PN-ABD-006
62126

Agroecological Constraints to Crop Production in West Asia and North Africa, and Their Impact on Fertilizer Use

International Center for
Agricultural Research in the Dry Areas

and

International Fertilizer Development Center

Agroecological Constraints to Crop Production in West Asia and North Africa, and Their Impact on Fertilizer Use

by

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Presented at the

Workshop on Fertilizer Sector Development and Agricultural Production in Selected Countries of the Mediterranean, Middle East, and North Africa

held during

May 1-14, 1988, IFDC, Muscle Shoals, Alabama, U.S.A.

Library of Congress Cataloging-in-Publication Data

Workshop on Fertilizer Sector Development and Agricultural Production in Selected Countries of the Mediterranean, Middle East, and North Africa (1988 : Muscle Shoals, Ala.) Agroecological constraints to crop production in West Asia and North Africa, and their impact on fertilizer use.

(Paper series / International Fertilizer Development Center ; P-9)
Bibliography: p.
"International Center for Agricultural Research in the Dry Areas."
1. Dry farming—Middle East—Congresses. 2. Dry farming—Africa, North—Congresses. 3. Crops—Middle East—Ecology—Congresses. 4. Crops—Africa, North—Ecology—Congresses. 5. Fertilizers—Middle East—Congresses. 6. Fertilizers—Africa, North—Congresses. 7. Agricultural ecology—Middle East—Congresses. 8. Agricultural ecology—Africa, North—Congresses. I. Cooper, P. (Peter), 1944- . II. International Fertilizer Development Center. III. International Center for Agricultural Research in the Dry Areas. IV. Title. V. Series: Paper series (International Fertilizer Development Center); IFDC—P-9.
SB110.W67 1988 630.5'86'0956 89-15447
ISBN 0-88090-074-1

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Edited by E. N. Roth
Cover design by T. McGee and P. Thompson
Typesetting, Design, and Layout by P. F. Sandlin

IFDC publications are listed in *Publications of the International Fertilizer Development Center*, General Publication IFDC—G-1, which is available free of charge.

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Introduction

Rainfed farming systems in West Asia and North Africa have evolved over centuries in response to prevailing environmental conditions. Weather patterns have remained relatively unchanged, and farmers today face the same weather- and soil-induced constraints that early farmers faced. Likewise, current crops, cropping systems, and livestock production practices, which have been shaped by these constraints, are similar to those practiced for hundreds of years (Watson, 1974; White, 1963, 1970). In contrast, the socioeconomic environment, at both the farm and national level, has changed radically. Population increases, rural migration to urban centers, and agricultural policies favoring industrialization have resulted in greater production demands being placed on rainfed agricultural systems, which originally evolved with a purely subsistence orientation (Figure 1).

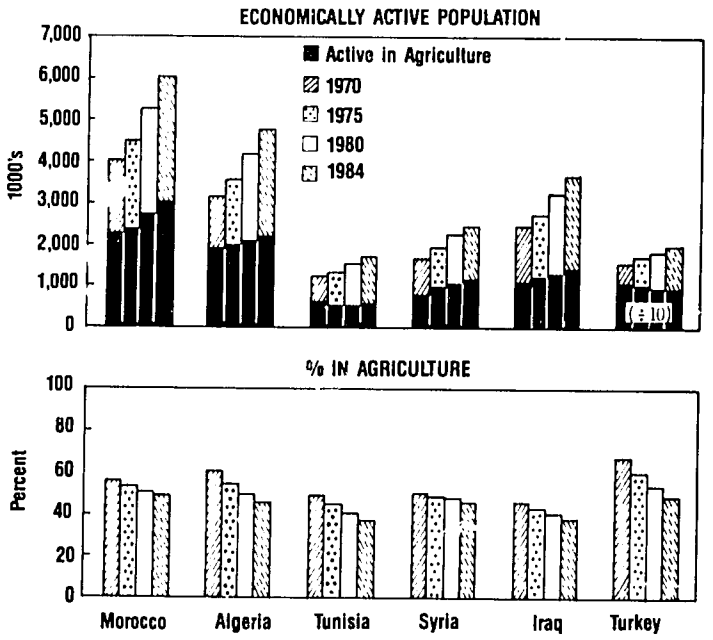


Figure 1. Economically Active Population in Selected Countries of West Asia and North Africa.

Land suitable for rainfed agriculture is finite and except in Sudan is currently all used for some sort of production. Yet in the immediate future (by the year 2000), substantial increases in regional food and feed demands are predicted (Table 1). To meet these demands, agriculture in West Asia and North Africa could respond in two principal ways. It is predicted that about 20% of the required increase in production is possible through increased cropping intensity (e.g., fewer fallows). Most of the remainder must come from higher yields per crop. Only 7% can come from increases in the area cultivated (FAO, 1987). Without the means and knowledge to achieve the required yield increases, farmers are responding by extending cultivation to more and more marginal land, and such fragile environments can rapidly become degraded.

Table 1. Actual and Predicted Demand for Major Agricultural Products in West Asia and North Africa.

	1983	2000
	(million tonnes)	
Wheat	69	105
Barley	19	37
Maize	18	25
Rice	11	18
Pulses[a]	4	6
Vegetable oils	5	9
Meat[b]	7	13
Milk	36	60
Sugar	12	22

a. Chickpea, lentil, and faba bean.
b. Beef, mutton, and poultry.
Source: FAO, 1987.

However, with the advent of modern farming techniques, the potential now exists for farmers to increase the productivity of their lands by overcoming many

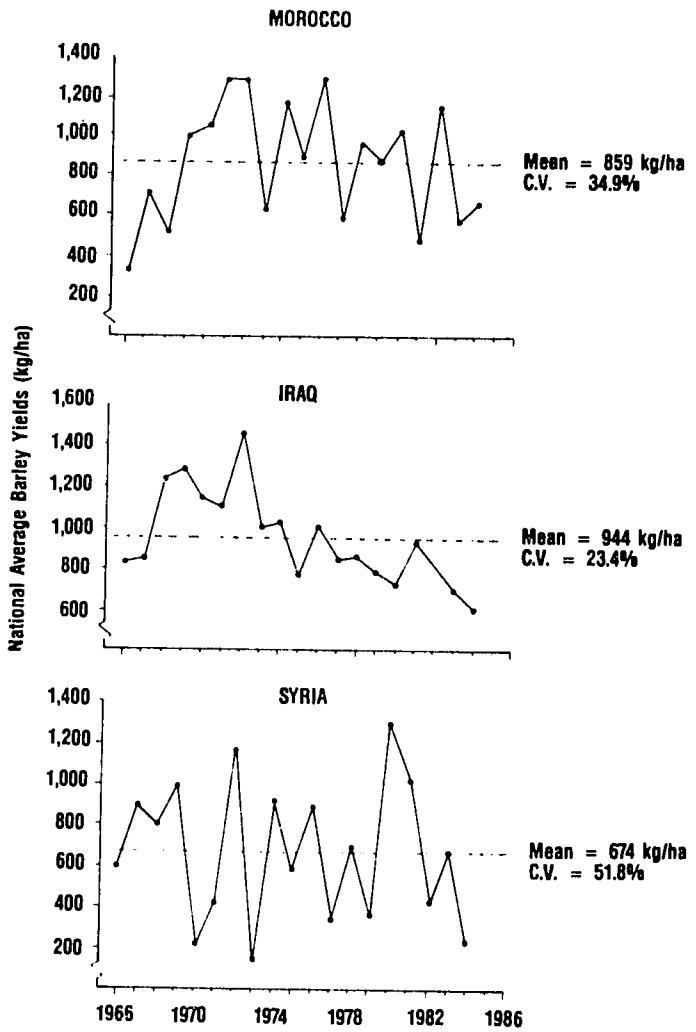
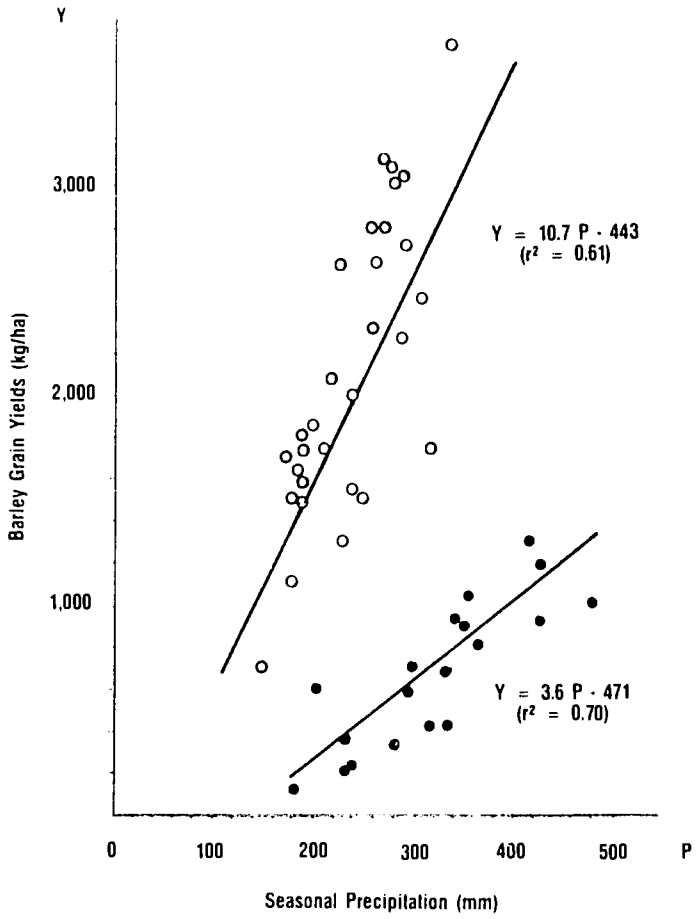


Figure 2. Yearly Variation in National Average Barley Yields in Morocco, Iraq, and Syria, 1966-84.

of the constraints (pests, diseases, poor soil fertility, primitive tillage implements, limited access to new crop species and genotypes) that have previously kept their yields low. *In this context, fertilizer has a proven potential to make a substantial and economic contribution.* Nevertheless, in the rainfed agricultural systems of West Asia and North Africa, a background of limited, variable, and often chronically deficient rainfall combined with large seasonal changes in air temperatures will always provide a major element of uncertainty and variability in actual crop production (see Figure 2). This interaction between rainfall amounts and the profitability of new technology is particularly evident in the case of fertilizer (Figure 3).



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In addition, fertilizer is a costly input at both national and farm levels, and in order to promote maximum benefit from its use, scientists are faced with the challenge of producing well-targeted recommendations that take into account the pronounced environmental variability.

In this paper we will describe some of the major characteristics of the region's climate and soils and indicate how these two interact to determine crop yield potentials. We will provide an overview of agriculture in the region, highlighting the general association between expected rainfall and the type of farming practices that have evolved. We will also point to the close integration of livestock (principally sheep) into these cropping systems and show how this association of crops and livestock can affect farmers' choices of new technologies. We will go on to describe the impact of important agroecological factors on fertilizer responses, and finally we will indicate areas of research that we believe should be of high priority in West Asia and North Africa.

Soils of the Region

Included among the diverse soils of the region are 21 of the major soil groups recognized in the FAO/UNESCO soil map of the world. However, just seven of those groups account for 86% of the 125 million ha 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 listed, 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 and 600 mm Seasonal Rainfall.

Soil Group[b]	Area (10^6 ha)[a]		
	North Africa	West Asia	Total
Vertisols (Vertisols)	1.2	4.1	5.3
Xerosols (Aridisols)	5.6	22.0	27.6
Cambisols (Inceptisols)	7.0	10.2	17.2
Luvisols (Alfisols)	3.8	7.7	11.5
Yermosols (Aridisols)	3.1	6.3	9.4
Lithosols (Lithic subgroups)	5.4	20.6	26.0
Regosols (Orthents, Psamments)	2.4	7.9	10.3

a. Area data from Kassam, 1981.
b. Equivalents in USDA *Soil Taxonomy* are given in parentheses.

Calcareous soils, formed from limestone residuum, predominate. They vary widely in texture, depth, slope, and stoniness. Medium to heavy textured soils are common, and many of these exhibit serious cracking when dry, resulting in root shearing and moisture loss through evaporation from depth.

Calcium carbonate plays an important role because of its direct effect on soil pH. High pH decreases the availability of micronutrients 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 yielding irrigated systems (El-Fauly, 1983; Haddad et al., 1979).

Calcium carbonate also has an important effect on the availability of phosphate 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 has not been applied. Crop responses to applied phosphate are widespread (Harmsen, 1984; SMAAR/ICARDA, 1985, 1986, 1987).

Organic matter levels are generally low, and in some soils, particularly silts, structural stability is poor. In such soils surface capping (crusting) by rainfall can cause serious problems in seedling emergence and surface run-off (Plate 1). Organic nitrogen levels are also low, and nitrogen deficiency is widespread. Responses to nitrogen fertilizers are therefore also common (Keulen, 1977; Anderson, 1985).

Losses of nitrogen from the rooting zone through deep leaching seldom occur because the wetting front does not usually penetrate beyond 1.50 m depth except in very wet locations or in light-textured soils. Nevertheless, residual responses to applied nitrogen appear to be rare. Significant losses of nitrogen as volatilized ammonia can occur where urea is top-dressed (Plate 2). Temperature and moisture conditions at the time are important in determining the extent of such losses (Moneim, 1985; Vlek et al., 1981).

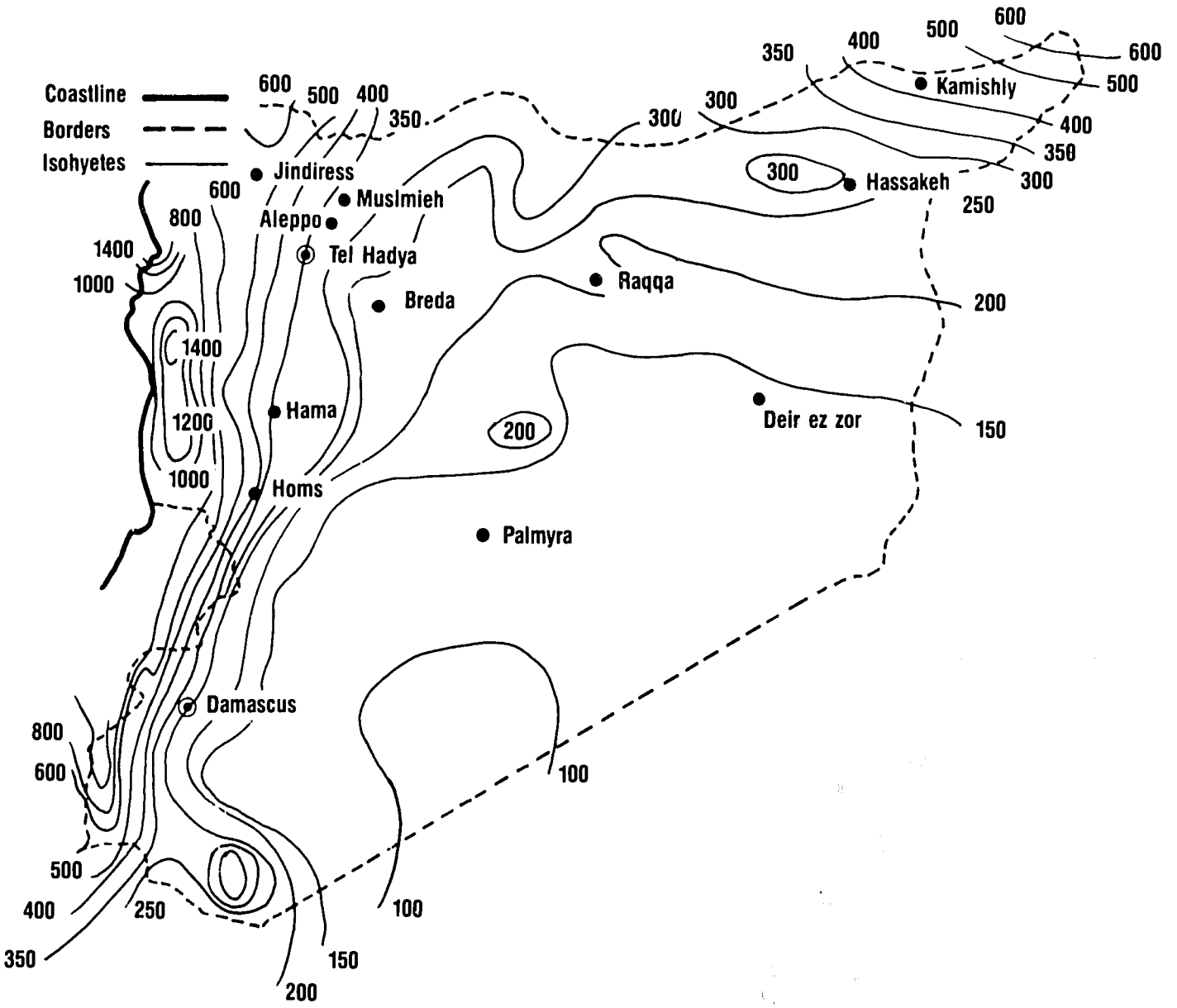


Figure 4. Rainfall Isohyet Map of Syria.

Climatic Characteristics

In the Mediterranean region, the rainy season begins in about October and ends in May or June. Most rain occurs during the cool or cold winter months (December-January-February). At the beginning and end of the season, rains are less reliable. Summers are hot and arid.

The quantity of rainfall is determined by proximity to the coast or to significant topographical features such as mountains. There are steep gradients in precipitation across short distances, and changes as great as 3-4 mm/km are common; the Syrian isohyet map illustrates this fact (Figure 4). In general, coastal areas are wettest, and they support intensive horticulture and agriculture. Declining rainfall with distance inland leads to systems dominated first by wheat then by barley, before arable land gives way to large expanses of steppe grazing lands and desert in the interior of land masses. These systems are described in more detail in subsequent sections.

Rainfall varies not only in space but also in time. Large differences are recorded in both the total amount (Figure 5a) and its distribution through the season (Figure 5b). The length of the rainfall season is essentially the same at three sites across a rainfall transect in Northwest Syria (Figure 6a). There is, however, a progressive reduction in the probability of rain falling on any one day as the total rainfall decreases. This is especially so in January, February, and March, as reflected in the number of wet days during the season (Figure 6a and b). Estimation of cumulative probability distribution functions (Figure 6c) provides a way to estimate and illustrate the frequency of occurrence of significant events, such as droughts.

Variation in temperatures in space and time is also important. Winter months (December-January-

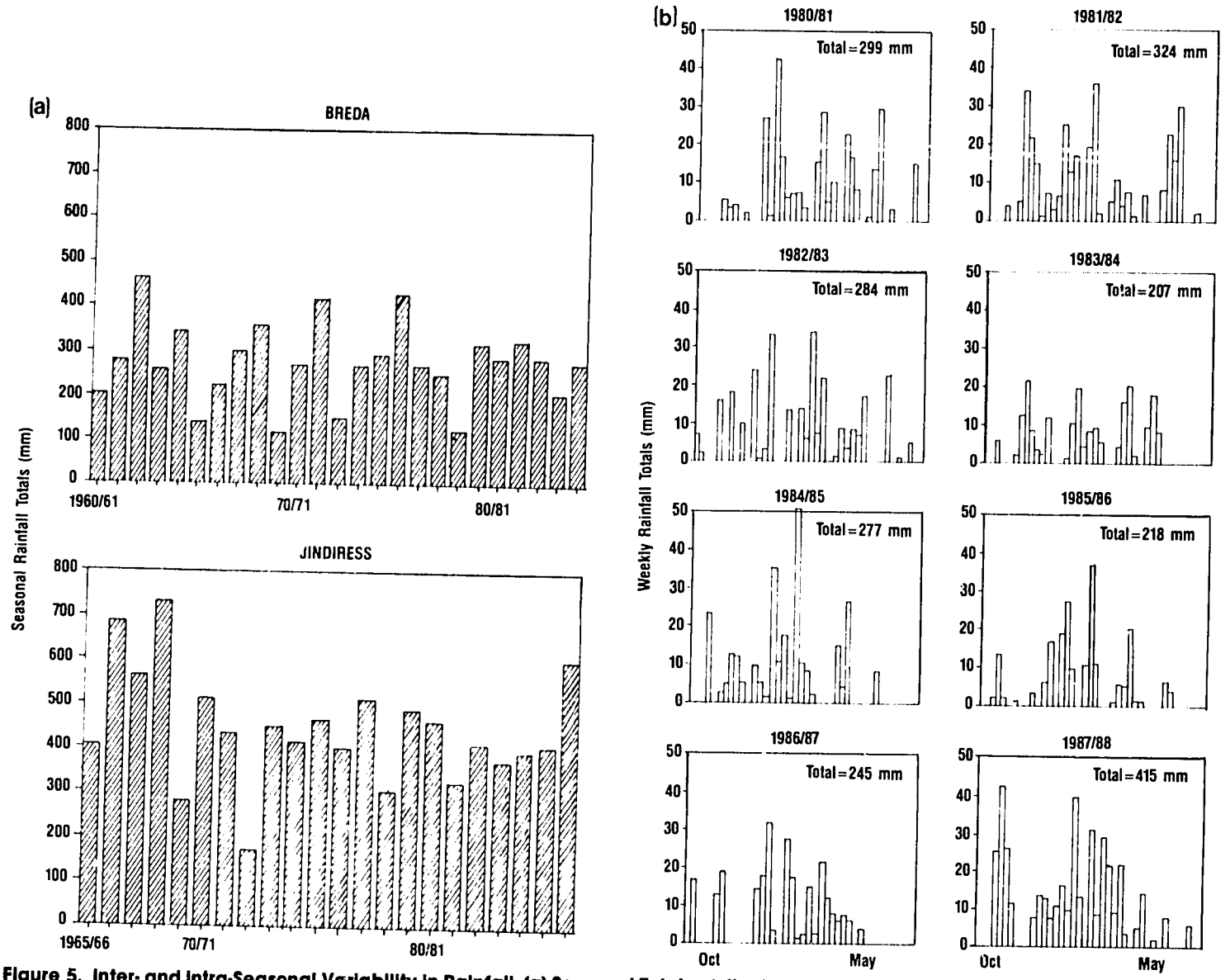


Figure 5. Inter- and Intra-Seasonal Variability in Rainfall: (a) Seasonal Totals at Jindiress and Breda, N.W. Syria; (b) Weekly Totals for Eight Seasons at Breda.

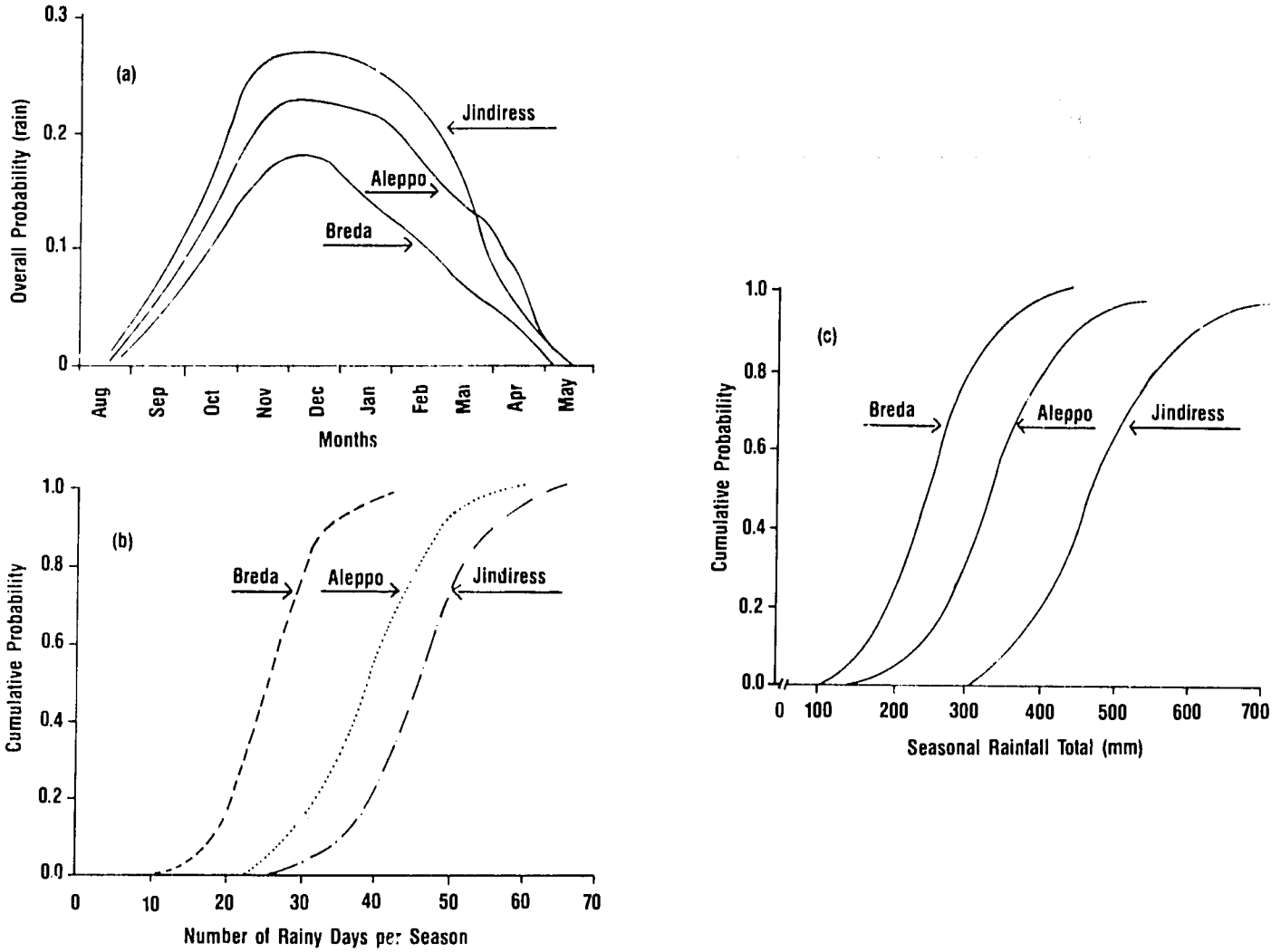


Figure 6. Variability Associated With Rainfall at Three Sites in N.W. Syria; (a) Seasonal Distribution of Probability of Rain Events; (b) Cumulative Probability of Seasonal Number of Rain Days; and (c) Cumulative Probability of Seasonal Rainfall Totals.

February) are cool or cold, and temperatures are suboptimal for plant growth. A strong continental influence causes winters in West Asia to be quite cold, and plateau areas experience severe frost and prolonged snow cover. Milder conditions prevail in North Africa, except for small areas in the Atlas Mountains (Table 3).

Table 3. Mean Monthly Maximum and Minimum Temperatures During the Growing Season for Sites with Different Elevations in West Asia and North Africa

Location	Elevation (m)	Maximum Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Minimum Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
West Asia																			
Tabriz, Iran	1,362	13.3	6.9	3.3	10.3	15.0	23.6	28.8	32.3	33.9	2.0	-3.4	-4.9	-5.5	-0.1	3.6	10.3	14.7	18.6
Diyarbakir, Turkey	677	16.7	9.3	6.5	9.1	14.1	20.4	26.5	33.3	38.2	4.3	-0.4	-2.6	-1.1	1.8	6.7	10.9	15.8	21.5
Aleppo, Syria	395	19.1	12.1	10.4	12.8	16.6	22.4	28.6	33.8	36.4	6.2	3.6	1.8	2.4	4.7	8.4	12.6	17.4	20.0
North Africa																			
Ifrane, Morocco	1,640	14.0	9.0	9.0	11.0	13.0	16.0	18.0	24.0	31.0	1.0	-3.0	-5.0	-3.0	-1.0	3.0	4.0	9.0	12.0
Setif, Algeria	1,080	14.0	10.0	9.0	11.0	14.0	18.0	22.0	28.0	33.0	1.0	1.0	1.0	3.0	6.0	9.0	13.0	17.0	17.0
Marrakech, Morocco	460	21.0	18.0	18.0	20.0	22.0	24.0	28.0	31.0	36.0	10.0	7.0	7.0	8.0	10.0	12.0	15.0	17.0	20.0

Source: World Survey of Climatology, H. E. Landsberg (Ed.), Vols. 9 and 10.

In the spring, temperatures rise rapidly; super-optimal temperatures and large vapor pressure deficits (VPD) occur widely in late spring and early summer when crops are maturing.

As with rainfall, temperatures vary from year to year, causing the length of the growing season to vary by as much as 3 to 4 weeks. Extreme low temperatures due to radiation frosts are an unpredictable hazard in much of the region's lowlands.

During the winter when temperatures and vapor pressure deficits are low, rainfall usually exceeds the water use of crops, and water accumulates in the soil profile. As temperatures rise in the spring and crop canopies develop, water use becomes greater than the supply from rain. Crops then depend on stored soil water to finish growth and almost always are stressed before harvest.

The amount of stored water available at this time depends not only on total seasonal rainfall and its distribution but also on soil type and depth. Soil depth is especially important because even in a wet year not enough water can be stored in shallow soils to supply the needs of crops. Temperatures and moisture availability interact to determine the length of the grain filling period and play an important role in yield formation (Figure 7).

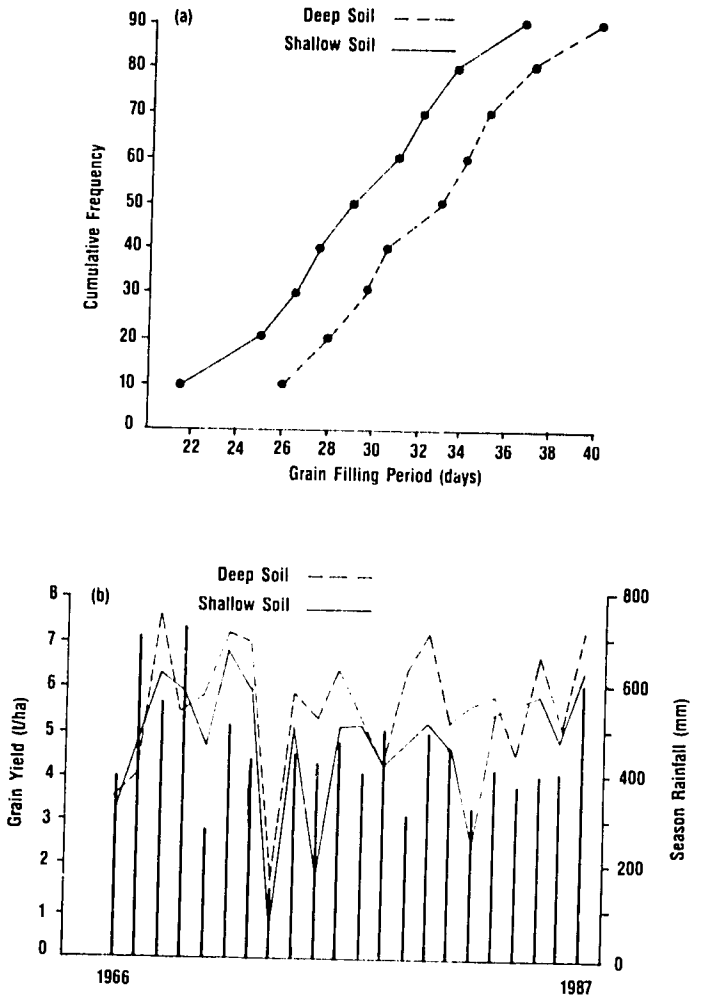


Figure 7. Computer Simulation (SIMTAG Wheat Growth Model) of the Effect of Soil Depth and Rainfall on (a) the Length of the Grain Filling Period and (b) Grain Yield of Wheat (var. Mexipak) at Jindiress, N.W. Syria, 1966-87. (Vertical bars show seasonal rainfall).

Farming Systems of the Region

Four broadly defined agricultural systems have evolved in response to the prevailing climatic and soil conditions (Plate 3).

1. Steppeland and native pastures.
2. Systems dominated by livestock and barley production.
3. Systems dominated by wheat, food legume, and summer crop production.
4. Irrigated systems.

Steppeland and Native Pastures—Native pasture is used primarily for the grazing of small ruminants.

Where rainfall exceeds 250 mm, it includes land that is too steep or too stony, or where the soil is too shallow for arable agriculture (Plate 4). In West Asia such pastures usually occur on the foothills and slopes of mountain ranges, while in North Africa they may also be found on sandy soils. The vegetation is dominated by annual grasses, legumes, and herbs, and the perennial vegetation is severely degraded.

Where rainfall is below 200 mm, native pastures cover most of the land surface although at the wetter margin barley cultivation is encroaching. Communal ownership of land is increasing, replacing the old tribal control which broke down earlier this century. Restrictions to open access may exist, especially in high-rainfall areas. Originally a shrub steppe or even savanna woodland, the land is now characterized by ephemeral vegetation of very low productivity (Plate 5). Soil chemical fertility is usually higher than in arable lands that have been depleted by many years of cultivation and cropping.

Stocking rates are difficult to estimate but probably reach 1 sheep/ha in areas of higher rainfall. Native pastures rarely support livestock on a year-round basis and are grazed mainly in winter (low-rainfall areas) or spring (high-rainfall areas). For that reason, the use of native pastures is to a greater or lesser extent integrated with the wheat-based and barley/livestock systems.

Barley/Livestock Farming Systems—Adjacent to the dry steppe (between approximately 200 and 350 mm rainfall), the production of livestock (principally sheep and goats) continues to be the dominant enterprise and provides the bulk of farmers' income

through sales of dairy products, meat, and wool. Barley, by far the most common crop, is grown without inputs. Both grain and straw are used as livestock feed. Throughout the region, a barley/fallow rotation still predominates, but increasingly, fallow is being regarded by farmers as an inefficient use of land. With greater availability of mechanization for tillage operations, continuous barley production is becoming more common despite being detrimental to yield (Plate 6). Such yield reductions are associated with a range of factors including reduced moisture supply, lower soil nitrogen availability, and a buildup of root pathogens.

Native pastures form an important component of the annual feeding cycle of livestock in the winter and spring; smaller flocks use local grazing areas and weedy fallows, and large flocks use the steppeland. Flocks are mobile and in summer, after harvest, graze crop residues (Plate 7). In dry years they may be moved to the higher rainfall, wheat-based systems, and to irrigated areas where they graze cereal stubbles and other crop residues. This grazing may be permitted through leasing arrangements with local farmers, or it may be a right of the transhumant population in the existing social system.

Potential production in the barley/livestock systems is lower and more variable than in the wheat-based systems. Few national governments have developed policies that favor the introduction of improved technology into these c. r areas; yet throughout the region, urbanization and rising incomes are leading to an increased demand for the livestock products they generate.

Because of the production risks inherent in the environment and the lack of available technology, few farmers are prepared to invest in costly inputs such as fertilizer. Faced with increased density of rural population and a national demand for more livestock products, farmers have responded by cultivating more and more marginal land for barley and overgrazing the natural pastures. Now these factors severely threaten the natural resource base. Many farmers are forced to seek off-farm employment to supplement and secure their income.

Wheat-Based Systems—In the higher rainfall areas (between approximately 350 and 600 mm average seasonal rainfall), the main crop is wheat. Bread wheat predominates at the wetter end of this range, but durum wheat forms the basic staple at the drier end. A wheat/fallow rotation is common, but in wetter areas and on good deep soils wheat is grown in rotation with food legumes and summer crops such as melon, maize, sesame, sunflower, and cotton. Among the legumes, chick-pea predominates in wetter areas and lentil in drier ones. Tree crops are often an important source of income (Plate 8). On smaller farms, many farmers own both sheep and dairy cattle; on such farms some barley is grown, and both grain and straw are used as feed, together with other crop residues such as wheat stubble and lentil straw. Local native pastures on hilly terrain and weeds and volunteer cereals on fallow land are grazed as well. Where local water supplies exist (wells, seasonally filled dams or rivers), supplemental irrigation of both winter and summer crops is profitable c d is becoming increasingly common (Plate 9).

Potential crop production is high in the wheat-based systems, and farmers are financially more secure. National Agricultural Research Systems (NARS) have allocated most of their research and development resources to these areas and have in many cases been successful in developing improved technology, supported by policies that have encouraged rapid adoption by farmers. In particular, nitrogen and phosphate fertilizers are increasingly being used on wheat, food legumes, summer crops, and orchards.

Irrigated Farming Systems—In the driest regions, with annual rainfall below 150 mm, farming is possible only under irrigation using available surface water or groundwater. The main examples occur along the Nile River in northern Sudan and Egypt, along the Euphrates in Syria and Iraq, along the Jordan River, and in Saudi Arabia. Less common is cultivation based on water harvesting and wadi farming. Examples are found in the Yemen Arab Republic, northwest Egypt, and Baluchistan Province of Pakistan. Associated with irrigated farming systems is the extensive grazing of native pastures by camels, goats, sheep, and cattle, integrated with the seasonal use of the residues from irrigated crops.

Irrigation alleviates the major constraint of rainfed farming, a low and variable moisture supply. It is not surprising, therefore, that high levels of inputs, especially fertilizer, are almost universally used by farmers who practice irrigation. Wheat is a major crop, but cotton and other cash crops (sugarcane and sugar beets), and berseem clover in Egypt, can be more important to farmers' incomes.

Substantial research has facilitated, and agricultural policies encouraged, the adoption of improved production practices and the resultant achievement of high and stable yields. These high yields will, however, be sustainable only as long as proper attention is paid to irrigation scheduling and drainage. In many parts of West Asia and North Africa, salinity is increasingly causing severe problems.

There is considerable interdependence between irrigated and rainfed farming systems. Crop residues from irrigated systems are frequently used as supplemental feed for livestock from rainfed systems. Transfer of feedstuffs between the systems may be subsidized.

Agroecological Factors Affecting Fertilizer Response

Water Use Efficiency and Fertilizer Use

In the rainfed farming systems, it is important that whatever water is available be used as efficiently as possible. In such situations, the concept of water use efficiency (WUE) is a useful guide to ways of improving the management of crops. It expresses production in terms of yield per hectare per millimeter of available water, and for best returns farmers must seek ways to maximize it.

Cooper (1983) defines it as

$$WUE = \frac{TE}{(1 + Es/T)} \text{ (kg/ha/mm)} \qquad [1]$$

where

TE is the seasonal average transpiration efficiency of the crop (kg/ha/mm),
Es is the amount of water lost as evaporation from the soil underneath the crop (mm), and
T is the amount of water transpired by the crop (mm).

Moreover, it can be shown that the seasonal transpiration efficiency of the crop is inversely related to the average vapor pressure deficit of the air during crop growth (Bierhuizen and Slatyer, 1965). Thus:

$$WUE = \frac{k}{VPD\ (1 + Es/T)} \text{(kg/ha/mm)} \qquad [2]$$

where k is a crop constant.

Crops grown in humid regions, where the VPD is much lower, will always achieve greater water use efficiency.

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 4), meaning that water is used much more efficiently when nutrient deficiencies are corrected.

This interaction is largely due to more rapid growth and canopy development during the winter period (Plate 10). 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 (Figure 8). In other words, fertilizer reduces the ratio Es/T and thus leads to greater WUE (Equation 2).

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 2 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 2).

Fertilizer also enhances root growth (Cooper et al., 1987) and so may increase a crop's ability to extract moisture during the spring and early summer months when it depends entirely on what is stored in the soil (Figure 9). The extent to which such enhanced extraction is possible will depend on the amount and distribution of seasonal rainfall.

Table 4. 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	O	NP	O	NP	O	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

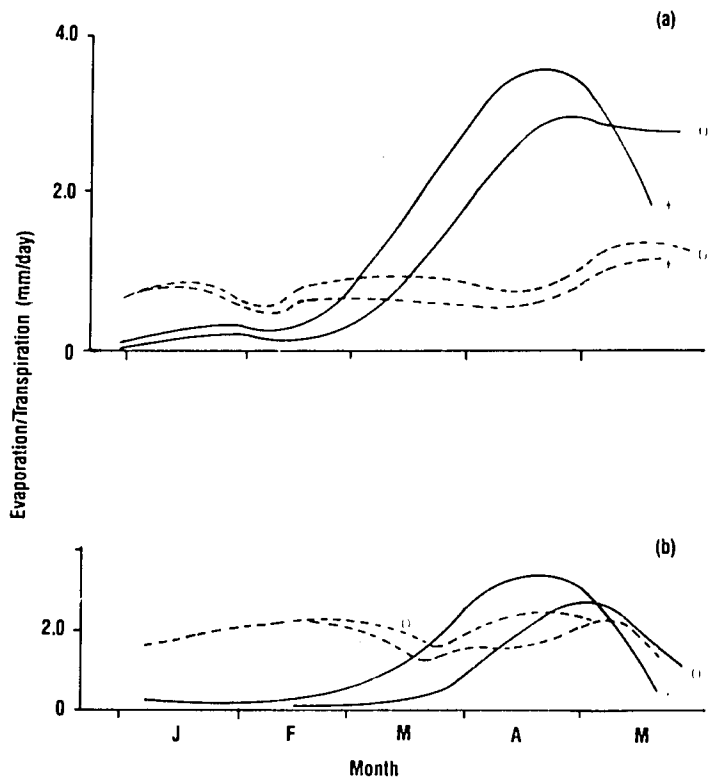


Figure 8. Seasonal Pattern of Evaporation From Soil (---) and Crop Transpiration (—) Under Barley (cv. Beecher) in the Presence (+) and Absence (o) of Fertilizer at (a) Jindiress and (b) Breda in N.W. Syria, 1983.

Plate 1
Poor structural stability of silty soils with a low organic matter content can lead to surface crusting, rainfall runoff, and restricted seedling emergence. Such soils are widespread in West Asia and North Africa.

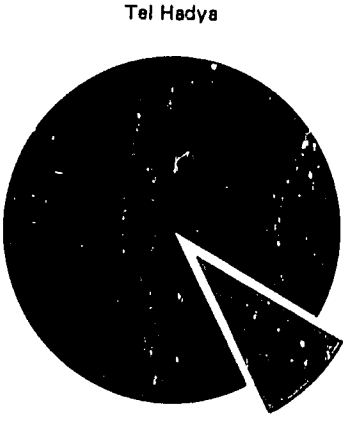


Plate 2
Nitrogen recovery from urea fertilizer trials on wheat at two locations in Syria, 1984/85 (Source: Moneim, 1985).

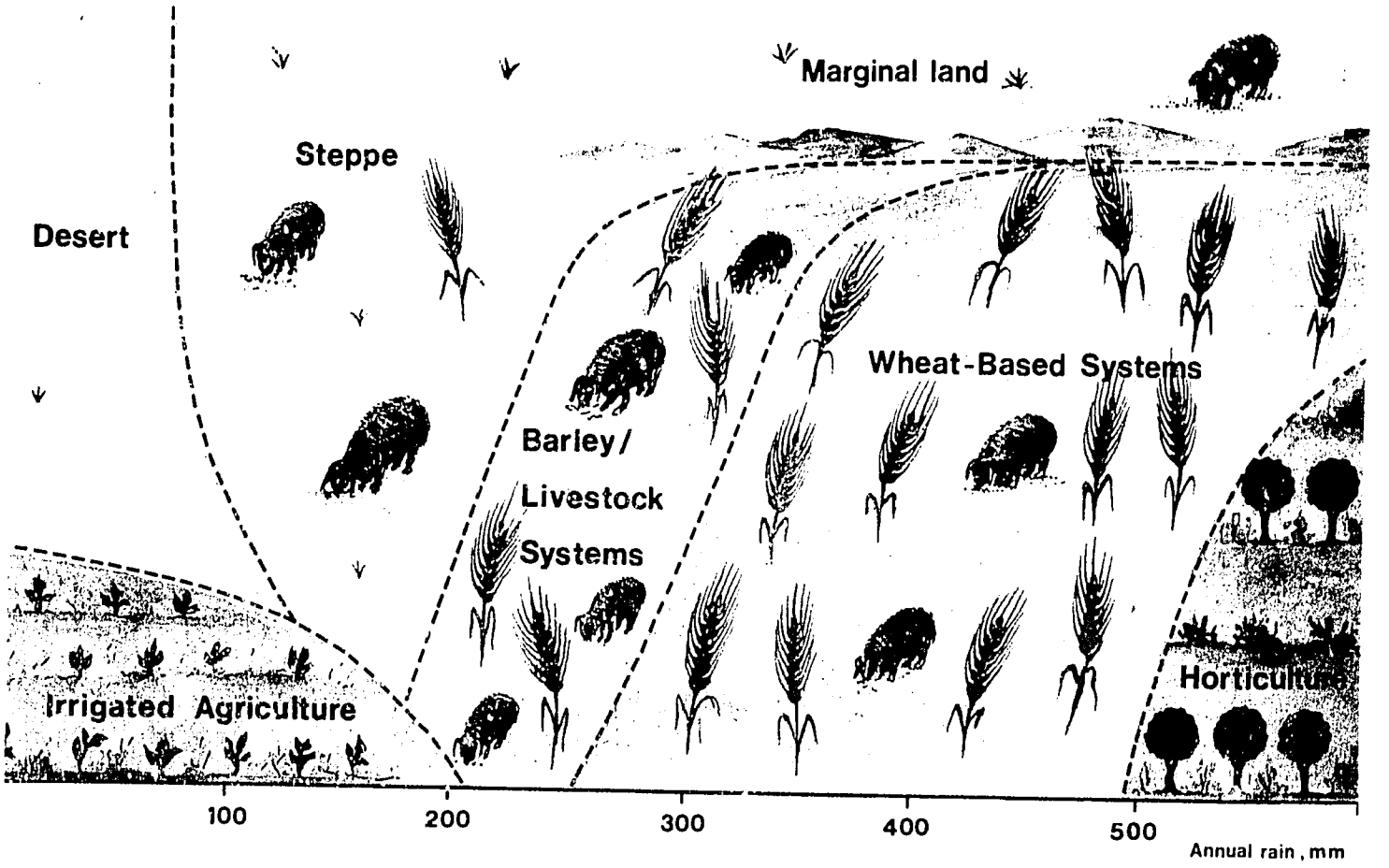


Plate 3
Broadly defined farming systems in West Asia and North Africa are associated with long-term average seasonal rainfall.

Plate 4
Marginal grazing areas with shallow, rocky, and steeply sloping soils are an important component of the annual livestock feeding cycle throughout the farming systems of West Asia and North Africa.

Plate 5
In the very dry areas (<200 mm rainfall/season), native steppeland has become severely degraded through overgrazing.

Plate 6
In barley-livestock farming systems, farmers are extending cultivation onto marginal soils (background), and the traditional fallow is being replaced by continuous barley production (foreground).

Plate 7
Cereal stubbles and other crop residues are the principal source of feed for livestock during the summer and early autumn months.

Plate 8
Tree crops, such as olives, are an important source of income for many farmers in the wheat-based farming systems.

Plate 9
When irrigation water is available, farmers frequently apply it to winter-sown crops, such as wheat, to supplement rainfall. Supplemental irrigation greatly increases and stabilizes crop yields.

Plate 10
Phosphate fertilizer application to the plot on the left promoted vigorous early growth of barley and rapid ground cover compared with the control on the right. Soil evaporation losses were reduced and crop transpiration increased.

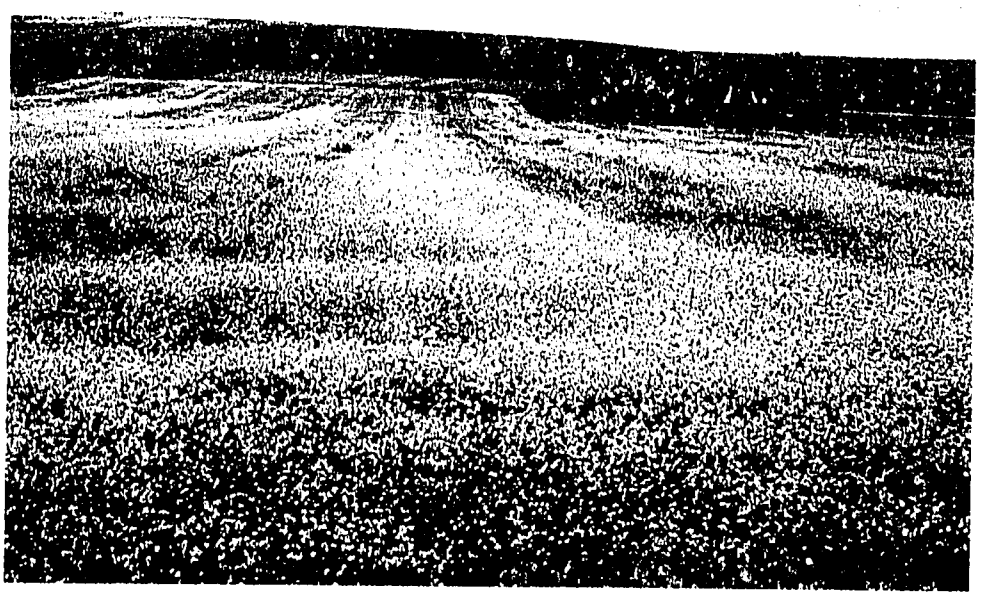


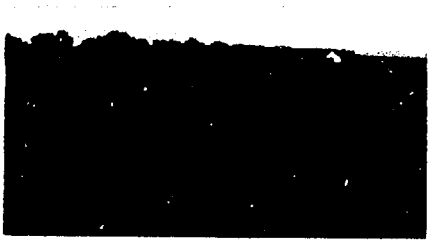
Plate 11
Weeds (principally *Sinapis arvensis*) posed a serious problem in a farmer's lentil field near Aleppo, Syria (foreground), whereas the use of a chemical herbicide has resulted in an almost weed-free crop of wheat (background).

Plate 12
Weed control and nitrogen fertilizer effects on a wheat crop in N.W. Syria.

Location: Jindiress, Syria 1983 Crop: Bread Wheat (var Mexipak)

Soil: Chromic Vertisol Rainfall: 417 mm

+N -WC	+N +WC	-N -WC	+N -WC



An application of "Bromoxynil Plus" in February gave good control of weeds in the plot on the right.

Without weed control, 100 kg/ha of N-fertilizer trebled weed dry matter production in the plot on the right

Grain Yield Responses of Wheat to 100 kg/ha N with and without Weed Control (t/ha)

	N_o	N_{100}
WC-	1.47	1.32
WC+	1.98	2.65

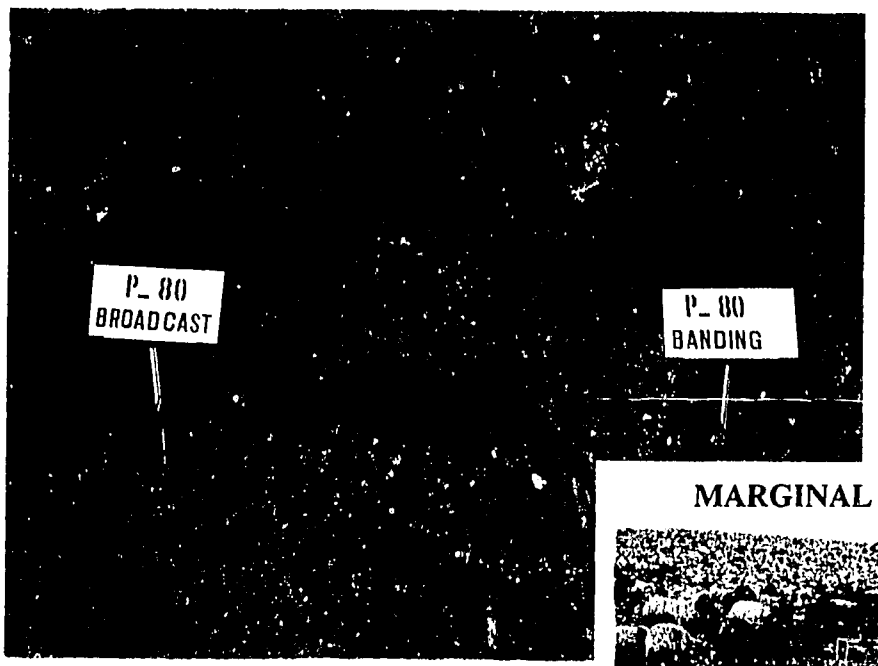


Plate 13
Precision placement of 80 kg P_2O_5/ha with wheat seed resulted in much more vigorous early growth in the plot on the right compared with the same amount broadcast and incorporated in the soil prior to seeding in the plot on the left.

MARGINAL GRAZING LAND IMPROVEMENT

Plate 14
Phosphate fertilizer application to natural pastures on marginal grazing areas results in an increase in the plant population and yield of native legume species.

	kg P_2O_5/ha applied			
	0	25	60	LSD (0.05)
Seed yield of legume population (kg/ha)	21	68	99	22.0

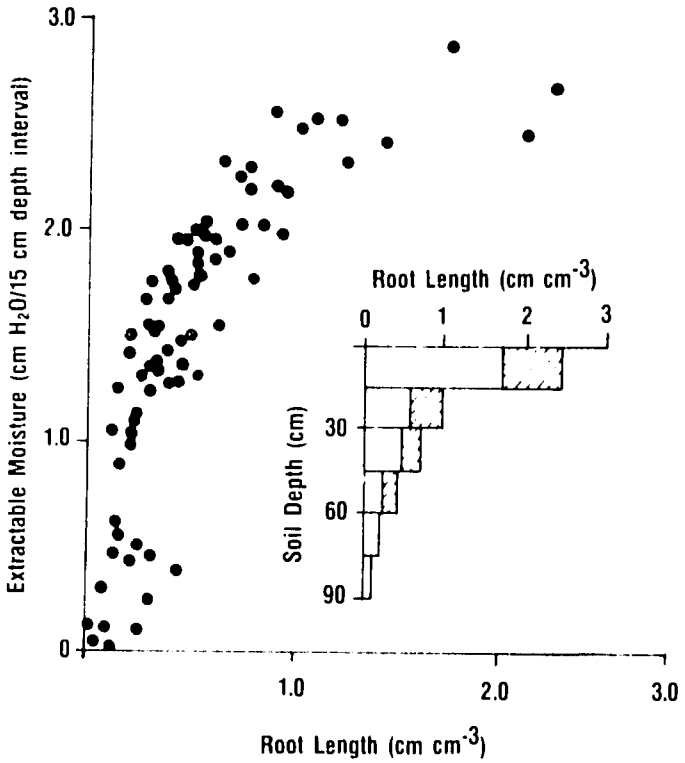
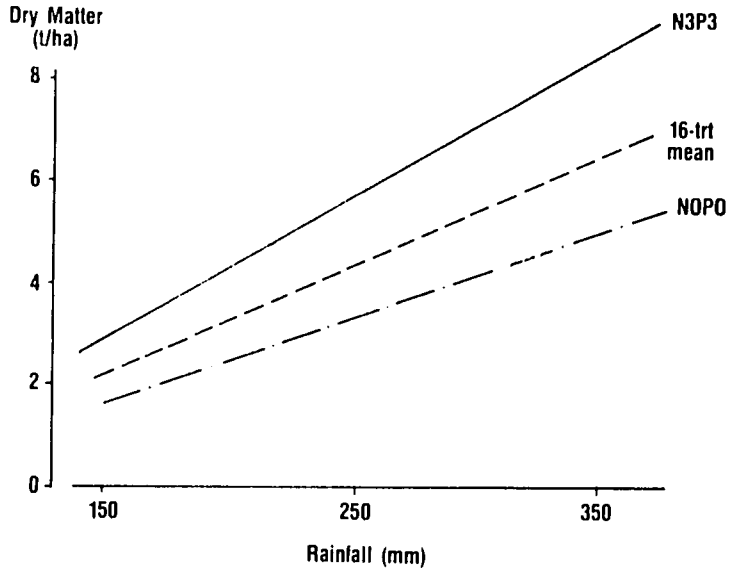


Figure 9. The Relationship Between Root Length Density of Barley and Plant Extractable Soil Moisture in Discrete Soil Layers. Inset Figure Illustrates the Fertilizer-Induced Increase (shaded area) in Root Length Density.



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

Figure 10. Regressions of Barley Dry-Matter Response to Seasonal Rainfall Under Different Fertilizer Regimes From 32 On-Farm Trials in Syria (SMAAR/ICARDA 1985, 1986).

Rainfall Amounts and Fertilizer Responses

Crops respond to improved nutrition, but the response is governed by the availability of water. In absolute terms, responses to balanced fertilizer applications are greatest at higher rainfall (Figure 10). The size of the response at any level of rainfall depends upon the amount of fertilizer applied, the crop, rainfall distribution, and soil type and depth. Nonetheless our data show that, when severe nutrient deficiencies exist, fertilization can increase yields even where rainfall is very low.

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.

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 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 (Figure 11), showing that there is always a yield response to balanced fertilizer application, indicate that the risk will be low, and adoption by farmers appears to be feasible. The residual effects of fertilizer, discussed in a later section, further improve the prospects for a good financial return.

Soil Fertility Levels and Fertilizer Responses

The availability of nutrients in the soil at the time of sowing is highly variable, particularly in the case of nitrogen and phosphorus. Many factors are associated with this variability, and some will be discussed in more detail later.

Clearly, the levels of available nutrients initially present in the soil determine the amounts of additional nutrients that are required from fertilizer application. Farmers would benefit greatly from knowing the fertility status of their soils before sowing because they could then adjust their fertilizer rates accordingly. Soil testing for available P and N is commonly used for this purpose in many parts of the world but is rare in West Asia and North Africa.

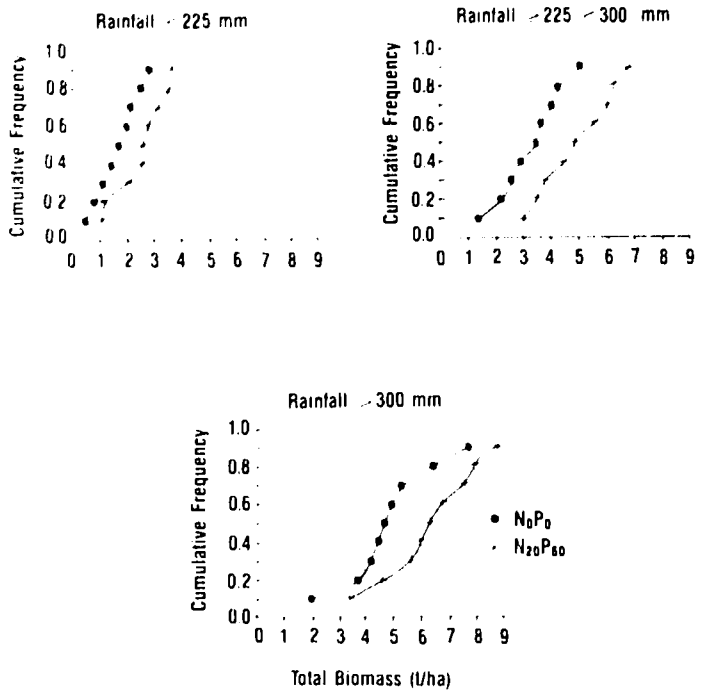


Figure 11. Cumulative Frequency Distribution of Total Biomass of Barley as Affected by Balanced Fertilizer Applications and Rainfall Amounts. Data Derived From 75 On-Farm Trials (SMAAR/ICARDA 1985,1986,1987, 1988).

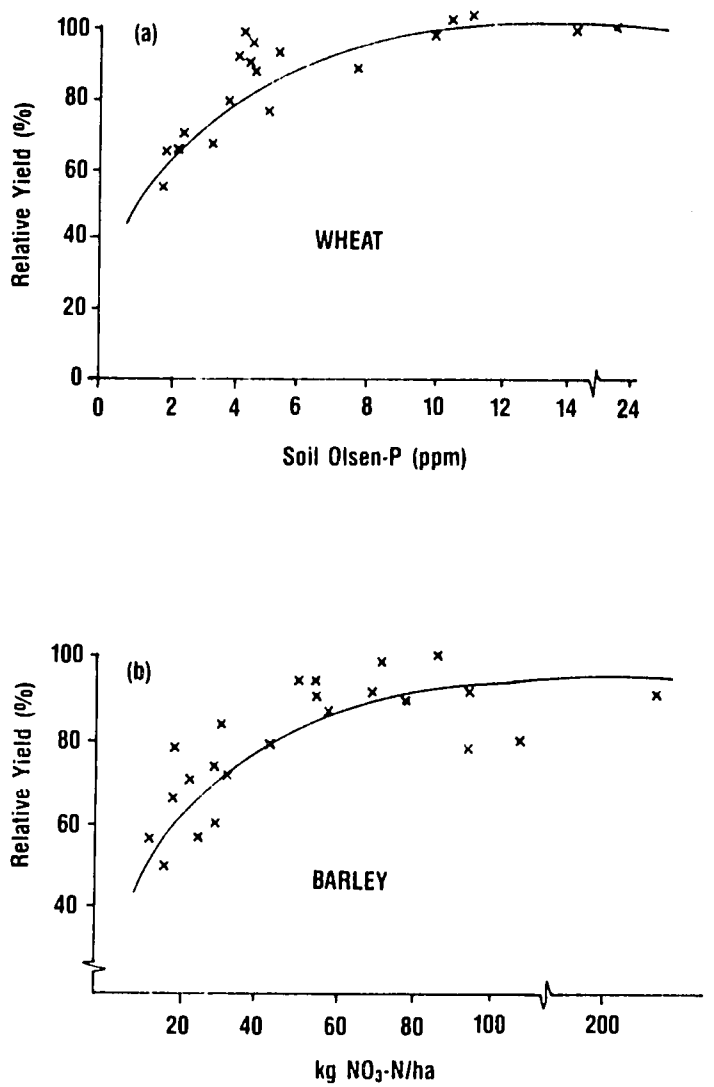


Figure 12. Relative Dry-Matter Production (% of estimated maximum) of Cereal Crops as Related to (a) Olsen-P Content at Sowing in the 0-20 cm Soil Depth Interval and (b) Nitrate-Nitrogen Content at Sowing in the 0-60 cm Soil Depth Interval.

Available P in calcareous soils can be determined through the Olsen extraction procedure, and there is a good relationship between the levels of available P determined by this method and crop responses to P fertilizer (Figure 12a). Critical levels of available P can be determined above which economic yield responses are unlikely.

Attempts have often been made to estimate nitrogen availability from the amount of organic N in the soil, but the predictive value of this technique is poor. However, the use of incubation methods appears promising. In recent trials across 40 sites in northern Syria, the linear correlation coefficient of grain yield on mineralization potential improved from 0.36 to 0.71 if the calculation was limited to sites with low initial levels of soil mineral-N.

Nitrate-nitrogen (or total mineral-N) is a useful indicator, and critical levels, similar to those for available P, can be determined (Figure 12b).

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. The interaction between these responses and the level of available nutrients in the soil differs for nitrogen and phosphate fertilizer. Figures 13 and 14 are derived from data from over 50 on-farm trials conducted in cooperation with the Syrian Soils Directorate (SMAAR/ICARDA, 1985, 1986, 1987). Figure 13a illustrates that when rainfall is greater than a certain amount, which is soil fertility dependent, the increase in yield due to 60 kg P_2O_5/ha starts to level off and subsequently declines. With nitrogen, however, this decline is not observed (Figure 13b). 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 (Figure 14a and 14b).

These results confirm the wider observation that, in West Asia and North Africa, responses to nitrogen are

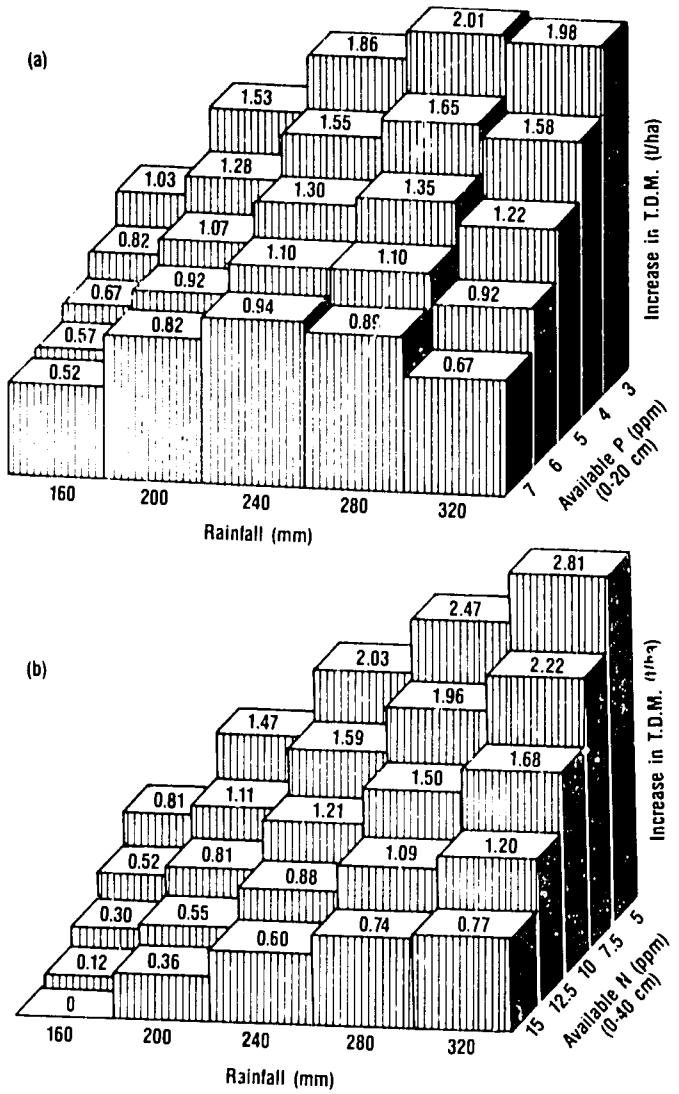


Figure 13. The Effect of Rainfall and Available Soil Nutrients on the Increase in Total Dry-Matter Production (T.D.M.) Resulting From (a) 60 kg P_2O_5/ha and (b) 40 kg N/ha.

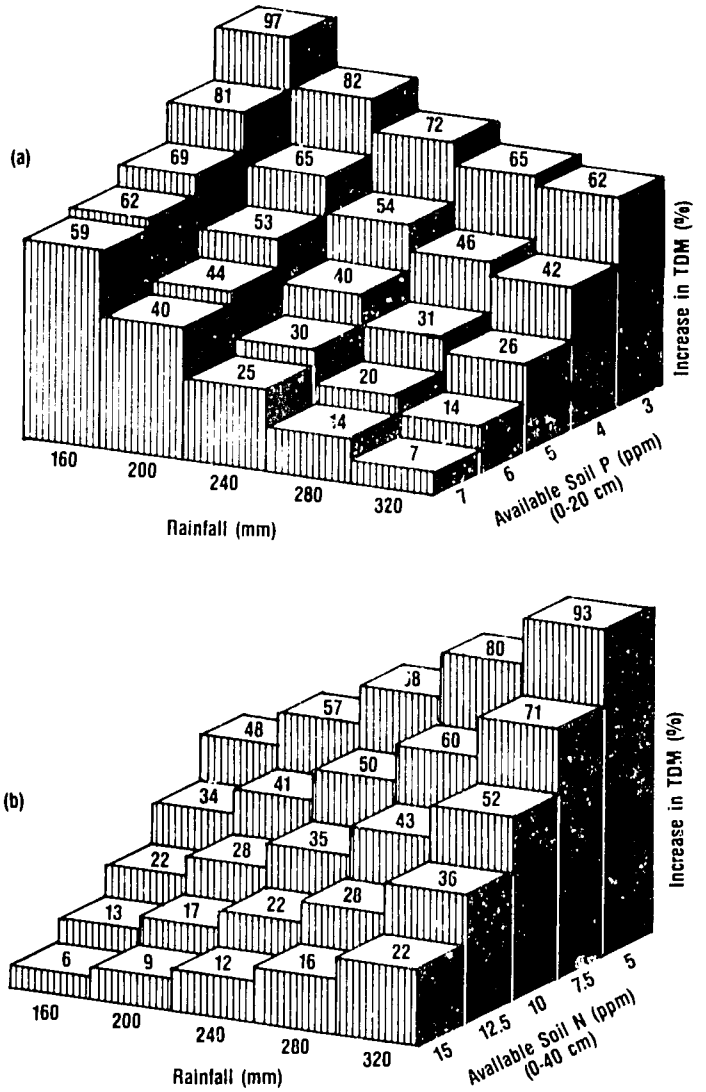


Figure 14. The Effect of Rainfall and Available Soil Nutrients on the Percent Increase in Total Dry-Matter Production (T.D.M.) Resulting from (a) 60 kg P_2O_5/ha and (b) 40 kg N/ha.

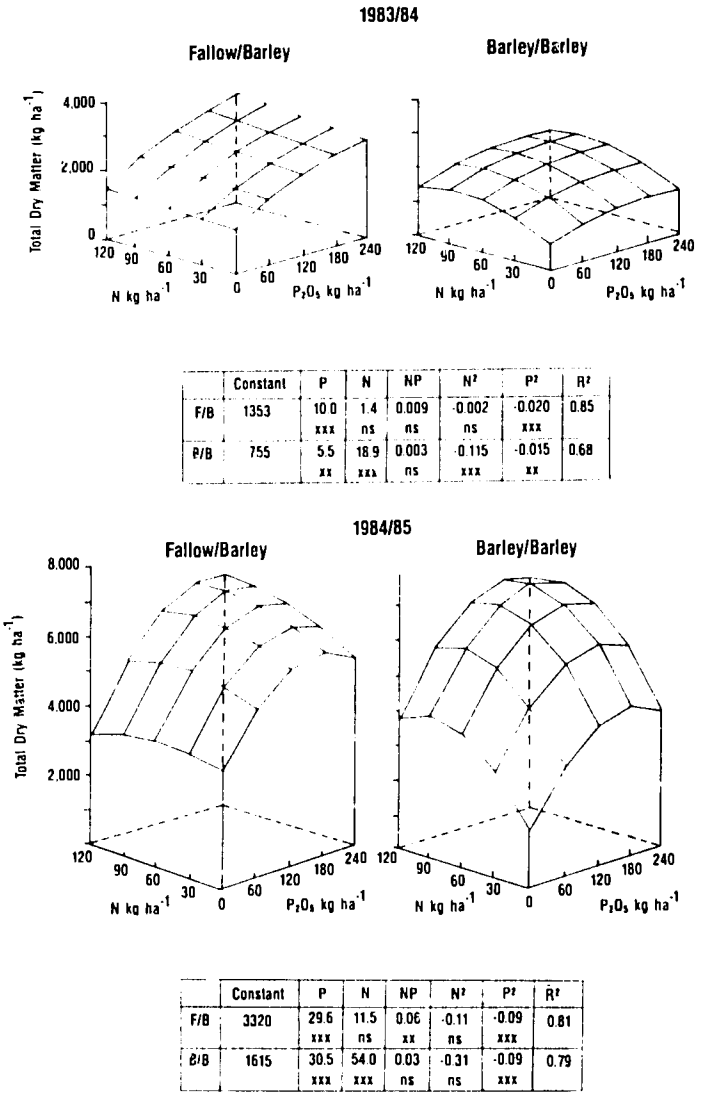
more important in wet years and locations when yield potentials are high. In dry years and locations, responses to phosphate are dominant, largely due to the very different mobilities of phosphate and nitrate in the soil.

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, chick-pea, or faba bean), by summer crops such as maize, watermelons, or sesame, or by a weedy fallow. Barley is most often preceded by a fallow (which may be clean or weedy) or increasingly is grown as a continuous crop (Figure 15).

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. Mineralization of organic nitrogen also occurs under legumes. The amount 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 > Chick-pea > Weedy Fallow > Cereal



	Constant	P	N	NP	N²	P²	R²
F/B	1353	10.0 xxx	1.4 ns	0.009 ns	-0.002 ns	-0.020 xxx	0.85
B/B	755	5.5 xx	18.9 xxx	0.003 ns	-0.115 xxx	-0.015 xx	0.68

	Constant	P	N	NP	N²	P²	R²
F/B	3320	29.6 xxx	11.5 ns	0.06 xx	-0.11 ns	-0.09 xxx	0.81
B/B	1615	30.5 xxx	54.0 xxx	0.03 ns	-0.31 ns	-0.09 xxx	0.79

Figure 15. 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, xxx = p≤0.01, xx = p≤0.05, ns = not significant.

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 effects of the preceding crop in the long term are shown in the results of a simulation study (Figures 16 and 17). Typical soil nitrogen and water contents following watermelons or lentils were used, together with historical rainfall and temperature records to predict the response of wheat to 80 kg/ha of applied N. Average seasonal rainfall at Jindiress and Muslmieh is 480 mm and 335 mm, respectively.

There is a reliable response to N at Jindiress, which is greater (7%) after lentil than after watermelon, as

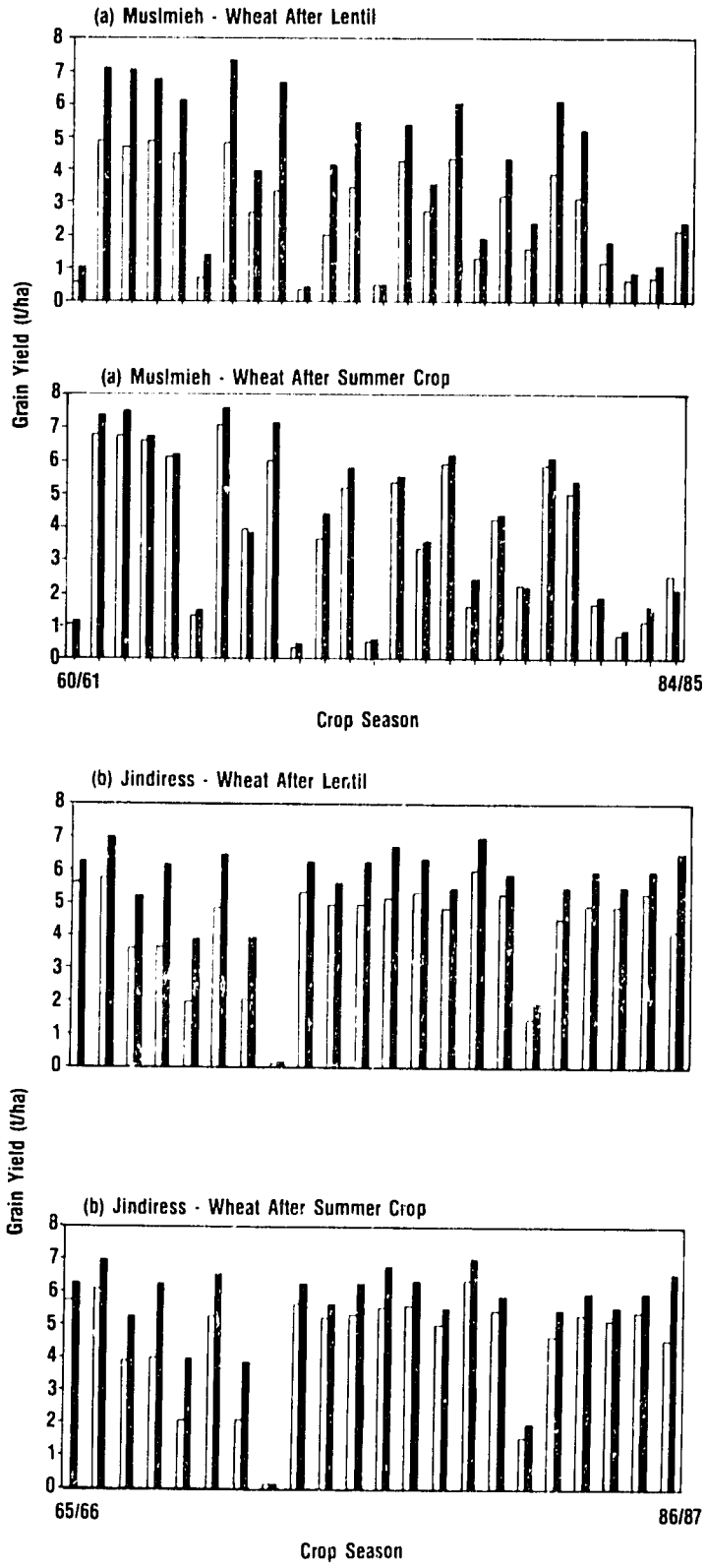


Figure 16. Simulated Wheat Yields (Ceres-N Wheat Growth Model) in Two Crop Rotations at (a) Muslmieh and (b) Jindiress, N.W. Syria. Open Bars, Zero N; Solid Bars, 80 kg N/ha.

would be expected from relative nitrogen availability after the two crops. At the drier site, Muslmieh, yields

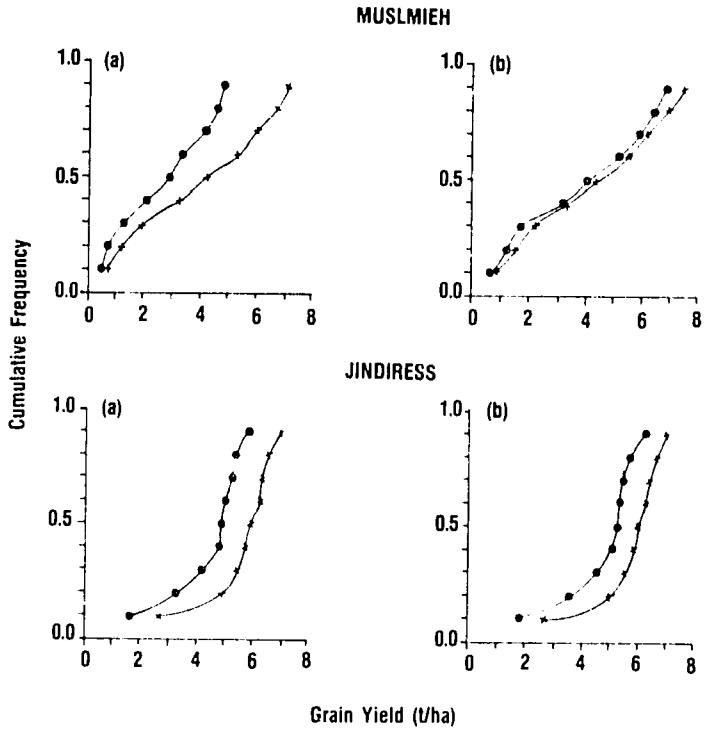


Figure 17. Cumulative Frequency Distribution of Simulated Wheat Yields (Ceres-N Wheat Growth Model) Following (a) Lentil and (b) Summer Crop at Two Locations in N.W. Syria With Zero (•) and Eighty (x) kg N/ha.

and the size of the response to N are both more variable, but the overall response to N following lentil is equally reliable and also greater (40%). The use of this quantity of N fertilizer following watermelon would not be profitable at Muslmieh, and, in fact, the predictions indicate small negative responses in a few years. Alternative strategies, such as adjusting topdressing rates according to the rainfall of the current season, obviously need to be assessed.

It is clear that well-targeted and economically optimum nitrogen recommendations should be developed, taking the effect of the preceding crop into consideration.

Weed Control and Fertilizer Responses

Weeds can present serious problems for farmers in West Asia and North Africa, 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 (Plate 11). Research has identified herbicides such as cyanazine and pronamide as being safe and economic for use on legumes, but they are not widely available to farmers. Farmers still rely on late sowing and subsequent hand weeding. Late sowing allows weeds that germinate with the early rains to be killed by the presowing tillage. However, late sowing also reduces yield potential, and hand weeding, which is expensive, is usually necessary. 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 5).

Table 5. 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 Grown in NW Syria Under Conventional Tillage

Fertilizer	Weed Control	E+T[a]	Dry Matter Lentil	Dry Matter Weeds	WUE Lentil	WUE Weed+Lentil
		(mm)	(kg/ha)	(kg/ha)		(kg/ha/mm)
+	-	270	1,128	1,084	4.2	8.2
+	+	237	2,038	37	8.6	8.8
-	-	255	667	685	2.6	5.3
-	+	218	751	72	3.4	3.8

a. E+T is crop evapotranspiration.

Weed infestations 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 (Plate 12). 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.

Phosphate Application, Immobilization, and Residual Effects

As soon as phosphate fertilizer is incorporated into calcareous soil, a process of immobilization begins, and the phosphate is transformed into less available or unavailable forms. The rate at which this reaction proceeds varies with soil chemical properties and rainfall amount and distribution (Figure 18). However, it may well be 2 to 3 years before the availability of phosphate in the soil falls back to its original prefertilization level, and residual crop responses to phosphate fertilizer may sometimes be observed even in the third year following application. The residual effects of phosphate fertilization have important implications:

1. The economics of fertilizer use is more properly evaluated over more than 1 year and over a sequence of crops.
2. Regular applications of phosphate fertilizer by farmers gradually increase the available phosphate status of their soils. The effect of 20 years' use of phosphate fertilizer can be seen by comparing the P status of fertilized wheat fields with that of barley

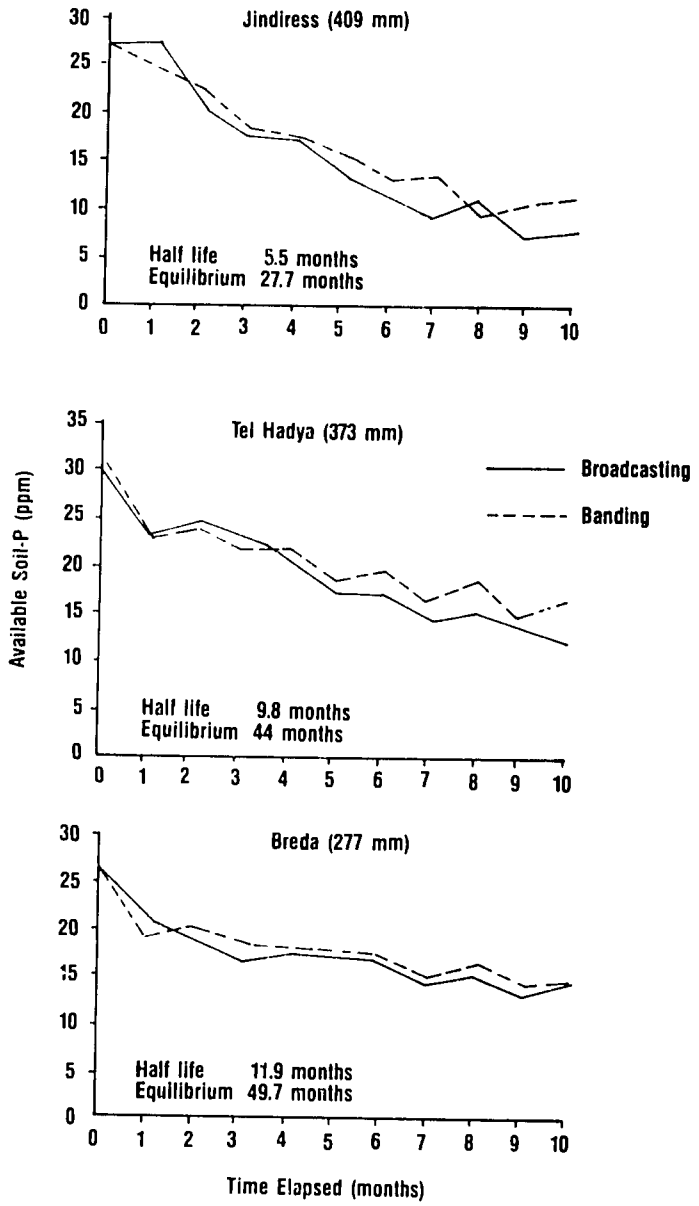


Figure 18. Effect of Banding and Broadcasting Phosphate Fertilizer (80 kg P_2O_5/ha) on its Availability With Time at Three Locations in N.W. Syria.

fields that were not fertilized (Figure 19). Phosphate buildup 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 most common method of applying both nitrogen and phosphate fertilizer is broadcasting, either by hand or through the use of tractor-mounted spreaders. Currently, little precision placement of fertilizer occurs.

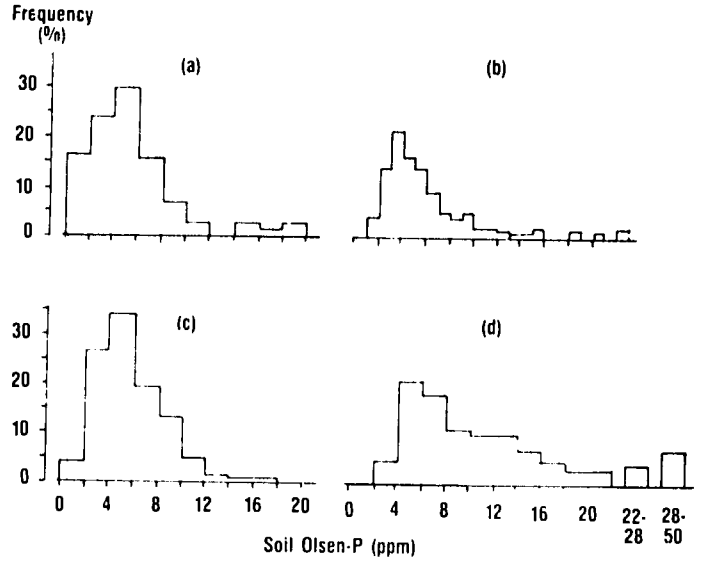


Figure 19. Distribution of Topsoil Olsen-P Values in Syria: (a) Barley and Wheat Fields, 1969; (b) Barley Fields, 1982; (c) Barley Fields, 1987; and (d) Wheat Fields, 1987.

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. It has been known for some time that (because of the immobility of P in calcareous soils) precision placement of phosphate with the seed results in more immediate availability to the growing roots and hence gives greater responses (Plate 13 and Figure 20). Drills that can sow seed and place phosphate fertilizer need not be expensive and would be economically attractive; such machines are already used in some countries.

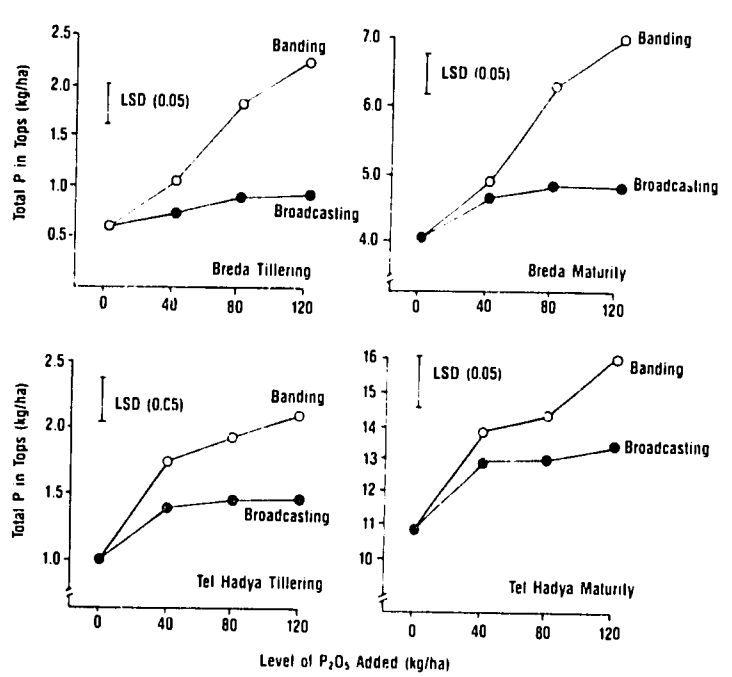


Figure 20. The Effect of Rate and Placement of Phosphate Fertilizer on Total P Uptake by Wheat (var. Sham 1) at Tillering and Maturity. Tel Hadya and Breda, N.W. Syria 1985.

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. They judge the potential of the season by the depth of soil wetting at the time of topdressing and modify their fertilizer rates accordingly (Table 6).

Table 6. Fertilization Rates, According to Rainfall, Used by Wheat Growers in Syria

	Phosphate			Nitrogen		
	Mean	SD	Sample Number	Mean	SD	Sample Number
	(kg/ha)					
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.

It is interesting that some farmers also modify their phosphate fertilizer rates on the basis of the rains received prior to seeding (Table 6) although in this case little extra benefit would be expected.

Fertilizer Use Across Agricultural Systems

As already indicated, countries in West Asia and North Africa have directed most of their research and development efforts towards irrigated areas and the higher yielding rainfed farming systems in which wheat, food legumes, and summer crops are produced. These efforts have been largely successful. Fertilizer recommendations were produced and policies formulated to assist farmers in adoption, and today fertilizer use in these farming systems is widespread. This is illustrated by the Syrian wheat growers' perception of the importance of fertilizer (Table 7). Similar results are reported from many other countries (ICARDA, 1985).

Table 7. Farmers' Ratings of Factors Affecting Wheat Yields (Percent of Farmers), Syria

	Importance		
Factor	Major	Minor	None
Nitrogen	74	23	3
Phosphate	53	23	25
Tillage	62	34	3
Weed control	20	54	26
Variety	20	31	49
Planting date	10	15	75
Seed rate	0	21	79

Source: Tully and Rassam, 1986.

This initial focus was undoubtedly correct, but research objectives now need to shift towards the identification of finely tuned and targeted recommendations that allow more efficient allocation and use of fertilizer. Moreover, great potential for phosphate and nitrogen fertilizers has now been demonstrated in the drier barley/livestock farming systems. Conservative estimates derived from fertilizer trials on barley in Syria indicate that if 70% of farmers used phosphate and nitrogen fertilizer (at low rates), then in "average" years, barley production would be increased by nearly 35%, equivalent to an additional 200,000 and 390,000 tonnes/year of grain and straw, respectively (Mazid and Somel, 1988).

In addition, recent research has shown that the productivity of marginal grazing areas, which form such an important part of the livestock feeding cycle, can also be dramatically improved through the application of small amounts of phosphate fertilizer. On these soils, where both N and P are deficient, legume species initially respond more vigorously to phosphate fertilizer, but later, as organic nitrogen levels build up, the grasses also increase their productivity (Plate 14).

Several factors point to the potential and importance of introducing fertilizers to the drier and more marginal areas:

1. Continuous use of phosphate fertilizer in the wetter areas has already resulted in a buildup of available phosphate (see Figure 19). In countries where fertilizer supplies are limited, lower "maintenance" dressings could now be applied on many farms, and the fertilizer thus saved could be reallocated to the drier areas where phosphate deficiencies are still severe.

2. Population growth, urbanization, and higher living standards all contribute to predicted increases in demand for livestock products and hence a derived demand for greater production of livestock feed (Figure 21). Barley will remain the most important single source of sheep feed, and the drier farming systems are the major producers of livestock and barley.

3. As national flocks increase in size, the pressure on the marginal grazing areas will also increase. If such areas are to support more intensive grazing, their productivity and management must be improved.

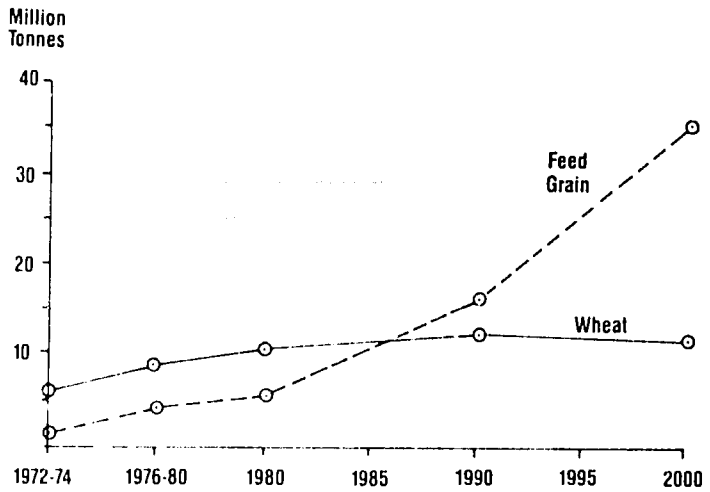


Figure 21. The Gap Between Supply and Demand of Feed Grains and Wheat in West Asia and North Africa: Historic Averages and Trend Projections. (From Khaldi 1984).

Priority Areas for Research

Characterization of Environment: Fertilizer Response Interactions Through On-Farm Research

In this review we have described how certain environmental variables can affect fertilizer responses. These include soil fertility, soil depth, 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 that 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 that 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 of repeated research.

To overcome the limitations of on-station fertilizer research, we believe that high priority should be placed on developing within national research programs the capabilities and facilities for conducting on-farm research. This approach would provide an additional opportunity for including the farmer as a partner in research. 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 the possible constraints to adoption that the farmers may face.

Many types of on-farm trials are possible, and these have been discussed in detail by Fakki (1988) with specific reference to West Asia and North Africa. The type chosen depends upon what is already known about the project area. If there is little information on, for instance, fertilizer use, the following represents a logical sequence of trials.

1. **Diagnostic Trials**—Diagnostic trials consist of simple plus/minus fertilizer comparisons for the major crops. Selection of representative trial sites is guided by the use of soil maps, rainfall isohyets, and a knowledge of the dominant crop rotations practiced by farmers. Sites should be characterized through soil analyses, rainfall measurement, and farm surveys that focus on describing existing production practices and crop yields. Additional soil sampling of surrounding fields can also be undertaken to obtain a more complete knowledge of the distribution and severity of plant nutrient deficiencies.

2. **Research Trials**—Once the researcher has ascertained the potential for fertilizer use, more complex factorial trials are required to identify economically optimum levels. The diagnostic trials will have allowed the researcher to identify preliminary "fertilizer response domains," which may comprise different combinations of expected rainfall, soil types, and crop rotation. These response domains will provide clear guidelines for site selection for subsequent trials. Again, sites should be fully characterized so that interactions between the physical environment and the fertilizer response surfaces can be quantified. Farmers' yields in surrounding fields can also be measured to allow preliminary identification of "yield gaps" between researcher-managed and farmer-managed crops and, hence, the likely impact of adoption.

3. **Testing Trials**—The "researcher-managed" on-farm trials described above provide a detailed understanding of fertilizer response:environment interactions (e.g., Figure 13) and lead to economically viable fertilizer recommendations targeted towards identified response domains within which a relatively uniform response may be expected. The next step is to test these recommendations under farmer management. For this, plots should be "field scale" in size, and treatment combinations should be kept to a minimum. A control versus the recommended fertilizer combination and rate may be sufficient. Only single replications are necessary at each location: if required, statistical analysis of the yields can be achieved by considering each location within a response domain as a replicate. At this testing stage, research

institutions remain involved in several ways: to provide inputs (fertilizer), to mark out plots of the correct size, and to give clear instructions to the farmer on how to use the fertilizer.

Farmer surveys are important to describe how the farmer manages his soil and crop and also his reaction to the effects of fertilizer. Such surveys should "follow up" with farmers in subsequent seasons to assess adoption rates and determine to what extent farmers have encountered constraints that have prevented the use of fertilizer.

Flexible Fertilizer Recommendations

Even within a single field, let alone a fertilizer response 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

We know already (see Figure 19) that phosphate application to calcareous soils over several years results in a steady increase in the level of plant-available P and that the 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; the greater the supply of moisture, the greater the response to N fertilizer (see Figure 13b). It has also been indicated that most of the nitrogen fertilizer applied to wheat and barley by farmers is topdressed. Because a large part of the season's rain will have fallen prior to topdressing, 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 topdressing. Analyses of long-term climatic records can predict the probabilities of receiving different amounts of rainfall thereafter, and "best-bet" nitrogen topdressing requirements can be determined.

Such models could be very valuable in following 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 should be given high priority as an area of research.

National Allocation of Fertilizer

In most countries of West Asia and North Africa, the functions of the fertilizer sector, i.e., fertilizer supply (including both imports and local production), distribution, and sales, as well as product prices, are centrally planned and controlled. The potential for decentralization or even privatization of the fertilizer sector therefore exists. However, all plans for the future should be based on in-depth studies of the total fertilizer sector based on the latest agronomic, economic, marketing, and production technology information and research techniques. ICARDA and NARS therefore have a key role to play in many aspects of the development of sound national fertilizer sectors.

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