kg/ha)	
		Laxia	*Dromolaxia*
Vetch-barley	0*	1720	2540
	30	1650	2620
Fallow-barley	0	1340	2250
	30*	1860	2540
Continuous barley	0	570	1510
	60*	1510	2300

* Optimum rate of fertilization.

1 in the vetch-barley and fallow-barley rotations, should be divided by two as barley is cropped every other year while in the continuous barley system these yields are obtained every year. Productivity of the vetch-barley rotation can be compared with the other two rotations only if vetch is converted to "barley equivalents" in nutritional value and cost of feeding stuffs. When comparing the rotations the total biological yield is also important, so the barley grain equivalent value of straw is included. However, the economic value of straw varies considerably in both time and place. "Barley equivalents" of vetch and straw are shown in Table 2. The calculations to convert vetch and straw to "barley equivalents" were based on metabolizable energy, digestible protein and current international prices for soybean and barley (Dr. T. Antoniou, personal communication).

Table 2 Economic productivity (kg/ha) (land use efficiency) and rainfall use efficiency (RUE) (kg/mm rainfall) of vetch-barley, fallow-barley and continuous barley cropping systems at two locations in Cyprus

Location Rotation	Fertilization kg N/ha	Barley grain A	Barley grain equiv. for forage B	Barley grain equiv. for straw C	Total "grain" biological yield	RUE A+B+C	Total "grain" yield of main products	RUE A+B
LAXIA								
Vetch-barley	0	860	1290	420	2570	9.9	2150	8.3
Fallow-barley	0	670	-	390	1060	4.1	670	2.6
	30	930	-	520	1450	5.6	930	3.6
Continuous barley	0	570	-	330	900	3.5	570	2.2
	60	1510	-	960	2470	9.5	1510	5.8
DROMOLAXIA								
Vetch-barley	0	1270	2050	710	4030	11.4	3320	9.4
Fallow-barley	0	1130	-	570	1700	4.8	1130	3.1
	30	1270	-	700	1970	5.6	1270	3.8
Continuous barley	0	1510	-	800	2310	6.5	1510	4.3
	60	2300	-	1620	3920	11.1	2300	6.5

Rainfall use efficiency of rotations

Rainfall use efficiency (RUE) was calculated by dividing the total biological yield and total "grain" yield of the main products of each rotation by the total rainfall during the period of the research. Vetch-barley is the most efficient rotation followed by continuous barley, fallow having the lowest efficiency because two years of rainfall are used to produce one crop with less than double the yield of barley in the other two rotations (Table 2). Nitrogen fertilization increased RUE in the fallow-barley and continuous barley system while fertilization had a negative effect on RUE in the vetch-barley rotation in the low rainfall area (250 mm), or had no impact in the 350 mm rainfall area.

Nitrogen economy of rotations

Nitrogen economy at the zero and at the optimum rate of fertilization of the three rotations is shown in Table 3. For the calculations the actual N yield of vetch was considered, while for barley grain N content of 2% N was used to calculate N yield. Nitrogen yield in straw was estimated on the assumption that straw to grain ratio was 1:1 and N content of straw 0.5%. These values are not precise, particularly when having different N rates, but the total N from straw was of minor importance for the N balance calculation.

Table 3. Nitrogen balance (output-input) of vetch-barley, fallow-barley and continuous barley cropping systems

Rotation	Fertilization kg N/ha	Balance (kg/ha/year)	
		Laxia	*Dromolaxia*
Vetch-barley	0	58	93
Fallow-barley	0	17	28
	30	8	16
Continuous barley	0	14	38
	60	-22	-2

Discussion

It has been shown that moisture conservation by fallowing is not important under the rainfall conditions of Cyprus. Furthermore, land and rainfall use efficiencies are inferior in a fallow-barley rotation compared to continuous barley cropping and a vetch-barley rotation. Replacement of fallow in the rainfed areas of the Mediterranean region is discussed in more detail by Papastylianou and Jones (1988). In Cyprus fallowing is not practiced any more. It has been replaced by continuous barley cropping, as a result of other than agronomic factors or productivity of the system.

The present report, in addition to the fallow-barley data, gives a comparison of continuous barley cropping with the vetch-barley system, by examining the productivity, the rainfall use efficiency and the N balance of the two systems. For all these comparisons the superiority of the vetch-barley system over continuous barley cropping is evident. Particularly striking was the superiority of the vetch-barley system in the N balance comparison, when the non-fertilized vetch-barley system had a positive value of 60 to 90 kg N/ha/year in contrast to the negative value of -2 to -22 kg N/ha/year of continuous barley cropping at optimum fertilization rate, 60 kg N/ha. Similar results were obtained in earlier studies with woollypod vetch (*Vicia dasycarpa* var. Lana) as the forage legume (Table 4). This is of particular importance for farmers who cannot afford, or have no access to N fertilizer. It should be emphasised that in the vetch-barley system fertilization was not only unnecessary, it in fact

Table 4. Output of N of barley for grain (B), forages (Woollypod vetch (*V. dasycarpa* var. Lana)) (L), and forage barley (F)), input of N fertilizer and balance of N in kg N/ha for a six year period, in rotations

Rotation	Nitrogen removed in barley grain plus straw		Nitrogen removed in the forage	Input of N fertilizer	Balance of N (output-input)
LB	195		292	130	357
LB*B	122	241	195	174	262
LBB	119				
FB	157		134	261	30
FBB	105	210	89	261	38
FBB	105				

* Data presented are for the crop underlined.
Source: (Papastylianou and Samios 1987).

reduced the productivity and the efficiency of the system. In the continuous barley system, even in the low rainfall areas, fertilization was important in order to obtain maximum rainfall use efficiency. The importance of fertilizer in increasing water use efficiency was also shown by Cooper *et al.* (1987a) under Syrian conditions.

Marketing of forage is one of the constraints for the expansion of the cultivation of forage legumes (Papastylianou 1990). Farmers who have animals to eat the vetch, so that they have no need to market their product, should consider using the vetch-barley system because, as it has been shown, it has higher productivity with lower N inputs than the other two systems compared.

Another constraint to adopting a certain farming system is policy based on non-agronomic factors. Therefore, government interference (subsidies, crop insurances and marketing) should take special care to avoid encouraging one system against another unless the system has advantages favouring the national economy and can be adopted by the farmers.

References

Cooper, P.J.M., Gregory, P.J., Keatinge, J.D.H. and Brown, S.C. 1987a. Effects of fertilizer, variety and location on barley production under rainfed conditions in Northern Syria. 2. Soil water dynamics and crop water use. Field Crops Research 16: 67-84.

Cooper, P.J.M., Gregory, P.J., Tully, D. and Harris, H.C. 1987b. Improving water use efficiency on annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23: 113-158.

Hadjichristodoulou, A. 1982. The effect of annual precipitation and its distribution on grain yield of dryland cereals. Journal of agricultural Science, Cambridge 99: 261-270.

Littlejohn, L. 1946. Some aspects of soil fertility in Cyprus. Empire Journal of Experimental Agriculture 14: 123-134.

Loizides, P. 1958. Fertilizer experiments in Cyprus. II. Cereals, Empire Journal of Experimental Agriculture 26:25-33.

Loizides, P. 1979. Crop rotations under rainfed conditions in a Mediterranean climate in relation to soil moisture and fertilizer requirements. Pages 23-28 *in* Proceedings of FAO Regional Seminar on Rainfed Agriculture in the Near East, Amman, Jordan.

Papastylianou, I. 1990. The role of legumes in the farming systems of Cyprus. Pages 39-49 *in* Proceedings of the Workshop on the Role of Legumes in the Farming Systems of the Mediterranean Areas, Tunis, June 20-24, 1988. (Osman, A.E., Ibrahim, M.H. and Jones, M.A., eds). Kluwer Academic Press, Dordrecht, The Netherlands.

Papastylianou, I. and Samios, Th. 1987. Comparison of rotations in which barley for grain follows woollypod vetch or forage barley. Journal of agricultural Science, Cambridge 108: 609-615.

Papastylianou, I. and Jones, M. 1988. Replacement of fallow in the rainfed areas of the Mediterranean region. Pages 822-825 *in* Challenges in Dryland Agriculture. A Global Perspective. *In* Proceedings of the International Conference on Dryland Farming, August 1988, Amarillo/Bushland, Texas, USA. (Unger, P.W., Jordan, W.R., Sneed, T.V. and Jensen, R.J., eds) Texas A&M University, College Station, Texas, USA.

Samios, Th. 1979. Cropping systems and constraints in Cyprus, pages 92-99 *in* Proceedings of the Fifth Cereal Workshop, Algiers. MAAR, Algeria, ICARDA and CIMMYT.

Crop Rotation Systems in the Yemen Arab Republic

M.A. AL-KHAWLANI[1], A.M. BAMATRAF[2] and A.A. SAEED[3]

[1] *ARA, Central Highland Research Station, Shamar, YAR*
[2] *ARA Headquarters, Dhamar, YAR*
[3] *General Directorate of Extension and Training, Sanaa, YAR*

Abstract

Unpredictable water supply and small and fragmented agricultural holdings in the rainfed areas strongly influence crop rotation systems in the Yemen Arab Republic (YAR). The country is characterized by extremely diverse agro-ecology, land and water resources, and agricultural activities. Crop rotation research in YAR is at a very early stage, and rotation systems are not very efficient. The purpose of this paper is to assess the existing practices of crop rotation in relation to differences in the country's environmental conditions, and to identify research priorities for improvement of agricultural activities. Assessment of existing crop rotation systems under rainfed conditions in the highlands and lowlands of Yemen showed that the principal rotation is traditionally a crop/fallow system, the importance of which is not realized by farmers. Understanding these systems and their impact on both yield and soil and water conservation should be given higher priority in future research activities. Increasing awareness among farmers of efficient water use should be the goal of on-farm trials on crop rotations.

Introduction

The limited arable land area and scarcity of water in the Yemen Arab Republic (YAR) are probably the most serious constraints to the development of agriculture in the country. The expanding population and modernizing society are increasing the demand for food, thus causing dramatic change in the traditional cropping pattern. However, the country's environmental and cultural variability does not allow for flexible regimes of soil and water management, land use planning, land tenure, and water right relations. For instance, the unpredictable water supply and the small and extremely fragmented land holdings in most rainfed areas strongly influence farm management decisions.

Better management of farm resources can help to ease the strain on the agricultural sector. The government supports increased development in agriculture through agricultural research to meet the expanding fresh food market. The problem faced by the Agricultural Research Authority (ARA) is how to change current inefficient farm practices, in both rainfed and irrigated systems, to more efficient ones. ARA identified research priorities for many agro-techniques; crop rotation has been given a relatively low priority (ARA 1986).

The purpose of the work presented here is to assess the existing practices of crop rotation in the Yemen Arab Republic with regard to differences in the country's environmental conditions. An equally important goal is to identify research priorities on the improvement of crop rotation practices.

Physical and Cultural Features of Yemen

Yemen Arab Republic has an area of approximately 20 million hectares out of which 1.35 million hectares are presently under cultivation. About 1.12 million hectares of this area are rainfed and 0.23 million hectares irrigated. In addition there are much larger areas that are marginally cultivated, once every two to four years, depending on rainfall. The country is characterized by extremely diverse agro-ecology, land and water resources, and agricultural activities.

Agro-ecological Regions

The topographical features of the country affect environmental conditions and consequently different cropping systems. For agricultural research purposes, the country is divided into five agro-ecological regions according to topography and prevailing climatic conditions (Bamatraf 1987). These regions are:

1. Tihama Coastal Plain; the western lowland strip 40 km wide and 500 km long bordering the Red Sea. This region has an arid tropical climate with high temperatures, high humidity, and low rainfall. The elevation ranges from sea level to 500 m;
2. Southern Upland; the southern parts of the mountain chain which are located 500-1500 m above sea level. It has different climatic conditions ranging from a hot tropical and subtropical climate in the bottom of intermontane valleys to temperate conditions on the high mountain slopes;
3. Central Highland; the central part of the Yemen mountains. The elevation ranges from 1500 to 3000 m above sea level. It has a dry temperate climate;
4. Northern Region; extends over the northern half of the mountain peaks from the center of the country to the border with Saudi Arabia. It covers the areas of Sanaa, Sadaa, and Hajja governorates which include upland and highland with altitudes of 500-1500m and 1500-3500m, respectively;
5. Eastern Plateau; the area sloping from the base of the central mountain chain to the Empty Quarter with altitude below 1500m. The climate in this region is hot and dry.

Major variations in environmental conditions also exist within these five regions.

Land and Water Resources

A soil survey covering most of the country's land area has been recently completed (King *et al.* 1983). About a quarter is classified as predominantly rock outcrop. Most soils are subject to alternate erosion/deposition processes causing about 60% of the country to be dominated by soils of the Entisol order. Other orders include Aridisols (8.7%), Inceptisols (4.3%), Mollisols (2.6%), and to a limited extent, Vertisols and Alfisols.

Most of the agricultural holdings are privately owned. Small farms are characteristic of farming systems in Yemen. About 72% of all holdings are less than two hectares in area, spreading over 20% of the cultivated land, and only 4% of total holdings are larger than ten hectares, but represent one third of the cultivable area (MAF 1983). The average farm size for the whole country is approximately 2.3 ha. Land fragmentation is another feature of the country's farm structure. The average number of parcels ranges from three to seven per holding. Differences in land tenure among regions also exist (Bamatraf 1988), which can be related to local topography.

Rain is the main source of all water in Yemen. Some is used at the location where it falls, some flows as surface runoff, and some percolates deeply to replenish the ground water. The only body of surface water in the country is the reservoir behind the newly constructed Marib Dam. The mountains have a great influence on the amount and distribution of rainfall in the country. In general, the amount of precipitation and its distribution vary with altitude, latitude, and distance from the Red Sea and Gulf of Aden (Grolier *et al.* 1981). The annual rainfall ranges from 300 mm in the south and north and increases towards the middle of the country to reach 1200 mm around Ibb. The rain falls in two seasons, the first during spring, extending from March through May, and the second, in summer, starts in July and stops by about the end of September.

The distribution and use of water are still governed by customary laws. Surface water rights, for example, grant water to the land nearest the water source and allow less water for downstream farmers (Bamatraf 1988). There is almost no control over ground water extraction; however, digging new wells that may be detrimental to existing wells is prohibited.

Agricultural Activities

There are two broad farming systems, i.e., rainfed and irrigated. Rainfed farming is practised in about 75% of the cropped land (MAF 1983). Data from a recent study (Bamatraf 1987), which subdivided cropped area of rainfed and irrigated farming systems, showed that about 50% of the rainfed area receives less than 450 mm rainfall, which is less than half of the evapotranspiration. Such a situation necessitates supplementing rainfall using one or more of the different water conservation techniques which have proved relatively efficient for thousands of years (Bamatraf and Al-Domi 1987). Irrigated areas are expanding at the expense of rainfed areas, as crops with a high demand for water have recently been given more attention, which has resulted in a change in cropping patterns.

Differences in environmental conditions among the agro-ecological regions make it possible to grow a wide range of tropical, subtropical and temperate crops. The average cropping pattern in YAR is given in Table 1 (MAF 1988). The most important crops grown in the country are cereals, which occupy 75% of the area under cropping, with sorghum (*Sorghum bicolor*) being the most significant. The grain is used for human food and other plant parts are used for animal feed.

Millet (*Panicum miliaceum*) is the next most important; it is planted under low rainfall conditions and may be intercropped with cowpea. Millet is also planted on sandy soils (marginal agricultural land) after the rains in the lowland of Tihama.

Maize (*Zea mays*) is grown in all regions under irrigation or supplemental irrigation except in areas receiving high rainfall. The demand for maize is increasing with the expansion of the poultry industry. Wheat and barley are grown mainly in the highlands and Eastern plateau. However, these two crops are grown in all farming systems, with wheat replacing barley as rainfall increases.

Vegetables (onion, tomato, potato, eggplant, carrot) are planted in nurseries in September and transplanted to the field one month later. Vegetables are planted after cereals, grown under irrigation. Data in Table 1 show a remarkable increase in areas grown to vegetables and fruits. Deciduous fruit orchards are established in the Central Highlands

Table 1. Area (1000 ha) and average yield (t/ha) of major crops in the Yemen Arab Republic during cropping seasons 1984-87

	1984		1985		1986		1987	
Crop	Area	Yield	Area	Yield	Area	Yield	Area	Yield
Sorghum/millet	694	0.39	690	0.41	660	0.71	653	0.73
Wheat	58	0.64	59	1.09	65	1.31	67	1.50
Barley	48	0.59	46	0.69	48	0.85	46	0.86
Maize	34	1.13	38	1.13	41	1.20	40	1.19
Total cereals	834	-	833	-	814	-	806	-
Legumes	30	1.67	25	1.77	27	1.73	24	1.63
Indust. crops	18	-	18	-	18	-	20	-
Vegetables	18	19.24	19	19.50	22	19.65	24	18.94
Alfalfa	11	4.23	11	4.69	12	4.85	13	5.02
Coffee	16	0.26	16	0.24	16	0.25	17	0.24
Date palm	-	-	10	1.37	10	1.35	10	1.51
Grapes	14	5.83	14	5.75	14	7.10	15	5.87
Other tree crops	15	5.86	16	5.53	16	6.50	17	2.33
Fallow*	331	-	331	-	331	-	331	-
Total	1287	-	1293	-	1280	-	1277	-

Source: MAF (1988)

* Estimate on basis of Agricultural Census, MAF 1983.

and Northern region, while tropical and sub-tropical fruits are grown in Tihama, the Southern Upland, and the Eastern Plateau. Crop yields are generally low, due to lack of water, low soil productivity, and inadequate cultural practices.

Assessment of Crop Rotation Practices

The aim of all cropping systems should be sustained maximum profit from the farming operation. Common constraints to crop rotations in various parts of YAR are a lack of predictable water supply which influences farm management decisions, and causes land fragmentation. In the rainfed areas crop choices for the seasons are based primarily at subsistence level for individual farm families, while on irrigated land, crop production is increasingly oriented towards the market.

Some previous descriptions of rainfed cropping systems in Yemen considered that no definite crop rotation was practised (Acres 1978; Kambal 1986). However, the agricultural Census (MAF 1983) indicated that about 8% of the cultivable land is left fallow annually for crop/fallow rotation. Bamatraf (1987) reported that data are not available on these fallowing practices, which remain to be investigated. Moreover, during his study, extension workers in three agro-ecological regions were interviewed concerning crop rotations; it was found that the reasons behind following the principal crop rotation are mainly tradition and habit. This indicates that the importance of crop rotation is not clearly realized by farmers.

Description of Selected Systems

As mentioned above, detailed information on the crop rotation systems in the country is so far lacking. However, systems in limited areas were described by a few investigators (Anon. 1978; Bisset 1984). Figure 1 illustrates approximate common crop rotation systems under rainfed conditions in the highlands and lowlands.

The highland rainfed crop rotation system (Bisset 1984) is a two-year cycle of cropping with two growing seasons in each year. The land is deep ploughed in November of the first

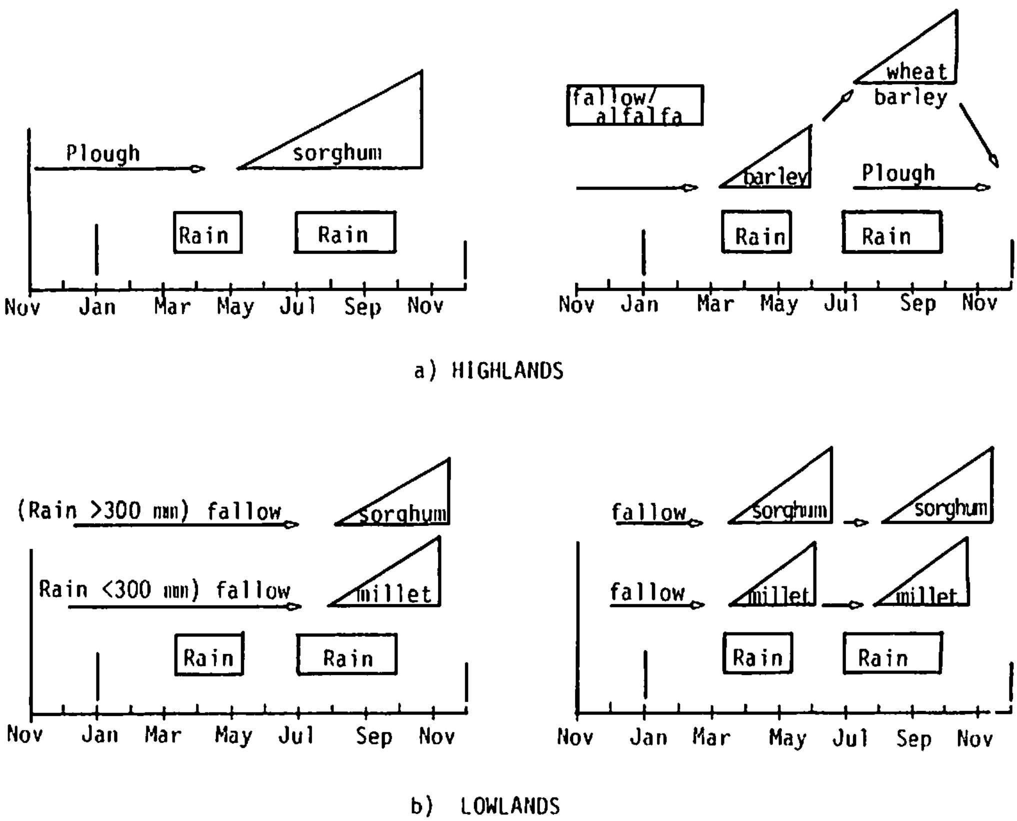


Fig. 1 Two-year cycle of crop rotation in the highlands and lowlands of Yemen.

year. Ox-, camel- or tractor-drawn ploughs are used for this cultivation which is mainly for controlling rhizomatous grass weeds (*Cynodon* spp.), and for leaving a rough surface to increase infiltration of rainfall. The land is left throughout the spring rains and cultivated in May for sorghum planting. Sorghum occupies the land for six months. After sorghum is harvested, the land is left with no-till until February of the following year. It is then cultivated to remove sorghum stumps and roots, to control weeds, and to prepare the seedbed. Barley or lentils are sown by hand. The crops are harvested in June, and the land is abandoned throughout the summer rains. In the autumn it is ploughed for the sorghum crop. If the rain is heavy, some farmers may have another crop in the summer. In this case, a spring crop, usually lentils, is followed by summer wheat or barley. The land is then ploughed for the sorghum crop.

The lowland rainfed cropping system is shown diagrammatically in Figure 1. The land is left fallow with no-till throughout the spring rains. The main benefit of this is water conservation, as the light-textured soils allow infiltration of rainfall and minimize evaporation. In mid-summer, sorghum is planted after ploughing in areas with annual rainfall of >300 mm while millet is sown in areas with rainfall <300 mm. They are harvested in winter. If the rainfall is high (above average), two crops can be grown a year. The first crop is planted after the first spring rain. The crops are harvested by the end of June and the land is left until August when the second crop of sorghum and millet is planted.

Crop Rotation Research Priorities

Improvement of water use efficiency (WUE) in rainfed agriculture is a centuries-old challenge facing the Yemeni farmer. Farm WUE is mainly achieved by water conservation engineering practices; i.e., terracing, water harvesting, and other small-scale water control devices (Bamatraf and Aldomi 1987). Less emphasis, however, was given to crop and soil management such as reduction of field water requirement through crop selection, soil mulching etc. Higher levels of crop production are strongly related to proper farm resource utilization. On-farm soil and water conservation could be achieved by designing appropriate crop rotations under prevailing climatic conditions.

Priority should be given to field surveys on existing crop rotation practices, whose impact on soil productivity and water use efficiency should also be investigated. This will enable researchers to understand farmers' problems with crop rotation more fully. On-station field trials on crop rotation should be conducted to solve real problems encountered by farmers. Integrated multi-disciplinary technological packages should be identified, tested, and finally transferred to farmers for adoption. On-farm trials should focus on increasing awareness among farmers of efficient water use through crop rotations under rainfed farming.

Conclusion

Improved water use efficiency under rainfed conditions is mainly achieved through traditional soil and water engineering practices, rather than proper crop and soil management. The principal crop rotation is a crop-fallow rotation which is greatly influenced by unpredictable water supply and fragmentation of cultivated land. Research results on crop rotation in the

YAR are lacking so far. In-depth understanding of existing crop rotation practices should come before any recommendations on improving such practices. Thorough investigations on the impact of these activities on both crop yields and farm resources should be conducted on-station. Increasing awareness among farmers about efficient water use should be the goal of on-farm trials on crop rotations.

References

Acres, B.D. 1978. Agriculture development in the montane plains, Yemen Arab Republic. Project Report No. 18, Land Resources Division, ODA, Tolworth, UK.

Agricultural Research Authority 1986. Agricultural research in Yemen Arab Republic: Problems, research activities, evaluation and future programs. Vol. 1 and 2. ARA publication, Taiz, YAR.

Anon., 1987. Marib Dam and Irrigation Project-Yemen Arab Republic. 12 Volumes. Study conducted by Electrowatt Engineering Services Ltd. in association with Hunting Technical Services Ltd., Boreham Wood, U.K.

Bamatraf, A.M. 1987. Supplemental irrigation in the Yemen Arab Republic. ARA report presented at the ICARDA/FAO regional consultation on supplementary irrigation in the Near East. Rabat, Morocco, Dec 7-9, 1987.

Bamatraf, A.M. 1988. Land tenure and water rights in Albaida, Dhamar, and Hodaida governorates. Yemeni-Dutch Seminar on Environmental profiles. Nov 26, 1988, Sana'a, Yemen Arab Republic.

Bamatraf, A.M. and Al-Domi, I.A. 1987. Water conservation techniques in Yemen Arab Republic. Paper presented at the second International Soil Correlation Meeting Jan 6-15 1987. ARA SW/TP1/87. Sana'a, YAR.

Bisset, P.G. 1984. Rainfed cropping systems in southern Qa, Jahran. Yemen Arab Republic Project Report No 81, Land Resources Division, ODA, UK.

Grolier, M.J., Tibbits, G.C., Jr. and Ibrahim, M.M. 1981. A qualitative appraisal of the hydrology of the Yemen Arab Republic from landsat images. Open-file Report 80-565 USGS. Reston VA, USA.

Kambal, A. 1986. Improvement of sorghum, maize, millet, and some grain legumes in the Yemen Arab Republic. Final Report of FAO Agronomist. ARA, Taiz, YAR.

King, J., Forbes, T. and Abughanem, A. 1983. Soil survey of the Yemen Arab Republic. Department of Agronomy, Cornell University. Final Report for Near East Bureau, Contract No. AID/NE-C- 1665. USAID, Washington DC, USA.

Ministry of Agriculture and Fisheries (MAF) 1983. Summary of final results of Agricultural Census in eleven provinces. Agricultural Statistics Project, Department of Planning and Statistics, MAF, Sana'a, YAR.

Yearbook 1987. Agricultural Statistics Department, 1988. General Directorate of Planning and Statistics, Sana'a, YAR.

The Introduction, Development, Management and Impact of Legumes in Cereal Rotations in Southern Australia

T.G. REEVES

Department of Agriculture and Rural Affairs, P.O. Box 69, Wangaratta, Victoria, Australia 3677

Abstract

Pasture and crop legumes are the basis of agricultural production in the cropping and grazing regions of southern Australia. The factors affecting their introduction, management and integration on farms are described in this paper. Whilst the southern Australian ley-farming system is "alive and well" it is now a more flexible system including grain legumes. Factors behind the rapid introduction of legume crops such as *Lupinus angustifolius* and *Pisum sativum*, in the 1970s and 1980s have been both biological and economic. Crop legumes such as lupins have been shown to fix between 34-138 kg N/ha per annum, reduce the carryover of cereal root diseases, and provide an opportunity to intensify crop rotations when this is economically desirable. A farming systems research approach, with strong emphasis on a continuum between research and extension, has resulted in the rapid adoption of crop legumes on farms. Benefits to livestock production have also been demonstrated. Both pasture and crop legumes are important in improving the utilization of rainfall. Wheat grown after a legume is shown to have a higher WUE than continuous wheat. Whilst some crop legumes are not generally efficient at converting water to grain, their water-use can be substantially more than pasture legumes and cereals, an important factor in catchment management. Crop legumes have complemented pasture legumes and cereals, enabling farmers to turn scarce rainfall into marketable produce even more efficiently.

Introduction

Legumes -- both pasture and crop -- are the cornerstone of agricultural production in the cropping and grazing regions of southern Australia. This has not always been the case, however.

In Australia today there are about 26 million hectares of sown pastures (Wheeler *et al.* 1987), together with approximately 1.6 million hectares of grain legume crops. The whole of this development has taken place in the last 50 years, with the greatest changes occurring even more recently, during the 1960s to 1980s.

The gross value of livestock production from these pastures was estimated to be 6659 million AUD (1.20 AUD = 1.00 USD) in 1985/86, and with the current high prices for wool, meat and milk would be considerably higher in 1988/89. Of course, leguminous pastures contribute much more to agriculture than simply the food supply for animals because broadacre cropping in Australia is very largely a ley farming system, reliant upon a period of legume dominant pasture to provide nitrogen for subsequent crops (Wheeler *et al.* 1987). Carter *et al.* (1982) estimated that this nitrogen accretion is worth 1500 million AUD annually.

The integration of crop legumes into these crop-pasture rotations (McCown *et al.* 1987) has added a new dimension to the farming systems of southern Australia and their adoption by farmers has been nothing short of dramatic. For example, in Western Australia alone, the area of sweet, grain lupins (*Lupinus angustifolius*) sown has increased from 12 thousand hectares in 1969 (Rowland *et al.* 1988) to one million hectares in 1988. In Victoria, an eastern state of Australia, the area of field peas (*Pisum sativum*) has likewise increased from 45 thousand hectares in 1983 to 300 thousand hectares in 1987!

In this case study paper, the development, adoption and management of legume-based crop rotations is described.

Setting the Scene - the Problems of Early Agricultural Development in Southern Australia

Climate

The climate in the southern Australian agricultural region is a mediterranean type with hot, dry summers and with rainfall concentrated in the cooler winter-spring growing season, May-October, (Puckridge and French 1983). Lack of rainfall and unreliability of rainfall remain as major factors limiting agricultural production in southern Australia. As average rainfall is below optimum for plant growth over much of the growing season in the wheat-sheep zone, farming systems that maximize water use efficiency are obviously critical.

Soils

The combination of fragile, infertile soils with highly variable rainfall requires farming systems, and particularly cropping systems, that protect the soil surface and facilitate the entry of rain where it falls.

Early crop production was not based on such systems, however, and the history of wheat yields in southern Australia reflects the inappropriateness of the systems being used at that time, and the subsequent impact of legumes and other improvements in more recent years (Fig. 1; Puckridge & French 1983). A noteworthy feature was that the continued use of bare fallowing for moisture conservation and the fallow-wheat rotation depleted organic matter, damaged soil structure and resulted in widespread erosion.

The remainder of this paper concentrates on the development and enhancement of legume-based cropping systems.

The Effects of Pasture-Legume Rotations on Soil Fertility and Crop Yields

The legume-based pastures introduced widely into cropping rotations in the 1950s and onwards were based on self-regenerating species of *Trifolium subterraneum* (neutral to acidic soils) or *Medicago* spp. (neutral to alkaline soils).

The net increment of soil nitrogen resulting from symbiotic nitrogen fixation varies with the productivity of the legume sward but under southern Australian conditions is usually from 35 to 100 kg N/ha/annum. Not only is soil nitrogen increased but soil structure improves

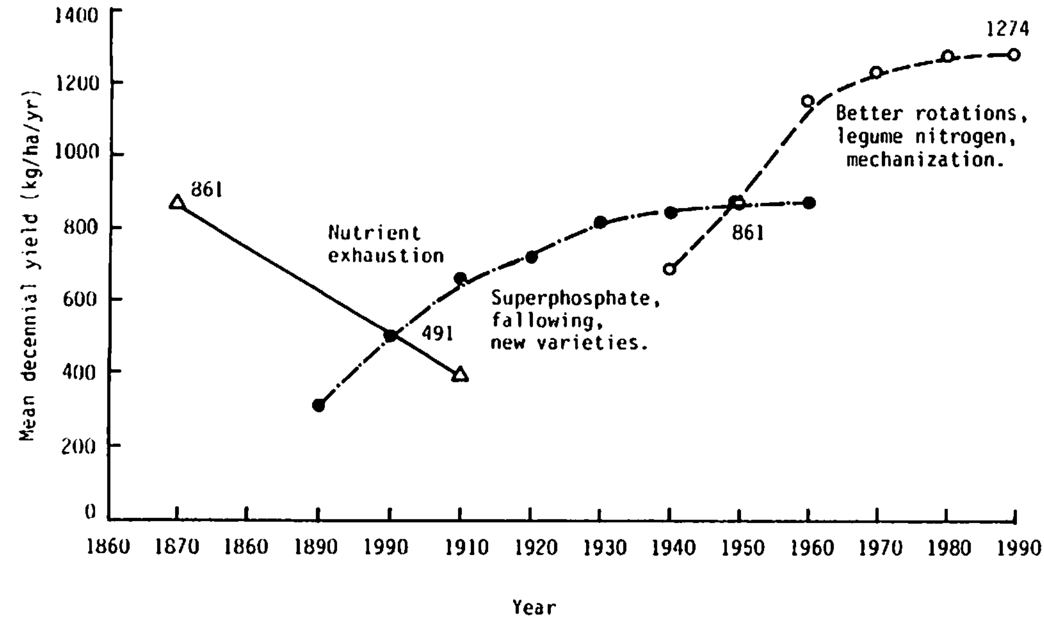


Fig. 1 **Australian wheat yields 1860-1980. Unweighted means in 10-year intervals.**

during the pasture phase, providing a sound basis for subsequent crop production. Ellington *et al.* (1979) have shown the changes in soil nitrogen and soil structure associated with a subterranean clover ley-wheat rotation (Figs 2 and 3).

When these pasture-crop rotations were initially established, and even as late as the 1960s, it was considered that they satisfied all the attributes of a stable, sustainable farming system. However, by the 1970s it was clear that a number of biological and economic factors were beginning to have a significant influence on the future productivity and usage of these legume pasture-crop rotations.

Pasture-Crop rotations - Diagnosing the Problems

The factors arising that influenced the stability of the pasture legume-crop rotation could be categorized under four headings:

1. Problems of pasture re-establishment and productivity
2. Increasing cereal crop diseases, particularly root-rots
3. Soil problems, particularly soil acidity and salinity
4. Economic pressures to increase cropping at the expense of pastures and livestock

In diagnosing the problems in the first category Carter *et al.* (1982) comprehensively stated the factors influencing medic rotational pastures in South Australia.

The diagnoses of the problems in the second category -- increased crop disease incidence -- are exemplified in the work of Griffiths (1986). As total soil nitrogen increased

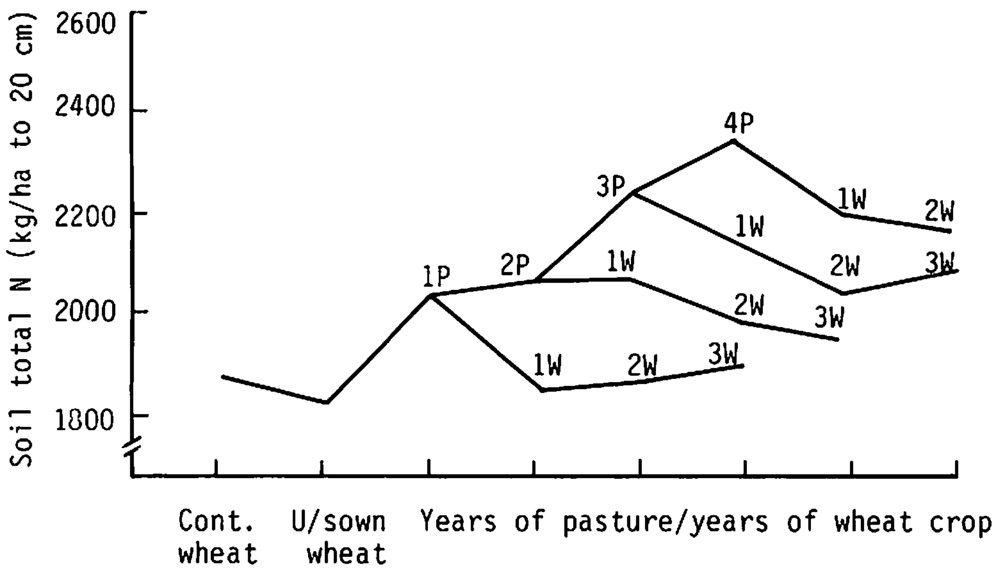


Fig. 2 Changes in levels of soil total nitrogen following years of legume-based pasture (P) and years of wheat crop (W) at Rutherglen, Victoria, Australia.

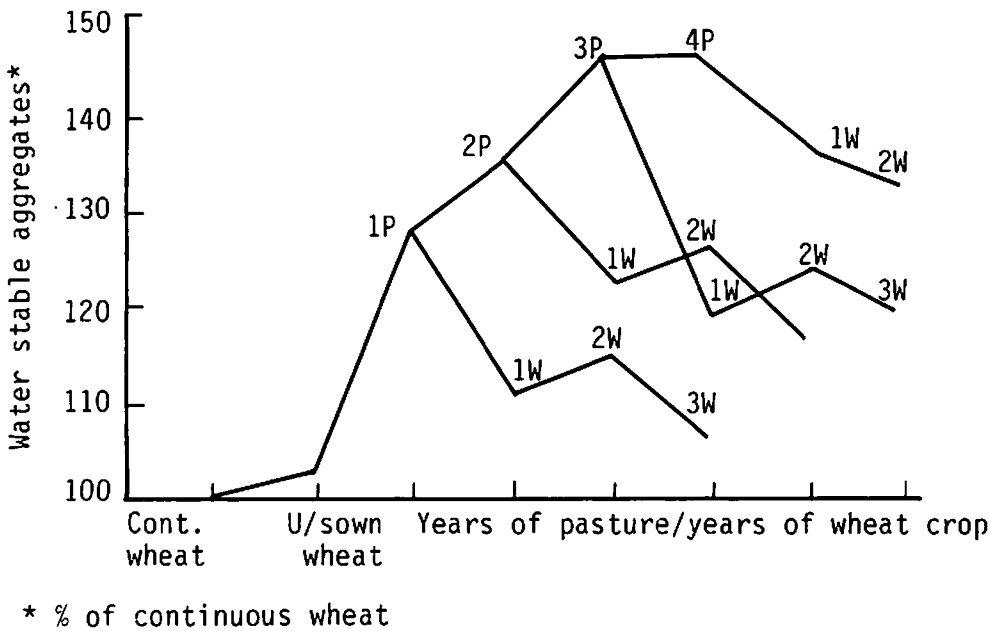


Fig. 3 Changes in soil structure as indicated by the level of water-stable aggregates (relative to continuous wheat) following years of pasture (P) and years of wheat crop (W) at Rutherglen, Victoria, Australia.

under legume leys, annual grassy weeds eg. *Hordeum leporinum, Lolium rigidum* and *Bromus spp*. became more dominant. These grasses not only competed with the pasture legumes but also carried over root disease and weed problems into the subsequent cereal crop. The most significant of these diseases is take-all (*Gaumannomyces graminis*).

Thirdly, soil acidity and soil salinity are increasing significantly in southern Australia. It is estimated that 14 million hectares have strongly acidic surface soils whilst soil salinization is estimated to have affected approximately 1 million hectares. The growth of annual legume based pastures has greatly increased carbon and nitrogen inputs into these ecosystems and on the more acid soils this has accelerated soil acidification (Helyar 1987). Similarly, the removal of native vegetation and its replacement by annual crops and pastures has long been known to induce soil salinity (Nulsen and Baxter 1982).

Finally, economic and market factors have significantly influenced the balance between crops and pastures. With increasing prices for wheat and other grains in the 1970s to 1980s, farmers were faced with an economic scenario that demanded more intensive cropping than the pasture-wheat rotation could provide.

This combination of factors resulted in a major research effort into more intensive cropping rotations utilizing grain legumes and other crops in cereal rotations.

Researching Grain Legume-Cereal Rotations

1. Effects on soil fertility

Reeves *et al.* (1984) showed that narrow-leafed lupins (*Lupinus angustifolius*) significantly increased soil mineral nitrogen levels, resulting in average N increases of 41 kg/ha (0-20 cm) after lupins, (harvested for grain). Similar results have been obtained on a range of sandy to sandy loam soils in Western Australia (Rowland *et al.* 1988), and in other parts of Australia (eg. Herridge and Doyle 1988).

Evans *et al.* (1987) were able to show, using ^{15}N studies, that the potential benefit of lupins to soil N varied from 34 to 138 kg N/ha across years and sowing dates. Nitrogen fixation appeared to be inversely affected by levels of soil mineral N. In subsequent work (Evans *et al.* 1989), however, it appears that nitrogen fixation by peas is more sensitive than lupin nitrogen fixation to soil nitrate levels.

Evans (1989) observed that due to the inhibition of N- fixation by soil mineral N, decreases in soil total N may occur when rotating lupin and wheat crops in high fertility soils. However in lower fertility soils, and where crop residues are retained in a minimum tillage system, it is considered that soil organic N can be at least maintained. Lupins have also been reported to influence soil structure (eg. Reeves 1984).

2. Effects on crop disease incidence

The advantage of legume crops over legume pastures, or cultivated fallow, in reducing the incidence of diseases in subsequent cereal crops is based on better weed management. Highly effective herbicides are used in legume crops for controlling grassy weeds involved in the carryover of cereal diseases.

Simazine and trifluralin are used for pre-emergence weed control in lupins and a range of post-emergence herbicides have become available in recent years eg. diclofop-

methyl and fluazifop-butyl. Not only does the grassy weed control obtained reduce disease carryover, but importantly it generally, significantly and economically increases the yields of grain legume crops in the year of application. That is, the farmer gets an immediate return as well as a longer-term return. This contrasts with grassy weeds in fallow or legume pastures where control is either costly and difficult, or undesirable, and any benefits only accrue in subsequent years.
Table 1 shows the results obtained by Griffiths (1986) where the inclusion of grain legumes and/or rapeseed in a rotation significantly reduced the build-up of cereal cyst nematode, a serious pest-disease of wheat in parts of southern Australia.

Table 1. Effects of various rotations on Cereal Cyst Nematodes at a low fertility site with high levels of CCN

Year 1	Year 2	Year 3	Year 4	Year 5	CCN Cysts per 10 plants	Wheat yield t/ha (year 5)
Wheat	Fallow	Wheat	Fallow	Wheat	139.00	0.9
Wheat	Fallow	Lupins	Rape	Wheat	6.00	1.5
Wheat	Lupin	Wheat	Peas	Wheat	21.33	1.1

3. Water-use efficiency in cereal-legume rotations

Water deficit, particularly during stem elongation, flowering and grain filling phases is the major constraint to grain yields in most parts of southern Australia (Hamblin *et al.* 1987). There has been a great deal of research on crop water use not only in relation to grain yields, but also in relation to overall catchment management (Nulsen and Baxter 1982).
Reducing soil evaporation by increasing the rate of leaf area expansion and crop growth can be influenced by a range of factors under the farmer's control. One of the most important is soil fertility, and in many parts of southern Australia inherent nitrogen levels are insufficient to produce rapid early crop growth.
Increases in water use and grain yield from legume nitrogen are generally larger than from fertilizer sources; disease breaks, better grass weed control and other factors are involved. In Table 2, Hamblin *et al.* (1987) showed that on a deep sand-plain soil, wheat WUE increased from 7.9 kg/ha/mm (second wheat crop with nil N) to 12 or 13 kg/ha/mm after legumes. In this case grain legumes and pasture legumes were equally effective in increasing water-use and grain yields of wheat.
Very few comparisons have been made between the WU of pasture legumes versus grain legumes *per se* (cf. their effect on WUE in subsequent cereal crops). However drainage -- the movement of water below the rooting depth -- can be an important process on light textured soils. Accordingly depth of root penetration may be an

Table 2. Water use (WU mm*) and grain yield (GY t/ha) of wheat following wheat, harvested grain legumes, and ungrazed pasture legumes

Fertilizer Nitrogen added (kg/ha)	Previous species									
	Wheat		Lupin [1]		Pea[2]		Serradella[3]		Subterranean clover [4]	
	WU	GY	WU	GY	WU	GY	WU	GY	WU	GY
0	228	1.8	244	2.5	241	2.7	242	2.8	252	3.3
50	nd	3.0	nd	3.3	nd	3.0	nd	2.7	nd	3.1
335	242	2.9	240	2.9	nd	2.6	nd	3.1	231	2.9

* LSD: P 0.05 = 10 mm
[1] *Lupinus angustifolius* L. cv. Yandee
[2] *Pisum sativum* L. cv. Dundale
[3] *Ornithopus compressus* L. cv. Pitman, ungrazed (138 kg N equivalent)
[4] *Trifolium subterraneum* L. cv. Northam, ungrazed (115 kg N equivalent)
nd: not determined

important property, determining, over the season, the total water supply to the crop (Perry *et al.* 1986). Hamblin and Hamblin (1985) showed maximum root depth and biological yields of crop and pasture species on deep sandy soils.
Their results showed that lupin root systems extended to a depth of 190 cm compared to 113 cm for wheat, 65 cm for peas and 70-90 cm for a range of pastures species including *T. subterraneum* and *M. polymorpha.* Lupins would have an extra 40-70 mm of water at depth compared to the pasture species.
Nulsen and Baxter (1982) similarly showed (Table 3) that rainfall percolation to ground water was considerably less under cereal rotations containing lupins than under those with subterranean clover.
When comparing the WU of grain legumes versus wheat G.R. Steed (personal communication) showed that lupin crops are capable of extracting much more water than wheat from a sandy, clay loam. He demonstrated that E_T/E_o for lupins was on occasions >1.0. However, he also pointed out that whilst lupins have a great ability to

Table 3. Possible recharge under four crops grown on sandy loam soils

Site	Growing season rainfall (mm)	Recharge (mm) under:			
		Wheat	Barley	Lupins	Clover
Kondut	162	47	9	80	125
Cunderdin	258	139	83	61	162

extract water, their WUE, or ability to convert moisture to grain is low. J.B. Griffiths (personal communication) confirms this for the Victorian Mallee (alkaline, sandy loams) where the average WUEs for wheat, peas and lupins were 9.2 kg/mm/ha, 6.7 kg/mm/ha and 3.8 kg/mm/ha, respectively. It needs to be remembered, however, that biological yield of legumes (pasture and grain) is important in rotations as a major determinant of N-fixation.

Getting the Message to Farmers

The best research in the world is of little value if it does not have an impact on the appropriate clients. In the case study being considered here -- adoption of grain legume rotations -- the major clients were farmers, and by any standards, the impact of this research and development program on farmers in southern Australia has been very great.

There were 4 critical factors in the successful program:

1. sound economic benefits could be demonstrated in the short and longer terms
2. the technology was robust and well developed
3. the technology was in line with farmer values
4. research/development/extension on grain legumes has truly been a continuum with an emphasis on a farming systems approach.

This sequence is described by Reeves (1989).

The Situation Today, and Future Directions

As a result of the factors described above both grain and pasture legumes are widely grown on Australian farms.

The balance between them is controlled by several factors, including the economics of livestock and grain production, the development of new cultivars, and the packages of technology needed to grow them. Both crop and pasture legumes significantly increase subsequent cereal yields on farms.

The development of new farming systems is an incremental process. As McCown *et al.* (1987) concluded, "the southern Australian ley system is alive and well. The present version is a more flexible, adaptive one that includes grain legumes, N fertilizer, direct drilling and stubble retention". Grain legumes have complemented pasture legumes and cereals, enabling farmers to improve further the efficiency of turning scarce rainfall into marketable produce.

References

Carter, E.D., Wolfe, E.C. and Francis, C.M. 1982. Problems of maintaining pastures in the cereal-livestock areas of southern Australia. Pages 68-82 *in* Proceedings of 2nd Australian Agronomy Conference, Wagga Wagga, NSW, Australia.

Donald, C.M. 1981. Innovation in Australian agriculture. Pages 57-86 *in* Agriculture in the Australian economy (Williams, D.B., ed.). Sydney University Press, Australia.

Ellington, A., Reeves,T.G., Boundy, K.A. and Brooke, H.D. 1979. Increasing yields and soil fertility with pasture/wheat/grain legume rotations and direct-drilling. Proceedings of the 49th ANZAAS Congress, Auckland, New Zealand.

Evans, J,. Turner, G.L., O'Conner, G.E. and Bergersen, F.J. 1987. Nitrogen fixation and accretion of soil nitrogen by field-grown lupins (*Lupinus angustifolius*). Field Crops Research 16: 309-322.

Evans, J. 1989. Predicting N_2 fixation in crops of *Lupinus angustifolius L.* and soil nitrogen balance in lupin-cereal rotations in south-eastern Australia. Field Crops Research, (in press).

Evans, J., O'Conner, G.E., Turner, G.L., Coventry, D.R., Fetell, N., Mahoney, J., Armstrong, E.L. and Walsgott, D.N. 1989. Temperate crop legumes in south-eastern Australia: 1. Dependence on N_2 fixation and uptake of soil nitrogen compared in lupin, field pea and other legumes. Australian Journal of Agricultural Research, 40: 791-805.

Griffiths, J.B. 1986. Intensive cropping in the Mallee. Pages 110-118 *in* Proceedings of "Our True Potential" seminars, Western Australia. I.C.I. Australia.

Hamblin, A.P. and Hamblin, J. 1985. Root characteristics of some temperate legume species and varieties on deep, free-draining entisols. Australian Journal of Agricultural Research 36: 63-72.

Hamblin, A.P., Tennant, D. and Perry, M.W. 1987. Management of soil water for wheat production in Western Australia. Soil Use and Management 3: 63-69.

Helyar, K.R. 1987. Nutrition of plants in acid soils. Pages 159-171 *in* Temperate pastures, their production, use and management. Australian Wool Corporation Technical Publication, CSIRO, Australia.

Herridge, D.F. and Doyle, A.D. 1988. The narrow-leafed lupin (*Lupinus angustifolius L.*) as a nitrogen-fixing rotation crop for cereal production. II Estimates of fixation by field-grown crops Australian Journal of Agricultural Research 39: 1003-1015.

McCown, R.L., Cogle, A.L., Ockwell, A.P. and Reeves, T.G. 1987. Nitrogen supplied to cereals in legume ley systems under pressure. Pages 292-314 *in* Advances in Nitrogen Cycling in Agricultural Ecosystems, CSIRO, Townsville, Queensland, Australia.

Nulsen, R.A. and Baxter, I.N. 1982. The potential for agronomic manipulation for controlling salinity in Western Australia. Journal of the Australian Institute of Agricultural Science 48 No. 4: 222-226.

Perry, M.W., Delane, R.J., Tennant, D. and Hamblin, A.P. 1986. The growth and grain yield of lupins in relation to the soil water balance. Pages 112-128 *in* Proceedings of 4th International Lupin Conference, Geraldton, Western Australia.

Puckridge, D.W. and French, R.J. 1983. The annual legume pasture in cereal-ley farming systems of southern Australia: a review. Agriculture, Ecosystems and Environment 9: 229-267.

Reeves, T.G. 1984. Lupins in crop rotations. Pages 207-226 *in* Proceedings of 3rd International Lupin Conference, La Rochelle, France.

Reeves, T.G. 1989. Communication and the farmer. Pages 4-8 *in* Proceedings of an International Conference on Communication in Agriculture. University of New England, Armidale, NSW, Australia.

Reeves, T.G., Ellington, A. and Brooke, H.D. 1984. Effects of lupin-wheat rotations on soil fertility, crop disease and crop yields. Australian Journal of Experimental Agriculture and Animal Husbandry 24: 595-600.

Rowland, I.C., Mason, M.G. and Hamblin, J. 1988. Effect of lupins and wheat on the yield of subsequent wheat crops grown at several rates of applied nitrogen. Australian Journal of Experimental Agriculture 28: 91-97.

Wheeler, J.L., Pearson, C.J. and Robards, G.E. 1987. Temperate pastures, their production, use and management. Australian Wool Corporation Technical Publication, CSIRO, Australia

Legumes can contribute nitrogen to the system in cereal-legume rotations, but there may be a need to inoculate with appropriate *Rhizobium* spp (Beyene). However, once the population of Rhizobium has built up in the soil it is not always necessary to continue inoculation (Reeves).

Although it is often held that pasture legumes contribute more nitrogen to systems than grain legumes do (Moussadeq), in Australia grain legumes such as *Lupinus angustifolius* can be at least as effective as pastures based on *Trifolium subterraneum* (Reeves). In Cyprus, the lack of response of barley in a barley/vetch rotation to applied nitrogen (Avcin) was due to the contribution of 60 to 90 kg N/ha by the vetch which is harvested for hay (Papastylianou).

However, the amount of N which is accumulated is very dependent on management. When crops are harvested by hand pulling the whole plant, much of any nitrogen which is fixed may be removed (Gharbi). The plant material (leaves, stems, pods, roots) which is left on the field during hay making or combine harvesting may be the main source of N. Alternatively, legumes may not contribute N but still benefit the system by fixing the amount which they themselves require, so reducing the quantity that is taken up from the soil (Papastylianou).

Pasture legumes, when grown for two or three years, have a beneficial effect on soil structure and can increase total soil nitrogen. Grain legumes usually contribute only to the mineral N component (Reeves).

The benefit of a fallow between a legume and a cereal crop even where soil water storage is not important (Farah) undoubtedly results from control of pests and diseases. For example, nematodes which infest a broad spectrum of species, and the carry-over of cereal root diseases on grasses in pasture can be reduced by introducing a fallow. Mineralization of nitrogen during the fallow period may also provide part of the benefit (Reeves).

A problem in the use of Medicago spp in a ley system is maintenance of a seed store in the soil, to avoid the necessity for regular reseeding of the legume. It is possible to reduce the amount of seed that is sown initially to low rates (2 kg/ha) by extending the pasture phase to two or three years to build up seed reserves. Persistence of the legume then relies on the degree of hardseededness of the variety to ensure that enough viable seed remains after the cereal phase to re-establish the pasture (Amor; Reeves).

In some rotations, the need for cultivation for weed control delays sowing beyond the optimum time (Dafalla). In this case the best approach is to sow early and rely on early post-emergence herbicides, or to use short-term residual herbicides (Amor).

Concern about very high levels of mineral N following a legume phase (Khaldi) may be justified in a very small proportion of years when vigorous vegetative growth of a cereal may cause severe moisture stress and loss of the crop before grainfilling (haying-off). However, in the main, a legume-cereal rotation will give greater water use efficiency than a fallow-cereal one. Data from Syria (Harris *et al.*, this volume) are echoed by data from South Australia.

The stability of cereal yields does not appear, in general, to be much affected by the replacement of fallow with a legume under Australian conditions. This appears to hold for both coarse textured soils and heavy clays (Reeves; Amor). In both soil types yields at low levels of fertility are probably more stable where a fallow is employed, not because of water stored in the fallow but because of greater mineralization of N. Questions of stability and risk in the evaluation of systems including rotations can probably be best addressed by economic models, such as linear programs. These bring together technical and economic information and emphasize the interactions between the components of systems (Jones).

Transfer of Information to Farmers

Transfer of Information to Farmers

D.R. HICKS

Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108, USA

Abstract

The transfer of information from researchers to farmers is a key process in the adoption of new technologies that improve and enhance the standards of living for farmers and the society of which they are a part. Publicly supported extension services are vital in this process of transfer of information. Extension teaches people how to determine their needs, how to find solutions to those needs, and assists them as they make changes to improve their lives and standards of living. To accomplish these objectives, extension services are active partners in the processes of generating knowledge, formulating recommendations, disseminating information, and evaluating the successes of adopted technologies. Extension plays a major role in farmers' decisions on whether and how to use agricultural inputs. As a result, increased production and efficiency of production are clearly due, in part, to the programs of agricultural extension.

Introduction

The objectives of this paper are to discuss the subject of transfer of information and the importance of agricultural extension services in the process of information transfer. I will discuss the organizational structure of an extension service, the techniques of information transfer, the adoption process, and present models for generating recommendations and transferring information.

It is appropriate to begin with definitions of the three functional processes: transfer of information, agricultural extension, and technology transfer. Transfer of information involves processes to develop an educational understanding of a technology. A popular new term often used synonymously with transfer of information is "technology transfer". Swanson and Claar (1984) defined technology transfer as having two functions: the educational function, and the input supply and agriservices function. The latter function is important in agricultural development, but it should be separated from the "educational function" which is synonymous with "transfer of information".

Maunder (1973) defined agricultural extension as "a service or system which assists farm people, through educational procedures, in improving farming methods and techniques, increasing production efficiency and income, bettering their levels of living, and lifting the social and educational standards of rural life." Swanson and Claar (1984) wrote "extension is an educational process to communicate useful information to people and then help them to learn how to use it to build a better life for themselves, their families, and their communities." Although Maunder (1973) uses the term "service" in his definition, both agree extension is a process of teaching farmers about improved agricultural technology with emphasis on how to use it. Agricultural extension then is synonymous with "transfer of information", but lacks the service component of technology transfer.

Regardless of how agricultural extension is defined, the primary goal of extension is to conduct educational programs in selected subject matter areas to help farmers solve problems in a socially desirable and personally satisfying way.

There are both public and private "agricultural extension services". The most common is the public entity, generally referred to as "agricultural extension service" or simply "agricultural extension". However, there are information transfer programs in the private sector which are called "customer services" or "consulting services". These efforts place more emphasis on "service" (what to do) than on education, and their efforts have been increasing in the past few years, particularly from private consulting services.

Organizational structure

The organizational structure of Colleges of Agriculture in the U.S. Land-Grant University System is presented in Fig. 1. There are differences among states, but basically the structure and lines of administration are as shown in the figure. I recognize that this structure is not the only one functioning in the world, but it has served the U.S. well and I can use it to emphasize some important points of philosophy relative to an agricultural extension service.

The four functions of research, teaching, extension, and international programs are

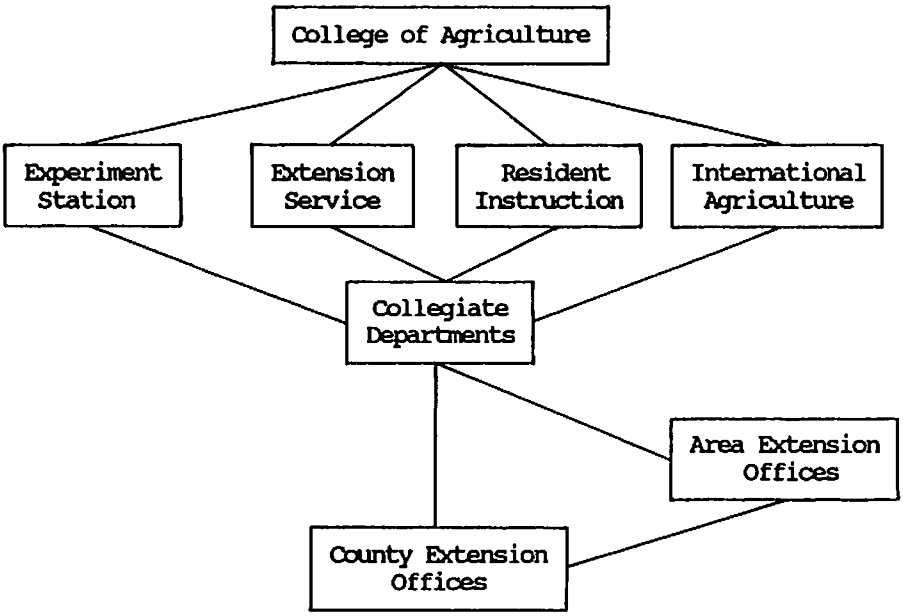


Fig. 1 Organizational structure of colleges of agriculture in the land-grant university system.

under the umbrella of the College of Agriculture with the collegiate departments having responsibility for all four functional areas. An important concept is that all the functions are closely linked and administratively responsible to the Dean of the College. Off campus, there are county and area extension offices which are the "outreach" units of the University with faculty who are academic personnel of the University.

In the collegiate departments, the faculty are responsible for the extension, research, and resident teaching functions. These functions are closely integrated; many faculty hold split appointments. Teaching and extension split appointments exist, but common splits in responsibility are 75% research - 25% extension or 75% extension - 25% research. Split appointments ensure that both functions (research and education) related to the subject matter are developed. Splits broaden the responsibilities of scientists, but the split should remain 75% or greater for one program component to ensure a major focus in a functional area. The split appointment concept is a key factor in faculty cooperation and it ensures more effective programming and delivery.

Extension services in most of the world are not organized as I have described for the land-grant system. It is important to recognize that education and research functions are more closely coordinated when they are administered under one organization. However, other systems of organizational structure can be effective in the transfer of information. People of the organization are the key element for success. If an organization has sufficient resources and well trained personnel that are committed to the task, the organization will be successful in transferring information.

Publicly supported extension services are vital in promoting technology adoption which is the first step in increasing agricultural efficiency and improved standards of living for farmers and the society in which they are a part. A strong and effective extension service is essential to meet this objective. To remain a strong organization, an extension service must:

1. have a dedicated, professional staff oriented towards understanding and serving the farm family,
2. maintain a current research-knowledge base through linkages with research organizations,
3. have adequate financial support to maintain field offices, transportation, and communication systems,
4. have a continuous and effective in-service training program,
5. be free from regulatory and input supply responsibilities,
6. have farmer input to guide program priorities, and
7. have a competitive salary system with incentives for professional development and advancement.

Model for Information Flow

The flow of information is represented in Fig. 2. Research of both public and private groups generates basic knowledge, the initial step in the generation and flow of information. Applied research continues the process of generating information that results in technology that can be recommended to farmers. Farmers receive recommendations from consultants, industry personnel, and/or personnel of the public institutions. The process should result in a unified

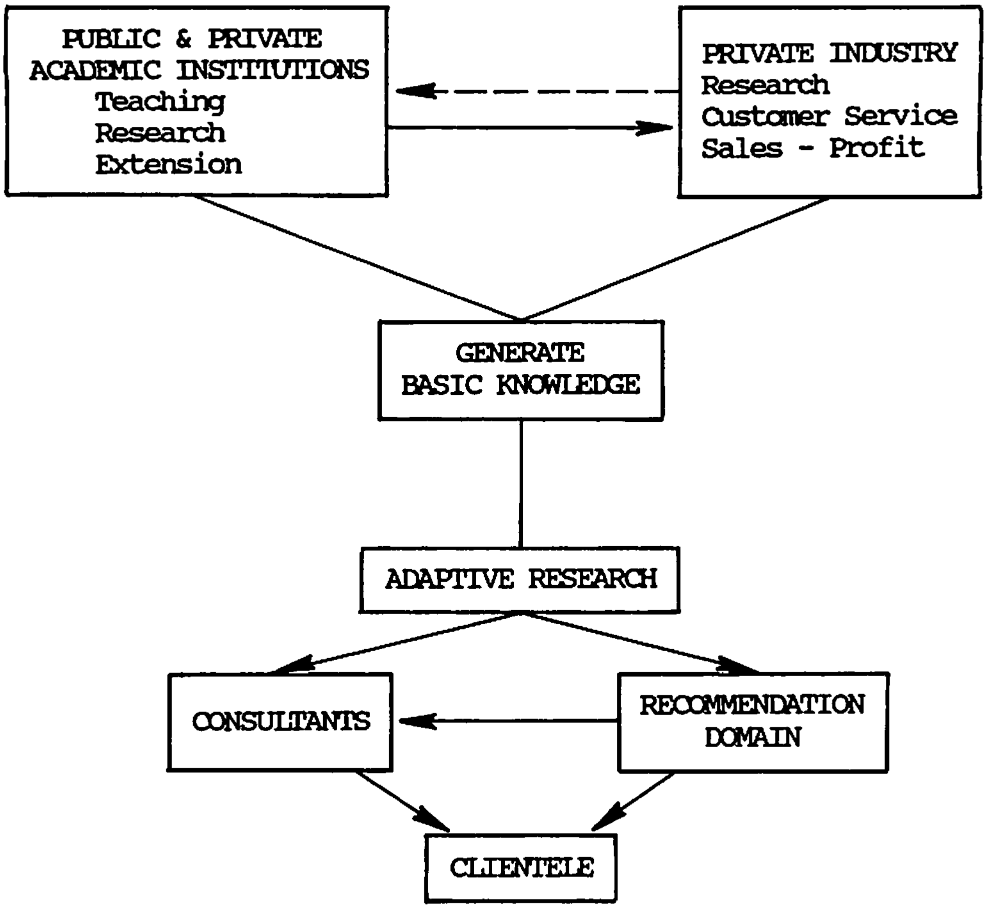


Fig. 2 Generation and flow of information.

message, regardless of where it comes from. Farmers pay directly for information from private consultants, and pay indirectly for advice from industry and public personnel as they buy products and pay taxes.

The Adoption Process

There are five stages in the adoption process - awareness, interest, evaluation, trial, and adoption. Extension has a primary responsibility in most of these stages. The first stage - awareness - is a major function of extension. People must first become aware of new ideas, practices, or products. After awareness, an individual becomes interested in the new technology. How will it help them? How will it work? Interest will stimulate people to seek more information on the subject; extension should have that information in a form readily understandable for those interested persons. The unbiased information provided by extension can help the individual evaluate the practice or product. When a person decides to try the new practice, extension can help by providing specific information on how to use the product, how much to apply, when to apply, etc. that is specific for their situation. At the adoption stage, extension can continue to advise the farmer by helping to evaluate the success of the new technology and by fine-tuning the technology to fit the farmers' individual conditions.

When has information been transferred? If a person learns a new technology, he or she has become informed about that subject. But, has transfer of information occurred if one decides not to adopt the technology? I believe it has, although adoption is the ultimate objective of the process of transfer of information. Some will argue that information transfer has not occurred without adoption. Agricultural extension can promote adoption, but the choice is the farmer's; it is the function and responsibility of extension to provide the information, so the farmer can make a knowledgeable decision.

An important factor in adoption or acceptance of information is the credibility of the source. Extension services generally are perceived to be reliable sources of unbiased, research-based information. However, credibility is a trait of individuals, an earned characteristic, and one that individuals must continue to possess to be effective agents of transfer of knowledge.

Model for Generation of Recommendations

Before technology can be transferred, there must be a system for developing recommendations. Byerlee (1986) defined recommendation as "that practice that farmers, given their resources and objectives, would employ if they had all the information available to the researchers". This definition implies that a recommendation considers the capital situation of the farmer and that necessary inputs are available to the farmer. It is important that all recommendations meet the tests of scientific repeatability, economic feasibility, and practical feasibility. That is, is the recommendation statistically significant at some reasonable level of confidence? Is it profitable? Can the technology be adopted within the constraints of a given production environment? For example, recommending the use of hybrid cultivars is not practically feasible if there is no system for producing quality, hybrid seed.

Who should formulate recommendations? Figure 3 presents a model for developing them. It is a continual process. A technical group composed of several people (researcher, subject matter specialists, extension personnel, input supply dealer and credit representatives, and farmer) utilize the research information pool to begin the process, and improve and redefine the recommendations as further information is accumulated. Recommendations are forwarded to local extension personnel who may "fine tune" them for local conditions; the subject matter specialist may help in this process. The extension worker releases and promotes the recommendations to farmers using various techniques. Experiences of the technology gained are fed back to the technical group for their evaluation and consideration to improve the recommendations.

The concept of multidisciplines should be stressed in the recommendation development domain because production practices cross disciplines. In almost all instances real

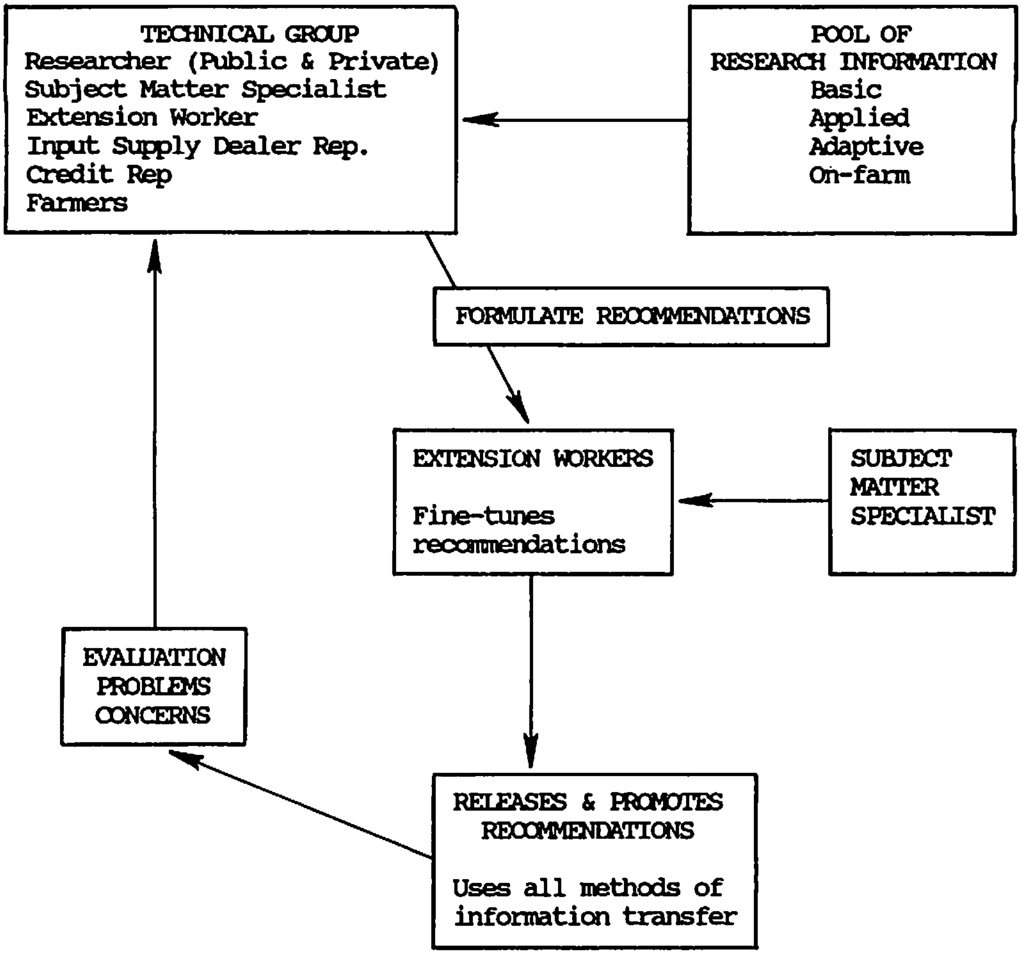


Fig. 3 Model for developing recommendations.

problems do not fit within a single discipline; multi-disciplinary teamwork is essential. For example, several years ago I was encouraging earlier planting of corn (*Zea mays* L.) in the upper Corn Belt of the U.S. At the same time the extension entomologist was advising farmers that the earliest planted fields of corn would be the fields most likely to have cutworm damage. After discussion, we concluded that the recommendation to plant early was well founded, because the yield response to early planting always existed, while cutworm injury depended upon a number of unpredictable events such as temperature and air currents to bring the moths. And with timely scouting, cutworm control was chemically feasible.

The technical group can quickly become so large that it becomes cumbersome and ineffective in developing recommendations, but all available technical knowledge should be considered by the technical group. The process should be flexible so it can remain functional.

Transfer of information is the responsibility of every agricultural worker at all levels -- scientist, subject matter specialist, etc. -- especially those publicly employed. Some recognize that transfer of information is a partial responsibility that they have, even though the words may not appear in their job descriptions. But many don't; and as a result there are research results sitting on desks and in files because researchers don't think it is their job to disseminate them ("that's extension's job"); or they are uncertain about their results; or they are not willing to "make a recommendation"; or they work alone and others don't know about their work; and/or they can't or don't want to work as a team, etc.

Methods for Transfer of Information

The teaching methods and tools for transferring information are given in Fig. 4 and are organized for individual, group, or mass categories (Prawl *et al.* 1984). These methods as such don't require further discussion. The extension workers must select the best method(s) and repeatedly use them. They must also recognize that there are many clientele in all stages of the adoption process and the kind of message or information they need may be different, depending upon their stage in the adoption process. Therefore, several teaching methods and tools will be useful in reaching all audiences. Repetition and variety are important characteristics of an educational program. The message is always the same, but the techniques to deliver it change. For example, an individual might become aware of a technology at a group meeting, the publication he takes home allows him to learn more about it, he reads about it in a farm magazine, and he hears the local extension agent talk about it on his radio program. These are all methods to transfer information, and the repetition is important.

TEACHING APPROACH	INDIVIDUAL	GROUP	MASS
TEACHING METHOD	Office call Letter Demonstration Farm Visit Self-directed learning	Meeting Tour/Field Day School/Clinic Workshop Demonstration Lecture	Exhibit Radio Television Fair/Show Movie Newspaper
TEACHING TOOL, AID, DEVICE, TECHNIQUE	Telephone Computer Audiotape Videotape Chart Chalkboard Bulletins Models Tools Specimens	Photograph Poster Leaflet Bulletin Movie Panel Flip charts Projected visuals	Gaming Simulation Television Buzz sessions Role playing Displays Circular letter

Fig. 4 Teaching methods and tools for the transfer of information.

On-farm Testing

Since on-farm testing is a method of information transfer, I want to address the issue of conducting on-farm research, on-farm testing, and demonstrations. New technology should be developed under very controlled conditions such as occur in laboratories and on fields of experiment station farms. When a technology is found to be statistically and economically feasible under the controlled conditions of research locations, I submit that the technology should be equally applicable to farm conditions. However, the magnitude of the response may be different. On-farm research, to me, means research conducted by scientists on farms the same way they conduct research on experiment stations. That is, the trials are replicated, properly designed, and well managed, but they occur on a farm. The farm location may be unique because of environment, soil type, climate, weed population, etc. This is commonly referred to as researcher-managed trials. Certainly it is important to test new technology under the conditions typical in the area where it may become adopted technology.

On-farm testing can also serve as a demonstration. It is common knowledge that farmers adopt technology more quickly after seeing for themselves. Demonstrations provide that opportunity. Other advantages of on-farm trials are that they establish contact between the farmer and the researcher and they get researchers into the field where real problems exist. The latter is an important factor for the farmer in establishing the credibility of the researcher.

Summary

The philosophy of the extension service in the U.S. Land-Grant System is that people must be reached where they are at their present background of education and level of interest and understanding. The aims and objectives are not fixed: they must be modified on the basis of individual and social needs. "It is the function of the extension service to teach people to determine their own needs and the solution of their own problems; to help them to acquire knowledge and to inspire them to action. The basic philosophy of extension education is to teach people how to think, not what to think. Another basic principle is that the extension worker teaches people to help themselves, not do things for people" (Prawl *et al.* 1984). This concept and philosophy has created a successful and effective program for the transfer of information from researchers to farmers.

References

Byerlee, D. 1986. Some common sense about farmer recommendations and extension advice. CIMMYT, Islamabad, Pakistan.

Maunder, A.H. 1973. Agricultural extension: A reference manual (Abridged edition). Food and Agricultural Organization of the United Nations, Rome, Italy.

Prawl, W., Medlin, R. and Gross, J. 1984. Adult and continuing education through the cooperative extension service. University Printing Services, Columbia, Missouri, USA.

Swanson, B.E. and Claar, J.B. 1984. The History and Development of Agricultural Extension. Pages 1-19 *in* Agricultural extension: A reference manual (second edition). Food and Agricultural Organization of the United Nations, Rome, Italy.

Experience of Agricultural Technology Transfer in Ethiopia

DESTA BEYENE, HAILU BEYENE and ADUGNA HAILE

Institute of Agricultural Research, P.O. Box 2003, Addis Ababa, Ethiopia

Abstract

The transfer of research findings into technology packages which can be widely adopted by farmers constitutes a major problem in the development of agriculture for increased crop productivity in Ethiopia. Various extension strategies including the training and visit (T&V) system have been tried since 1954 to accelerate the transfer and adoption of improved technologies. The on-farm research approach has proven successful in all the agricultural zones of the country. Results from on-farm verification trials have demonstrated that technology packages recommended by the National Agricultural Research System (NARS) are effective, as indicated by yield increases of 50 to 150% with the improved technologies. Major steps have been taken to strengthen the linkage between research and extension. However, additional efforts are required to develop effective systems for accelerating the transfer and adoption of improved technology for increased agricultural production.

Introduction

The main objective of the national agricultural research system (NARS) in Ethiopia is to generate appropriate technologies that can be used to raise agricultural productivity, and in collaboration with the extension services, the NARS has developed systems for generating and transferring agricultural technologies to farmers.

Successful transfer of such technologies requires the combined efforts of researchers, extension or development agents, political leaders and, of course, the farmers themselves. In this paper we will focus on our experience in Ethiopia with the generation and transfer systems of agricultural technology in crop and soil management. The participation of the various groups in the process will be discussed.

Research and Extension

Agricultural research in Ethiopia is conducted mainly by the Institute of Agricultural Research (IAR), and to a lesser extent by the Alemaya University of Agriculture. There are more than 25 research centers and sub-centers in the country. These research centers are supported by a large number of trial sites in selected agro-ecological regions. Major emphasis is on research work on crops, livestock and soils.

Agricultural extension is the direct responsibility of the Ministry of Agriculture (MoA). The Extension Services Department coordinates the activities of the development agents involved in the transfer of agricultural technology in the different regions.

In Ethiopia several different extension strategies have been tried since 1954, including a) maximum package project, 1954-1970, b) minimum package projects 1 and 2, 1971-1981, and c) training and visit (T&V), 1983-1988.

The T&V system of agricultural extension is a recent introduction in Ethiopia. The basic organizational unit of the extension services is the *wereda* (sub-district level) office where the staff includes one supervisor, one to four development agents, a cooperative agent, a home economics agent, and a book-keeper. The *wereda* functions are assisted by a mobile group of subject matter specialists (SMS) located at *awraja* (district) level. The SMSs would include an agronomist, a crop protectionist, a livestock man, a socio-economist, a cooperatives man and a home economist. In this system, four to 10 peasants nominated by Peasant Associations serve as contact farmers who would be visited by development agents once in three weeks or a month. Operationally, one development agent is responsible for one Service Cooperative, which includes three to four peasant associations and a farming population of 1300-1700 farmers (which is considered too high a ratio according to the conventional T&V system).

The T&V system has been found to be effective on pilot schemes in six *weredas* of the Shewa and Arsi administrative regions (the central zone of the country). The aim of the extension strategy is to increase smallholder production through the provision of farm inputs on credit and other support services. The strategy is also expected to help develop the institutional and technical capacity of the extension services. It has now been taken as a model for the whole country under the new food self-sufficiency drive. However, the full implementation of the program is hampered by the high cost of the T&V system and by inadequate funds available for the extension system.

Technology Generation and Transfer Process

Research projects are based on an evaluation of problems faced by farmers. The first step in the process is a diagnostic survey, undertaken by research economists in collaboration with extension workers (Table 1). The input of several disciplines of research are required at this stage.

The results of the diagnostic surveys are used to formulate the research programs to be undertaken by scientists at the research centers. This on-station research activity is primarily aimed at generating the basic technology needed to solve the problems. However, this technology must be validated for technical and economic appropriateness before it is recommended for use. This is done through multi-location on-farm testing and is carried out by on-farm research groups in collaboration with extension workers. The final stage of the process is the demonstration of the technology to extension workers and leading farmers through pilot-production demonstrations. The objective at this stage is mainly to train the development agents and subject matter specialists in communicating the validated technology to a wider group of farmers.

On-Farm Research

The history of on-farm research in Ethiopia dates back to 1976/77 when the Department of

Table 1. Processes in the generation and transfer of technology

Activity	Objective	Responsibility
Diagnostic survey ↓	to identify bottlenecks in production	Researchers in close collaboration with development workers
On-station research ↓	to develop basic solutions	Researchers
On-farm research ↓	to verify the appropriateness of the proposed solution	Researchers in collaboration with development workers and farmers
Pre-extension demonstration ↓	to familiarize the verified technology to development workers and contact farmers	Researchers in collaboration with development workers and farmers
Mass-popularization	to familiarize the technology to users	Development workers

Source: Seme 1988.

Socio-Economics and Farm Management Studies (renamed Agricultural Economics) initiated demonstration programmes around two main research centers of IAR (Bako and Holetta). However, these trials were not based on surveys and the farmers were unwilling to accept the recommendations which evolved. The farmers' reluctance prompted an enquiry into why they did not adopt the recommendations; this led to a better understanding of their practices and circumstances. As a result, a multidisciplinary farming systems survey and package testing program was launched (Franzel and Hailu 1989). The multidisciplinary survey was different from the conventional farm management survey in that it emphasized the identification of farmers' problems as perceived by farmers. The survey helped to fill the gap in the understanding of the systems and was used to plan a package testing program. The packages developed included improved varieties, recommended cultural practices, and fertilizer types and rates for each major crop. From the packages developed at the research center and tested on farmers' fields, some innovations were adopted by farmers while others were rejected, although they had shown good performance at the research centers. The lessons learnt were used to modify the survey and trials in order to focus even more directly on farmers' problems.

In recent years (1984-1988) the research conducted by NARS scientists has become more farmer-oriented, and has focused on solving agricultural problems to make them acceptable to and feasible for farmers. Much of the change in approach has come about as a result of the adoption of on-farm research. Three types of on-farm trials have been commonly practised in the agricultural research system. The first one is the *exploratory trial*, where researchers seek to define and better understand production constraints. The aim is to determine the variables that are limiting production. In the *determinative trial*, the objective is to determine an appropriate solution to a well-defined problem of the farmer. Researchers use a determinative trial as a basis for making a tentative recommendation. The *verification trial* seeks to verify a recommendation under farmers' conditions, by comparing it to the farmers' current practice, and possibly other treatments.

Formulation of Recommendations

There is a clear procedure for recommending and releasing new varieties. Breeders nominate new varieties for recommendation and their performance is evaluated by the National Variety Release Committee, which decides the release of new varieties. But for cultural practices there is no systematic procedure for formulating recommendations. Different departments make different, and sometimes contradictory recommendations concerning the same cultural practice. For example, for the Holetta area, there are three different recommendations concerning fertilizer levels for the cereal tef (*Eragrostis tef*). The tef team recommends 60 kg N and 60 kg P_2O_5/ha based on on-station trial results. However, based on the results of on-farm trials in the Holetta area application of only 23 kg P_2O_5/ha was found to be the optimal rate, giving the highest economic returns per hectare. In contrast, the MoA recommends 41 kg N and 46 kg P_2O_5/ha based on results from on-farm fertilizer trials carried out in different parts of the country. There is obviously a need for establishing a system for releasing recommendations on cultural practices, and a need for each research center to have a technical committee to clear new technologies to be transferred to farmers in the area.

Research and Extension Linkage

The need for a close link between NARS and extension is fully realized by both researchers and development workers. In 1985, zonal Research and Extension Liason Committees were established in five zones in order to make agricultural research more responsive to the needs of peasant agriculture, and to make agricultural extension services more effective. They are composed of senior NARS and MoA staff, and meet three to four times a year.

Their responsibility at a regional level is to provide overall guidelines with regard to research priorities, and linkage between NARS and extension services. This involves the identification of problems to be addressed by research, review of research findings, approval of extension recommendations, and monitoring the operations of the research-extension linkage within the zone. The research and extension coordination division at each IAR center plays a leading role in directing and controlling the activities of the Research and Extension Liaison Committee in each zone. Each IAR center has an Extension Task Force, composed of senior research staff with the Director of the Research Center as the Chairman and the Head of the Research and Extension Division as the Secretary. The Task Force is responsible for ensuring that researchers spend at least 25% of their time on extension-related activities pertaining to their research areas. These include the training of development agents and subject matter specialists, visiting demonstration fields, organizing field visits for policy makers, and preparing technical manuals and leaflets.

Current Achievements

Demonstration trials carried out on farmers' fields in the different regions of the country have clearly shown the superiority of improved technology over the traditional system (Jamal 1985; Hiruy *et al.* 1988; Adugna and Elias 1989), but more work needs to be done on assessing the economic feasibility and acceptability of these new technologies. The improved management practices include the use of new cultivars, row planting, proper seed-bed preparation and seed rate, fertilizer application, timely weeding, and use of broad-bed and furrow.

Yield results of different crops from demonstration trials are shown in Table 2. These results clearly demonstrate that yield increases of more than 50% are possible for all the crops through the adoption of the improved technology. Despite this fact, the transfer and adoption of improved technology is a very slow process in Ethiopia. This can be attributed to five major constraints: (i) poorly developed national extension infrastructure, (ii) lack of conducive policies with respect to pricing and marketing, (iii) limited national infrastructure for input distribution, marketing, transportation and storage, (iv) slow progress in the creation of an efficient research-extension linkage and (v) low economic feasibility or acceptability of some new technologies.

Table 2. Mean grain yields (t/ha) of different crops in demonstration trials in farmers' fields under two management systems

			Grain yield		
Area	Crop	No. of sites	Traditional management practice	Improved management practice	% increase
Holetta	Bread wheat	55	1.54	2.83	83.8
	Barley	4	1.42	2.11	48.6
	Tef	18	0.78	1.46	87.2
	Faba bean	28	0.98	1.70	84.2
	Mustard	5	0.95	1.57	65.3
	Linseed	1	0.45	0.75	66.7
Nazrat	Sorghum	6	0.70	1.75	150.0
	Haricot bean	9	0.70	1.27	81.4
Bako	Maize	7	2.01	5.12	154.7
	Sorghum	6	2.00	4.45	122.5

Source: Hiruy *et al.* (1988).

Conclusion

As a result of the low level of technology transfer, the impact of research on national crop production has been very limited. To date, improved seeds are used by only 3% of the peasants, and fertilizers by only 15%. Interestingly, some positive measures are now being taken to correct the situation and accelerate the transfer of technology for improved crop productivity. Thus, the government is now allocating the necessary financial and manpower resources to support the research and extension linkage. Simultaneously, efforts are also underway to improve the national infrastructure.

References

Adugna Haile and Elias Zerfu 1989. Recommendation and adoption of improved technology. Pages 154-170 *in* proceedings of the 20th National Crop Improvement Conference, 28-30 March 1988, Addis Ababa, Ethiopia. Institute of Agricultural Research, Addis Ababa, Ethiopia.

Franzel S., and Hailu Beyene 1989. Farming systems research in the Institute of Agricultural Research: Challenges and issues. Paper presented at the IAR/ISNAR Research Management Workshop, 23-28 January 1989, Debre Zeit, Ethiopia.

Hiruy Belayneh, Hailu Beyene and Seme Debela 1988. Experiences in farming systems research in Ethiopia. Paper presented at the Research-Extension Administrators Workshop, Eastern Africa, Nairobi, 14-18 November 1988.

Jamal Mohammed 1985. Effects of sowing dates and seed bed preparation methods on the yield of wheat. Ethiopian Journal of Agricultural Science 7: 81-88.

Seme Debela 1988. Crop production research in Ethiopia. Paper presented at the Subregional Seminar in Africa, Addis Ababa, 4-7 October 1988.

Transfer of Improved Production Technology to Farmers in the Gezira

SAEED M. FARAH

Gezira Research Station, P.O. Box 126, Wad Medani, Sudan

Abstract

Wheat is an important strategic commodity for the Sudan. The major production region is the Gezira, on about 230 000 ha. However, the average yield is only 1.2 t/ha. The centrally situated Gezira Research Station (GRS) has been carrying out intensive work on the most suitable cultural practices for production of crops including wheat. It was found that more than 4 t/ha of wheat grain could be obtained under research conditions. The low yield under large scale production was mainly because an effective extension service was lacking and few farmers had adopted the technology which had been generated on-station.

Faba bean is the most important food grain legume in the Sudan. Its production is confined to the Northern Provinces of the Sudan in an area of about 24 000 ha, which provide about 60 000 tonnes of grain per annum.

When financial support from OPEC and IFAD and technical backing from ICARDA and CIMMYT became available to Sudan, through the Nile Valley Project (NVP), GRS scientists, in collaboration with extensionists, scheme managers and farmers, were able to verify the improved production technology of wheat in farmers' fields, and participating farmers were able to obtain yields ranging between 2.42 and 3.66 t/ha.

It was also possible to initiate on-station trials on faba beans and to test the improved production package in farmers' fields in the Gezira, which is not regarded as a traditional area for faba beans. Grain yields of more than 2 t/ha were obtained in most farmer-managed trials with very profitable net returns.

Such encouraging results in both commodities have increased the management's and government's interest in the production of wheat, and the farmers' enthusiasm for growing faba beans.

Introduction

Wheat

Wheat is the second most important cereal, after sorghum, in the Sudanese diet. At present the area under cultivation is about 295 000 ha of which 230 000, 42 000 and 21 000 ha are in the Gezira, New Halfa and Northern Region and White Nile Schemes, respectively (Fig. 1). Wheat came to Sudan many centuries ago probably from Egypt. Until about 1940 wheat cultivation was confined to the Northern Region where climatic conditions are more favourable than in other regions. However, cultivable land was restricted to the narrow strips of land along the Nile.

In recent years the decline in cotton prices and the transfer of the Wadi Halfa people from the Northern Region to New Halfa area, coupled with the increased consumption of wheat by the Sudanese directed the Government's attention to producing wheat in other parts of the country. The Gezira was the obvious choice mainly because of the availability of land and water. The winters in the Gezira may once have been regarded as too warm for wheat, but the scientists at GRS had by then shown that a reasonable yield could be obtained by manipulating some cultural practices and using adapted varieties.

The first wheat crop in the Gezira was planted in the 1959/60 season in an area of about 2520 ha. An average yield of 1.05 t/ha was obtained in that season. This low yield was mainly because few farmers had adopted the improved technology. In spite of this low yield the Government insisted on giving wheat a proper position in the Gezira scheme by utilizing part of the fallow phase of the rotation. The area under wheat varied from season to season depending on various factors of which the most important was irrigation water. The area increased from about 19 000 ha in 1960/61 to its maximum ever of 238 000 ha in 1975/76, out of the proposed area of 255 000 ha. However, the diversification and intensification program of the Gezira scheme has failed to achieve the hoped-for results because of several agronomic reasons, of which the most important were:

1. The additional crop area created additional demands for water, which could not be met, especially during October-November when the peak water requirements for cotton, the planting irrigation for wheat and the final irrigation for groundnuts and sorghum overlapped.
2. Reduction in the fallow area led to a decline in fertility.
3. The absence of an effective extension service for crops other than cotton meant that farmers were not acquainted with proven agronomic practices. This is clearly demonstrated by comparing the yield obtained in experimental plots of research stations with those achieved in farmers' fields (Table 1).

Faba bean

Faba bean is the most important food grain legume in the Sudan. It used to be one source

Table 1. Yield (t/ha) of crops in research plots and in farmers' commercial fields

Crop	Farmers' fields	Research plots	% Increase
Cotton	1.65	4.04	145
Wheat	1.26	4.29	240
Groundnuts	1.43	6.67	366
Sorghum	1.31	7.14	445
Tomatoes	4.76	11.90-23.80	150-400
Onion	9.52	14.30	50

Source: Ishag and Ageeb (1987)

of cheap protein for the poor. However, in recent years, due to greatly increased consumption of this commodity by a large sector of Sudanese, prices have risen tremendously.

The production of faba bean is mainly confined to the Nile and Northern Provinces (traditional regions) (Fig. 1), in an area of about 24 000 ha, which provides some 60 000 tonnes per annum. It is grown on small holdings with pump irrigation, which makes cost of production rather high. With financial support from the NVP a program of work was carried out over the last eight years. The efforts of this program not only increased yields of this commodity in the traditional regions, but also made possible the economic production of faba bean in the non-traditional regions, namely the Gezira, Rahad and New Halfa Schemes.

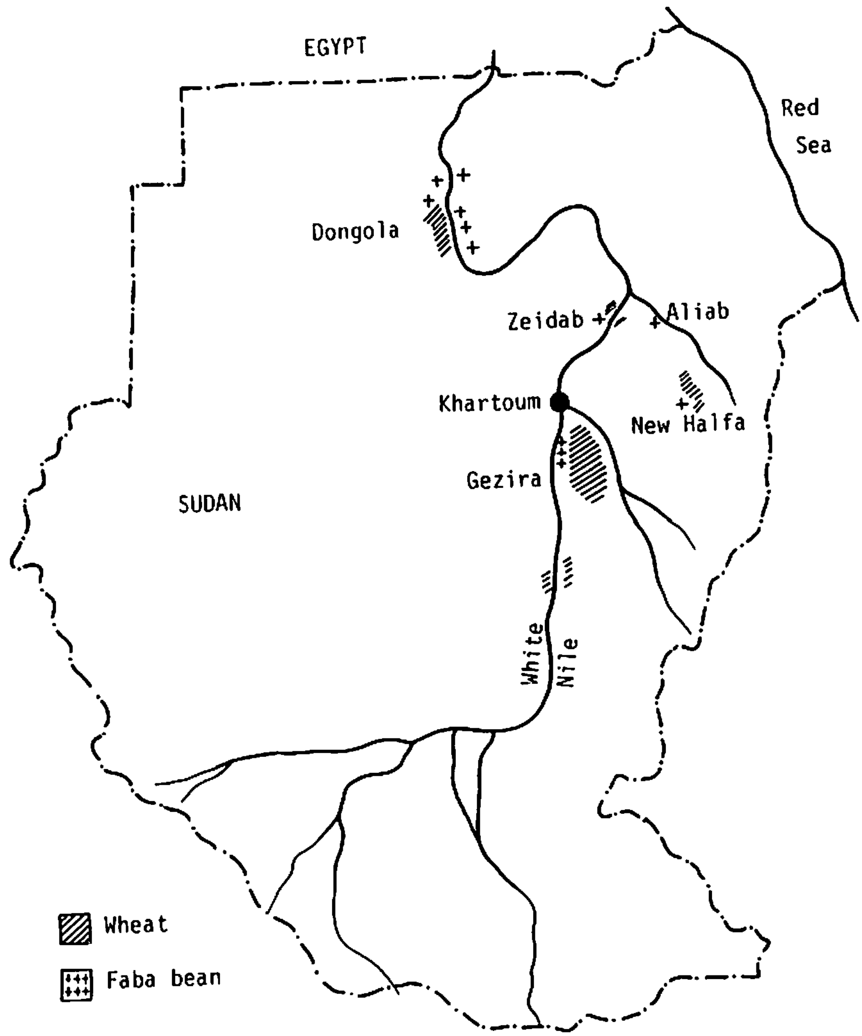


Fig. 1 Wheat and faba bean production areas in Sudan.

Extension service in the Gezira

The extension service in the Gezira was established in 1958. It is relatively small, with about 348 field inspectors and only 22 extensionists, i.e. about one extension officer for every four to five thousand farmers, or 1:40 000 ha cultivated land.

The Gezira is considered as a scheme in which transfer of research results is quite feasible with the farmers. When a recommendation has been passed by the Specialized Technical Committee of the ARC, the Manager of the Scheme will apply it directly to the farms. Examples are the use of improved high-yielding varieties, herbicides, insecticides and fertilizers. The field inspectors help in persuading the farmers to follow the recommended practices.

This paper describes research findings and the process of transfer of improved production technology to Gezira farmers. Wheat is used as a case study, but reference is also made to parallel work on faba bean.

Generation of Improved Production Technology. Wheat: a case study

Wheat was first introduced to the Gezira Research Station in 1918. In 1956 an intensive program of research was initiated to find out the optimum agronomic factors of production. The testing of new varieties started in the 1960s, the main sources being CIMMYT and ICARDA. From 1963 to the present, six varieties have been released, of which Condor and Debeira are the two most widely used for commercial production today in the Gezira.

Land preparation and sowing

Very little work has been carried out on effects of land preparation and sowing methods on wheat in the Sudan. However, three methods, namely broadcast and ridging, broadcast and harrowing, and machine drilling are now practised.

Seed rate

Most trials showed that there were no significant differences within a wide range of seed rates (48-190 kg/ha). For commercial production 120 kg/ha is now recommended.

Sowing date

Because of the short season (90-100 days) timely sowing of wheat is vital for obtaining high yields. Although previous findings (Rogner 1959; Khalifa 1962; Akasha 1967) showed that the highest yields were obtained from sowing during October, in recent years only 1% of the Gezira farmers sow their wheat in October, less than 5% by mid November while more than 90% wait till the end of November.

This late sowing practice was tested by Ageeb (1987). His results were in conformity with the majority of the farmers' practice (Table 2), so the previously recommended date, October 15 to November 15 was changed to 1-21 November (Ageeb 1988).

Fertilizer

Previous trials (Khalifa 1962; Akasha 1967; Ali 1979) indicated a marked response to N,

Table 2. Effect of sowing date on grain yield (t/ha) of different wheat varieties at Wad Medani

Variety	Sowing Date					
	Oct 15	Oct 29	Nov 12	Nov 26	Dec 10	Mean (± 88)
Condor	2.24	3.17	3.63	3.76	3.61	3.28
Debeira	2.35	3.30	3.68	3.64	3.20	3.23
Wadi El Neil	2.76	3.56	3.96	3.49	3.04	3.36
Mean (± 160)	2.45	3.34	3.75	3.63	3.28	

Source: Ageeb (1987)

erratic response to P and little response to K. Recently, however, substantial responses were obtained from applications of P (Ageeb and Abdalla 1987). Their results show that the addition of 43 kg P_2O_5/ha may increase yield by 52% over the yield obtained from the recommended dose of 86 kg N/ha alone (Table 3, Sites 3 and 4).

Irrigation Scheduling

Based on previous trials (Khalifa 1967; El Rayah 1970; Farbrother and Adam 1975) and, taking into consideration other crops in the rotation and the capacity of the canals, wheat in the Gezira is irrigated at 14-day intervals. However, some recent trials have shown that watering every 21 days during the vegetative growth stage would not result in a significant reduction of the grain yield (Farah 1987).

Weeds

Weed control in wheat has never been a serious problem in the Gezira. This is mainly because

Table 3. Effect of NPK on grain yield (t/ha) of wheat (var. Condor)

Treatments	Sites				
	Dirweesh	W.Sulfab	K. El Gidad	El-Gadid	Mean
86 kg N/ha	4.57	2.35	2.62	1.75	2.82
129 kg N/ha	4.74	2.29	2.97	1.47	2.87
43 kg N + 43 kg P_2O_5/ha	3.15	2.84	3.25	2.60	2.96
86 kg N + 43 kg P_2O_5/ha	4.45	3.06	3.98	2.66	3.54
86 kg N + 43 kg P_2O_5 - 43 K_2O/ha	4.48	3.14	3.93	2.42	3.49
129 kg N + 64.5 P_2O_5/ha	5.27	3.37	4.35	3.00	4.00
S.E. ±	0.26	0.09	0.20	0.09	

Source: Ageeb and Abdalla (1987)

wheat follows cotton in the rotation. Furthermore a large proportion of the remaining weeds are controlled during land preparation. Lately, however, a heavy infestation of Sudan grass (*Sorghum sudanese*) has become a common feature of wheat fields. The source and means of control of this weed deserve investigation.

Pests and Diseases

The only insect pest of economic importance to wheat is aphids, which are easily controlled by a single spray of Ekatin. Wheat in the Gezira is generally free of diseases. A recent survey in farmers' fields showed the presence of the fungus yellow leaf spot (*Helminthosporium tritici-repentis*) but its effects on yield are not yet apparent.

Technology Transfer to Farmers

Technology transfer to farmers is generally achieved through two main channels as follows:

National Technical Committees

The ARC has organized several National Technical Committees to cover a wide spectrum of crops and areas, e.g. the Crop Husbandry Committee, the Cotton Variety Committee, the Pest and Disease Committee etc. Membership on these committees comes from the National Coordinators and Scientists of ARC, Managing Directors of the main agricultural production schemes and corporations, the Directors of Extension and Seed Administrations, the National Council for Research, and Faculties of Agriculture. They serve the dual purpose of adoption of Improved Production Technology in the production sector and the feedback for further on-station research (Fig. 2).

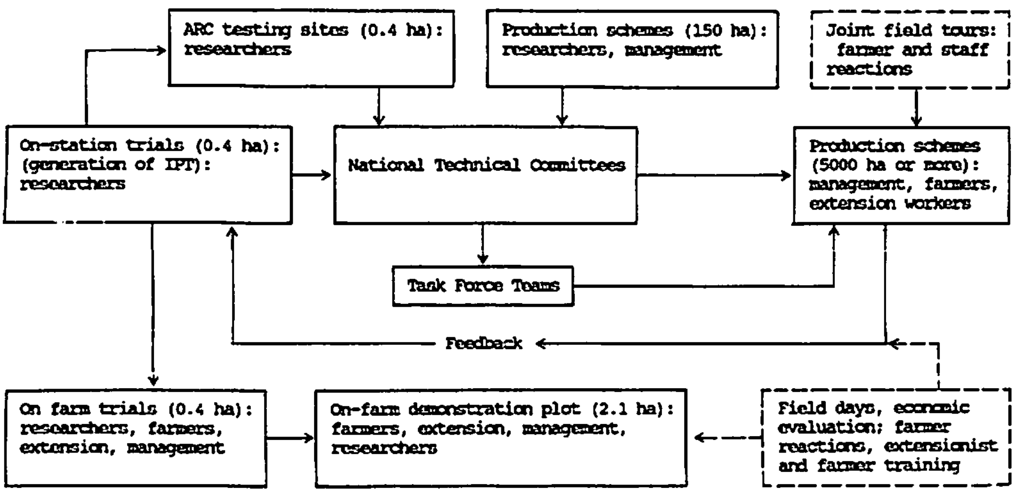


Fig. 2 Strategies for transfer of improved production technology (IPT) to farmers.

When a certain Improved Production Technology has been generated by researchers through small-scale on-station trials at ARC stations and testing sites under well controlled conditions, or through large-scale on-farm trials in the production schemes, the researcher will submit his results as a recommendation to the National Technical Committee for their consideration and approval. A recommendation may then be obtained by the managers of the schemes and applied directly to the farms. Examples include seeds of improved high-yielding varieties of crops, use of aerial spraying of insecticides, rates of fertilizers etc.

ARC has also organized several Task Force Teams to interact with the production sector through the regular joint field tours to monitor crop development, protection etc. and to report on them. Membership of these Task Force Teams comes from ARC scientists, schemes management, Ministry of Irrigation, extension, farmers, and faculties of agriculture. The Task Force Teams also give advice on problems arising at any time during the season, as well as obtaining feedback for additional on-station trials.

On-farm Trials

The National Coordinator of the particular crop (usually the researcher) calls for a meeting with representatives of the scheme's management, farmers and extension. He will then brief them about the improved technology which he intends to test in farmers' fields as researcher-managed trials. The size of these trials is in the range of about 0.4 ha, and they are situated at one end of a farmers' holding (2.1 ha). The participating farmers are encouraged by certain incentives, for example, free land preparation, seed, fertilizers and crop protection. The researcher will then have a close follow-up of the trial regarding crop development data collection, and finally statistical and economic evaluations are carried out.

If the results of these trials show promise they are formulated and executed as farmer-managed demonstration plots. Extension workers, management staff and researchers join in these trials. However, all operations are the responsibility of the farmers. They are supplied with all the inputs which they can not obtain from the scheme or cannot afford to buy, in order to fulfil the requirements of the new technology. These include land preparation, fertilizer etc. The size of the trials is a complete farmers' holding (2.1 ha).

These trials represent the final test for the new technology in the process of transfer. When the crop is mature a field day is organized at the site. All the farmers in the block in which the trial was conducted are invited to see the crop being harvested, and assess its yield and economic value, in comparison with those of neighbouring farmers who did not apply the improved technology. Such a gathering also provides an opportunity for management and farmers to express their reactions towards the new technology, as well as furnishing feedback for further on-station trials. It is also useful for training both farmers and extensionists in the Improved Production Technology.

Achievements in Terms of Increased Productivity and Incomes to Farmers

Wheat The following Improved Production Technology package was suggested for wheat:

- Discing, harrowing and levelling of the land.
- Machine sowing of 140 kg/ha of seed.
- Placement of 43 kg P_2O_5/ha by machine.

- Broadcasting of 80 kg N/ha by machine.
- Dividing the 2.1 ha field into 60 equal plots to facilitate uniform irrigation.
- Watering the crop every 14 days.

This package was demonstrated in 1986/87 in three blocks in the Gezira with nine farmers participating in each block. The yields, variable costs, and gross and net benefits of these trials are presented in Table 4 and Fig. 3. The average yields/ha of the package farmers exceeded those of non-package farmers in the same block by 55, 39% and 10%, and their net returns by LS 847, LS 517 and LS 19 per hectare, respectively (1 USD = 4.55 LS).

Encouraged by these results, and at the request of many other farmers, the package was tested in the 1987/88 season at seven locations with a total number of 47 farmers. The yields in all seven blocks ranged between 2.42 and 3.66 t/ha with an average increase in yield of 71, 92, 117 and 138% over the average yields of same number, block, group and scheme (Table 5). In another farmer-managed trial, funded by Global-2000 and ICARDA, in an area of 19 ha, two factors (good land preparation and the addition of 43 kg P_2O_5/ha) were demonstrated in a number of locations in the Gezira. A field day was organized at one of these locations to illustrate the impact of the technology, comparing yields and net benefits of the improved package with those of neighbouring non-package farmers (S.Ali Nur, personal communication). Table 6 shows that average yields of the improved package exceeded those of neighbouring farmers by 75%, and that each extra pound spent by the improved package farmers, was recovered with nearly 10 pounds extra. These results were very acceptable to participating farmers and they urged wider application.

Table 4. Comparison of wheat yields of Improved Production Technology package farmers with those of non-package farmers

Block		Yield (t/ha)	Gross benefits (LS*/ha)	Variable costs (LS/ha)	Net benefits (LS/ha)	Marginal rate of return (%)
1. Derweesh	Package farmers	3.94	2770	404	2366	
	non-package farmers	2.55	1792	273	1519	647
	block average	1.83	1289	349	940	1396
2. Dolga	package farmers	3.47	2439	618	1821	
	non-package farmers	2.50	1755	451	1304	312
	block average	1.33	937	373	564	513
3. Debeiba	package farmers	2.34**	1647	344	1303	
	non-package farmers	2.12	1491	207	1284	17
	block average	1.43	1004	196	808	335

Source: Ageeb *et al.* (1987)
* 1 USD = 4.55 LS
** The cultivar in this block was Giza 155 which lodged and hence reduced the advantage of Improved Production Technology

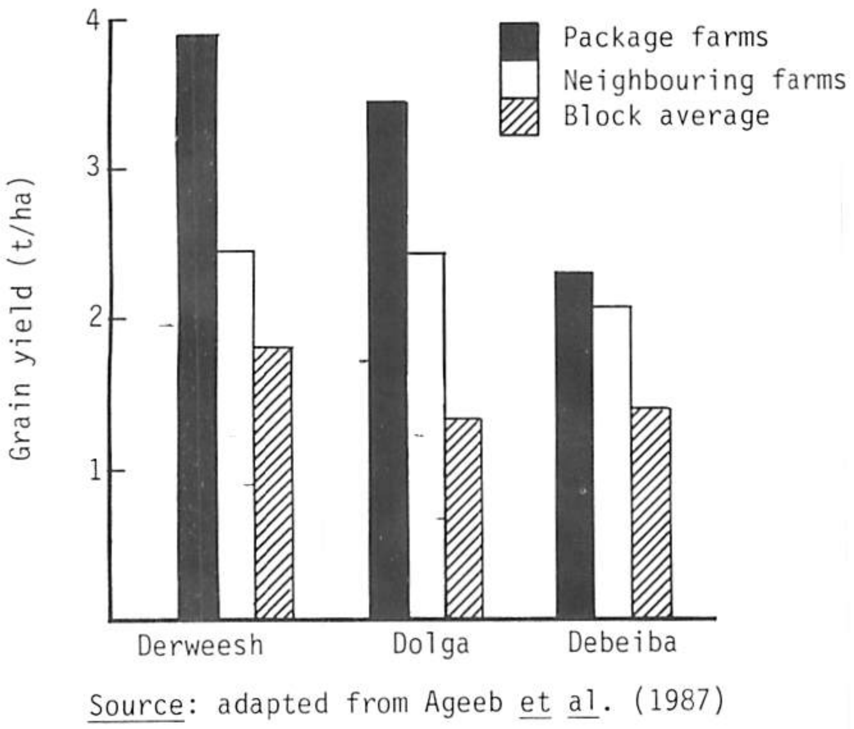


Fig. 3 Comparison of grain yield (t/ha) of package farmers and neighbouring farmers at three blocks in the Gezira.

Table 5. A comparison of wheat yields (t/ha) in demonstration plots with those of farmers in the same number, block, group and scheme

				Yield				
Group	Block	Area (ha)	Number of farmers	Demonstration plots	Same number	Same block	Same group	Scheme
Centre	Derweesh	20.6	8	3.66	-	1.67		
	A. Hakam 1	20.6	9	2.48	-	1.45		
	A. Hakam 2	7.6	4	2.46	-		1.45	
W. Haboba	W. Sulfab 1	18.9	6	2.68	1.62	1.05	1.05	
	W. Sulfab 2	18.9	8	2.42	1.62			
Northern	Mailing 1	18.9	6	2.71	1.60	1.48	1.24	
	Mailing 2	18.9	6	2.59	1.61			
Total		124.4	47					
Mean				2.71	1.61	1.41	1.25	1.14
Increase (%)					71	92	117	138

Source: Ageeb *et al.* (1987)

Table 6. Comparison of costs/benefits of wheat production by farmers at Faragalla farm in the Gezira (1988/89)

Operation		Improved Production Practices		Traditional Practices
Land prep.	(LS/ha)	205		205
Disc harrowing	(LS/ha)	48		-
Seed	(LS/ha)	193		193
Urea	(LS/ha)	200		200
Phosphorus	(LS/ha)	100		-
Spraying	(LS/ha)	314		314
Irrigation	(LS/ha)	38		38
Harvesting	(LS/ha)	107		107
Threshing	(LS/ha)	250		143
Empty bags	(LS/ha)	250		143
Transportation	(LS/ha)	374		214
Total cost	(LS/ha)	2079		1557
Yield	(t/ha)	5.00		2.86
Gross benefits	(LS/ha)	13 000		7429
Net benefits	(LS/ha)	10 921		5872
Extra benefits	(LS/ha)		5049	
Extra cost	(LS/ha)		522	
Ratio of extra benefit to extra cost			9.67	
Marginal rate of return (%)			967	

By courtesy of S. Ali Nur, Extension Unit, Gezira

Faba bean Research during the first four seasons through the NVP at GRS resulted in the following package for faba beans:

- Planting on both sides of 80 cm ridges.
- Placing 2-3 seeds in holes spaced 20 cm.
- Planting during the first week of November.
- Addition of Rhizobium and/or 43 kg N/ha at sowing.
- Watering every 14 days from planting time to flowering and every 7-10 days thereafter.
- Manual weed control or chemical with supplementary hand weeding.
- Chemical spraying to control insects.
- Harvesting and threshing by hand.

The above package was first tested in farmers' fields as researcher-managed trials/yield maximization plots for three seasons. The results were very encouraging and participating farmers obtained yields ranging between 1.3 and 2.3 t/ha and net returns ranging between 1358 and 1552 LS/ha. Following this success some interested farmers were approached to join the project in what we called farmer-managed trials/pilot production plots. On average the size of these trials was about 0.42 ha, situated at one end of the wheat plots (Table 7). The project supplied these farmers with seed, technology package and free pest control. There were only three farmers in the first season 1985/86, but this rose to 84 in 1987/88 (Table 8). Many others who could not manage to join the project bought their own seed from the scheme and grew it on their private farms within the Gezira or along the banks of the Blue Nile.

Data on yield and economic analysis for the 1986/87 season are presented in Table 9. They show that the average seed yields in some locations exceeded 3 t/ha with net returns of up to LS 6570/ha.

These results clearly demonstrate the success and profitability of growing faba bean in the Gezira environment.

Table 7. Participating farmers, cultivated area (ha) and faba bean seed yields (t/ha) in farmer-managed trials in 8 blocks of the Gezira Scheme in 1987/88

Block	No. of farmers	Av. area	Av. seed yield	Yield range
1. Wad El Ataya	5	0.33	2.45	2.02-2.99
2. El Remaitab	5	0.34	2.06	1.70-2.66
3. Hamad El Neil	7	0.59	1.99	1.03-3.42
4. Derweesh	24	0.47	2.14	1.19-3.18
5. Kumur	7	0.47	1.67	1.07-2.36
6. Debeiba	5	0.58	1.43*	1.19-1.69
7. Mailing	14	0.24	2.09	1.33-2.74
8. Kab El Gidad	17	0.37	1.09*	0.43-2.19

Source: Ageeb (1988)

* These blocks suffered from late sowing and insect damage.

Table 8. Participating farmers, average faba bean yield (t/ha) and net returns (LS/ha) in three consecutive seasons in the Gezira

Season	No. of farmers	Av. seed yield	Net returns
1985/86	3	2.03	4325
1986/87	23	2.18	3972
1987/88	84	1.87	3931

Source: Ageeb (1988)

Table 9. Faba bean yields and net benefits of Improved Production Technology at 5 locations in 1986/87 in the Gezira

Block	No. of farmers	Av. yield (t/ha)	Price (LS/t)	Gross benefits (LS/ha)	Variable costs (LS/ha)	Net benefits (LS/ha)
Turabi	5	2.28	2390	5449	2029	3420
Debeiba	4	3.00	2690	8070	1927	6143
W. Hemeidan	5	3.25	2760	8970	2400	6570
W. Adam	4	1.05*	3100	3255	1640	1615
W. El Lethi	5	1.30*	3140	4082	1955	2127

Source: Ageeb *et al.* (1987)

* These locations suffered from water shortage and received 4 irrigations less than other locations.

Problems Faced in Technology Transfer

The joint efforts of researchers, extension workers, economists, scheme's management, and farmers have clearly demonstrated that wheat yields could be substantially increased, and that faba bean cultivation in the Gezira environment is feasible and profitable. However, some problems still face transfer of the technology to the farmers, as follows:

1. The number of extension workers is small compared to the number of farmers and the area of the scheme. Efforts should be made to increase the ratio of extensionists to farmers through training additional extension agents as well as improving the technical ability of those in action at present.
2. Training the Gezira field inspectors with extension principles would increase their ability in the transfer of improved production technology to farmers.
3. The present facilities offered to both researchers and extensionists, for example, transportation, housing and operation funds, are meagre and need to be improved.
4. Crop production in the Gezira is still mainly focussed on cotton, which receives most of the inputs, for example, better land preparation, fertilizers and credits. Extending such services to all crops in the rotation should enhance Improved Production Technology transfer of these crops to farmers.
5. Awareness of many farmers of the benefits of the Improved Production Technology for wheat and faba bean is limited to a small area of the scheme. Regular meetings, seminars and field days by researchers and extensionists in various parts of the scheme and more demonstration trials to disseminate information to a wider sector of farmers are essential.

References

Ageeb, O.A., El Feki, H. El Fattah, A. Musa, A. and Ibrahim, K. 1986. Pilot production and

demonstration plots. Second National Wheat Coordination Meeting. ARC/ICARDA/OPEC, ARC, Wad Medani, 20-22 July, 1987.
Ageeb, O.A. 1987. The response of three wheat cultivars to sowing date at Medani. Third National Coordination Meeting. ARC/ICARDA/OPEC, ARC, Wad Medani, 4-6 Sept. 1988.
Ageeb, O.A. 1988 A note on the optimum sowing date for wheat in Gezira. Crop Husbandry Committee Meeting. ARC, Wad Medani, 22 May 1988.
Ageeb, O.A. and Abdalla, H.H. 1987. The response of wheat to NPK fertilizers in farmers' fields in Gezira. Third National Coordination Meeting. ARC/ICARDA/OPEC, ARC, Wad Medani, 4-6 Sept. 1988.
Ageeb, O.A., Guvele, C.A. and Ibrahim, I.K. 1987. Gezira on-farm pilot production and demonstration plots. Third National Coordination Meeting. ARC/ICARDA/OPEC, ARC, Wad Medani, 4-6 Sept., 1988.
Akasha, M.H. 1967. Gezira Research Station Annual Reports for 1967, Wad Medani, Sudan.
Ali, F.M. 1979. Gezira Research Station Annual Reports for 1979, Wad Medani, Sudan.
El Rayah, A.H. 1970. Gezira Research Station Annual Reports for 1970, Wad Medani, Sudan.
Farah, S.M. 1987. Effects of four irrigation regimes on the growth of wheat. Third National Wheat Coordination Meeting. ARC/ICARDA/OPEC, ARC, Wad Medani, 4-6 Sept. 1988.
Farbrother, H.G. and Adam, H. 1975. Three GRS techniques for the assessment of the first water requirements. Technical Notes on Water Use No. 4, ARC, Wad Medani, Sudan.
Ishag, H. and Ageeb O.A. 1987. Agricultural Research/Extension linkages in Sudan. Workshop on Planting and Programming of Agricultural Research. ARC/ISNAR, Wad Medani, 30 Nov.-2 Dec. 1987.
Khalifa, M.A. 1962. GRS Annual Report for 1962, Wad Medani, Sudan.
Rogner, W.A. 1959. GRS Annual Reports for 1959, Wad Medani, Sudan.

The Role of On-Farm Research in the Transfer of Information

P.R. Hobbs

CIMMYT, P.O. Box 1336, Kathmandu, Nepal

Abstract

The paper discusses the role of on-farm research primarily as a research tool to increase the efficiency of research and the feedback of information to station scientists, and secondarily as a transfer of relevant information through extension to farmers. A definition of on-farm research and a conceptual diagram of the steps involved is presented. On-farm research involves diagnosing the situation and the development and testing of solutions for well defined problems on-farm. Feedback to scientists ensures the relevance of the future research. On-farm research complements on-station research and is a part of farming systems research. Examples of deep tillage, fertilizer and mixed cropping of wheat plus brassica are used to highlight the importance of on-farm research in developing solutions for the more complex, post-Green Revolution problems faced by farmers interested in increasing productivity and sustaining production. The results are recommendations that stand a better chance of adoption by farmers.

Introduction

On-farm research is a tool or research methodology that improves the efficiency of research and increases the chances that farmers will adopt recommendations. The approach generates and verifies results in farmer fields. The research hopefully involves the local farmers and extension workers. In this respect it adds positively, in a secondary manner, to the transfer of information. However, it is not a primary tool for information transfer in the sense of extension, although it is an important conduit for feedback of information to the scientists at the research station.

On-farm research is not a substitute for on-station research, but rather complements it and acts as a feedback mechanism to ensure that it is better focussed and more relevant. This is a very critical issue in the present post-Green Revolution era where the initial easy gains in productivity from improved varieties and nitrogenous fertilizers seem to be peaking, and in some places even declining. The second generation problems that need to be solved for further gains in productivity, are more complex and interactive in nature. They are crop management-related, site-specific and require a much better understanding of the local problems and causes of low productivity. Figure 1 outlines the major differences between the traditional and on-farm research approach. A program without an on-farm research component will not be as efficient at developing recommendations for these second generation problems as a program with this methodology fully functional. Information transfer to farmers will also be improved where on-farm research complements on-station research, since recommendations will be better tailored to meet farmer needs.

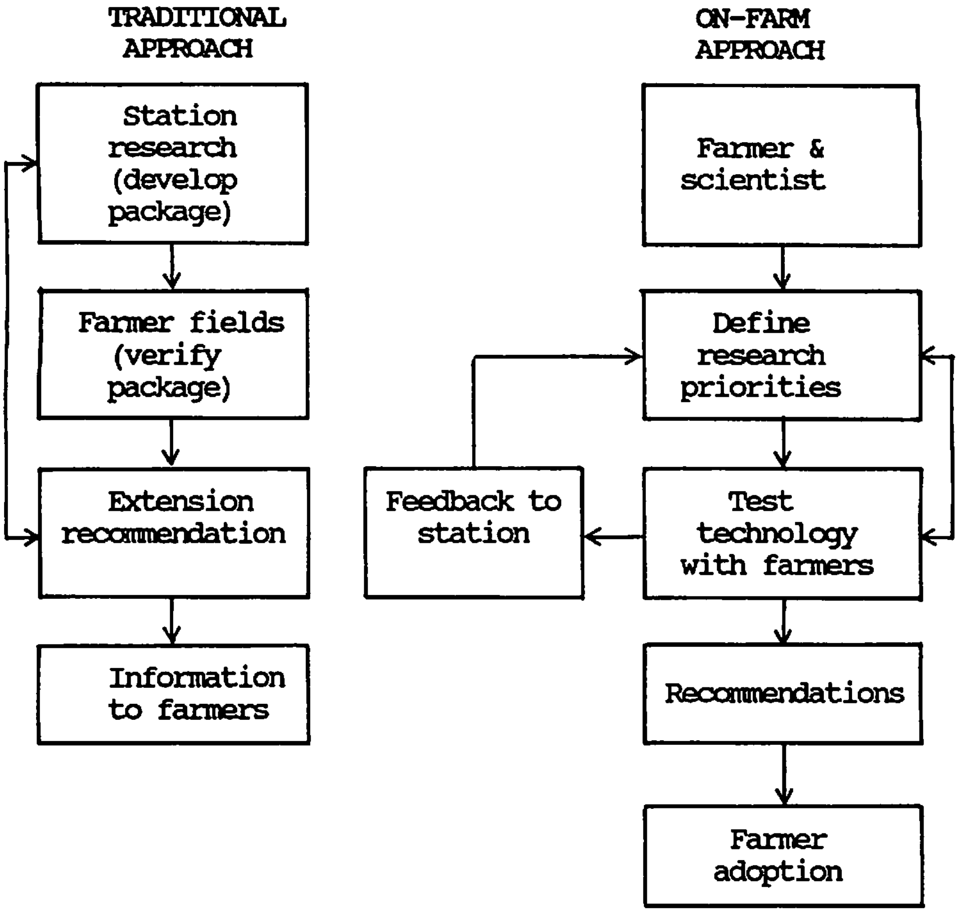


Fig. 1 Comparison of the traditional versus the on-farm research approach.

A brief discussion of on-farm research follows. The rest of the paper uses on-farm rainfed wheat results from Pakistan to highlight the usefulness of on-farm research (OFR) and various components of this methodology in developing recommendations and information for farmers.

Definition of On-farm Research

Over the past decade, on-farm research has been steadily incorporated into research agendas in many countries. Numerous approaches have emerged with a range of definitions and terms. Some of these approaches have been reviewed by Harrington *et al.* (1989). They prefer to use the term "On-Farm-Client-Oriented-Research" (OFCOR) as a model for present research activities, which was defined by Merrill-Sands and McAllister (1988) as follows:

"OFCOR is a research approach designed to help research meet the needs of specific clients, most commonly resource poor farmers. It complements, and involves a client-oriented philosophy, a specific research approach and methods, and a series of operational activities carried out at the farm level. These activities range from diagnosis and ranking of problems, through the design, development, adaptation, and evaluation of appropriate technological solutions. Farmers are directly involved at various stages in the process".

Figure 2 is a generalized approach for OFCOR (Harrington *et al.* 1989). It is an approach to help plan and organize research activities whether they be on-farm or on-station. The final outcome should be a recommendation that stands a better chance of adoption by farmers.

Farming systems research (FSR) includes OFR, and the term "On-farm research with a farming systems perspective" (OFR-FSP), coined by Byerlee *et al.* (1982) adds further definition to the above, since this approach:

a. Views a commodity crop as an integral part of a system with changes evaluated in terms of productivity of the total system.
b. Identifies constraints and opportunities for change in productivity at the farm level for well defined groups of farmers.
c. Utilizes a multidisciplinary team of scientists for analysis of farmer problems.

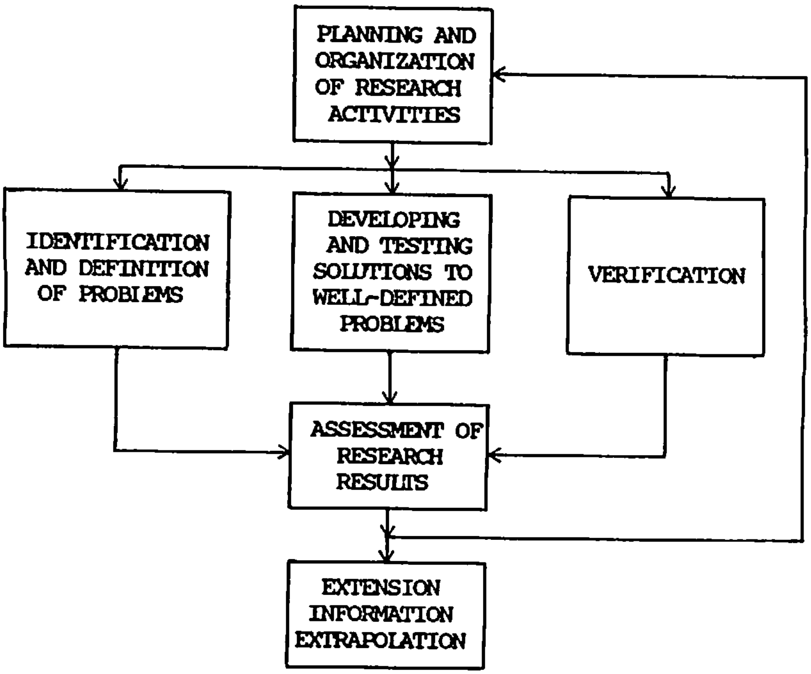


Fig. 2 A generalized approach to OFCOR, featuring functional processes.

Research on single commodities, in isolation, is no longer sufficient to guarantee an increase in productivity at the farm level. An interaction perspective of crops with other crops, and farming activities within a system, also requires consideration. On the other hand, research on all aspects of a farming system at the same time can lead to confusion. For reasons of practicality, it is better to break a system down into its components and research each component individually, keeping the systems perspective in mind. The farming system of the surrounding command area should be the overall mandate of a station, and the component commodities and disciplines should be integrated by the Director of Research to solve high priority problems and interactions.

Diagnosis of the Problems

On-farm research is not just the testing and verification of technology in farmers' fields. Identification and definition of the problems in selected research sites, and a description and understanding of farmer management systems and productivity is crucial for proper research planning (Byerlee *et al.* 1989).

An informal survey is a usual first step in identifying researchable themes and describing the system in the area. This informal survey need not have a questionnaire but instead can be conducted using a set of guidelines developed and updated each day by the team as information is developed. This type of survey places scientists of different disciplines in direct contact with farmers and extension workers so they can observe and discuss management and problems in the field.

Table 1 is an example of descriptive information collected from an informal diagnostic survey conducted in the rainfed wheat areas of Pakistan's Punjab. Some of the important points from this table are:

1. Two distinct land types are found - *lepara* land near the homestead that receives farmyard manure (FYM) and is more intensively cropped, and *mera* land further from the homestead.
2. Planting date is earlier than optimal (15th Nov in irrigated areas) probably because this makes better use of residual monsoon moisture. There are no conflicts of planting date with previous crops.
3. Land preparation is probably excessive and causing some problems
4. In three quarters of the wheat fields wheat is mixed with brassica (mustard) in a mixed cropping system. (Brassica is used for fodder)
5. Fertilizer use is about 50% of the recommended rate
6. Most of the farmers have small (<4 ha) land holdings but manage their own land.

The diagnostic survey can also be used to develop hypotheses concerning problems and causes of low productivity. Figure 3 is a set of interactions for low yields in the rainfed wheat areas of Pakistan.

The diagnostic survey also provides guidance for further follow-up activities such as:

a. analysis of secondary data
b. other exploratory and formal surveys -- e.g. crop cut surveys to measure yield, fodder

Table 1. Characteristics of project area for wheat, Rawalpindi District, 1982-85, Punjab, Pakistan

Land type	*Lepara* = 30%, *Mera* = 70%
Previous crop	Kharif 20%, Fallow 80%
Next crop	Maize 10%, Sorghum 39%, Peanut 34%, Pulse 14%
Major cropping pattern	*Lepara* = wheat-maize/sorghum-wheat-maize/sorghum *Mera* = wheat-sorghum-fallow-fallow
Planting dates	Sept 23 to Dec 10th; mean = Nov 1st before Oct 24 = 23%; Oct 24-Nov 15 = 71%
Harvest dates	mean = 25 April
Crop duration	206 days
Land preparation	8.3 ploughings; range from 2-20 36% animal, 47% tractor, 17% both
Seed rate	94 kg/ha, 90% between 50-150 kg/ha
Seeding method	64% *pora* (animal), 31% tractor, 5% = broadcast
Intercropping	75% mixed brassica, 25% pure. (Brassica for fodder)
Fertilizer	mean = 43 kg N, 36 kg P_2O_5, 0 kg K/ha Farmyard manure (FYM) 4.1 t/ha N-users 89% = 5 to 150 kg N/ha P-users 72% = 5 to 183 kg P_2O_5/ha FYM-users 32% = 0.1 to 28 t/ha
Weed control	80% = none, 20% = hand
Variety	86% = Lyp 73, 6% local (N.B. 1986/87 50% = Pak81)
Tenure	90% owners
Farm size	mean = 2.8 ha <2 = 46%; 2-4 = 40%
Threshing	74% bullock, 16% other (N.B. 1986/87 95% thresher)
Average rainfall:	winter = 266 mm; total = 843 mm

calendar surveys, seed and input surveys etc. to further define the problem

c. monitoring of selected farmers' fields to obtain long-term data for measurement of sustainability
d. laboratory tests to elaborate the problem further e.g. nutrients, moisture, soil physical properties etc.
e. more detailed observation in farmers' fields e.g. pests, weeds and disease incidence, plant stands etc.
f. on-farm trials.

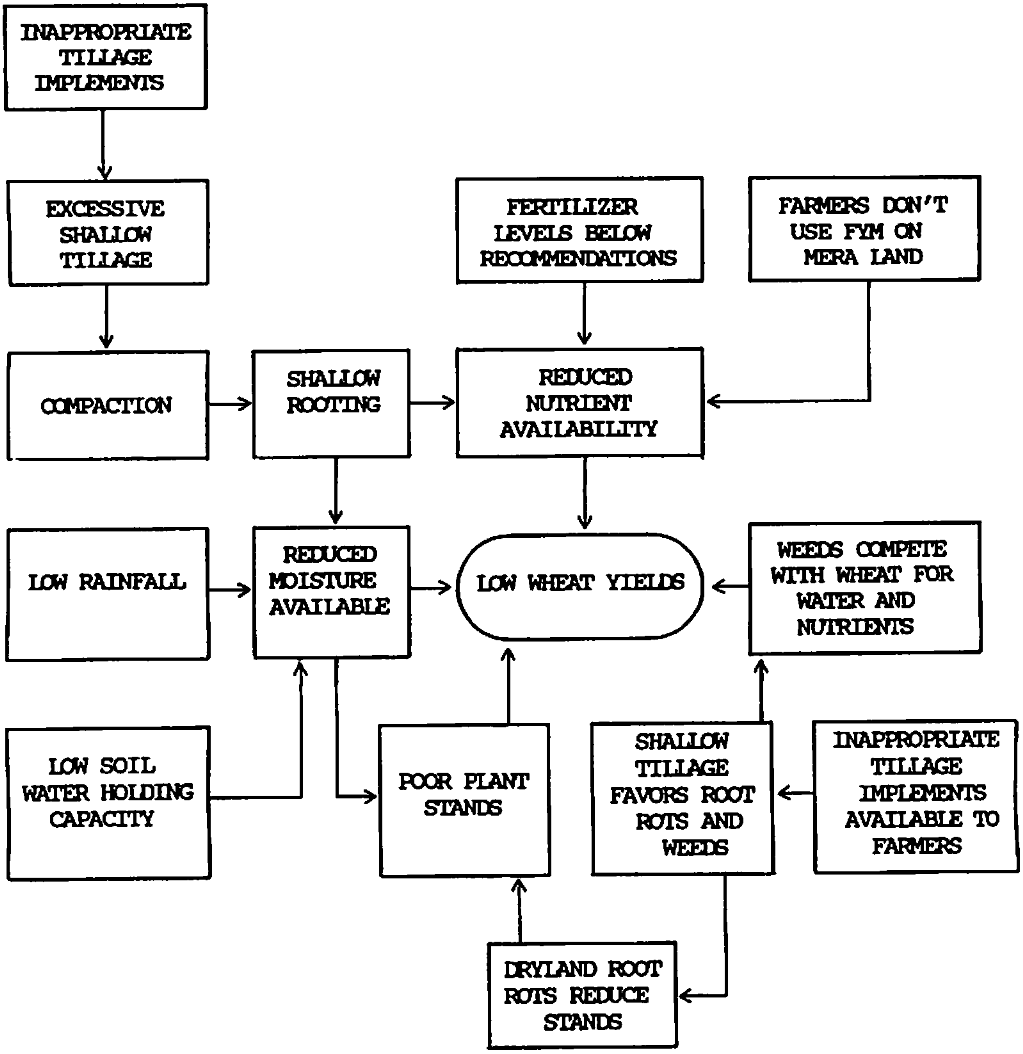


Fig. 3 Analysis of problems and causes of low wheat yields in rainfed wheat areas in Punjab, Pakistan.

We used a more formal integrated crop production survey following the diagnostic survey in Pakistan. This type of survey focused on specific farmers' fields during harvest, although some general farm level data (draft power, cropping patterns) were collected. The specific field data included detailed crop management data, direct observation of agronomic variables (plant population, weeds, soil type, etc.) and a crop cut for determining yield (Hobbs *et al.* 1989).

These data were subjected to multiple regression analysis to give some ideas of the major factors contributing to yield. The following is an equation developed from four years of work in Pakistan:

$$\text{Yield (kg/ha)} = \underset{}{0.958} + \underset{0.08^{*}}{5.84\,P} - \underset{0.126}{0.0431\,P^2} + \underset{0.0001}{656\,\text{Pakuser}} + \underset{0.0005}{386\,\text{LDT}}$$

$$+ \underset{0.04}{326\,\text{DTE}} - \underset{0.0021}{445\,\text{DWE}} + \underset{0.01}{255\,\text{PTM}} + \underset{0.0066}{37.7\,\text{PLN}}$$

P = kg P_2O_5/ha
P^2 = phosphorus square
Pakuser = Dummy for users Pak 81 0=other
LDT = Land type 0=*mera* 1=*Lepara*
DTE = Dummy for ownership 0=owner 1=tenant
DWE = Dummy for weeds 0=none 1=weedy
PTM = Planting method 0=other 1=tractor drill
PLN = Number of ploughings
R^2 = 0.27; * = significance; n = 420

Although this only accounts for 27 percent of the variation in yield (soil moisture, fertility and climate parameters could not be included) it does offer a first estimation of variables important in determining yield.

On-farm Trials

On-farm experimentation is used to verify recommendations under relevant farmer situations. It can also be used to describe and diagnose problems better. The following three experiments highlight some of the results in Pakistan.

1. *Deep tillage*

The diagnostic survey had identified excessive shallow tillage as a possible problem for rainfed wheat in Rawalpindi District, Pakistan. Preliminary observations in farmers' fields showed shallow, poor rooting and the presence of a thick compacted soil layer, below 10 cm, in some fields.

The first year of on-farm trials included tillage treatments at various depths using a chisel plough (25 cm), mouldboard (30 cm), sub-soiler (45 cm) and cultivator (10 cm). Only the mouldboard treatment gave a significant yield increase (Khan *et al.* 1986). Deeper rooting with the mouldboard treatment explained the benefit.

In the next four years, 67 comparisons of mouldboard versus cultivator experiments were placed in farmers' fields (Razzaq *et al.* 1988). The results are shown in Fig. 4. Overall, the mouldboard plots out-yielded the cultivator plots by 0.8 t/ha. The increase in percent of yield was greater in the dry years of 1983/84 and 1984/85 (38.5%) than the wet years of 1985/86 and 1986/87 (21.6%). Additional data showed that the mouldboard plots had better rooting (Fig. 5), more nutrients, fewer weeds, less dryland footrot, lower penetrometer readings, less termite damage, and more available moisture. The mouldboard ploughing was done at the onset of the monsoon rains, in the summer, and allowed more infiltration of water into the profile. In terms of economics, one mouldboard ploughing plus a cultivation before seeding was less expensive than the eight cultivations used by farmers. Also, less fuel was used (Razzaq *et al.* 1988).

This type of trial was not done on-station because most of the farm had already been deep ploughed by mouldboard. The station would also only represent a few of the soil types

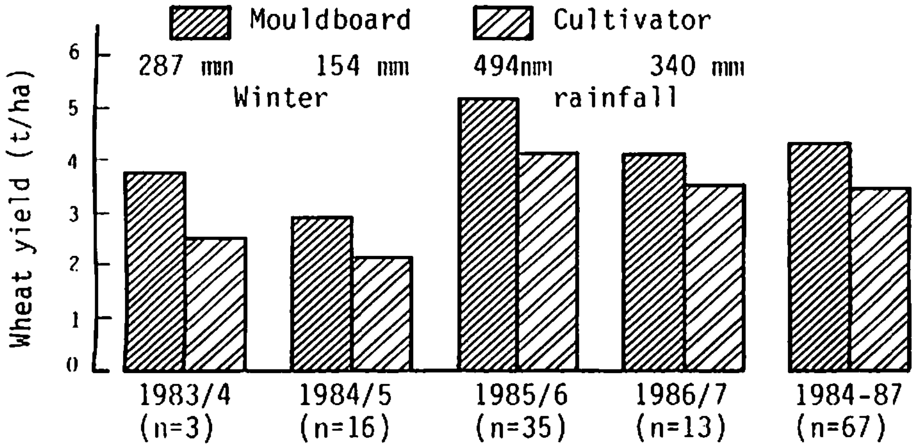


Fig. 4 A comparison of mouldboard (35 cm) and cultivator (10 cm) tillage in rainfed areas of Punjab, Pakistan, on the yield of wheat, 1983/84 to 1986/87.

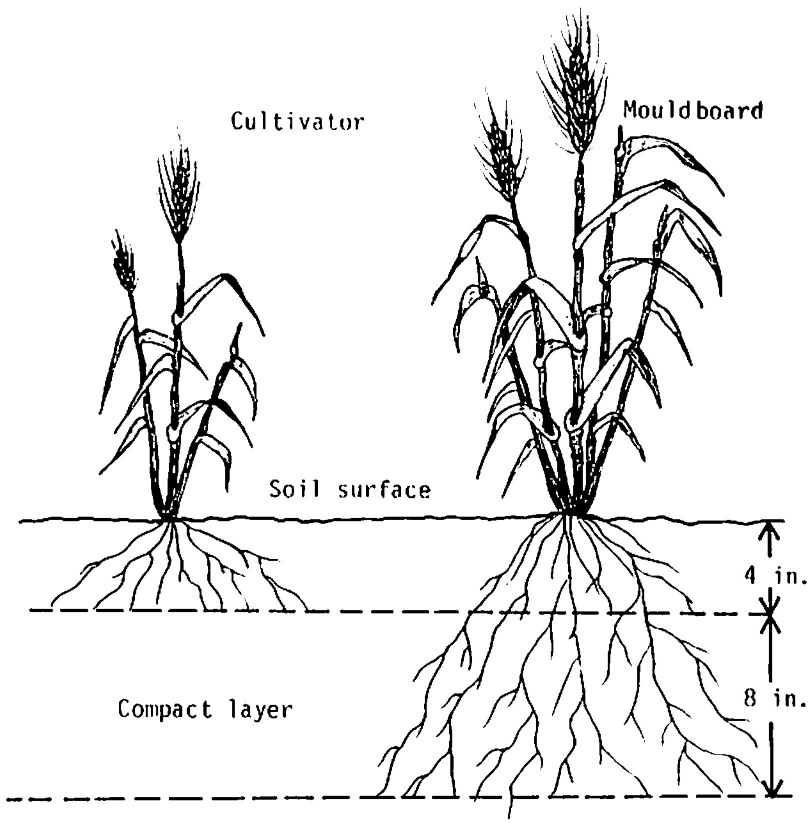


Fig. 5 Wheat rooting profiles of the cultivator and mouldboard ploughed treatments in February following drought in the 1983/84 *rabi* season in Rawalpindi district, Pakistan.

found in the rainfed areas of the Punjab. On-farm experimentation was essential for this type of trial.

The 67 trials also allowed measurement of the variation in response to mouldboard ploughing in the command area. Table 2 lists some of the results from the work done in 1984/85. Response varied from an increase of 3% to 120%. Further research is under way to determine what factors are responsible for this variability. This will allow a better understanding of the compaction problem and improve the information and recommendations available for farmers and extension.

2. *Fertilizer trials*

Fertilizer trials designed to provide recommendations and information for farmers have little relevance when conducted on-station. Prior history of fertilizer use and management of crops

Table 2. The effect of two primary tillage treatments on the grain and straw yield (t/ha) of rainfed wheat at 16 sites in the 1984/85 winter season in Islamabad and Rawalpindi Districts

Locations	Grain yield		Straw yield		% increase MB/CU grain
	MB	CU	MB	CU	
Tarlai	1.87	1.21	3.92	3.08	54
Thandopani	2.96	2.32	6.21	5.90	28
Barakhu I	2.28	2.21	4.78	5.00	3
Barakhu II	2.34	1.08	4.91	2.74	117
Barakhu III	4.60	2.09	9.65	5.31	120
Golra	2.76	1.81	5.79	4.61	53
Hardoghar	1.64	1.59	3.44	4.00	3
Rawat	3.67	2.39	7.70	6.08	54
Rakhmor I	2.60	2.40	5.45	5.00	8
Rakhmor II	3.46	2.96	7.26	7.00	17
Daultala I	4.07	3.65	8.53	8.00	12
Daultala II	5.58	5.14	11.70	11.00	9
Fatejhang I	1.78	1.35	3.73	3.44	32
Fatejhang II	3.00	1.64	6.29	4.17	83
NARC I	1.96	1.19	4.30	3.16	65
NARC II	1.74	1.05	3.47	2.54	66
Average	2.89a	2.13b	7.07a	5.06b	36

MB = Mouldboard, CU = Cultivator

on-station usually create a different situation than that found in a farmer's fields. Station soils are usually only representative of some of the farmer soil situations.

On-farm fertilizer trials are more relevant. Incomplete factorial designs are good for farmer field trials and provide the response curve data needed for agronomic and economic analysis. Full factorial designs, replicated over many locations, are difficult to manage on-farm.

Once response curve data are available, multiple regression analysis can be used. Table 3 shows the results from Pakistan for two areas -- Islamabad (300 mm winter rainfall) and Chakwal (150 mm winter rainfall) -- and a wet and dry year for Islamabad (Razzaq *et al.* 1988). Also included in the equation are some management differences between sites and interactions with N and P.

Table 3. Multiple regression coefficients obtained from incomplete factorial fertilizer trials in farmers' fields for rainfed wheats in Punjab, Pakistan

Areas	Islamabad		Chakwal
Factors	Wet year	Dry year	
Nitrogen	19.461**	14.45**	14.131**
Nitrogen square	-0.0486**	-0.09**	-0.07198**
Phosphorus	13.874**	11.47**	17.657**
Phosphorus square	-0.0514*	-0.077	-0.952**
N x P	-0.0188$^{.46}$	0.068$^{.14}$	0.0637**
Potassium	na	na	na
Tillage MB vs. CU	492**	449**	399**
Previous crop	1194**	858**	na
Land type	na	672**	1456**
Farmyard manure	1882**	na	na
LT x N	-3.745**	na	na
LT x P	na	-6.04**	-4.274**
FYM x P	-3.881$^{.16}$	na	na
Other interactions	na	na	na
No. of sites	34	24	26

Tillage	MB = 1	CU = 0
Previous crop	Fallow = 0	Maize = 1
Land type	*Lepara* = 1	*Mera* = 0

MB = Mouldboard, CU = Cultivator

The coefficients and data can be used with a computer spread-sheet to calculate various recommendations (Fig. 6). This shows various N-P-K rates for different marginal rates of return, calculates the VCRs and GNRs for different fertilizer levels and can be used to determine the best recommendation for a fixed cost. The data can be divided into areas with similar responses so that recommendations can be produced for different soil types,

ISLAMABAD DISTRICT MERA LAND 1985/86. No Farmyard manure (FYM).
(Data from on-farm fertilizer trials in rainfed areas in Punjab, Pakistan)

(i)

Curve Coefficient

Constant:		2981
a = N	:	19.46
b = NN	:	-.0486
c = P	:	13.87
d = PP	:	-.0514
e = NP	:	.0189
f = K	:	0.00
g = KK	:	0.0000

Notes b &/or d can only be 0 if e is 0

(ii)

Max. Rec. Fert. Levels	Minimum VCR	Prices (PKR/kg)	Marginal rate of Return (MAR)
N: 200	N: 2.0	N 5.6	w= 0.5
P: 200	P: 2.0	P_2O_5 4.4	x= 1.0
K: 100	K: 5.0	K_2O 0	y= 1.5
		Crop 2.0	z= 2.0

(iii)

MAR	N	P_2O_5	K_2O	YIELD INCR.	YIELD	COST	PRFT	VCR	GNR
.5	184	136	0	3342	6323	1627	5057	4.1	10.4
1	167	122	0	3205	6186	1471	4940	4.4	11.1
1.5	150	108	0	3029	6010	1314	4744	4.6	11.7
2	133	95	0	2814	5795	1158	4470	4.9	12.4

(iv)

At Fixed Rates	N	P_2O_5	K_2O	YIELD INCR.	YIELD	COST	PRFT	VCR	GNR
	51	40	0	1377	4358	461	2293	6.0	15.1
	37	37	0	1122	4103	370	1874	6.1	15.2
	100	0	0	1460	4441	556	2362	5.2	14.6
	100	50	0	2119	5100	779	3460	5.4	14.1
	100	50	50	2119	5100	859	3380	4.9	10.6
	150	100	50	2981	5962	1359	4604	4.4	9.9

VCR = Benefit/Cost Ratio; GNR = Grain Nutrient Ratio

Yield = Constant + $\underline{a}N + \underline{b}N^2 + \underline{c}P + \underline{d}P^2 + \underline{e}NP + \underline{f}K + gK^2$

Optimal N = $(r_N - \underline{b}^2)/2\underline{c}$. Optimal P = $(r_P - \underline{d})/2\underline{e}$

where $r_N = W_N (1+R)/P_g$. W_N = field price N. R = marginal rate of return.

P_g = field price output adjusted for difference between experimental and farmers yield.

Fig. 6 Example of a spreadsheet for the estimation of economically optimum fertilizer application showing i) the predictive model, ii) parameters of the estimation, iii) estimates of optimum fertilizer recommendations, and iv) recommendations for optimized expenditure of limited funds.

years etc., using calculated coefficients. The benefit of this type of analysis is the development of a conditional recommendation. Instead of providing a farmer with an optimal, but single recommendation, information on fertilizer use can be tailored to his ecological and financial situation.

The one factor that is missing from this fertilizer work is the concept of sustainability. Obviously, if potash is not used, it will become limiting and eventually be needed to maintain productivity. However, this new research thrust is still in its infancy and ways of handling sustainability and its relation to on-farm trials still need to be worked out.

3. *Intercropping*

The diagnostic survey highlighted the importance of mixing wheat with brassica in the rainfed areas of Pakistan. The farmers mainly used the brassica for fodder although some seed was harvested. The amount left for seed depended on the brassica growth in any one year: the better the growth, the more left for seed.

Obviously, since 75% of the farmers practice mixed cropping, it cannot be ignored when recommendations are made to farmers. A set of experiments were done at the experiment station to evaluate mixed cropping. This is an example of where more precision was needed than possible on-farm and the experiment station was able to complement and provide further information on an important farmer practice.

The economic analysis of some of the results is shown in Figs 7 and 8 (Hobbs *et al.* 1985). The experiment kept the wheat population constant and varied the brassica population by using different percentages of the recommended brassica seed rate. The brassica was allowed to either set seed or was harvested for fodder. The results in Fig. 7 show that the farmer is correct in mixing brassica with wheat since all combinations were more economic than wheat alone. Mixed cropping was also better than intercropping, mainly because the brassica population and fodder production was lower in the intercrop geometry. For brassica seed, wheat alone was best (Fig. 8).

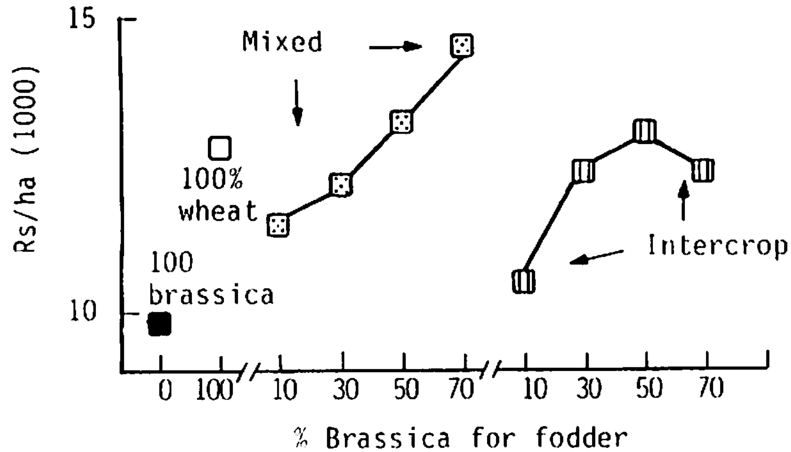


Fig. 7 **Total gross returns (PKR/ha) for monocrop wheat and brassica compared to wheat mixed and intercropped with increasing population of brassica for fodder at NARC, Islamabad, Pakistan, 1982/83.**

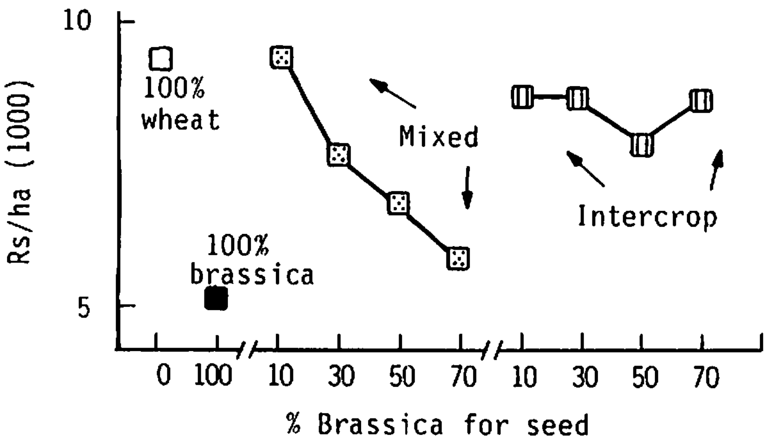


Fig. 8 Total gross returns (PKR/ha) for monocrop wheat and brassica compared to wheat mixed and intercropped with increasing population of brassica for seed at NARC, Islamabad, Pakistan, 1982/83.

This is a very complex type of experiment and very difficult to duplicate in terms of farmer practice because of the wide variability found in farmers' fields with respect to brassica populations and timing of the removal of fodder. Add to this the possibility of changing wheat and varieties, fertilizer rates, dates of planting, spacings and other management factors and the complexity becomes very difficult to unravel. However, the results obtained so far do highlight the need to include this system when developing recommendations. Obviously, more work is needed to improve the efficiency of this system.

Conclusions

On-farm research is an essential research tool for solving the present and future more complex post-Green Revolution crop management problems and providing more conditional, relevant recommendations to farmers. On-farm research is a process of diagnosis for well defined problems on-farm. It increases the efficiency of research, in that feedback from on-farm trials guides future research planning. The subsequent recommendations to farmers will then be more relevant and stand a better chance of adoption.

References

Byerlee, D., Harrington, L. and Winkelman, D. 1982. Farming systems research: issues in research strategy and technology design. American Journal of Agricultural Economics 64 (5): 897-904.

Byerlee, D., Heisey, P. and Hobbs, P.R. 1989. Diagnosing research priorities for small farmers: experiences from on-farm research in Pakistan. Quarterly Journal of International Agriculture, June, 1989.

Harrington, L.W., Read, M.D., Garrity, D.P., Woolley, J. and Tripp, R. 1989. Approaches to on-farm client-oriented research: similarities, differences and future directions. To be published in Proceedings of the International Workshop on Developments in Procedures for FSR/OFR, Bogor, 13-17 March 1989.

Hobbs, P.R., Razzaq, A., Hashmi, N.I., Munir, M. and Khan, B.R. 1985. Effect of mustard grown as a mixed or intercrop on the yield of wheat. Pakistan Journal of Agricultural Research Vol 6 (4): 241-247.

Hobbs, P.R., Razzaq, A. and Hashmi, N.I. 1989. A survey of wheat production practices and yields in Rawalpindi District of the Punjab from 1983-1985. PARC/CIMMYT publication 89-1. Islamabad, Pakistan.

Khan, B.R., Khan, B., Razzaq, A., Munir, M., Aslam, M., Ahmed, S., Hashmi, N.I. and Hobbs, P.R. 1986. Effect of different tillage implements on the yield of wheat. Pakistan Journal of Agricultural Research 7(3): 141-147.

Merrill-Sands, D. and McAllister, J. 1987. Strengthening the integration of on-farm client-oriented research and experiment station research in national agricultural research systems (NARS): Management lessons from nine country case studies. ISNAR/ OFCOR comparative study No. 1. The Hague, The Netherlands.

Razzaq, A., Hashmi, N.I. and Hobbs, P.R. 1988. Wheat on-farm research in *barani* areas of Northern Punjab: Synthesis of results from six years of experiments. PARC/ CIMMYT publication 88-10. PARC, Islamabad, Pakistan.

The Study of the Transfer of Information to the Farmers in Andalusia, Spain

JORGE DE JUAN-ARACIL

Estacion de Explotacion Agraria, Jerez de la Frontera, Cadiz, Spain.

Introduction

Spain is mainly a rural country. In the 1950s it was suffering from international isolation, still under the effects of the last civil war, and had an almost self-sufficient economy,

The mass media showed the youth a golden life far away from the fields. The fields meant work and more work, and the town less work and more comfort, free time and places to spend it in, so villagers who had reached a high enough standard of living went away to the cities, or crossed the borders looking for a better future. The older and less progressive villagers remained. The rural population became older, generally clinging to tradition and refusing to adopt new ideas, new techniques, new advances, and new varieties. There was clearly a better future in the towns, and the differences between town and country grew wider and wider.

The problem of rural migration affected the whole economy of the country, so the Extension Service of Agriculture (SEA) was created in 1957, with the main aim of raising the standard of living for the rural population. It was not directed at agriculture itself, but at the farmers and their circumstances. If these could be improved the vicious circle would be broken, the rural way of life, traditionally undervalued, would become more attractive and the differences between town and country become less.

How was it to be done? The family was taken as the focus: the philosophy was to improve the standard of living for the rural family through changes in attitudes so that they could make better use of their resources. This involved a comprehensive program of (i) keeping the farmer informed of new developments, (ii) teaching his wife, and (iii) educating their children.

The basic cell was the Regional Agency, which covered a natural geographical area. An agency was established with at least one regional agent (a technician from a university or polytechnical school) and an agent for home economics. The former was a specialist in agricultural extension and information who promoted changes in structural and social attitudes. The latter was generally a woman who taught the wives of farmers and agricultural workers how to improve their homes by making better use of their resources; preserving food, spinning, weaving, dressmaking, knitting, furniture renovation, electrical maintenance, home decorating, and organizing consumer goods cooperatives. When major problems arose the agent could consult the special regional agricultural advisor who was in charge of two or three regions. An agent of an area, which coincided with the province, coordinated the activities. He was responsible to the regional director of the Province. The regional director was responsible to the Director General in SEA Headquarters in Madrid. Within the regional areas, consisting of more than one province, specialized technicians were experts in one or more subjects of special interest in that particular area.

First a study was made of each area to establish a working program, annual projects and long term projects. Information was gathered from:

i) individual visits to farms and houses,
ii) regional extension offices,
iii) telephone calls, and
iv) letters.

The results were disseminated through meetings, demonstration of methods, excursions and workshops, and through the mass media; bulletins, pamphlets, newspapers, letters, radio and cinema.

Usually the demonstrations took place at the farm of an innovative farmer. Farmers were shown the effects of applying new technology, such as new crops and varieties, fertilizers, control of pests and diseases, and the improved techniques and varieties were demonstrated.

A network of agricultural technical schools prepared the younger generation.

Nowadays, since the division of the country into autonomous regions, the number of regional centers has been increased and each has created a network of agricultural trials like the existing ones, with the support of the research centers. Their results are published and distributed among the agriculturists free of charge.

The situation in Andalusia

Approximately half of Andalusia's 87 000 km^2 is cultivated. It has a population of six and a half million, mostly in rural areas, and many people are without full-time employment and in poor economic circumstances.

Figure 1 shows the agricultural technical schools, extension offices and research stations in Andalusia.

Research experiments are aimed at comparing, in the field at the technical level of the farmers, the results of using the materials, the new techniques, and the new technologies, against those of the usual traditional practices. The research must be founded on statistically-designed trials and demonstration of results, and the spectrum must be wide, including all possible aspects of farming, from seed densities and pesticides to drip irrigation, irrigation with salt water, no-till, cost/benefit ratios, etc.

Keeping to the basic principle that if the farmer flourishes so does agriculture, the Andalusian Extension Service has maintained its objective, with plans which are reviewed every year. The basic plan is adapted according to current information about the types of assistance available, credits in general, and especially the new economics brought about by membership of the European Economic Community (EEC) Common Market. Every year a report is prepared, showing the needs for research to the departments with R + D (research + development).

Economic Rationalisation

Following the previous programs, farms producing cereals, olives, fruit, for example have

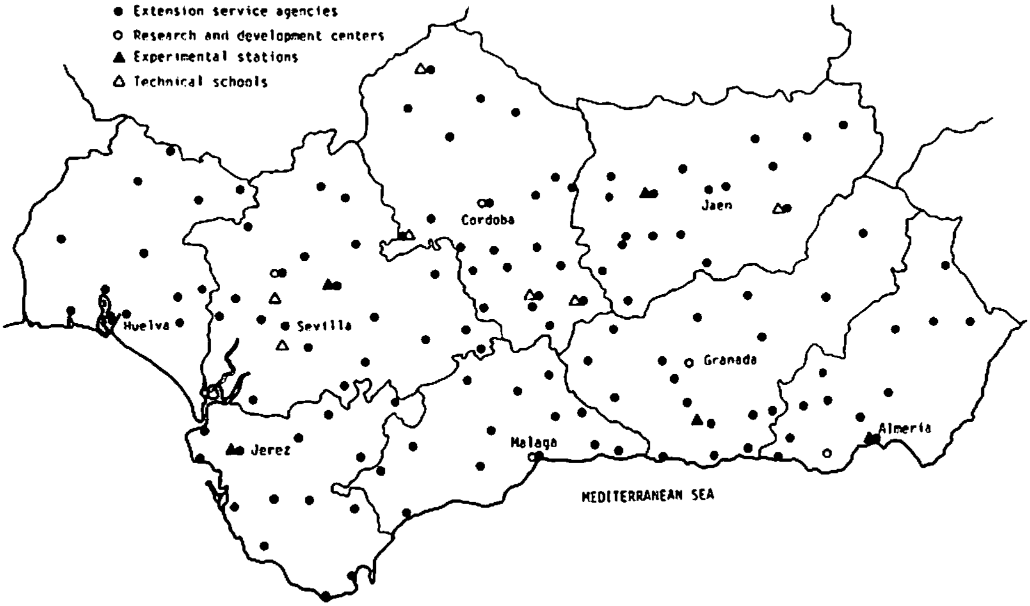


Fig. 1 **The agricultural extension service in Andalusia, Spain.**

been divided into

1) units too small to be viable
2) family businesses
3) landholders

Extension agents advise the first to change to intensive cultivation using irrigation or greenhouses or, if necessary, to be abandoned: the second, if they need it, to be converted to a more progressive pattern as cooperatives: the third look after themselves.

Methodology

The means of reaching the communities has remained more or less the same, that is, with small networks regional in character, demonstrations of results, technical meetings, and more modern methods of communication, such as video and television.

At the individual level, the aim is to attract the youngsters to the land with specific credits to buy farms, and with education facilities to increase their knowledge of agriculture.

At the home level, the aim is to improve the home by introducing better eating habits, developing the family orchards and gardens to produce more for home consumption, preserving foods, and extending the use of freezers and household electrical equipment with the help of cheap credits.

At the community level, development is concerned with making new roads, new irrigation schemes, new electricity lines, always, if possible, in cooperatives.

At the commercial and industrial level, new trade is being sought, and groups of farmers are marketing their produce in cooperatives, ensuring that it will meet EEC standards.

Conclusion

The Extension Service in Spain has been a great success, mainly because it has reached the farmer and his environment, focussing on the people rather than the agriculture.

Information about new agricultural technology can only be successfully transferred if that technology is truly appropriate, i.e. if it is what the farmer needs and wants, within the limits of his resources (Dafalla; Bahram). Agricultural research must therefore be based on a thorough and complete knowledge of the farmer and his situation. A critical factor in identifying appropriate technology is the involvement of all the appropriate people, researchers, extension workers, farmers, marketers and economists, and bringing them all together at the planning stage. Thereafter they should be continuously involved in a multidisciplinary team to provide advice and direction to the researchers at critical stages during the development of the technology. Developing technology that is really appropriate is much more likely when communication is good: it is essential to listen to farmers, as well as to tell them the results of research (Reeves). A one-way flow of information, from the top down, is often a recipe for disaster: it may work in developed countries, where the social, cultural and economic gaps between scientists and farmers are likely to be small, but it may not be successful in many developing countries. It is just as important to inform researchers of the farmers' priorities, perceptions and reactions as it is to inform the farmer of research recommendations (Jones). It is also important to inform developers, or policy-makers. Constraints at farm level are related to constraints at national level - prices, loans, etc - and the developer needs to be involved in the system too (Khaldi). There are farmer needs, and there are government policies, and they are not necessarily the same. Research and extension personnel together have the responsibility of communicating to government policy-makers what is agriculturally desirable and feasible.

In Australia farmer groups are a very powerful way of facilitating the transfer of information. They can also be useful sources of information about the impact of extension: it is easier to access such groups than to deal with individuals. Their major strength is that farmers feel free to air their own ideas and often identify their own problems. They therefore not only feel that they have 'ownership' of the problems to be researched, but also sometimes demand the research, and extension. Farmer groups may include:

- Neighbourhood discussion groups
- Land care (conservation groups)
- Specific industry discussion groups, e.g. dairying, poultry farming, cropping.

On-farm trials have a special role to play in technology transfer. The choice of farm on which to conduct the trial is very important. Location is obviously one criterion, and so is the kind of farmer (Khaldi); he/she should be respected in the community and be something of a leader, progressive, cooperative, and successful (Hicks). There can be *difficulties* in conducting on-farm trials; with equipment, for example, which the farmer may not own, or which may be in poor condition; or researchers may not have the knowledge and practical skills to carry out the traditional methods in control plots, and local extension staff may not either (Durutan; Kalayci). Wherever possible the farmer situation should be duplicated. On-farm research must have a methodology flexible enough to meet all site-specific circumstances; there are no cookbook recipes available, nor should there be (Hobbs).

Synthesis of Working Group Discussions and Recommendations

Synthesis of Working Group Discussions and Recommendations

I. General issues of concern expressed by all working groups

To help meet the very large projected food and feed deficits within West Asia and North Africa, and to ensure that production increases are sustained over the long term, national and international agencies must give greater priority to improved crop and soil management and the conservation of natural resources.
Three major issues need to be addressed:

1) Linkages
2) Priority of resource allocation
3) Training

Linkages

- Multi-disciplinary linkages are essential. At the moment these are constrained by existing research infrastructures which are often departmentalized on a commodity or discipline basis.
  N.B. It is also important to try to avoid overlapping or conflicting research programs and advice to extension agents and farmers.
- Good linkages between policy makers-researchers-extension agents-farmers will greatly help in the development of relevant research programs and the transfer of information to farmers. Current infrastructures and lack of awareness make it very difficult to establish such a chain of linkages.
- Also although linkages may have been established, they are often broken by enforced staff movement.
- Multi-national and regional linkages are not well established within crop and soil management research. Such networks and information transfer systems would greatly enhance the efficiency and status of agronomic research and extension.

Priority of resource allocation

- National agencies must give greater priority to agricultural research and extension, and create conditions which encourage men and women in the region to commit themselves to a career in agriculture.
- Within the agricultural research and extension sector, national agencies should give greater priority to crop and soil management research and the conservation of the natural resource base upon which future agriculture will depend.
- Much of this research is long term in nature. National and international agencies and research workers themselves must give such research higher priority and recognise that "quick" solutions are not always possible, and may be misleading.
- On-farm research has a vital role to play in:

  1) Developing relevant research programs through better scientist-extension-farmer links.

2) Development of more precisely targeted recommendations in variable environments.
3) More realistic *economic* evaluations.
   Greater priority and resource allocation should be given to such research.

Training

Achieving sustainable production increases in the harsh and variable environments of West Asia and North Africa is going to pose a continuing challenge. To meet this challenge, governments must continue and expand their investment in training.

In general, the region has a deficit of skilled manpower in:

- Agronomy (and a range of related disciplines)
- Livestock science
- Rural sociology and economics

In particular, the region would benefit enormously from the creation of a permanent and specialized regional training center for Extension Agents.

II. Tillage and stubble management

The main issue is the development of tillage that is appropriate, and of stubble management *systems* for soil and water conservation, plant growth, and sustainable production.

Major Under-Researched Issues

1. Tillage-residue-livestock interactions
   (The use of stubble for water and soil conservation compared with the current practice of using stubble for livestock feed)
2. Effectiveness of stubble retention for water infiltration and reduced evaporation
3. Effectiveness of primary tillage on water infiltration and retention
4. Efficient use of additional soil water through good management (nutrients, weed control, rotations), and the role of chemical weed control in reduced tillage
5. Research and development on appropriate tillage equipment and planters
6. Availability of spare parts and technical know-how about setting and maintaining machinery.

Research Strategy

1. There should be long-term, multi-disciplinary, multi-factor trials on the major soil types of a country. These could be on research stations or on-farm, but must be well-controlled.
2. Such research should be integrated into national programs to ensure long term commitment and continuity.
3. Site characterization is essential for comparisons and extrapolation of findings.

4. Tillage equipment must be realistic for adoption by farmers.
5. Training in usage and maintenance of equipment is essential.
6. Local practice should be included as control.
7. All research must include monitoring of economic and social factors.

Constraints to Research

1. Interactions of tillage-residue-livestock are complex and control is difficult.
2. Tillage equipment is often site (soil type) specific, and expensive.
3. A multi-disciplinary approach to research is lacking within the region.
4. There are not enough experienced research scientists.
5. Training is inadequate.
6. Continuity of research funds and personnel (scientists and support staff) is needed.

Possible Solutions

1. Long-term government commitment at planning stage is required.
2. Special project research funding is needed from national government or external sources.
3. Young research graduates should be involved.
4. Support staff must be trained.

III. Crop establishment

Major Under-Researched Issues

1. Appropriate methods of seedbed preparation
2. Determination of interaction of seed rate/plant density with environmental factors
3. Matching of varietal characteristics to environments
4. Prediction (modelling) of appropriate time of sowing for continuous cropping.

Lower Priority Issues

1. Plant arrangement and row spacing
2. Crusting of soils
3. Seed dressings
4. Seed size and depth of planting

Research Strategies

1. Environmental characterization is important for extension of results beyond site of experiment.
2. Multi-disciplinary research should be linked to multi-factorial experiments.
3. A regional agronomic network should be set up to enhance information exchange.

Constraints to Research

1. Lack of facilities for training

2. Poor status of agricultural research -- reflected in poor logistic support and operational funds
3. Poor communication amongst regional and national scientists.

Possible Solutions

A regional information transfer mechanism in order to:

1. Facilitate research
2. Give individual researchers a wider sense of support
3. Offer training opportunities

IV. Fertilizer management

Major under-researched issues
and appropriate research strategies

i. *Phosphate dynamics:* depletion/build up of soil-P availability over time, its relation to fertilizer regime, cropping pattern and soil type, and its basic soil chemistry.

Strategies for Research:

Long-term trials
Site characterization

ii. *Efficient nitrogen fertilization:* rate, method and time of application: development of recommendations flexible enough to take account of locality, season, previous crop and rainfall situation.

Strategies for Research:

On-farm research
Site characterization

iii. *Diagnostic techniques:* for assessing N and P availability and fertilizer need, in particular standardization of analytical methods and determination of critical levels -- in soil, but also perhaps, for N in plant -- in relation to soil type, recent fertilizer use and crop sequence.

Strategies for Research:

Site characterization
Regional information network

iv. *Fertilizer interactions*: with other management practices (e.g. tillage, weed control) and soil moisture conditions, leading to targeted recommendations for specific rotations, management levels, etc.

Strategies for Research:

Multi-disciplinary research
Multi-factor research
Long-term trials
Site characterization

v. *Micro-nutrient deficiencies*: simple methods are needed to identify and anticipate micro-nutrient problems according to soil type/crop/intensity of production.

Strategies for Research: Site characterization
Regional information network

vi. *Economic dimension*: economic analysis of fertilizer trials; recommendations to farmers based on results of on-farm trials and studies of related socio-economic factors and risk.

Strategies for Research: Multi-factor research
Multi-disciplinary research
On-farm research
Site characterization

Lower Priority Issues

- Phosphate placement: banding v. broadcasting
- Comparison of fertilizer forms (high v. low analysis; compounds)
- Microbiological aspects -- rhizobia and mycorrhiza
- Modelling fertilizer response
- Use of N^{15} and P^{32} to study fertilizer efficiency.

Wider Issues (i.e. *Fertility* Not Just *Fertilizer* Management)

- Soil physical properties (evolution in relation to rotation, soil organic matter content)
- Legume effects on soil N dynamics
- Organic manures
- Long-term monitoring of fertility; nutrient balances.

Constraints to Research		*Strategies most affected*
i. *Financial*		
Manpower	- numbers - training - salaries/incentives/inequalities	All
Operations	- equipment - vehicles, operating costs	On-farm research Long-term research Site characterization
Travel	- conferences, etc.	Information network

ii. *Organizational*

Institutional barriers (Research v. Extension; but also within Research)	Multi-disciplinary research
Bureaucratic procedures	On-farm research Multi-disciplinary research Information network
Staff changes	Long-term trials

V. Weed control

Major Under-Researched Issues

1. Change in population and species of weeds due to shift in farming system from fallow to continuous cropping, taking livestock interaction with the systems into consideration
2. Knowledge of weed flora and emergence patterns in winter sown crops
3. Economic and agronomic analysis of the systems
4. Integrated weed control in food legumes, particularly broadleaved and parasitic weeds (chemical use and cultural practices such as sowing date, interrow cultivation, solarization, etc.)
5. Integrated weed control in cereals, particularly grassy weeds (use of chemicals and cultural practices such as tillage, sowing date, planting pattern, etc.)
6. Selection of crop varieties with higher competitive ability
7. Control of late germinating weeds.

Research Strategies

1. farmer monitoring
2. long-term trials
3. multi-disciplinary research
4. multi-factor trials
5. site characterization
6. regional agronomic network

Constraints to Research

1. Insufficient infrastructure
2. Integration of different disciplines
3. Involvement of researchers, extension and farmers from planning onwards

VI. Crop rotations

Major Under-Researched Issues

1. Fallow replacement by annual legumes

   - Identification of suitable legume species
   - Studies of water and N balance
   - Economic analysis

2. Ley farming system

   - Social, cultural aspects need to be defined
   - Is a new technology feasible for introduction?
   - Need to find more adaptable varieties or species
   - Need to study the effect of ley farming on the chemical and physical characteristics of soil and water use efficiency

3. Integration of livestock into cropping systems

   - Effects on soil properties and soil compaction
   - Determine stocking capacity
   - Economics of cereal-legume-livestock systems

4. Cropping sequences

   - Alternatives for various climatic situations
   - Need to fit the system into local situation

5. Need to have methods for economic evaluations

Research Strategies

1. Multi-disciplinary approach
2. Long-term, well-designed experiments
3. Group experiments with similar objectives in the region but slightly different species and approach according to local conditions
4. Initial trials-experiment station
5. Introduction of new technology (new varieties, new planting techniques, seeding date...) to farmers already using some type of rotation
6. Determination of crop sequence effects on shorter term basis and on farmers' fields
7. Careful consideration of design and method of analysis of rotation experiments before initiation of actual field trials

Constraints to Research

1. Commitment to long-term trials lacking
2. Expensive in terms of land, time, personnel and finance
3. Quick results are expected but may be misleading
4. Procedures for conduct of rotation experiments not well understood. Not many good

past examples are available
5. Long time-lag between initiation of trials and usable (and publishable) results
6. Demonstration of results in farmers' fields difficult because of time and land required from farmer

VII. Transfer of information

Major Issues Concerning Extension

1. Inclusion of extension officers and farmers in project teams from the outset
2. Establishment of extension/rural sociology training center in region (a possible role for ICARDA was suggested by participants)

Major Constraints to Extension Services

1. Attitudes of governments/policy makers to rural development
2. Government infrastructures, financial support, etc.
3. Low credibility of extension workers: skills, roles, career development
4. Poor knowledge of extension skills/methods/technologies
5. Lack of economic information

Possible Solutions

1. Upgrading of extension services/manpower, funds and support
2. Specialized training:
   - Inter-regional travel
   - Travelling workshops
   - Establishment of extension/rural sociology/research training center
3. Greater use of electronic media
4. Planned projects

Constraints to Farmer Adoption

1. Poor linkages, poor coordination between research extension and farmers
2. Unavailability of inputs (seed etc.) and lack of technical support services for farmers
3. Advice to farmers often conflicting, instead of clear and targeted
4. Level of education of farmers

Possible Solutions

1. Improvement of relationships between each group in the research- extension-adoption continuum through:

   - Better organizational structures
   - Multi-disciplinary project teams involving researchers
   - Regular training and/or workshops
   - Technological transfer coordination committees for regions

APPENDIX

GUIDELINES FOR WORKING GROUPS

In order to assist in the synthesis of working group discussions and the production of important recommendations, the Workshop Organizers request that Working Group Chairman structure their reports according to the framework laid out below.

PART ONE RESEARCH ISSUES IN WEST ASIA AND NORTH AFRICA

1) What are the major under-researched issues of relevance to the working group?

   (a)__________ [very short descriptions of one
   (b)__________ or two lines per topic]
   (c) etc.

2) What is the order of priority of the above issues?
   [List the above topics in order of priority]

3) Does the working group have any special "research strategy" recommendations for the above topics?

   [Research strategies include such issues as "on-farm research", "multi-disciplinary research", "long-term trials", "multi-factor trials", "regional information networks", "site characterization" plus any other issue you may identify as being important in enhancing the *quality* and *relevance* of research]

4) What constraints do National Agricultural Researchers face in conducting such research, and using recommended research strategies? Also indicate how they may be overcome.

PART TWO TRANSFER OF TECHNOLOGY AND FARMER ADOPTION

1) What factors limit or contribute to the adoption of technology related to the working group topic?

   (a) __________ [very short descriptions of one
   (b) __________ or two lines per topic]
   (c) etc.

2) What recommendations does the working group have for enhancing the transfer of technology?

(a) ———————— [these may be general comments or
(b) ———————— refer to specific factors identified
(c) etc. in (1) above]

3) In the opinion of the working group, what are the major constraints facing extension services in West Asia and North Africa?

(a) ———————— [very short descriptions of one
(b) ———————— or two lines per topic]
(c) etc.

4. What would be the most effective way of overcoming the above constraints?

(a) ———————— [these may be general comments or
(b) ———————— refer to specific factors identified
(c) etc. in (3) above]

List of Participants

Australia

T.G. Reeves,
Department of Agriculture and Rural Affairs,
P.O. Box 69,
Wangaratta,
Victoria 3677, Australia.

M.W. Perry,
Division of Plant Industry,
Department of Agriculture,
Baron-Hay Court,
South Perth 6151, Western Australia.

R. Amor,
Department of Agriculture and Rural Affairs,
176 Wellington Parade,
East Melbourne,
Victoria 3002,
Australia.

Afghanistan

Ghulam Mohammed,
Agricultural Research Institute,
The Ministry of Agriculture and Land Reform,
Kabul, Afghanistan.

Nuruddin Hariq,
Agricultural Research Institute,
The Ministry of Agriculture and Land Reform,
Kabul, Afghanistan.

Algeria

Mokhtar Zair,
ITGC Research Station,
Tiaret, Algeria.

Ali Zeghida,
ITGC,
El Khroub,
25100 Constantine, Algeria.

A. Hamadache,
ITGC,
El-Harrach, Algeria.

Chile

Pedro Del Canto Selgado,
INIA Est. Quilamapu,
Casella 426,
Chillan, Chile.

Cyprus

Ioannis Papastylianou,
Agricultural Research Institute,
Nicosia, Cyprus.

Egypt

Ismail A. Ahmed,
Field Crops Research Institute,
Agricultural Research Center,
Giza, Egypt.

Mohammed A. Shykhoun,
Field Crops Research Institute,
Agricultural Research Center,
Giza, Egypt.

Ahmed M. Rammah,
Field Crops Research Institute,
Agricultural Research Center,
Giza, Egypt.

England

Peter J. Gregory,
Department of Soil Science,
The University of Reading,
Reading RG1 5AQ,
England.

Current address:
Dryland Crops and Soils Research Unit,
Lab. for Rural Research,
Private Bag,
P.O. Wembley,
Wa 6014, Australia.

Ethiopia

Desta Beyene,
Soil and Water Management Department,
Agricultural Research Institute,
P.O. Box 2003,
Addis Ababa, Ethiopia.

Iran

S. Shahoei,
Soil and Water Research Institute,
North Karegar Ave.,
Tehran, Iran.

M.J. Mohammadi,
Soil and Water Research Institute,
North Karegar Ave.,
Tehran, Iran.

P. Abdolmalaki,
Soil and Water Research Institute,
North Karegar Ave.,
Tehran, Iran.

Italy

Charles Ofori,
Senior Officer, Soil Management,
FAO, Via delle Terme di Caracalla,
00100 Rome, Italy.

Jordan

Anwar Battikhi,
Soil and Irrigation Department,
Faculty of Agriculture,
University of Jordan,
Amman, Jordan.

Libya

Rafa Alazzabi,
c/o Dr. Taher Azzabi,
Director International Cooperation,
Libya Agriculture Center,
Tripoli, Libya.

M.S. Elsayah,
c/o Dr. Taher Azzabi,
Director International Cooperation,
Libya Agriculture Center,
Tripoli, Libya.

Morocco

A. Bouzza,
INRA,
P.O. Box 451,
Rabat, Morocco.

Hda El Baghati,
Direction de Production Vegetale,
Ministere de l'Agriculture et de la Reform
Agraire,
Rabat, Morocco.

F. Moussadeq,
Institut Agronomique et Veterinaire,
Hassan II,
Rabat Instituts, Morocco.

Nepal

Peter Hobbs,
CIMMYT,
P.O. Box 1336,
Kathmandu, Nepal.

Pakistan

B.R. Khan,
AZRI,
Brewery Road,
Quetta, Pakistan.

D. Rees,
ICARDA,
P.O. Box 362,
Quetta, Pakistan.

Sudan

D. Ahmed Dafalla,
Western Sudan Agricultural Research Project,
P.O. Box 125,
Khartoum North, Sudan.

F. Bin Zeid,
Director,
Agricultural Extension of Eastern Region,
Kassala, Sudan.

Saeed M. Farah,
Gezira Research Station,
Wad Medani, Sudan.

Syria

Elias Jabbour,
Director, Soils Directorate,
P.O. Box 113,
Douma, Syria.

Mazen Hami Naji,
Soils Directorate,
P.O. 113,
Douma, Syria.

Ali Shehadeh,
Directorate of Agricultural Scientific Research,
Damascus, Syria.

A. van Schoonhoven,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

P.J.M. Cooper,
FRMP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

Current address:
ICRAF
P.O.Box 30677
Nairobi, Kenya.

E. Acevedo,
CP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

Current address:
CIMMYT,
AP 6-641,
06600 Mexico DF,
Mexico.

M.A. Jones,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

M.J. Jones,
FRMP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

M. Pala,
FRMP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

Hazel C. Harris,
FRMP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

A.E. Osman,
PFLP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

Said Silim,
FLIP,
ICARDA,
P.O. Box 5466,
Aleppo, Syria.

Current address:

ICRISAT,
Patancheru P.O.,
AP 502 324, India.

Spain

Jorge de Juan-Aracil,
Estacion de Explotacion Agraria,
Jerez de la Frontera,
Cadiz, Spain.

Tunisia

Rhaoudha Khaldi,
INRAT,
Tunis, Tunisia.

Salah Khalfallah,
Ingenieur en Chef,
Direction Sols,
Tunis, Tunisia.

Azaiez Gharbi,
15 Rue 6486 Cite Romana,
Le Bardo 2000, Tunisia.

Turkey

Atakan Gunay,
Ministry of Agriculture, Forestry and Rural Affairs,
General Directorate of Project and Implementation,
Agricultural Research Department,
Bakanliklar/Ankara, Turkey.

Baydur Yilmaz,
Director,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Current address:
TMO Research Department
Ankara, Turkey

Mengu Guler,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Nedret Durutan,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Mehmet Karaca,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Abdulkadir Avcin,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Muzaffer Avci,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Hatice Eyuboglu,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Emel Karagullu,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Veli Bostanci,
TARM,
P.K. 226,
Ulus/Ankara, Turkey.

Fahri Altay,
Director,
P.K. 17,
Eskisehir, Turkey.

Mufit Kalayci,
Agricultural Research Institute,
P.K. 17,
Eskisehir, Turkey.

Visal Ozkan,
Agricultural Research Institute,
P.K. 17,
Eskisehir, Turkey.

Nazmi Ulgen,
Director,
Soil and Fertilizer Research Institute,
P.K. 54,
Yenimahalle/Ankara, Turkey.

Necdet Yurtsever,
Deputy Director,
Soil and Fertilizer Research Institute,
P.K. 54,
Yenimahalle/Ankara, Turkey.

Fikret Eyuboglu,
Soil and Fertilizer Research Institute,
P.K. 54,
Yenimahalle/Ankara, Turkey.

Orhan Dogan,
Director,
Soil and Water Research Center,
Lodumlu/Ankara, Turkey.

Hakan Dogan,
Agricultural Research Institute,
Erzurum, Turkey.

Nurettin Kayitmazbatir,
Bahri Dagdas Int. Cereal Research Institute,
Konya, Turkey.

Ekrem Kun,
A.U. Faculty of Agriculture,
Field Crops Department,
Diskapi/Ankara, Turkey.

Basri Halitligil,
Turkiye Atom Energi Kurumu,
Tarimsal Arastirma Md.,
Besevler/Ankara, Turkey.

M. Sefik Yesilsoy,
C.U. Faculty of Agriculture,
Cukurova University,
Balcali/Adana, Turkey.

Byrd Curtis,
CIMMYT,
P.K. 226,
Ulus/Ankara, Turkey.

USA

E.Floyd Bolton,
Crop Science Department,
Oregon State University,
Corvallis,
OR 97331, USA.

Dale Hicks,
University of Minnesota,
1991 Buford Circle,
209 Agronomy Building,
St. Paul,
MN 55108, USA.

R.I. Papendick,
USDA/ARS,
215 Johnson Hall,
Washington State University,
Pullman,
WA 99164-6421, USA.

James F. Parr,
USDA/ARS,
Beltsville,
Maryland 20705, USA.

Yemen

Abdulla Abdul-Rahman,
Agricultural Research Authority,
P.O. Box 5788,
Taiz, Yemen.

Mohmud Al Khowlani,
Agricultural Research Authority,
P.O. Box 5788,
Taiz, Yemen.

المركز الدولي للبحوث الزراعية في المناطق الجافة
ايكاردا
ص. ب. 5466 ، حلب ، سورية

INTERNATIONAL CENTER FOR AGRICULTURAL
RESEARCH IN THE DRY AREAS
ICARDA, P.O. Box 5466, Aleppo, Syria

ICARDA-247/500/Dec 1991