FAO SOILS BULLETIN 12

the response of wheat to fertilizers

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS ROME

C O N T E N T S

I. INTRODUCTION

Man has used wheat as a food since prehistoric times. It was apparently grown in the Middle East as early as 15,000 B.C., it appears in writings from as early as 550 B.C. and many of the plant's characteristics were probably well known to man 2,000 years ago (Quisenberry and Reitz 1967).

Wheat is grown extensively over a broad range of climatic conditions and soils and consequently has a wide geographical distribution. It is the national food in over 40 countries and the main staple for over one third of the world's population. In Europe and the USSR for example, over 30 percent of the calories come from wheat (Brown 1963). In addition to starch it contains other valuable nutritive materials notably proteins, minerals and vitamins. The amino acid yield per hectare from wheat far exceeds that of animal products for every one of the essential amino acids. The minerals and vitamins especially in foods derived from whole grain products and enriched flour are significant nutritionally (Hegsted 1965, McGillivray and Bosley 1962, Reitz 1964).

The total annual production of wheat has increased from 171 million metric tons in 1948-1952 to 308 million tons in 1966 (FAO 1967)*. During the same period the area under wheat has increased from 173 to 217 million hectares (15 percent of the world's arable land), and the world average yield from 990 to 1,420 kgs per hectare. In 1966 the production of wheat represented 28 percent of the total production of all cereals. The corresponding figures for its nearest competitors, rice and maize, were 23 and 22 percent respectively in the same year.

Because of the overall importance of wheat in human nutrition throughout the world including most developing countries, the present study was introduced:

1. To summarize the data of wheat production on global, regional and country basis.
2. To examine the factors affecting the production and hectare yields with special reference to use of fertilizers and the response of wheat to fertilizers.
3. To obtain a realistic picture of the possibilities of improvement of wheat production in the future.

This working paper was prepared as a preliminary step to the fulfilment of the above tasks.

Chapter II consists of a short description of the background and development of high yielding varieties.

In Chapter III an overall description of climatic conditions and soils in the wheat growing areas of the world is given with special reference to the influence of these factors on wheat yields.

In Chapter IV an effort is made to give a general picture of wheat cultivation in relation to other agricultural crops and land use in 88 individual countries where wheat is regularly grown and has a more or less important role in their agricultural production. Trends of development of wheat areas, production, and yields and fertilizer consumption per hectare during the past two decades are given for all the countries for which the relevant data were available. Some essential characteristics and problems of wheat cultivation connected with the efficacy of fertilizer use in various countries are also shown with the aid of examples from fertilizer trials results.

Although most factors affecting the response of wheat to fertilizers are basically similar in different countries, the extent of their mutual importance varies greatly from one country, or district, to another. No attempt has therefore been made in this paper to cover all the factors in every country, but an endeavour has been made to select some of the essential problems in different environmental conditions on the basis of the literature available. It is obvious, however, that in trying to discuss a large variety of problems and covering world-wide geographical conditions, there may have been unnecessary repetition of many subjects while other important features may have been neglected, often because of lack of available data.

Among the indirect factors affecting response to fertilizers, climate is first, especially annual and regional differences in rainfall often related to soil moisture content. These aspects have been

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* The statistical data of wheat production, area, yields, trade and fertilizer consumption, used in this paper, are obtained from FAO Production Yearbook Vol. 21, 1967, and FAO Trade Yearbook Vol. 21, 1967, unless stated otherwise.

considered in connection with about 20 countries (including France, U.S.S.R., Canada, U.S.A., Iran, Iraq, Jordan, Lebanon, Pakistan, Syria, Turkey, Algeria, South Africa, Tunisia and Australia).

Responses related especially to soil factors, such as soil types, physical condition of soils, leaching, pH, salinity, nutrient status or trace elements have been briefly discussed in connection with over a dozen countries (incl. Czechoslovakia, France, East and West Germany, Hungary, Ireland, Romania, U.K., U.S.S.R., Chile, Japan, Kenya, South Africa and Australia, etc.). The reader's attention is also called to the effects of cultivation methods and practices on responsiveness; these include cultivation history, rotations (N-fixing legumes), tillage methods, dates of seed and fertilizer application, irrigation, fertilizer forms and placement in conditions prevailing in about two dozen countries (e.g. Belgium, Czechoslovakia, Finland, France, Italy, Netherlands, Romania, Sweden, Switzerland, U.K., U.S.S.R., Canada, U.S.A., Afghanistan, India, Japan, Pakistan, South Africa, Sudan, Tanzania, Tunisia, Australia and New Zealand).

Special emphasis is placed on the role of high yielding, fertilizer responsive, varieties in about 20 countries where these varieties of Mexican or other origin have been tested. In several of these countries (e.g. Mexico, Afghanistan, India, Iran, Iraq, Pakistan, Turkey and Morocco) wheat production has reached or is about to reach entirely new dimensions due to the impact of these varieties accompanied by higher fertilizer use.

Other factors affecting the response of wheat to fertilizers, such as the use of growth regulators (CCC), problems of plant diseases and insects as well as factors affecting the quality of wheat have also been discussed in connection with wheat growing in several countries. For some developing countries estimates of future wheat production have been quoted (FAO Indicative World Plan).

In Chapter V the relationships between wheat yields and fertilizer use per arable hectare, both on regional and national bases, are illustrated by graphs. The trends of both these measures during the past two decades contribute to the estimate of fertilizer responses on national basis which, within certain limitations, enables one to make an overall summary of the response of wheat to fertilizers. The differences in the response potential in countries with different fertilization levels are also shown. In the last chapter a general summary of the mutual ratios of different fertilizer nutrients used in different countries and of changes in fertilizer forms used is also given.

II. HIGH YIELDING VARIETIES

During the last two decades the systematic and undeviating work of wheat breeders has resulted in the development of high-yielding, disease and lodging resistant, semi-dwarf wheat varieties. This work, often called "The Wheat Revolution", started in Mexico in 1943 by the Rockefeller Foundation, with Dr. J. George Harrar as its leader, continued under the leadership of Dr. Norman E. Borlaug* from 1945 and of Dr. Ignacio Narvaes from 1960 (Stakman et al. 1967).

The primary need was to develop rust-resistant varieties because of the fatal weakness of Mexican bread wheats but soon the wheat programme was expanded to develop varieties of general superiority and wide adaptability. Therefore the campaigns for varietal improvement and soil improvement went hand in hand. The increased use of fertilizer created the need for stiff-straw varieties that could remain erect while utilising it, and it created the desire to convert as much of the fertilizer energy as possible into grain instead of wasting it in building more straw than was needed.

As a result of this successful teamwork Mexico has more than trebled her wheat yields and quadrupled her wheat production since 1943 and became independent of foreign wheat in 1956 being now one of the wheat exporters.

The first high yielding variety, released in 1948, was Yaqui 48 (selection from Kentana 48), followed by RockMex (selection from Kenya 324) and Gabo 48 (an introduction from Australia). Since the early fifties a number of new varieties like Chapingo 53, Mayo 54, Huamantla Rojo, Lerma Rojo, Nadadores, Nainari 60 and Sonora 60, resulting from the extensive crossing programme have been released from time to time. Mayo 64, Lerma Rojo 64, Sonora 64, Panjamo 62, Bajio 66, Yaral 66, Noroesto 66, Roqui 66, India 66, Pitic 62 and Tobari 66 are among the latest semi-dwarf wheats (Hafiz 1968).

The main advantage of the new varieties is that they are short in stature and can utilize higher rates of fertilizer and more irrigation water without premature lodging. To make maximum use of these wheats they must be fertilized with high rates of nitrogen and phosphorus and irrigated adequately. They do not require more fertilizer but they are able to utilize more fertilizer efficiently (Fig. 1).

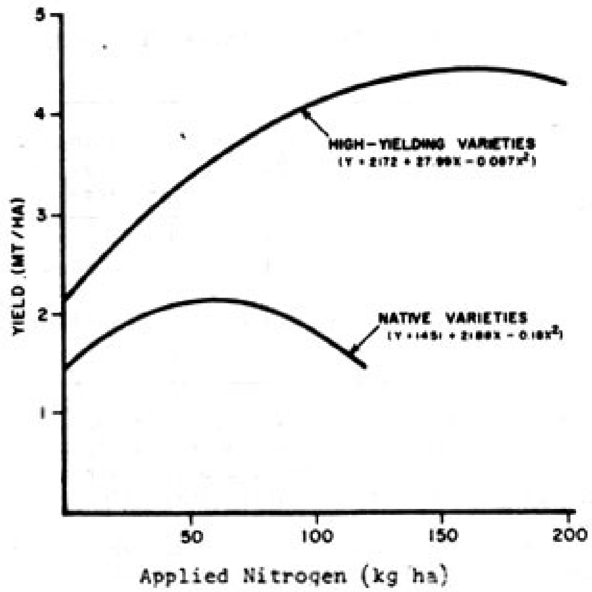

Figure 1. Generalized curve for the response of wheat to nitrogen applications. (Russel et al. 1970).

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* Since 1960 The Director of International Wheat Improvement Project of the Rockefeller Foundation.

The dwarf varieties have broad, green leaves and an efficient photosynthetic ability. They also have well developed root systems that tend to grow deeper than those of tall varieties. The dwarfs have a high tillering ability and because of this the short plant height does not necessarily lead to less straw. Frequently, they produce more straw (Saxena and Sirohi 1967, Wright 1968, Russel et al. 1970).

In addition to fertilization, the new high yielding varieties differ considerably from the traditional tall varieties also in other agronomic characteristics such as depth and date of sowing and irrigation requirements, etc., necessitating marked changes in their cultural practices. The new seeds produce crops in shorter time periods than most traditional varieties, and thus sometimes make it possible to raise additional crops. Therefore, in order to make agronomic recommendations, it has been necessary to conduct precise experiments to learn the best cultivation methods and treatments required by these varieties in different conditions. Some of these are discussed in connection with fertilizer trials in individual countries.

Mexican-bred wheats began to emigrate to other countries as soon as they were fully formed, and some were sent abroad while still in process of formation. Among the first countries receiving new wheats from Mexico were Guatemala, Colombia, Ecuador, Chile, Bolivia and Paraguay. In Colombia and Chile national wheat improvement programmes were started in 1950 and 1955, respectively. The International Wheat Improvement Project established by the Rockefeller Foundation in 1959 has the ambition to convert possibilities into realities everywhere by operating on three coordinated points: (a) ecological experimentation, (b) basic research, and (c) educational activities (Stakman et al. 1967). Due to its operations, often in cooperation with the Food and Agriculture Organization of the United Nations, high yielding Mexican varieties have been tested, adopted or developed further in numerous countries.

In some areas, the new varieties have spread with extraordinary rapidity, while in others the development has been slower depending on the circumstances in the individual countries. The improved wheat varieties spread rapidly on the irrigated wheat area in Mexico from 1949 to 1956.

At present, the improved seed is used on nearly all of Mexico's wheat area, of which nearly 90 percent is irrigated and more than two-thirds is fertilized (FAO 1968, b). In Pakistan and India 40 and 25 percent of the wheat area, respectively, were planted to high yielding varieties in 1968/69 (Table 1).

Table 1. Diffusion of high yielding varieties in five countries (Rice 1969).

Country	Total wheat area 1968/69	Area planted to high yielding varieties			
		1965/66	1966/67	1967/68	1968/69
	- 1000 hectares -	- 1000 hectares -			
Afghanistan	2.228	-	2	26	122
India	15.970	3	518	2.944	4.050
Pakistan	6.000	5	101	958	2.438
Turkey	8.106	-	0.6	170	721
Morocco	1.978	-	-	0.2	5

Further, in Tunisia, Iran and Morocco 12,000, 9,000 and 5,000 hectares, respectively, were planted to improved varieties and areas of undetermined size were planted in Argentina, Brazil, Ecuador, Peru, Cyprus, Iraq, Jordan, Lebanon, Israel, Saudi Arabia, Kenya, Libya, Rhodesia, South Africa, Sudan, Australia, southwestern USA and Europe (Stakman et al. 1967, CIMMYT 1969).

Until about three years ago, concern was still expressed by a number of commentators that the world was losing the race between population and food production. The evidence usually cited was "recent trends" in population and food production, shifts in patterns of grain trade, and a decline in surplus grain stocks. There were even predictions of impending man starvation. This atmosphere of crisis was an important factor in the rapid adoption of new high yielding varieties. Especially the governments of some Asian countries became concerned over their food problems, and the availability of high productive grains seemed to offer a solution. In some instances, governments supported high priority programmes to ensure that farmers would quickly adopt use of the new seeds. Predictions of food shortages are still being made but in the past three years opinions have been expressed that the world outlook has changed radically. Evidence cited to support this view includes falling grain prices, increased grain stocks, and the rapid spread of the new high yielding varieties (Willet 1969).

In countries where wheat improvement programmes, with high yielding varieties, are already in an advanced stage, the results are most encouraging and in some of these countries, e.g. Mexico, India and Pakistan, revolutionary increases of wheat production have been achieved as shown in Chapter IV.

III. WHEAT GROWING IN RELATION TO CLIMATES AND SOILS

III. a. General Climatic Limitations

It is obvious that through the long history of wheat cultivation the main wheat production has more or less stabilized in certain areas where the climatic conditions and soils are such that wheat can favourably compete with other higher yielding crops.

The bulk of the world's wheat is produced on lands with less than optimum precipitation, which seems to be around 800 mm per year, varying with the seasonal distribution of rainfall and prevailing temperatures. Even though it is difficult to define the lower limit of precipitation for wheat it may be stated that little wheat is grown in regions with less than 230 mm of precipitation (Royen 1954). On the other hand, in more humid regions the lower protein content and competition of other more yielding crops limit the wheat production.

Although wheat is grown in a relatively wide temperature range very little wheat is produced in subpolar climate regions with less than 100 days growing season. The main climatic factor setting the northern and southern limits of effective wheat production (about 67°N in Norway and Finland and 45°S in Argentina) is low temperature. The same factor limits the production also at high altitudes, even at the lowest latitudes. At the Equator for example, the practical limit of wheat growing is up to an altitude of about 12,000 ft. or about 3,700 m (Peterson 1965). In warm humid regions the susceptibility of wheat to diseases limits its production and practically no wheat is grown in regions of tropical rainy climate and little in regions of humid subtropical climate such as southern China and southern United States. Toward the Equator the limiting factor is essentially a combination of high temperature and humidity (Royen 1954).

III. b. Areal distribution and yields in relation to climate

Climate is a most complicated factor affecting the growth of crops since in different parts of the world different partial climatic factors may dominate in determining crop growing. Therefore, in this study no attempts to obtain a complete analysis of climatic factors on the growth of wheat are made. However, since the bulk of wheat production takes place in areas receiving less than optimum rainfall it is obvious that inadequate precipitation is likely to be the most important climatic factor limiting the growth of wheat and thus determining the quantity of yield (Figs. 2 and 3).

To assess the relationship between wheat growing and climate, world wheat maps (Callaghan and Millington 1956, Guidry 1964, Reitz 1967, Royen 1954) were compared with a world map of climate. The climate map used was that of Papadakis (1968) which is based on principles of crop ecology and a draft of which is available at a scale of 1:5,000,000. The results of the comparison are summarized in Table 2 where the distribution of the wheat areas of 44 countries covering over 90 percent of the world's total wheat area into climatic groups is given. The Humidity Index (Papadakis 1966), an index relating precipitation and potential evapotranspiration, gives an indication of moisture available for crop growth in each climatic subgroup.

Estimations of average Humidity Index for the wheat areas of each country and of average wheat yield within each climatic group were calculated on the basis of the relative distribution of climatic groups using the principle of weighed averages.

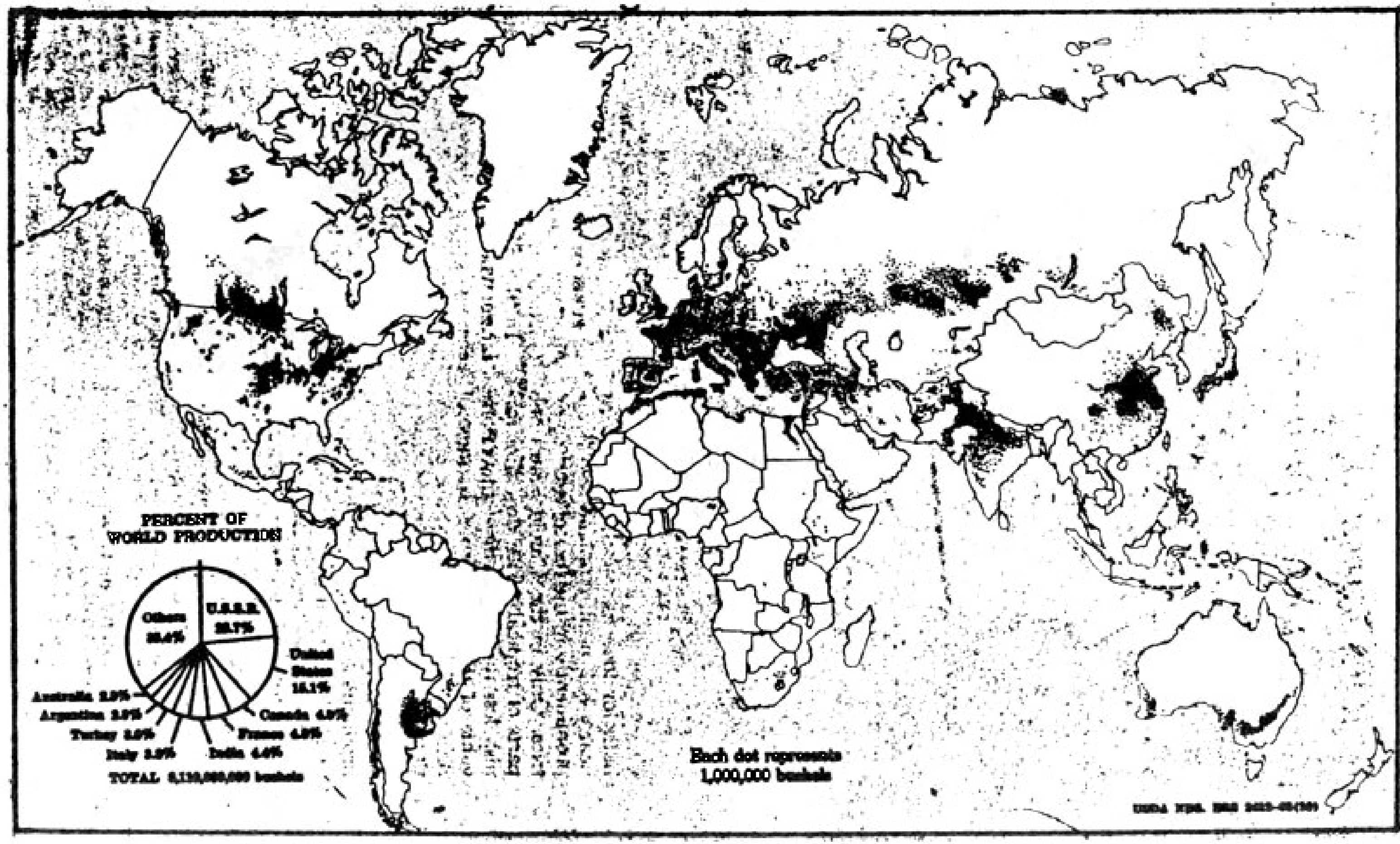

Figure 2. World wheat production, average 1957-61 (Guidry 1964).

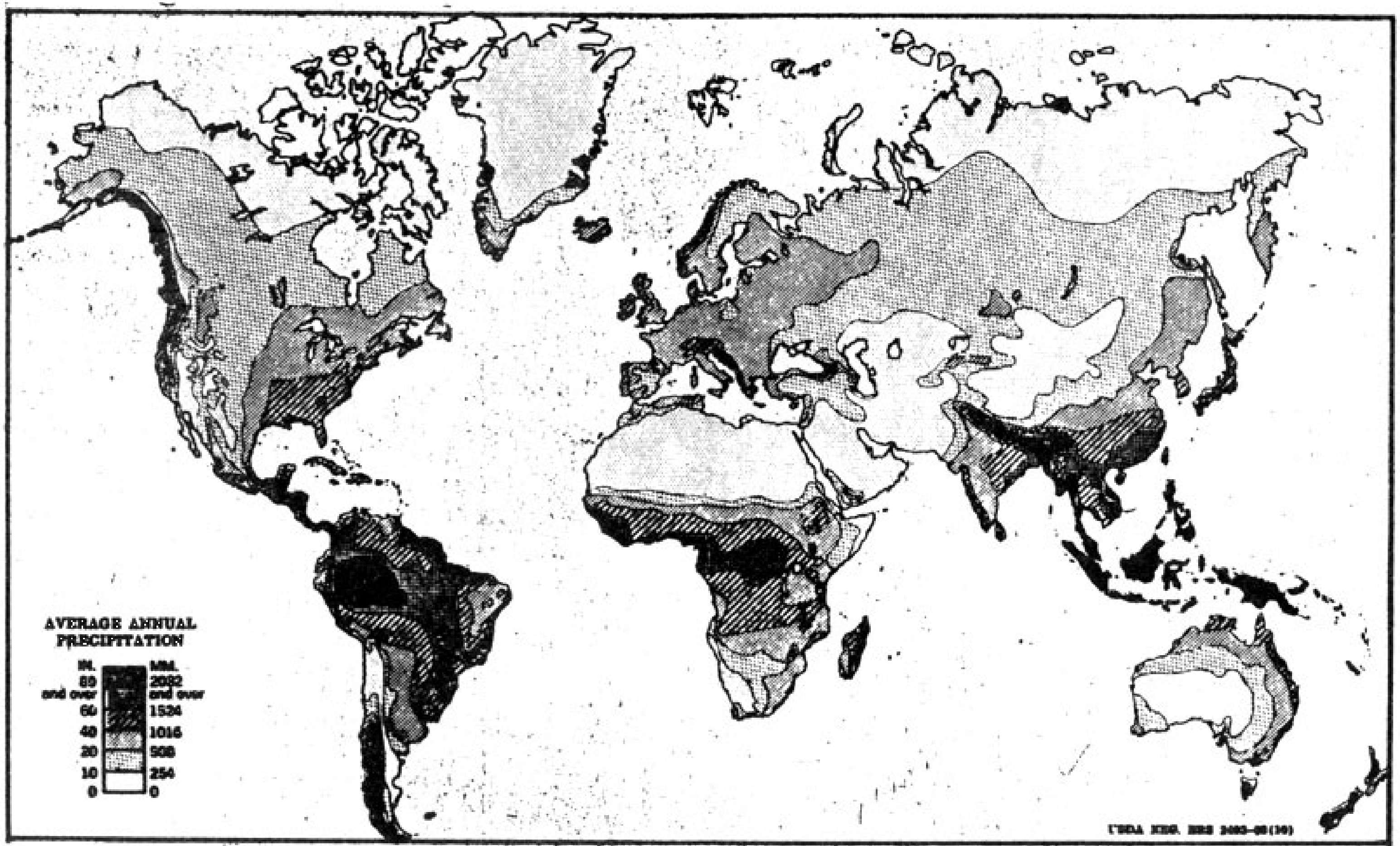

Figure 3. Average annual precipitation (Guidry 1964).

Over one half of the wheat area of the world is in areas of Steppe climate, a more or less dry climate with cold winters and Humidity Index varying from about 0.5 to 1.0, usually around 0.7. The climates of the two largest subgroups, Semiwarm and Cold Steppe, prevail in 40 to 50 percent of the world's wheat area and are typical for most wheat growing areas in U.S.S.R., Canada (Alberta, Manitoba, Saskatchewan), U.S.A. (e.g. Kansas, Nebraska, N. and S. Dakota) and some Eastern European Countries like Bulgaria, Hungary, Romania and Yugoslavia. Considerable wheat is growing also in areas of Warm and Monsoon Continental Steppe climates especially in Mainland China. Typical wheat yields are around 1600 kg/ha but depending on fertilizer use may vary from less than 1000 to over 2000 kg/ha.

Mediterranean climate, characterized by dry summers and more or less humid winters and where Humidity Index is usually 0.3–0.5 is prevailing in about 13 to 17 percent of the world's wheat area. This is typical climate for Mediterranean countries both in southern Europe and northern Africa as well as in Turkey. Elsewhere wheat is growing under these climatic conditions especially in S. and W. Australia, South Africa and inland Washington, U.S.A. The success of a crop depends on the start of the summer season. A start in April (Northern Hemisphere) is hazardous, earlier it is impossible without irrigation and later usually satisfactory. Yields are usually about 1100 kg/ha, often as low as 700 kg/ha (North Africa) but may be 1500 kg/ha or higher if more fertilizer is used. It is probable, however, that the primary limitation is water, not plant nutrients.

About one tenth of the wheat area occurs in areas of Subtropical climates, where the winter is sufficiently cool. In India and Pakistan the climate is very dry, Humidity Index about 0.4 and irrigation is required if the humid season is short. In Mainland China and Uruguay it is often too humid, (H.I. around 2) with consequent disease problems, and rains may interfere with harvesting. In both cases the yields are low, in the region of 800–1000 kg/ha and little fertilizer is used.

Of the other areas there is extensive wheat growing (8–10%) in the Marine climates prevailing in most European countries, in parts of U.S.S.R., Chile, New Zealand and in Ontario, Canada. Within this climate, moisture is usually not a limiting factor in crop growth and with Humidity Indices of 1.3 to 1.5 heavy fertilizing produces heavy yields, usually in the 3000–4000 kg/ha range.

The temperature range within the group of Marine climate is relatively wide and consequently the wheat yields in both extreme temperature conditions (Warm and Cold Temperate subgroups) are considerably lower, 1600–1800 kg/ha.

About 5-6 percent of the world wheat area occurs in Humid Continental regions, in Mainland China, North and South Korea, Japan, U.S.S.R. and U.S.A. (Illinois, Indiana, Ohio). The Humidity Index is high, 1.3–1.6 and the yields vary from less than 1000 kg/ha (North Korea, China) to over 2000 kg/ha (Japan, U.S.A.) depending on fertilizer use.

Pampean climates, which are similar to the Steppe climates except that the winters are mild, exist on about 3–4 percent of the world wheat area. Humidity Index is usually 0.6–0.7. In the Typical Pampean climate of Argentina crops frequently fail because of drought but high yields in good seasons compensate. The wheat yields tend to be about 1200 to 1500 kg/ha but in the Marine Pampean climate, where the Humidity Index is a little higher, and with heavy fertilization, yields exceeding 3000 kg/ha (New Zealand) can be produced.

The areal distribution of wheat land according to Humidity Index is summarized in Fig.4.

Somewhat over one fourth of wheat land is in areas of very dry climate, H.I. 0.6 or less, mainly in Mediterranean, Subtropical (Monsoon and Hot) and Pampean climates. Over one half occurs within the humidity range of H.I. 0.6 to 1.0, mainly under Steppe climate and only about one fifth in humid (H.I. over 1.0) climates, Marine Humid Continental and Humid Subtropical.

The relation between national wheat yields (1962–66) and average Humidity Index of wheat areas of 44 countries, with special reference to the level of fertilizer use, is given in Fig. 5 and summarized in Table 3.

It can be seen that regardless of the humidity of climate:

- in countries using less than 40 kg fertilizers per arable hectare the yields are less than 1600 kg/ha.
- in countries with 40–110 kg/ha fertilizer use the yields are within the range of 1700–2100 kg/ha.
- in countries using over 110 kg/ha the yields vary from about 2000 to 4400 kg/ha.

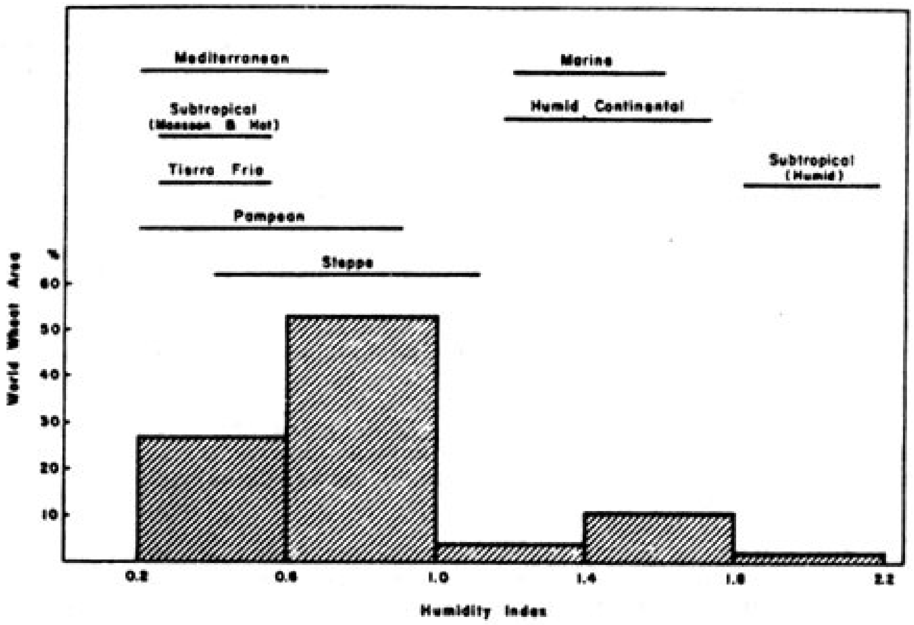

Figure 4. Areal distribution of wheat land in relation to humidity of climate.

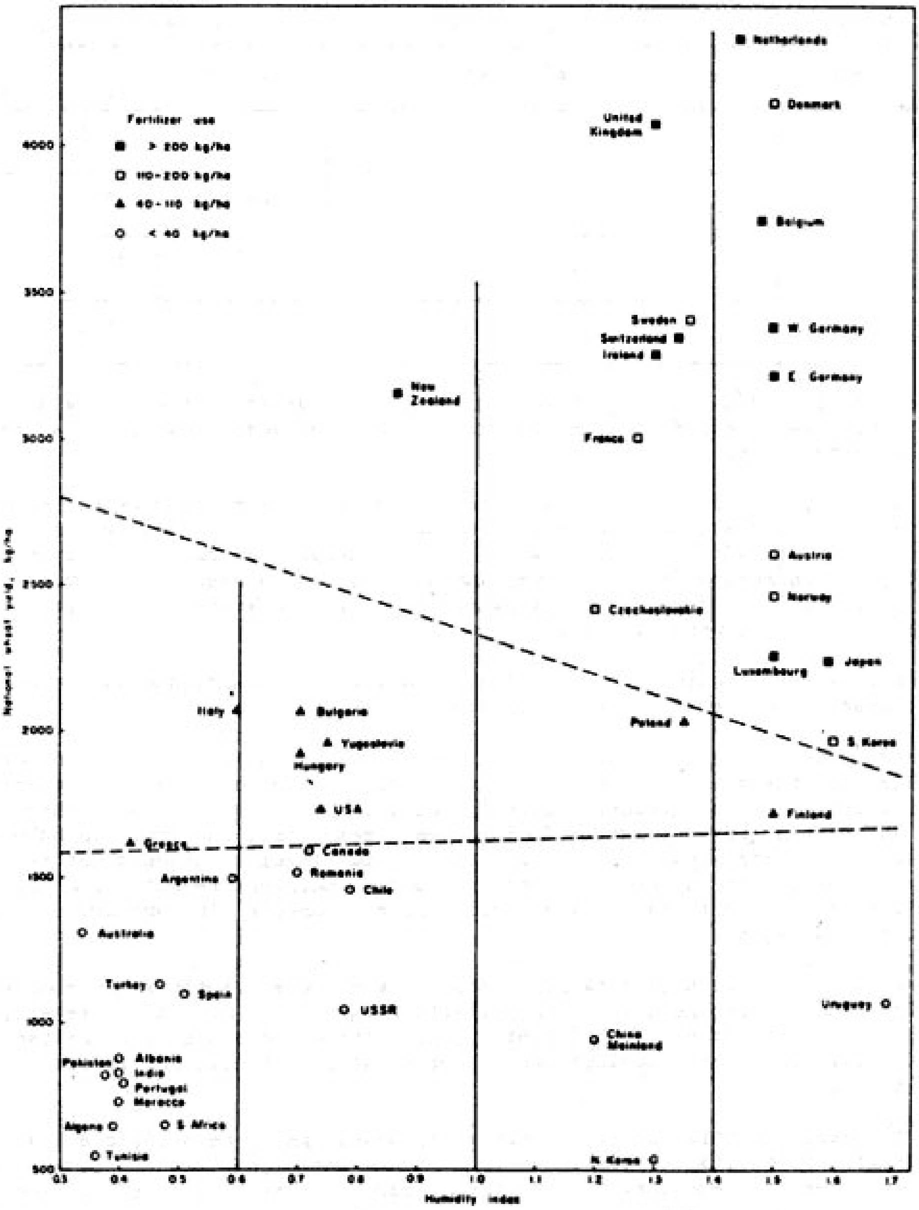

Figure 5. National wheat yields of 44 countries as related to humidity of climate and level of fertilizer use.

Table 3. Averages of national wheat yields (kg/ha) within four humidity classes and three fertilizer use classes (The number of countries within parentheses).

Humidity Index	Fertilizer use, kg. per arable hectare						Average
	< 40		40 - 110		>110		
< 0.6	(12)	910	(2)	1850	(0)		1330 *
0.6 - 1.0	(4)	1410	(4)	1920	(1)	3160	2163
1.0 - 1.4	(2)	740	(1)	2030	(6)	3250	2007
> 1.4	(1)	1075	(1)	1720	(10)	3050	1948
Average		1034		1880		3153 *	-

*/ The average 1330 kg/ha is apparently too low because of lack of yield data on the lowest humidity-highest fertilizer use class. For the same reason, the average 3153 may be too high.

It is obvious that the yield differences between the three fertilizer use classes are more clear than those between the humidity classes. However, it is apparent that increases by fertilizing are possible only where moisture is sufficient to grow the heavier crop. Generally, it is probable that in drier areas modest yield increases from relatively small dressings of fertilizer (mostly N) would be the most economic proposition. In wetter parts experience, e.g. in Western Europe, has shown that heavy fertilizing can produce very high yields.

The effect of soils must be considered as soils also vary with climate, and the nature of the soil has an important bearing on the fertilizer response.

In the driest wheat regions the soils are frequently Solanchaks and Solonetz, being affected by salts which accumulate in the soil because there is insufficient leaching rainfall to remove them. These salts will often depress yields. Secondly the lack of water reduces weathering and many soils are sandy and retain little moisture from the wet season till the dry. Thirdly, low production and high summer temperatures lead to a low equilibrium level of organic matter in the soil and this also reduces water retention. Further, it reduces nutrient retention, nitrogen levels, and structural stability (and hence tillability and erosion resistance). The production from these soils is often less than 1000 kg/ha.

In the soils receiving somewhat higher rainfall most of these disadvantages are removed. Salts are leached but not bases and soils are neutral in pH. with adequate organic matter levels, moderate amounts of clay, sufficient depth for good rooting, good structure and so on. Kastanozems, Chernozems and Phaeozems are examples. These are excellent wheat soils but high production levels are prevented by lack of moisture.

In still wetter climates the soils are more leached of bases, pH's are acid, clay movement to form argilluvic horizons is typical, organic matter contents are higher, and in general only the application of fertilizers is necessary to make them capable of very high yields. The Orthic Luvisols (Grey-Brown Podzolic soils) are typical.

Wheat is capable of yielding a reasonable crop under both dry and cool conditions and tends to be supplanted by other crops in more favourable areas. Most of the world's wheat lands are, therefore, found in rather inhospitable climates with cold winters and long dry summers. About 80 percent of these areas are more or less deficient in moisture (H.I.<1.0) and crops liable to failure in dry years.

III. c. Distribution of soils in wheat areas.

In general, wheat prefers soils within the texture range from clay loams to silts, containing fair amounts of lime and humus and having neutral to slightly alkaline reactions. However, it can be successfully grown on a large variety of soils with proper soil management, fertilizing and moisture control practice. An estimation of the distribution of wheat growing on various soils is given in Table 4. The estimation is based mainly on maps showing the distribution of wheat production areas and on corresponding soil maps (FAO 1968c, Callaghan and Millington 1956, Guidry 1964, Royen 1954, Reitz 1967). In the new classification system of soils developed by the Soil Resources Office (FAO), for the soil map of the world, and described in detail by Dudal (1968), the soil units used in various parts of the world are correlated under universal legend. This makes it possible, for the first time, to give a relatively homogeneous picture of wheat soils in various parts of the world. However, because of the small scales of both soil and wheat production maps too detailed interpretation of the maps are to be considered with reservations.

The most common wheat soils are the Chernozems, making up some 55-63 million hectares or somewhat less than one third of the total wheat area. The bulk of Chernozems is located in the USSR where more than one half of its wheat is produced on these soils. Other substantial Chernozem-wheat areas are in North America where they make almost one half of the wheat soils in Canada and some 10-12 percent of those in the USA. About three quarters of Chernozems were classified as Haplic (normal) Chernozems (including Rego Black and Orthic Black Soils in Canada's Haploborolls in USA's and Typic Chernozems in USSR's classification systems). Luvic (washed) Chernozems with illuvial clay accumulation (Eluviated Black soils, Canada; Argiborolls, USA; and Podsolized Chernozems, USSR), are almost as common as the Haplic ones in Canada but the total acreage of these is greatest in the USSR. Some Calcic Chernozems with substantial lime or gypsum accumulation exist in the wheat belts of USSR and USA.

The second largest group of wheat soils are the Luvisols, covering some 35-43 million hectares or about one fifth of the world's total wheat land. About a half of them have been classified as Brunic (brown) Luvisols (including Grey-Brown podsolic soils, Australia, Canada; Sols Lessivés modaux, France; Parabraunerde, Germany; Hapludalf and Haploxeralf, USA; Podsolized brown forest soils, USSR) while Chromic (coloured), Luvisols (Terra Rossa, Australia, Italy; Red Brown Earths, Australia; Terra Rossa and Terra Fusca, Germany; Sols fersiallitigues lessivés, France; Solos Mediterraneas Vermelhos ou Amarelos, Portugal; Rhodoxeralf and Haploseralf, USA; Cinnamonic soils, USSR) are somewhat less extensive. Brunic Luvisols are the dominating wheat soils in most European countries but also outside Europe, e.g. India, Turkey and USA, much wheat is grown on these soils. Most extensive Chromic Luvisol wheat areas exist in Australia, Mainland China, Turkey and other Mediterranean countries. Other subgroups of Luvisols are less important as wheat growing soils.

The third largest soil group of wheat areas is that of Kastanozems (including Brown and Dark Brown soils, Canada; Ustolls, USA; Chestnut soils of the dry steppe, USSR) covering some 30-37 million hectares or about one sixth of the world's total wheat land. These are the dominating soils in North American wheat lands where they make over one half of USA's, about one half of Canada's and one third of Mexico's wheat soils. Elsewhere wheat is grown extensively on these soils in the USSR, Argentina, Mongolia, Turkey and in some North African countries. Luvic Kastanozems with illuvial clay accumulation dominate in USA and Mexico while in most other countries Haplic Kastanozems with simple, normal horizon sequence exist more extensively. Some North African wheat soils belong to the subgroup of Calcic Kastanozems including substantial lime or gypsum accumulation in the profile.

The fourth largest group of wheat soils is the Phaeozems (including Brunizems, Argentina; Hapludolls and Argiudolls, USA; Degraded and Podsolized Chernozems and Grey Forest soils, USSR). Most of these soils are located in Eastern Europe (USSR, Romania, Bulgaria, Yugoslavia, Czechoslovakia) and in South and North America (Argentina, Uruguay, USA, Mexico), totalling 15-20 million ha of wheat land.

The fifth group of soils having more than local importance as wheat soils is the group of Cambisols. For these soils (13-17 million hectares), which are relatively evenly distributed all over the world excluding the most northern and southern countries, the typical features are changes in colour, structure and consistency resulting from weathering in situ. Most of these soils in wheat areas have been classified as Eutric (good) Cambisols (including Orthic brown forest soils, Canada; Braunerde, Germany; Sols bruns modaux and Sols bruns eutrophes tropicaux, France; Eutrochrepts, Ustochrepts and Xerochrepts, USA).

The soils described above cover over 80 percent of the world's wheat land. The remaining groups of soils have more or less only local importance like Gleysols in the Netherlands, United Kingdom, Mainland China, Japan and UAR, Vertisols in Uruguay and India, Fluvisols in Italy, Chile and UAR, Solonetz in Australia, Planosols in South Africa and Podsols in Scandinavian countries, Austria and North Korea. In some soils like Xerosols wheat can only be grown successfully under irrigation.

Table 4. An estimation of the distribution of main soil groups in the wheat growing areas of 47 countries covering nine tenths of the world's total wheat area (xxxx=over 50%, xxx= 30-50%, xx= 10-30% and x= less than 10% of wheat area).

	Fluvisols	Gleysols	Rhegosols	Rendzinas	Andosols	Vertisols	Xerosols	Solonetz	Planosols	Kastanozems	Chernozems	Phaeozems	Cambisols	Luvisols	Podsols	Wheat area (1000 ha)	Aver. National yield 1962-66 (kg/ha)
Albania		x												xxxx		130	880
Austria				xx									xxx	xx	xx	314	2606
Belgium													xx	xxxx	x	216	3742
Bulgaria												xxxx		xx		1142	2076
Czechoslovakia				x								xx	xxx	xxx		889	2416
Denmark		x												xxxx	x	94	4140
Finland		x												xxx	xxx	209	1700
France				xxx									xx	xxx		3992	2998
Germany, East													x	xxxx	x	484	3206
Germany, West				x									xx	xxx	x	1384	3386
Greece		x											xxx	xxx		1018	1622
Hungary		xx						x					xx	xxx		1072	1912
Ireland													xx	xxxx	x	53	3284
Italy	xx	xx	xx										xx	xx		4274	2072
Luxembourg				xx									xxxx			67	2230
Netherlands		xxxx														148	4388
Norway															xxxx	2	2510
Poland													x	xxxx	x	1699	2002
Portugal													xxx	xxx	x	523	792
Romania		x										xxx		xxx		3034	1520
Spain													xxxx	x		4190	1102
Sweden														xxxx	xxx	191	3392
Switzerland				xx										xxxx		111	3354
United Kingdom		xxx											x	xxx	x	906	4084
Yugoslavia		xx										xxx	xx	xx		1833	1982
U.S.S.R.										x	xxxx	xx		x		69985	1042
Canada										xxx	xxx					12016	1592
Guatemala													xxx	xxx		40	798
Mexico										xx		xx		xx		633	2270

Table 4 (Cont'd...)

	Fluvi sols	Gley-sols	Rhego-sols	Rend-zinas	Ando-sols	Verti-sols	Xero-sols	Solo-nets	Plano-sols	Kasta-nozems	Cherno-zems	Phaeo-zems	Cambi-sols	Luvi-sols	Pod-sols	Wheat area (1000 ha)	Aver. National yield 1962-66 (kg/ha)
U.S.A.		x								xxxx	xx	x	x	x		20180	1732
Argentina	x		x				x		x	xx		xxx				5214	800
Chile	xx				xx								x	xxx		784	1462
Uruguay						xxx						xxx				380	1054
China, Mainland		xx												xx	x	(27000	950)[1]
India	x					xx	x						xx	xx		12656	828
Japan		xxx			xxx								x			421	2270
Korea, North															xxxx	160	(530)[2]
Mongolia										xxxx						320	964
Turkey							xx			x			xx	xxx		8069	1134
Algeria	x									xx			xx	xxx		1475	638
Libya			xxx				xx	xx								180	240
Morocco	x			x						xxx			x	xx		1635	730
South Africa									xxxx					xx		1030	661
Tunisia	x									xxx			x	xx		845	541
U.A.R.	xxx	xxx														605	2692
Australia						x		xxx						xxx		8205	1300
New Zealand													xxxx	xxx		81	3170
Total																199939	(1264)
Percent of total area	1-2	5-7	<1	<1	<0.2	2-3	1-2	1-2	<1	15-19	28-32	8-10	6-8	18-22	1-2	100	

1) Estimations based on earlier data.

2) Average of two years.

III. d. Wheat yields in relation to soils.

A general description of soils of wheat areas and an estimation of their distribution were given in the previous chapter. Because also data of national yields are available it is possible to make estimations* of wheat yields obtained on different soils, however, with certain reservations:

(a) It must be borne in mind that an average yield harvested from a certain soil cannot be considered as an index of the potential of this soil to grow wheat.

(b) Climatic factors are correlated to yields and soils and their effect may be greater than that of soil itself.

(c) Soil and crop management, including fertilization, irrigation, varieties and plant protection, etc. vary considerably from one area to another and consequently from one soil to another causing differences in yields which are not directly related to soils.

(d) Therefore, the estimations of wheat yields given below must be considered as results of all the combined effects (soils, climate, management, etc.) rather than soils alone. In other words, these figures are estimates of yields harvested from various soils in prevailing conditions, not the estimates of the growing potential of the soils.

Table 5. Estimation of yields of wheat grown on different soils in wheat growing areas in 47 countries covering about nine tenths of the world's total wheat area.

Soils	Estimated yield, kg/ha	Soils	Estimated yield, kg/ha
Gleysols	2600	Phaeozems	1500
Luvisols	2100	Chernozems	1300
Podsols	1900	Kastanozems	1100
Cambisols	1800	Solonetz	900
Fluvisols	1700	Vertisols	900
		Xerosols	700

The average yield estimated from Gleysols (2600 kg/ha) is considerably higher than yields from any other soil. This is mainly because these soils are more or less dominant in the Netherlands and the United Kingdom (Table 4) in both of which abundant fertilizers have been used, climatic conditions are favourable, and consequently national yields are among the three highest in the world.

Luvisols and Cambisols, ranking second and fourth in yields (2100 and 1800 kg/ha) are typical wheat soils in most European countries and have been subject to relatively heavy fertilization, which, naturally, has contributed to the high yields.

The average yield of wheat grown on Fluvisols is as high as 1700 kg/ha mainly because of the high yields in U.A.R., where these soils are relatively more abundant than in other countries.

In spite of the low yields in North Korea, where Podsols are the dominating soils, the average wheat yield on Podsols amounts to about 1900 kg/ha due to higher yields in North and Middle Europe where most of these soils exist.

Phaeozems, existing mostly in Eastern Europe and in Southern America, Argentina and Uruguay, yield up to 1500 kg/ha.

* Yield estimations given in Table 5 were calculated on the basis of the relative distribution of different soils in wheat growing areas of 47 countries and on corresponding average national yields using the principle of weighted averages.

Chernozems, which usually have been considered as one of the best soils, produced an average yield of 1300 kg/ha. The reason for the relatively low yields, however, is apparently not the low yielding potential of these soils but their location in the semi-arid areas of USSR, Canada and USA, where moisture is the main limiting factor of crop growth.

Partly for the same reason the wheat yields obtained on Kastanozems, Solonetz, Vertisols and Xerosols are lower than those of other soils in more humid areas. Particularly the low yields obtained in conditions of very low precipitation in Libya lower the average yields on Xerosols and Solonetz.

The difference between the lowest and highest wheat yields obtained on different soils is almost fourfold (Table 5). Even though it is evident that much of the difference is due to climatic conditions and varying soil and crop management practices, the quantitative contribution of these factors is very difficult to evaluate. However, it may be safely stated that the growing potential of the various soils is much more uniform than is indicated by the figures in Table 5.

IV. WHEAT PRODUCTION, FERTILIZER USE AND FERTILIZER

RESPONSES IN DIFFERENT COUNTRIES

IV. a. Europe

In 1948-52 Europe (excluding U.S.S.R.) contributed 23.3 percent and in 1962-66 22.8 percent of the world's total wheat production. In 1966, on the average, about 18.5 percent of the arable land in Europe was under wheat some of which was grown in every European country (Except Iceland). However, nine countries contributed 50 million tons or about 80 percent of the total production: France (11.3 million tons); Italy (9.4); Romania (5.1); Spain (4.8); Yugoslavia (4.6); West Germany (4.5); Poland (3.6); United Kingdom (3.5) and Bulgaria (3.2). The production per capita (140 kg) exceeded the world average by about 56 percent and the yields harvested were far higher than in any other region of the world.

1. Albania

Wheat is the second crop in importance (after maize) in Albania where it was grown on 130,000 hectares or on 26 percent of the cultivated land area in 1966. The production, 115,000 tons, corresponded to 60 kilograms per capita. From 1948-52 to 1962-66 the average annual wheat production increased by 20,000 tons or 22 percent.

Table 6. Area, production and yield of wheat and fertilizer use - Albania.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizer kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	94	89	950	-	-	-	-
1962-66	122	109	880	4	7	2	13
Incr. (+) or decr. (-)	+28	+20	-70	-	-	-	-

This increase was entirely obtained by increasing the wheat area since the average hectare yields decreased during the corresponding period. One reason for the low yields (second lowest in Europe) is apparently the low level of fertilizer use which, for example, in the latter period given above, was only 13 kilograms per arable hectare and less than in any other European country. Toward the end of this period the consumption of fertilizers increased to about 17 kg/ha, most of the increase consisting of phosphates. No commercial fertilizers are produced in the country.

2. Austria

Wheat is the most important grain crop in Austria where it was grown on 314,000 hectares or on 19 percent of the arable land in 1966. The corresponding figures for barley, rye and oats were 230,000, 144,000 and 126,000 hectares respectively.

The wheat production, 897,000 tons, corresponded to 123 kg per capita in 1966. The consumption of wheat as food was 59 kg per capita in terms of flour in 1966/67 (Int. Wheat Council, 1968).

Table 7. Area, production and yield of wheat and fertilizer use - Austria.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	204	348	1710	13	20	16	49
1962-66	284	741	2610	46	67	81	194
Incr. (+) or decr. (-)	+ 80	+ 393	+ 900	+ 33	+ 47	+ 65	+ 145

Austria more than doubled its wheat production from 1948-52 to 1962-66. More than half (58%), of the 393,000 tons increase in production is due to increased national yield and the rest (42%), due to expansion of wheat area.

A substantial increase in the annual use of fertilizers, from 49 kg per arable hectare in 1948-52 to 194 kg/ha in 1962-66 has raised the average Austrian farmer to twelfth as a consumer of fertilizers, harvesting also the twelfth highest wheat yield in the world. A similar trend seems to continue, since in the end of the latter period (in 1966), the consumption of fertilizers was 211 kg/ha and the average national wheat yield 2,860 kg/ha.

Differing from most other countries the use of potassium fertilizers now considerably exceeds that of nitrogen and phosphorus and about 45 percent of the increase in fertilizer use since 1948-52 is due to potassium. If the increase of the average national wheat yield is considered as an index of response to increased use of fertilizers since 1948-52, the response factor would be 6.2 kg wheat per 1 kg nutrient given in fertilizers. A response of about half of that would still be economical in Austrian conditions*).

Austria imports almost all of its potassium and about one half of its phosphorus but produces 2.5 times as much nitrogen fertilizers as is used in the country itself.

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*) 1966 prices: Average price for the three nutrients based on the ratio of their use in practice.

3. Belgium

In Belgium, as in most European countries, wheat is the principal grain crop covering about 24 percent of the arable land and 43 of the cereal area in 1966.

In spite of the relative importance of wheat in Belgian agriculture and of very high yields (fourth highest in the world in 1962-66), the production (660,000 tons in 1966) corresponds to only about 86 kg per capita because of the high population. This is somewhat less than what is consumed as food within the country. (Int. Wheat Council 1968).

Table 8. Area, production and yield of wheat and fertilizer use - Belgium.

Periods and Change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	163	525	3220	84	93	130	307
1962-66	216	810	3750	158	138	194	490
Incr. (+) or decr. (-)	+ 53	+ 285	+ 530	+ 74	+ 45	+ 64	+ 183

From the five year period of 1948-52 to that of 1962-66 the production of wheat increased by 285,000 tons or 54 percent. About two thirds (67%) of this increase was due to 53,000 hectares expansion in annual wheat cultivation area and one third (33%) to increase in average annual yield.

For a long time Belgium has been one of the three leading countries in fertilizer consumption with Netherlands and New Zealand. In 1948-52 307 kilograms of nutrients per arable hectare were applied in mineral fertilizers, an amount that even now is exceeded only by five countries. In 1966 the consumption was 520 kg (168 kg N, 160 kg P_2O and 192 kg K_2O) per arable hectare and the ratio between the three nutrients was somewhat changed in favour of nitrogen and phosphorus. About one half of the production of nitrogenous and one third of that of phosphate fertilizers have been used in Belgium, while potash has been imported.

Because of the high yield level in Belgium and already heavily fertilized soils the response of average national wheat yield to increased use of fertilizers is lower than in most other countries. (Fig. 36-37). Therefore, Belgian agricultural science has recently paid increasing attention to other factors affecting the crop growth. As an example, the interesting study carried out by Stryckers and van Himme (1966) on the interaction between growth regulator (CCC), herbicides and nitrogen fertilization is quoted here. According to their results, CCC (1.5-2 kg/ha) had no adverse effect on herbicidal properties, and its presence in the spray gave improved control of: Matricaria recutita in winter wheat using MCPA and DNOC; Stellaria media in spring wheat using MCPA; Alopecurus myosuroides and Apera spica-venti using DNOC and ioxynil; Poa annua in spring wheat using DNOC. Control of Poa annua by DNOC in winter wheat and of Stellaria media by ioxynil in spring wheat was adversely affected by CCC. Adding urea at 25 kg N/ha to CCC + growth substances tended to emphasize the shortcomings of the herbicides, especially on plots containing Polygonum persicaria and Stellaria media and where mecocrop was used, though top-dressing with N 1-2 weeks later also did this. Improvements in control of A. myosuroides and A. spica-venti in winter wheat with DNOC and Stellaria media in spring wheat with DNOC or ioxynil in the presence of CCC were obtained by adding 40 kg N/ha as urea. The reduction in straw length given by CCC alone was 5-25% in winter wheat. Figures for CCC and MCPA + CCC, respectively, for spring wheat were: 24-41%, depending on the variety. The effect of CCC on winter wheat was increased by adding 0.5 ioxynil-Na and still more by 5 kg DNOC-ammonium. Ioxynil by itself increased straw length. Effects on wheat were somewhat reduced by adding 40 kg N/ha as urea to the spray. Ear length was decreased by MCPA and increased by N. CCC plus herbicide reduced the number of fertile tillers; this was partially counteracted by N except for DNOC + CCC + urea in spring wheat and ioxynil + CCC + urea in winter wheat. Hoeing adversely affected tillering in winter wheat; this was counteracted by CCC plus topdressing with N. CCC tended to reduce grain yields even when herbicides were added, unless extra N was applied; 40 kg N/ha as ammonium nitrate, applied 1 week after spraying spring wheat, was more effective than adding urea to the spray.

4. Bulgaria

Wheat was grown in Bulgaria on 1,142,000 hectares in 1966 or on 25 percent of the arable land area. It was the most important cereal of the country covering an area equal to that of its four nearest competitors combined (maize 574,000, barley 416,000, oats 113,000 and rye 41,000 ha).

In 1966 Bulgaria produced 387 kh wheat per capita which was the highest in Europe (excluding USSR) and fourth highest in the world.

Table 9. Area, production and yield of wheat and fertilizer use - Bulgaria.

Periods and Change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1432	1776	1240	3.4	0.5	0.1	4.0
1962-66	1184	2442	2060	35.6	24.3	2.1	62.0
Incr. (+) or decr. (-)	- 248	+ 666	+ 820	+32.2	+23.8	+2.0	+58.0

From 1948-52 to 1962-66 the average annual wheat production increased by 37.5 percent. This is entirely due to the 65 percent increase in hectare yields because during the same period a considerable decrease in wheat area (17.4%) took place.

Very little fertilizers were used two decades ago. In 1948-52 the consumption was only 4 kgs per arable hectare but in 1962-66 the corresponding figures were 15 times higher or 62 kg/ha, which fairly well explains the substantial increase in the national wheat yield. The emphasis on fertilizer consumption has been on nitrogenous and phosphate fertilizers, while the use of potash fertilizers has been very low.

Bulgaria's fertilizer production in 1966 met the domestic consumption of nitrogenous fertilizers and about two thirds of phosphate fertilizer consumption.

In most Bulgarian field trials good responses to nitrogen and phosphorus have been obtained while to potassium wheat has responded somewhat less. Ermolaev (1965) found that on strongly leached chernozem soil the most favourable nitrogen-phosphate rate for dryland wheat was 80 kg N and 30 kg P_2O_5 per hectare. Additional phosphate doses increased the yield only insignificantly. Increases of protein and gluten contents of grain were mainly due to nitrogen while phosphate did not affect substantially these two qualities. Velchev and Balevska (1965) obtained both highest yield and highest monetary return when fertilizing Bezostaya wheat with 90 kg N and 60 to 90 kg P_2O_5 per hectare on slightly leached chernozem soils. The response to nitrogen was twice that to phosphate but both nutrients had the highest effectiveness in their combined use. Addition of 90 kg K_2O/ha had only a slight effect on yield in combination with low N and P rates while at high N and P application levels it exerted an inhibitory effect on wheat yields. Similar results were obtained by Draganov and Filipov (1966) on leached chernozem smolnitza soils.

On the basis of the results of trials carried out in 1959 - 1963 on leached chernozems Ermolaev (1964) found that the most suitable period for fertilizing winter wheat with ammonium nitrate was from the end of November to the beginning of May. Split application did not prove to be any better than single application at the most suitable time.

In three-year experiments on the fertilization of irrigated wheat the highest average yield, 4,750 kg/ha, exceeding the yield of check plots by 68 percent, was obtained with the combination of 160 kg N, 160 kg P_2O_5 and 160 kg K_2O/ha (Table 10) but the highest monetary return (132.3 leva/ha) was obtained with a 160 - 120 - 100 treatment.

Table 10. Results of three-year fertilization experiment on irrigated wheat near Pav likeni Bulgaria (Petkov, 1966).

Fert. Treatment $N - P_2O_5 - K_2O$ kg/ha	Yield kg/ha	Yield increase			Net profit Leva/ha	Response ratio kg grain/ kg nutr.
		kg/ha	Value Leva/ha	Costs Leva/ha		
check	2840	-	-	-	-	-
60-80-100	3850	1010	121.2	53.8	67.4	4.2
90-80-100	4230	1390	166.8	62.8	104.0	5.1
90-120-100	4260	1420	170.4	75.3	95.1	4.5
120-80-100	4410	1570	188.4	71.8	116.6	5.2
120-120-100	4510	1670	200.4	84.5	115.9	5.2
120-160-100	4470	1630	195.6	94.3	101.3	4.3
160-120-100	4720	1880	225.6	93.3	132.3	4.9
160-160-160	4750	1910	229.2	103.3	125.9	4.0

5. Czechoslovakia

Wheat was grown in Czechoslovakia on 889,000 hectares or on 16.5 percent of the arable land in 1966. It is the most important cereal of the country and constituted 38 percent of its cereal production in 1966. The production per capita (158 kg) is somewhat above the average of Europe. In spite of yearly variation in the wheat area there has been no change in the average wheat acreage from the five-year period 1948-52 to that of 1962-66.

Table 11. Area, production and yield of wheat and fertilizer use - Czechoslovakia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	785	1493	1900	10	12	15	36
1962-66	785	1896	2415	41	44	61	145
Incr. (+) or decr. (-)	± 0	+ 403	+ 515	+ 31	+ 32	+ 46	+ 109

Thus, the 27 percent increase in wheat production is a direct consequence of a similar increase in the national yield. The main reason for the higher yields during the latter period is apparently the threefold increase in the use of fertilizers. Potassium consumption exceeds that of the other two nutrients even though during recent years the relative increase of nitrogenous fertilizers has been somewhat higher. In 1966 the consumption of nutrients applied in fertilizers was 173 kg per arable hectare (52 kg N, 48 kg P_2O_5 and 73 kg K_2O/ha). The production of phosphate fertilizers approximately meets the consumption, while about 10 percent more nitrogenous fertilizers have been consumed than produced in the country. Practically all potash fertilizers are imported.

Among the most important factors limiting the efficient use of soils in Czechoslovakia are the unsatisfactory water condition of soils (27 percent of soils are in waterlogged condition) and the acidity of soils (66 percent require liming). Over one third of the agricultural land is succeptible to erosion, four fifths have too low humus content, and on half of the land the tillage layer is too shallow. About 50,000 hectares have been spoiled by coal mining, 40,000 hectares are saline and some 200,000 otherwise not fertile (Damaska 1966).

In Czechoslovakian conditions the time of ploughing and pre-sowing preparation of soils has a very substantial effect on the wintering and on yield of winter cereals, especially of wheat. In the experiments reported by Petr. et al, (1966) as much as 635 kg/ha (three-year average) yield increase was obtained by timely ploughing and tillage over those carried out after the optimum time. Relatively small differences due to fertilizer placement on wheat yields were found in the three-year field trials reported by Hrbacek and Ambrozova (1966). According to Kordik and Moudry (1966) the economic optimum of nitrogen fertilization of winter wheat (Fig. 6) varies from about 65 to 95 kg N per hectare depending on the method of application.

For split application both the maximum profit rates of N and yield increases obtained are higher than for single application but the difference in the response ratios (about 8 and 7 kg wheat per kg N, respectively) is rather small.

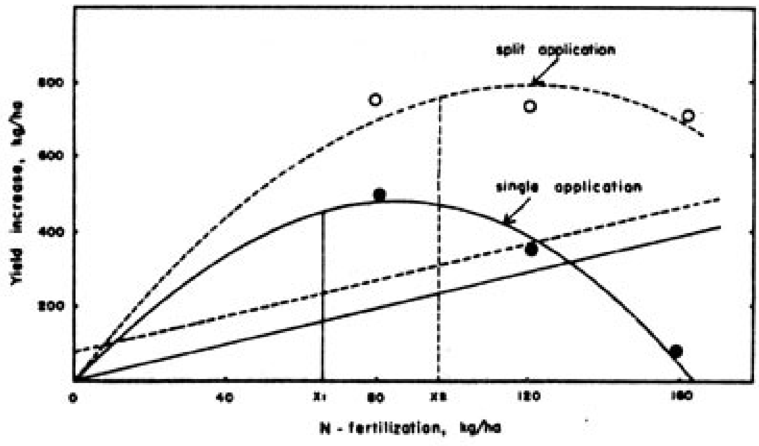

Fig. 6. Economic optimum of single (X_1) and split applications (X_2) of nitrogen for winter wheat (Kordik and Moudry, 1966).

6. Denmark

Wheat plays a relatively small role in Danish agriculture, in 1966 it occupied only 3.5 percent of the arable land area or less than one tenth of the fields under the major cereal, barley. However, because of the very high yields, second highest in the world in 1962-66 and highest in 1966, the production of wheat exceeds the consumption within the country. In 1966, for example, 81 kg wheat was produced per capita while the consumption as food (in terms of wheat flour) was 42 kg (Int. Wheat Council 1968). From the five-year period, 1948-52 to that of 1962-66, the wheat production almost doubled despite a large decrease during the latter period (644,000 tons in 1962, 390,000 tons in 1966).

Table 12. Area, production and yield of wheat and fertilizer use - Denmark.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	78	285	3,630	24	31	41	96
1962-66	127	527	4,150	64	45	65	174
Incr. (+) or decr. (-)	+ 49	+ 242	+ 520	+ 40	+ 14	+ 24	+ 78

About 81 percent of the 242,000 ton increase in production is due to the 49,000 hectares expansion in wheat area and 19 percent due to increased national wheat yield.

The consumption of commercial fertilizers in Denmark even though almost doubled from 1948-52 to 1962-66 is still relatively low compared with other countries obtaining wheat yields on a correspondingly high level (See Fig. 36 p.114). Besides favourable climatic conditions and advanced farming methods adopted by Danish farmers, the fact that the nutrients applied in commercial fertilizers are equalled by those brought into soil in farmyard manure (Landbrugsraadet 1967) at least partly explains the high yields.

In spite of increasing production of fertilizers in Denmark, about three fourths of nitrogenous, one fourth of phosphate, and all potash fertilizers were imported in 1966.

According to the report of CIMMYT (1969) the Mexican dwarf varieties Tobari 66 and Inia 66 are being grown successfully also in Denmark. At these high latitudes, it is necessary to use high rates of seeding (250 kg/ha) and heavy fertilization to obtain high yields. When properly sown and fertilized, the two Mexican varieties are reported to yield as highly as the best European spring wheat varieties, and have the advantage of being 2 to 2½ weeks earlier in maturity.

7. Finland

In Finland, the world's most northern agriculture country, oats and barley are the main cereals grown. In 1966 these covered 479,000 and 321,000 hectares respectively, while the wheat area was 209,000 hectares or 7.6 percent of the arable land. Because of climatic limitations wheat was grown mainly in the southern part of the country. In 1966 the production of wheat corresponded to 79 kg per capita. From 1948-52 to 1962-66 the wheat production increased by 66 percent, 81 percent of which was because of the increase in wheat area and 19 percent because of higher yields.

Table 13. Area, production and yield of wheat and fertilizer use - Finland.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	171	263	1,540	7	25	13	45
1962-66	254	436	1,720	32	43	35	110
Incr. (+) or decr. (-)	+ 83	+ 173	+ 180	+ 25	+ 18	+ 22	+ 65

During the latter period almost two and a half times as much commercial fertilizers were used as in 1948-52. The most substantial increase took place in the use of nitrogenous fertilizers. Since Finland is mainly a dairy country, nutrients brought into the soil in farmyard manure make a quite substantial addition (approximately 15 kg N, 10 kg P_2O_5 and 25 kg K_2O per arable hectare) to the figures given above. Finland is producing all the nitrogenous and about three fourths of the phosphate fertilizers used in the country but importing practically all potash fertilizers.

Both spring and winter wheats are growing in Finland on about equal areas. All of the most common winter wheat varieties, and three out of five of the best spring varieties, have been developed in Finnish breeding stations. To develop early maturing spring wheats is one of the breeders' main problems because of the short growing season (Manner, 1969). For this reason an early planting usually gives better results than late planting (Fig. 7, A).

Fertilizer placement to a depth of 10-12 cm. has proven to be a very beneficial treatment in Finnish condition improving both the quality and quantity of spring wheat yields. Examples of the results of fertilizer placement trials are given in Fig. 7, B and C.

The trials carried out in 1960-66 showed an average of 330 kg/ha (from 2520 to 2850 kg/ha), or 13 percent yield increase due to fertilizer placement over the broadcast fertilized plots when 52 kg N, 85 kg P_2O_5 and 59 kg K_2O /ha were used on the average (Larpes, 1968). Therefore it is estimated that in 1969 for about 35-40 percent of the spring cereals in southern Finland fertilizers were placed in rows under the seed rows for decreasing the effect of draught, obtaining a better fertilizer response and earlier maturity, thus improving the quantity and quality of yields (Larpes, 1969).

The effect of the time of fertilizer application, particularly of nitrogen, on the yield and protein content of winter wheats is quite considerable under southern Finland conditions (Table 14). Especially the advantage of spring applications on yield and late applications on protein content are obvious.

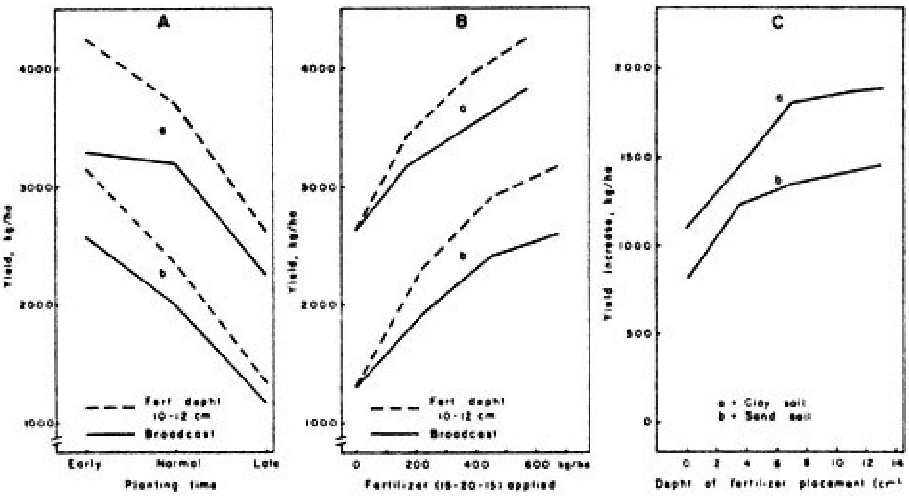

Figure 7. Effect of fertilizer (15-20-15, 600 kg/ha) placement and planting time (A), amount and method of fertilizer application (B), and depth of fertilizer (15-20-15, 600 kg/ha) placement (C) on spring wheat yields in sandy clay (a) and fine sand soil (b) in southern Finland (Larpes 1968).

Table 14. Effect of time of nitrogen application (100 kg/ha) on yield and protein content of winter wheat in S.W. Finland (Köylijärvi 1969).

Time of nitrogen application	Yield kg/ha	Yield incr. %	Response ratio kg/kg	Protein content %
Check (without nitrogen)	4870	-	-	10.4
20.9 (10 days after planting)	5520	13	6.5	11.7
30.10 (soil not frozen)	5520	13	6.5	11.8
9.12 (soil frozen)	5610	15	7.4	12.6
21.3 (35 cm snow)	5690	17	8.2	11.7
12.4 (snow melted)	5510	13	6.4	11.9
2.5 (normal appl. time)	6240	28	13.7	13.2
16.5 (late " ")	6080	25	12.1	14.3

The soils of Finland are relatively acid, in general, and liming is therefore a profitable practice. The average results of trials during 1928-1968 show that yield increases of most crops including wheat due to 2, 4 and 8 tons of lime per hectare cover the costs of liming in about 2, 3 and 4 years respectively, and the effect of liming lasts up to 20 years (Keränen and Marjanen 1970).

8. France

France is the fifth biggest producer of wheat in the world and first in Europe (excluding USSR). It is also one of the eight main wheat exporting countries In 1966 19.4 percent of the arable land of France was under wheat, which is the main cereal grown in the country. The corresponding figures for its nearest competitors, barley, oats and maize were 12.9, 5.3 and 4.7 percent, respectively. The production of wheat per capita was 228 kg and its consumption as food in terms of flour 82 kg (Int. Wheat Council 1968).

From the five-year period 1948-52 to that of 1962-66 there was no change in the average area annually under wheat and thus the 65 percent increase in production was wholly derived from the correspondingly increased yields. The threefold increase in fertilizer use is likely to explain the substantially higher yields of the latter five-year period.

Table 15. Area, production and yield of wheat and fertilizer use - France.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,264	7,791	1,830	13	20	18	51
1962-66	4,264	12,840	3,010	41	59	47	147
Incr. (+) or decr. (-)	± 0	+ 5,049	+ 1,180	+ 28	+ 39	+ 29	+ 96

France is practically self-sufficient in phosphate fertilizers and produces more nitrogenous and potash fertilizers than needed for its own use.

Even in a country like France where climatic variations between different years and districts are less pronounced than in many other countries, the effect of climatic differences on the response of wheat to fertilizers can be quite substantial. For example, a heavy autumn-winter rainfall can cause losses of nitrogen through leaching. These, however, can be compensated to a great extent by increased nitrogen fertilization (Tables 16 and 17).

Table 16. Effects of previous season (September-December) rainfall and nitrogen fertilization on the yield of winter wheat (Thiollet, 1966).

kg N/ha \ Sept.-Dec. rainfall, mm	1966 420 mm		1965 218 mm		Difference between the years, %
	Yield, kg/ha	No. of trials	Yield, kg/ha	No. of trials	
0	2350	166	3260	109	28
50	3430(22)*	71	4220(19)	63	19
80	3950(20)	166	4450(15)	110	11
110	4360(18)	166	4520(11)	109	3.5

*/ Figures within parentheses = response ratio, kg grain / kg N.

Table 17. Effects of winter (October-March) drainage and nitrogen fertilization on the yield of winter wheat (Studer and Thiollet, 1967).

Drainage (mm)	Grain yield, kg/ha			
	0 kg N/ha	50 kg N/ha	80 kg N/ha	110 kg N/ha
200	3000	3400 (8)*	3900 (11)	4200 (11)
300	2500	3200 (14)	3700 (15)	4100 (14.5)
400	2000	3100 (22)	3600 (20)	4000 (18)

*/ Figures within parentheses = response ratios, kg grain / kg N.

Therefore, the optimum of fertilization is also usually higher in years of heavy winter rainfall. E.G. in 1964-67 it was 115 kg N/ha on the average, but varied considerably in different years (Fig.8).

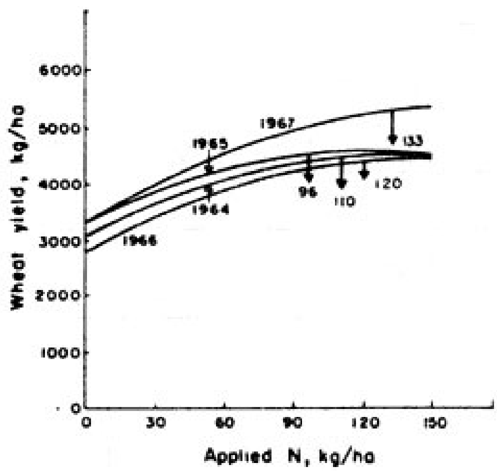

Figure 8. Average effects of nitrogen on wheat yields in four years and optimum nitrogen doses in each year. The results are based on 801 trials. Average P_2O_5 and K_2O applications were 101 and 86 kg/ha respectively. (Anonymous, 1968).

The optimum doses of N reported by Lecompt (1967) for the years 1964-66 were only 2-3 kg lower than those given in Figure 8 and the response ratios at optimum N levels were about 13 kg grain/kg N.

Besides annual and regional climatic differences other local factors may also have a marked effect on response. Results, from some main wheat growing areas of France, are reported in the following.

Table 18. Response of four wheat varieties to nitrogen fertilizer in two districts in 1964 (Lesage1565).

kg N/ha / Varieties	Grain yield, kg/ha							
	0	50	80	110	0	50	80	110
Etoile de Choisy	3140	4060	4420	4710	2560	3440	3630	3860
Languedoc	3130	4050	4430	4730	2400	3280	3540	3690
Champlein	3160	4060	4440	4810	-	-	-	-
Magali	-	-	-	-	2290	3150	3450	3570
Aver. yield, kg/ha	3150	4050	4430	4750	2420	3290	3540	3710
Aver. response ratio, kg grain / kg N	-	18.0	16.0	14.5	-	17.4	14.0	11.7
Resp. ratio between successive N treatments		18.0	12.6	10.7		17.4	8.3	5.7

Table 19. Average yields and response ratios of three varieties in 17 trials in Northern France and in the Paris district (Anonymous 1967).

kg N/ha / Variety	Yield, kg/ha			
	0	60	90	120
Rex	2430	3400	3750	4020
Aronde	2430	3610	4070	4170
Horizon	2620	3700	4090	4370
Average yield	2490	3570	3970	4190
Average response ratio	-	18.0	16.4	14.2

In northern France and in the Paris district the optimum dose of nitrogen in 1966 was 116 for variety Aronde and over 120 kg/ha for varieties Rex and Horizon.

Table 20. Average yield increases and response of wheat to nitrogen for six years (1962-67) in the plains of Neuville-du-Poitou (Studer and Thiollet 1967).

N appl. range kg/ha	Yield increase kg/ha	Resp. ratio kg grain/kg N
0 - 50 N/ha	800	16.0
0 - 80 "	1250	15.6
0 - 110 "	1600	14.5
50 - 80 "	450	15.0
80 - 110 "	350	11.7

Table 21. Wheat yields at different nitrogen fertilization levels. Average results of eight trials in Western France (Lesage 1964).

kg N/ha applied					
	at tillering	50	50	50	50
	at heading	0	20	40	60
	total	50	70	90	110
Yield kg/ha		3750	4210	4480	4570

The response ratio within the range 50-70 kg N/ha level was 24 kg grain/kg N, decreased to 13 kg/kg at 70-90 level and to 4.5 kg/kg at 90-110 kg N/ha level. The optimum dose in Western France was 98 kg N per hectare.

In Champagne by increasing the nitrogen fertilization by 60 kg/ha (from 50 to 110 kg/ha) the following response ratios were obtained (Chavange and Colas, 1965).

Year	1961	1962	1963	1964
kg grain/kg N	13.8	11.9	10.9	7.5

Even though the effect of the time of nitrogen application may vary in different years and districts, the four-year (1964-67) trials in wheat areas North of the Seine and Beauce-Brie (Anonymous, 1968), indicate apparent advantages of late N applications. The average yields of winter wheat of 32 trials with 110 kg N/ha, applied at different times, were as follows:

November	4540 kg/ha	February	4540 kg/ha
December	4490 "	March	4620 "
January	4390 "	April	4790 "

Split applications of nitrogen have been found to decrease the losses through leaching, particularly at high nitrogen levels (Studer and Thiollet 1967).

9. Germany, Eastern

Wheat was grown on 9.7 percent of the arable land in Eastern Germany in 1966. The corresponding figures for rye, barley and oats were 15.5, 10.5 and 5.2 respectively. Wheat production per capita (95 kg) was 45 kg less than the average in Europe but slightly above the world average.

From 1948-52 to 1962-66 there was a slight decrease in the wheat cultivation area but because of a 22 percent average increase in yields the average annual production was about 17 percent higher during the latter period.

Table 22. Area, production and yield of wheat and fertilizer use - East Germany.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	472	1,243	2,630	39	16	77	132
1962-66	451	1,453	3,220	74	58	114	246
Incr. (+) or decr. (-)	- 21	+ 210	+ 590	+ 35	+ 42	+ 37	+ 114

Potassium is the main nutrient given in commercial fertilizers even though during the last two decades the relative use of phosphate and nitrogenous fertilizers has increased more than that of potash. In 1966 the fertilizer consumption of 90 kg N, 66 kg P_2O_5 and 12.6 kg K_2O totalling 282 kg per arable hectare, was eighth highest, and the national wheat yield ninth highest, in the world. The production of nitrogenous and phosphate fertilizers corresponds to about three fourths of their consumption but over three times as much potash is produced as is used in the country.

Among the fertilizer trials, the long-term (1903-1962) fertilization experiments at Lauchstädt on Chernozem soil should be mentioned. The average results of the last ten years showed a 45 percent decline in wheat grain and a 50 percent decline in straw yields in plots which had received neither fertilizers nor manure as compared to those receiving both manure and NPK (Table 23).

In the case of the other three crops included in the experiments, yield declines were even greater (potatoes 80%, sugarbeets 61% and barley 61%).

The effect of farmyard manure (over the plots receiving no manure) was 10 to 15% in NPK and NP plots, around 25% in NK plots and 53-54% in N, PK and O plots. These results also clearly indicate the importance of balanced use of fertilizers, especially the principal role of NP combinations on this soil. In general, both manure and fertilizers affected straw yields slightly more than grain yields.

The uptake of nutrients by wheat varied between 46 to 94 kg N, 22 to 43 kg P_2O_5 and 41 to 100 kg K_2O/ha at low yield-low fertilization and high yield-high fertilization levels respectively. The applied farmyard manure as well as the annual N, P or K fertilizer applications were, in general, sufficient to prevent a serious decline in the soil nutrient status, and when manure was applied together

Table 23. Winter wheat yields (averages of 1955-1964) in a long-term (1903-1964) fertilization trial on Chernozem soil at Lauchstädt (Ansorge, 1966).

Fertilization: Farmyard manure *	Fertilization: Mineral Fertilizers **	grain yield kg/ha	grain yield relat.	Straw yield kg/ha	Straw yield relat.
20 tons/ha	NPK	4950	100 (100)	7980	100 (100)
"	NP	4970	100 (100)	7960	100 (100)
"	NK	4740	96 (96)	7460	93 (93)
"	N	4780	97 (97)	7610	95 (95)
"	PK	4090	83 (83)	6220	78 (78)
"	none	4210	85 (85)	6430	81 (81)
none	NPK	4500	100 (91)	7080	100 (89)
"	NP	4450	99 (90)	6920	98 (87)
"	NK	3800	84 (77)	5950	84 (75)
"	N	3430	76 (69)	5340	75 (67)
"	PK	2620	58 (53)	4060	57 (51)
"	none	2730	61 (55)	3970	56 (50)

*/ Applied every second year; cont. 61 kg N, 29 kg P_2O_5 and 81 kg K_2O/ha.

**/ Annual rates: 61 kg N (38 kg in combination with manure application), 75 kg P_2O_5 and 112 (100) kg K_2O/ha.

with fertilizers an improvement in the soil nutrient status followed. Farmyard manuring also increased the levels of soil magnesium and micronutrients (B, Cu, Mn, and Mo). In plots which received no manure and none, or one of the two only of the three fertilizer nutrients, depletion of soil nutrient reserves (for those elements which were not applied) was marked. It is apparent that on less fertile soils productivity would in most cases decline in a much shorter period of time.

The results of a series of nitrogen fertilization trials (Table 24) show that, on the average, nitrogen increases the yield of winter wheat up to 80 kg N/ha at which level no further yield response to nitrogen was obtained. Effects of nitrogen on protein content of grain and protein yield, however, were more linear. Nitrogen was most effective on low-yielding light soils which also had low soil-testing values.

Table 24. Average results of fertilizer trials on the effect of nitrogen on grain yield and protein content of winter wheat (Görlitz 1966).

Applied N kg/ha	Grain yield (aver. of 40 trials): Yield kg/ha 1/	Response ratio kg grain/kg N	Response to last kg N kg grain/kg N	Grain protein (aver. of 14 trials): % of dry matter 2/
0	3220	-	-	12.3
20	3510	14.5	13	12.6
40	3720	12.5	8	12.9
60	3850	10.5	4	13.2
80	3890	8.4	0	13.5

1/ grain yield (kg/ha): $y = 3220 + 16.63\,x - 0.1031\,x^2$

2/ protein content (%): $y = 12.3 + 0.015\,x$

10. Germany, Federal Republic

In West Germany the wheat area was somewhat larger than that of other cereals in 1966. It covered 16.9 percent of the arable land while barley, rye and oats occupied 15.7, 12.4 and 9.5 percent respectively. The production per capita was 79 kilograms.

During the last two decades there has been a considerable increase in wheat area, production and yields.

Table 25. Area, production and yield of wheat and fertilizer use - Germany, Fed. Rep.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1,020	2,669	2,620	44	49	80	173
1962-66	1,390	4,706	3,390	99	94	138	331
Incr. (+) or decr. (-)	+ 370	+ 2,037	+ 770	+ 55	+ 45	+ 58	+ 158

About 55 percent of the increase in production from 1948-52 to 1962-66 was due to expanded wheat area and 45 percent due to higher yields.

During the latter period the average West German farmer harvested sixth highest wheat yields in the world and ranked fourth as a consummer of fertilizers per hectare.

Potassium plays a major role in fertilizer use in West Germany although the relative proportion of the other two nutrients has been increasing. In 1948-52 potassium (K_2O) made 46 percent of the total consumption of fertilizer nutrients. In 1962-66 the figure was 42 and in 1966 39 percent.

West Germany is self-sufficient in all three fertilizer nutrients and is one of the leading fertilizer exporters.

Besides the large scale experimental work aiming at higher yields through correct fertilizer use much attention has recently been paid to investigations concerning the improvement of the quality of wheat produced in West Germany. For example, the results of three-year experiments including eight spring wheat and ten winter wheat varieties (Günzel 1968) indicate that considerable improvement both in the quality and quantity of yields can be obtained with late nitrogen applications. In these experiments late applications of N (100 kg/ha in four 25 kg doses in addition to 60-160-160) increased yields by more than 300 kg/ha on the average without causing lodging, increased the 1000 grain weight, increased the protein content of spring wheats from 10.6 to 15.3 and of winter wheats from 11.9 to 15.0 percent, and sedimentation values from 27 to 61 and 35 to 53, respectively. Boguslawski (1965) reported results on similar lines (Fig. 9).

The influence of CCC on wheat yield has also been the subject of several studies during recent years (e.g. Schröder and Rhode 1965, Hanus 1967, Martin 1968). The direct value of CCC seems to be in preventing losses in yield from lodging through shortening (18-29%) and strengthening the stalks and its indirect value in improving the quality and quantity of yield through allowing increasing use of nitrogen fertilizer. Grain quality, in general, was not significantly affected by CCC (without additional N fertilization). CCC proved beneficial not only in wet years but also in relatively dry years when there was no lodging. Winter wheats showed more response to CCC than spring wheats.

On Brown earths and Marshland soils of Schleswig-Holstein soil pH turned out to be the most important of the single soil factors affecting the yield of winter wheat (Spielhaus 1968). The correlation between these factors was highest on Marshland soils (Fig. 10) and in the case of winter wheat exceeding considerably that of other cereals examined (winter barley, oats and rye).

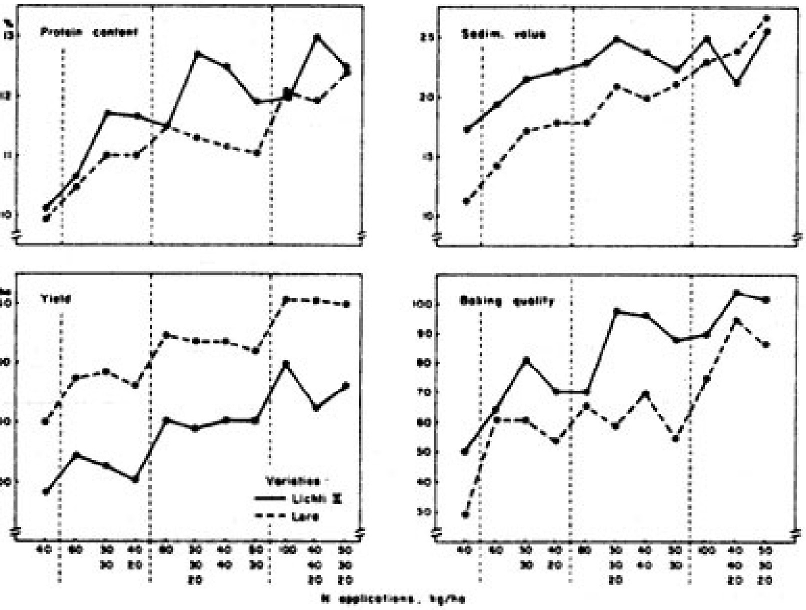

Figure 9. Effect of single dose and split applications of nitrogen on grain yield and quality of two spring wheats (Boguslawski 1965).

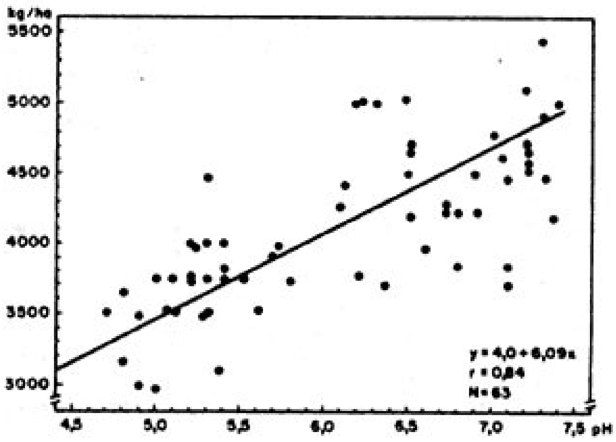

Figure 10. Relation between winter wheat yields and soil pH on Marshland soils in Schleswig-Holstein (Spielhaus 1968).

11. Greece

Wheat is the principal cereal crop of Greece, where it was grown on 26 percent of the arable land and covered over 60 percent of the total cereal area in 1966. The production per capita (185 kg is among the highest in Europe and only in Turkey is the per capita consumption of wheat as food higher than in Greece, 218 and 171 kg per capita respectively (Int. Wheat Council 1968).

From 1948-52 to 1962-66 the wheat production of Greece has been more than doubled. About 65 percent of the increased production is due to the 59 percent increase in average yields and 35 percent due to increase in wheat area.

Table 26. Area, production and yield of wheat and fertilizer use – Greece.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	878	894	1,020	6	5	1	12
1962–66	1,151	1,866	1,620	32	25	4	61
Incr. (+) or decr. (–)	+ 273	+ 972	+ 600	+26	+20	+3	+49

In spite of the fivefold increase in fertilizer consumption and substantial increase in yields both still remain below the average figures of Europe. The consumption of nitrogen and phosphorus were 6–8 times higher than potassium, which was as low as 4 kg K_2O per arable hectare. This is apparently due to sufficient potassium content of relatively arid soils.

The consumption of nitrogenous and phosphate fertilizers has practically been met by their rapidly increasing production in the country, but for potash Greece depends on imports.

12. Hungary

Wheat occupied one third (34%) of the area under cereal crops in Hungary in 1966 and 19 percent of the total arable land. Only the area of maize (22%) exceeded that of wheat. The production of wheat per capita (229 kg) was among the ten highest in the world. In spite of about 21 percent decrease in wheat cultivation area from 1948–52 to 1962–1966 the production increased by nine percent because of the simultaneous 39 percent increase in wheat yields.

Table 27. Area, production and yield of wheat and fertilizer use – Hungary.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	1,385	1,909	1,380	0.3	2.1	0.2	2.6
1962–66	1,089	2,088	1,920	30.8	20.0	9.6	60.4
Incr. (+) or decr. (–)	– 296	+ 179	+ 540	+ 30.5	+ 17.9	+ 9.4	+ 57.8

Only insignificant amounts of fertilizers were used during the former period and an essential reason for the higher yields of the latter period is apparently the considerably increased use of fertilizers consisting mostly of nitrogenous (one half) and phosphate (one third) fertilizers. The production of these fertilizers covers about nine tenths of the consumption while for potash Hungary depends on imports.

The response of wheat to fertilizers varies with soils. For example, on a soil classified as "chernozem with forest rests" which was well provided with phosphorus and potassium, winter wheat responded effectively to nitrogen. On the average (two years) 70 kg N/ha increased the yield by 781 kg/ha and 140 kg N/ha by 1040 kg/ha, the response ratios being 11.2 and 7.4, respectively. Phosphate application alone was ineffective but given together with high nitrogen doses resulted in a significant yield increase. The effect of phosphate was more linear than that of nitrogen within the range of its application (0 – 140 by P_2O_5/ha). The response of wheat to potassium was negligible (Koltay 1965).

On another soil which was poor in nutrients and had not been fertilized for decades, considerably greater responses were obtained in long-term experiments reported by Latkovics and Kramer (1968). The results of the last two years when the experimental fields were occupied by winter wheat, Bezostaya 1, are given in Table 28.

Table 28. Average yields (1966-67) of winter wheat (kg/ha) after different N, P_2O_5 and K_2O treatments (Latkovics and Kramer 1968). (Response ratios, kg wheat/kg of total nutrients applied, were calculated and are given within parentheses).

$N - P_2O_5 - K_2O$ treatments kg/ha	P_0		P_{30}		P_{60}	
	K_0	K_{45}	K_0	K_{45}	K_0	K_{45}
N_0	1340 (check)	1300 (-0.9)	1670 (11.3)	1600 (3.5)	1560 (3.7)	1500 (1.5)
N_{60}	2400 (17.7)	2210 (8.3)	2830 (16.6)	3100 (13.0)	3120 (14.8)	2830 (9.0)
N_{120}	2680 (11.2)	3580 (13.6)	3970 (17.5)	4190 (17.3	4040 (15.0)	4310 (13.2)

The highest yields, over 4000 kg/ha, were obtained with combinations 120-60-45, 120-30-45 and 120-60-0. The response ratio of wheat to nitrogen was 13.8, 18.5 and 20.2 at the three P-levels respectively and in the NPK combinations the effect of N was almost linear. Phosphorus fertilization was highly effective only at lower P application level and potassium only in combination with high nitrogen application.

Pekary (1968) points out that on heavy soils in the north-eastern region of Hungary complex NPK fertilization of winter wheat applied and ploughed in the autumn gives equally high yield increases as when applied in the conventional way, i.e., in several portions, thus cutting down the labour costs considerably. This may be due to inadequate rain to leach out nitrogen.

Hungarian winter wheat varieties, in general, appear to utilize medium doses of chemical fertilizers more effectively than high doses, while some foreign varieties, Bezostaya 1 in the first place, which is grown on more than 50 percent of the wheat area, respond to higher doses more effectively (Szabo 1966). Considerable yield increases, from 10 up to 60 percent has been obtained with spraying small amounts of CCC in connection with nitrogen fertilizer application. The optimal time of CCC application appears to be the stage of shooting (Adler 1965, Koltery 1968).

13. Ireland

The role of wheat in Irish agriculture is relatively small. In 1966 it was cultivated on only 4.4 percent of the arable land area while barley and oats, the major cereals of Ireland, comprised 15.6 and 8.2 percent of it respectively. A decreasing trend of wheat cultivation is obvious as can be seen from the figures given below. In 1966 the wheat area was no more than 53,000 hectares and the production was decreased to 185,000 metric tons in spite of the fifth highest wheat yields in the world (3,490 kg/ha) harvested in Ireland in that year. The use of wheat as food has also been decreasing as in most European countries but is still considerably higher, 86 kg flour per capita (Int. Wheat Council 1968), than the total production of wheat per capita which in 1966 was 64 kilograms.

Table 29. Area, production and yield of wheat and fertilizer use - Ireland.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	144	327	2,260	7	33	14	54
1962-66	87	286	3,290	30	95	76	201
Incr. (+) or decr. (-)	- 57	- 41	+ 1,030	+ 23	+ 62	+ 62	+147

Much of the over 1000 kg increase in hectare yields is obviously due to the fourfold increase in the use of fertilizers during the latter period. Differing from most other countries, phosphates and potash make up the bulk of commercial fertilizer consumption in Ireland (Table 119, p.120). About two thirds of nitrogenous and phosphate fertilizers are produced in Ireland but potash is imported.

Besides the three main nutrients, wheat has shown response to copper on some Irish peat soils. For example, on cutaway peat, yields on plots receiving 500 kg/ha nitrogenous fertilizer and no copper, failed completely (Fleming 1961). Copper deficiency in wheat was accentuated following nitrogenous fertilization, but also symptoms of nitrogen deficiency were obvious in all copper treatments without nitrogen on this soil. Residual effect of copper sulphate dressings as low as 8 kg/ha was sufficient to ensure good growth.

The growing of spring wheat in Ireland involves a greater risk than in most other European countries because of uncertain weather conditions during the ripening and harvesting period. On the other hand, in winter wheat production Ireland has an advantage over many countries as the weather during the period November-February is relatively mild and mainly due to earlier harvesting, production risks are much lower (Spillane 1968).

14. Italy

Wheat acreage of Italy is larger than that of any other European country excluding the European part of USSR and as a producer of wheat Italy ranks second after France. The relative proportion of wheat of cultivated land area, 28 percent, (71% of cereals) was exceeded only by Romania where the corresponding figure was 29 percent in 1966. The wheat production per capita was 181 kg and Italy is one of the eight leading wheat exporting countries in spite of the large quantity (121 kg/capita in terms of flour) consumed in their own country (Int. Wheat Council 1966, 1968).

Table 30. Area, production and yield of wheat and fertilizer use - Italy.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizer kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,705	7,170	1,520	10	18	2	30
1962-66	4,384	9,077	2,070	27	27	10	64
Incr. (+) or decr. (-)	- 321	+ 1,907	+ 550	+ 17	+ 9	+ 8	+ 34

The decrease in wheat cultivation area from 1948-52 to 1962-66 was compensated for by a simultaneous 36 percent increase in hectare yields causing an increase of about 27 percent in production.

Much of the yield increase can undoubtedly be attributed to the twofold increase in the use of commercial fertilizers in the latter period but some of it is undoubtedly due to improved wheat varieties. Half of the increase in fertilizer consumption consisted of nitrogenous fertilizers bringing their use up to the same level as that of phosphate. Italy is producing twice as much nitrogenous fertilizers as it uses and it is also self-sufficient in the other two main nutrients.

The extensive adoption of new varieties which are more responsive to fertilizers than the local ones has considerably changed the farmers' attitude to fertilizer use during the past decade or two. An example of the encouraging results of the experiments on nitrogen fertilization carried out in the early 60'ies is given in Fig. 11.

In addition to over 100 percent increases in yield due to nitrogen application, the varietal differences in the responsiveness are shown clearly. The variety "Abbondanza" which is 13-23 cm taller than "Campodoro" and 18-35 cm taller than "Mara" (depending on fertilization level) gives higher yields without nitrogen and shows good response to lower doses of nitrogen but is susceptible to lodging at higher nitrogen levels. The response ratios (kg grain/kg N) of the three varieties at the four (41, 82, 123 and 164 kg/ha nitrogen application levels were:

Abbondanza 19-20-11- 5
Campodoro 29-28-23-19
Mara 23-27-25-20

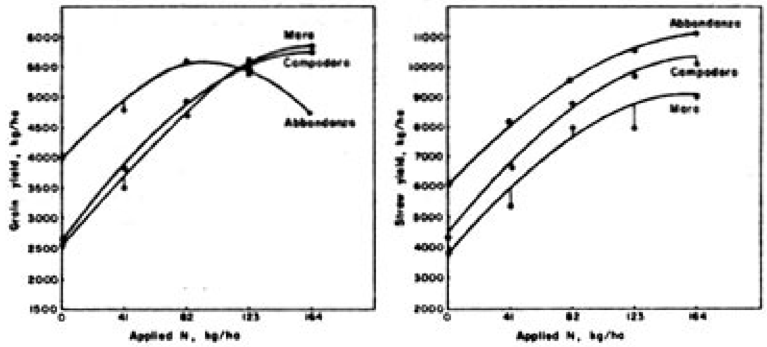

Figure 11. The effect of nitrogen fertilization on the grain and straw yields of three wheat varieties in central Italy (Bonciarelli 1964).

In another study in northern Italy (Antoniani 1965) the response ratios to nitrogen (averages of five varieties: Argelato, Mara, Funo, Leonardo and S. Pastore) varied from 15 (at 30 kg N/ha) to 8 (at 120 kg N/ha level). In both studies the increasing nitrogen applications were followed by significant increases in height of plants and number of stems per square metre and a decrease in thousand grain weight. The hectoliter weight of grain was not significantly affected or was slightly increased.

Split applications of nitrogen and late top dressings seem to be more effective in increasing the winter wheat yields than early applications and single doses (Bonciarelli 1963, Cervato 1964). For example, in central Italy an application of 40 kg N/ha in late December or early January gave significantly higher yields in three out of four years than equal applications in November or early December. The form in which the nitrogen was given (nitrate, ammonium or cyanamide) had apparently relatively small effect on yield, since only in one out of four years cyanamide was significantly more effective than nitrate, but in one year nitrate, and another year ammonium, gave the highest yields even though the differences were not statistically significant (Bonciarelli 1963).

The results of Venturi (1967) showed that nitrogen did not increase significantly the grain yield of sorghum but increased the yields of grain and straw of the succeeding wheat crop. However, the increases were higher when nitrogen was applied directly to wheat (Table 31).

Table 31. The direct and residual effects of nitrogen on grain and straw yields of wheat (kg/ha) when applied to preceding sorghum crop and directly to wheat (Venturi 1967).

N applied to sorghum kg/ha / N applied to wheat kg/ha	Grain yield				Straw yield			
	50	100	150	Mean	50	100	150	Mean
0	2476	2844	3610	2977	2001	2207	2655	2288
60	4086	4328	4677	4363	3418	3463	3615	3499
120	5184	5287	5328	5266	3988	4161	3954	4035
Mean	3915	4153	4538	-	3136	3277	3408	-

15. Luxembourg

The three main cereal crops of Luxembourg, wheat, oats and barley, covered 25, 19 and 18 percent of its cultuvated area respectively in 1966. The production of wheat per capita (101 kg) was somewhat above the world average but lower than that of Europe. Since 1948-52 relatively small changes in the wheat area have taken place and the production has increased mainly because of increasing hectare yields.

Table 32. Area, production and yield of wheat and fertilizer use - Luxembourg.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	16	30	1840	51	79	55	185
1962-66	18	41	2260	85	94	102	281
Incr. (+) or decr. (-)	+ 2	+ 11	+ 420	+ 34	+ 15	+ 47	+ 96

The use of fertilizers was on a relatively high level already in 1948-52 but increased further by over 50 percent by 1962-66. Potash and phosphates were used somewhat more than nitrogenous fertilizers. Luxembourg produces almost 20 times as much phosphate fertilizers as it uses itself but imports the other two nutrients.

16. Malta

About twelve percent of Malta's 16,000 hectares of arable land was under wheat and about an equal area under barley in 1966. Since 1948-52 the wheat area has been around 2,000 hectares, production 2,000-3,000 metric tons and hectare yields have varied from 1,100 to 1,600 kilograms per hectare. In 1966 the wheat production corresponded to about 6 kilograms per capita. Annual consumption of nitrogen fertilizers has been around 20 kg N per arable hectare during the last decade. Data on other nutrients were not available.

17. Netherlands

Almost one half (49% or 462,000 ha) of the arable land in the Netherlands (946,000 ha) was under cereal crops in 1966. Wheat was the most important of the cereals and covered 15.6 percent of the arable area. For barley, oats and rye the figures were 12.7, 10.5 and 7.8 percent respectively. Because of the high population density, however, only 48 kilograms of wheat were produced per capita, which is substantially less than the consumption, 62 kg flour per capita, in the country (Int. Wheat Council, 1968). From 1948-52 to 1962-66 Netherlands has almost doubled its wheat production. About 75 percent of the 305,000 ton increase was due to 54,000 hectares expansion of wheat area and 25 percent due to 730 kilograms average increase in hectare yields.

Table 33. Area, production and yield of wheat and fertilizer use - Netherlands.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	89	324	3,660	157	122	160	439
1962-66	143	629	4,390	323	118	143	584
Incr. (+) or Decr. (-)	+ 54	+ 305	+ 730	+ 166	- 4	- 17	+ 145

In Netherlands the resources of agricultural land in relation to the population are rather limited. This limitation has been largely compensated for by effective land use in Dutch agriculture. More fertilizers per hectare were used in Netherlands than in any other country in 1948-52 and since then, the average Dutch farmer has kept his position as the biggest consumer of fertilizers. He also harvested the highest wheat yields in the world during both periods mentioned above.

The ratio of different nutrients has changed considerably since 1948-52 (Table 119). The consumptions of both phosphate and potash fertilizers were slightly decreased and thus the increase in total fertilizer use is entirely attributed to nitrogen, the consumption of which was more than doubled. About twice as much nitrogenous and phosphate fertilizers have been produced than used in the Netherlands but practically all potash fertilizers have been imported.

Wheat in the Netherlands is usually fertilized quite heavily with nitrogen. Because of the risk of lodging, considerable attention has been paid to the effects of growth regulators and split applications of nitrogen in the fertilizer experiments during the recent years. Some of these are mentioned here.

Evidence has been obtained that moderate dressing with nitrogen in the beginning of growth, followed by supplementary dressings at shooting may shift dry matter distribution in favour of grain yield (Fig. 12).

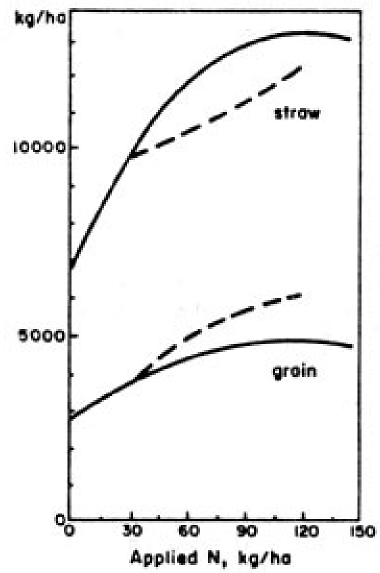

Figure 12. Effects of single dose applications of nitrogen at sowing (solid lines) and split applications (30 kg N/ha at sowing, the remainder at shooting - dotted lines) on the grain and straw yield of wheat (Jonker and de Jong 1966, ref. Kostic et al. 1967).

When comparing applications of supplementary nitrogen in solid form and in liquid form as a foliar spray, earlier results indicated that foliar spray of urea was less effective than top dressing with calcium nitrate, because urea caused visible damage to the leaves. However, relatively small doses of liquid urea applied as a spray were found more effective on winter wheat than calcium nitrate. E.g. Arnold and Dilz (1967) reported that aerial spray of urea at 11 kg N/ha rate applied just prior or at ear emergence gave as great a grain yield increase (200-300 kg/ha) as was obtained with 30 kg N/ha as calcium nitrate applied by conventional means.

In spite of the fairly short straw and relatively good lodging resistance of modern wheat varieties, yield losses from lodging can still be expected every year. Numerous trials carried out in the Netherlands have shown the beneficial effect of CCC in increasing yield through preventing lodging Tables 34 and 35) while none or only slight effects have been reported in conditions where no lodging appeared in check plots.

Table 34. An example of the effect of CCC at high nitrogen fertilization level on the yield and lodging index of two winter wheats and one spring wheat (Opal) variety. CCC was applied at a late tillering stage (de Vor et al. 1967).

Variety and site			Yield, kg/ha Control	3 kg CCC	6 kg CCC	Lodging index 1/ Control	3 kg CCC	6 kg CCC
Cleo	–	NHH	6070	6460	6640	4	7	8
Cleo	–	ZVI	6260	6740	6940	3	6	7
Stella	–	OFI	6570	7010	6940	6	9	10
Stella	–	WW	5850	5880	6100	5	6	8
Opal	–	OO	4650	4790	4960	6	8	9

1/ 10 = erect; 1 = completely lodged.

Table 35. Effect of nitrogen and CCC on yield, grain weight, and culm length of two wheats grown on different soils. CCC was applied at late tillering-early stem extension stage, 2,5 kg/ha for spring and 3 kg/ha for winter wheat (de Vos et al. 1967).

Applied nitrogen (kg/ha)	Spring wheat, Opal						Winter wheat, Gleo					
	Yield (kg/ha)		1000 grain weight (g)		Culm length (cm)		Yield (kg/ha)		1000 grain weight (g)		Culm length (cm)	
	Check	CCC	Check	CCC	Check	CCC	Check	CCC	Check	CCC	Check	CCC
0	2520	2300	42.3	40.5	77	46	6450	7480	46.3	46.8	99	73
30	3140	3190	42.2	40.8	77	48	5500	6970	42.0	45.8	93	79
60	4030	4010	43.8	42.1	86	52	5180	6760	41.1	44.9	91	80
90	4140	4560	44.2	43.1	84	56	4790	6450	41.0	44.1	93	81
120	4680	5120	44.2	42.9	89	58	5150	6570	42.0	43.9	95	78

The examples given in Table 35 represent circumstances which differ widely from each other. The spring wheat variety was grown on soil of low nitrogen content, and the effect of nitrogen was therefore pronounced with CCC having effect on yields only at high N-fertilization level. The winter wheat variety was instead grown on soil where nitrogen supply in the non-fertilized plots was already ample, and nitrogen had a diminishing effect on yields. Since severe lodging occured even on the O-N control plots, CCC was effective at all nitrogen levels.

In addition to applied and soil nitrogen level, as well as rainfall, the effect of CCC seems to depend on crops (wheat is generally more responsive than other cereals), varietal differences and on time and amount of applied CCC (time may be more important than amount) (van Burg and Arnold 1969).

18. Norway

Wheat has become less and less important in Norwegian agriculture because of its continuously decreasing cultivation area and production during the last two decades. In 1948–52 it was grown on 28,000 hectares and in 1962–66 the average area was about 6,000 hectares. In 1966 wheat was grown on only about 2,000 hectares, the production of which made approximately one percent of the total cereal production in Norway and corresponded to about one kilogram of wheat per capita. The main cereals in Norway, barley and oats, were grown on 188,000 and 41,000 hectares respectively in 1966.

Table 36. Area, production and yield of wheat and fertilizer use - Norway.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	28	52	2,060	39	42	54	135
1962-66	6	15	2,470	71	57	63	191
Incr. (+) or decr. (-)	- 22	- 37	+ 410	+ 32	+ 15	+ 9	+ 56

The ratio between the three main nutrients given in commercial fertilizers corresponds closely to the European average ratio during the two periods given above (Table 119, p.120), even though the consumption of fertilizers per hectare in Norway far exceeds the average European use. Since 1948-52 more than half of the increase in fertilizer consumption falls to nitrogenous fertilizers. The production of nitrogenous and phosphate fertilizers in Norway exceeded their consumption by factors of 5.8 and 1.6 respectively in 1966, while for potash Norway depends on imports.

19. Poland

Rye is the most important cereal in Poland where it was grown on about 4.4 million hectares in 1966. Wheat, the second in importance, occupied 1.7 million hectares or 20 percent of the cereal area and 11 percent of the arable land. The production 3.6 million tons, corresponded to 115 kilograms per capita which was 25 kg higher than the world average and 25 kg lower than the European average.

Table 37. Area, production and yield of wheat and fertilizer use - Poland.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1464	1833	1250	6	7	11	24
1962-66	1564	3175	2030	25	20	28	73
Incr. (+) or decr. (-)	+ 100	+ 1342	+ 780	+ 19	+ 13	+ 17	+ 49

Poland's wheat production increased by over 1.3 million tons or 73 percent from 1948-52 to 1962-66. This is mainly (90%) due to the 62 percent increase in hectare yields and the rest (10%) is due to the expansion of wheat cultivation area by 7 percent. It is apparent that most of the considerable increase in hectare yields is a consequence of the simultaneous threefold increase in fertilizer use. Relatively small changes in the ratio between the three main nutrients given in fertilizers took place. Poland produces both nitrogenous and phosphate fertilizers and has been practically self-sufficient in these but imports the potash fertilizers.

Most of the wheat grown in Poland is of the common bread species from winter sowing but also spring wheats are widely cultivated. Durum wheat is also produced.

According to recent results of fertilizer trials both winter and spring wheat yields seem to increase with increasing nitrogen application at least up to 90 kg N per hectare (Tables 38 and 39).

Table 38. Winter wheat yields as affected by nitrogen fertilization. Averages of two-year trials (Klupczynski 1967).

Applied N kg/ha	Grain yield kg/ha	Resp. ratio kg grain/kg N	Straw yield kg/ha	
0	3250	-	5820	Additional N applied:
60	3940	11.5	7410	
90	4170	10.2	8310	
60 + 30 1/	4230	10.9	8170	1/ at tillering
60 + 30 2/	4520	14.1	8530	2/ at shooting
60 + 30 3/	4170	10.2	8040	3/ at earing
LSD *	220	-	480	

Table 39. Spring wheat yields and protein content of grain as affected by nitrogen fertilization and seeding rate in trials over a period of three years (Mazurak and Mazurak 1968).

Applied N kg/ha	Grain yield kg/ha	Straw yield kg/ha	Prot. content of grain %
30	2190	3830	13.94
60	2500	3960	15.11
90	2690	4550	16.45
LSD *	258		
Seed rate kg/ha			
100	2290	3750	Differences not significant
150	2480	4040	
200	2530	4250	
250	2570	4450	
LSD *	57		

* LSD = Least significant difference at 0.05 level.

Split applications at the beginning of growth and at shooting gave both the highest yield and the highest response to nitrogen in the case of winter wheat. Increasing the rate of nitrogen or applying it as split also increased the protein, most of all glutelin, content of grain.

Increasing the seeding rate of spring wheat increased the net yield up to 150 kg seed per hectare but higher rates did not affect the yield significantly. The protein content of the grain was not affected by the seeding rate but was considerably increased with increasing nitrogen application.

20. Portugal

Wheat and maize are the chief cereals in Portugal. In 1966 wheat was grown on 523,000 hectares or on 12 percent of the arable area and maize on 473,000 hectares, covering altogether over 60 percent of Portugal's cereal area. The production of maize, however, was considerably higher (565,000 tons) than that of wheat (312,000 tons) because of the almost twofold difference in hectare yields, maize 1190 kg and wheat 600 kg per hectare. The production of wheat corresponded to 34 kilograms per capita, which is less than one half of the food consumption of wheat, 67 kilograms per capita in terms of flour (Int. Wheat Council, 1968).

Table 40. Area, production and yield of wheat and fertilizer use - Portugal.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	689	499	720	6	11	1	18
1962-66	661	527	795	19	13	4	36
Incr. (+) or decr. (-)	- 28	+ 28	+ 75	+ 13	+ 2	+ 3	+ 18

In spite of the four percent decrease in average annual wheat area from 1948-52 to 1962-66, wheat production increased by about six percent due to the increase of about ten percent in hectare yields. However, the average national wheat yield, being the lowest in Europe during both periods, was about half of the European average in 1948-52 but only somewhat over one third of that in 1962-66.

The consumption of fertilizers, even though doubled from the first to the latter period, is still the third lowest in Europe corresponding to about one third of the European average fertilizer consumption per arable hectare. The bulk of the increase in fertilizer use consists of nitrogenous fertilizer, raising its share to over half of the total consumption. During the nineteen-sixties Portugal has produced nitrogenous and phosphate fertilizers slightly over its domestic consumption but potash fertilizers were imported.

21. Romania

Almost two thirds of Romania's 10.5 million hectares of arable land were under cereal crops in 1966. The two main cereals, maize and wheat, covered 3.3 and 3.0 million hectares respectively. The share of wheat area of arable land, 29 percent, was the highest in Europe and wheat production per capita, 265 kilograms, second highest (after Bulgaria) in Europe and eight in the whole world. Wheat has been growing in Romania at least 2500 years (Staicu 1965).

Table 41. Area, production and yield of wheat and fertilizer use - Romania.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	2728	2778	1020	0.2	0.2	0.2	0.6
1962-66	2979	4536	1520	11.1	8.2	1.2	20.5
Incr. (+) or decr. (-)	+ 251	+ 1758	+ 500	+ 10.9	+ 8.0	+1.0	+ 19.9

The production of wheat increased by 63 percent from 1948-52 to 1962-66. Most (84%) of this increase was due to the 49 percent higher yields during the latter period and the remaining 16 percent due to the 9 percent expansion in wheat area.

The average annual rainfall throughout the country is 638 mm varying from 250 mm in the Danube Delta to over 1000 mm in the mountain zone. In the wheat zone the rainfall ranges from 400 to 800 mm and wheat is well adapted to this rainfall regime (Staicu 1965).

Only low responses to fertilizers were obtained with the old wheat varieties which were unable to use large quantities of fertilizers. Since 1957, when new highly productive wheat varieties were introduced, the picture, however, changed. For example, on a chernozem soil, the A_{15} variety used before 1958 yielded 812 kg/ha less than Bezostaya 1 without fertilizers and 1441 kg/ha less with 96 kg N + 96 kg P_2O_5/ha fertilization (Fig.13). Also some other varieties, like Skorospelka 3 and Triumph, showed a good ability to utilize large fertilizer rates. Similar results were obtained on podzolic soils in the Arges region, where Bezostaya 1 outyielded variety No 301 by 1357 kg/ha at N90 P90 fertilizer application level producing a yield of 4488 kg/ha, which was 180 percent higher than the yield (1600 kg/ha) without fertilizer application (Berindei et al. 1965). The response ratio in this case is as high as 19.4 kg grain per 1 kg applied nutrient. Somewhat more moderate responses to nitrogen and phosphorus were obtained in trials carried out on Smonitza, Podzolized Brown and Brown Forest soils (Avram 1965, Nicolae 1966 a, 1966 b, Bretan et al. 1966). In general, only slight or insignificant responses to potassium were obtained.

Phosphorus showed good responsiveness especially on soils of chernozem and steppe zones having a low natural supply of available phosphorus, but the responses obtained depend largely on the previous crops (Fig. 14).

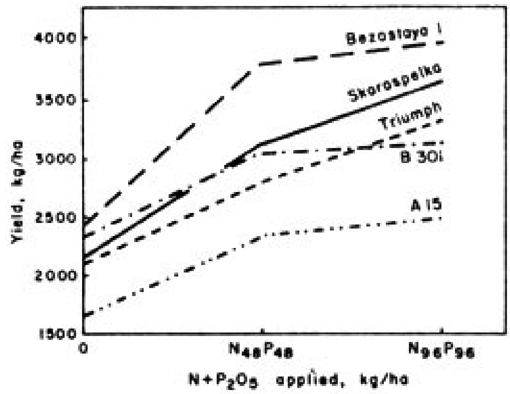

Figure 13. Effect of fertilizers on the main winter wheat varieties grown on chocolate Chernozem soil in Romania (Staicu 1965).

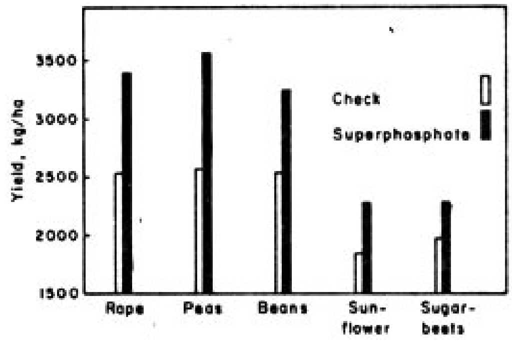

Figure 14. Effect of superphosphate (64 kg P_2O_5/ha) on the yield of winter wheat grown after different crops (Staicu 1965).

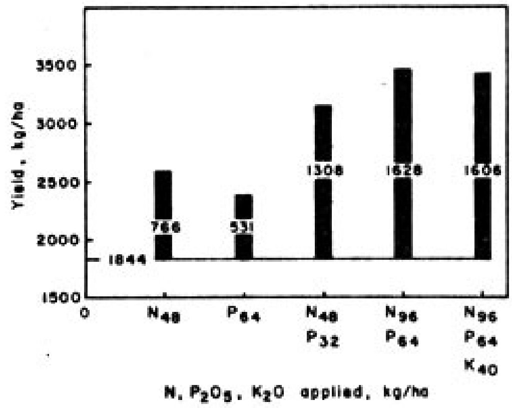

Figure 15. Effect of commercial fertilizers on the yield of winter wheat grown after maize (Staicu 1965).

The reason for the differences is believed to be the length of the fallow period between the harvesting of the previous crop and the planting of wheat. Rape, peas and beans are harvested in June-July while sunflower and sugarbeets in August-September. The longer the fallow period, the greater amount of nitrogen is mineralized from the organic supply of the soil. This may be seen from the higher yields obtained without phosphorus after rape, pea and beans as compared to those obtained after sugarbeet and sunflower. The higher amount of mineralized nitrogen also increased the efficiency of phosphorus (Staicu, 1965).

Owing to the extensive areas planted to maize, wheat is usually grown after maize, which leaves behind a soil poor in soluble nitrogen and phosphorus. Therefore, high yield increases have been obtained with these nutrients as shown by the results of 1958-62 trials (Fig.15). Nitrogen was more effective than phosphorus, and potassium had no increasing effect on the yield. The highest yield increase, 1628 kg/ha, was obtained when the highest rates of nitrogen and phosphorus were applied together and the best return with medium N and NP rates, response ratios 16.0 and 16.4, respectively.

When analyzing the contributions of different factors on wheat yields in Iasi region on the basis of the 1957-64 trials, Timariu et al. (1965) concluded that the average yield increase due to varietal factor was 408 kg/ha. Fertilizer was responsible for a yield increase of 370 kg/ha with an extensively grown variety Odessa 16 but 821 kg/ha with Bezostaya 1 variety. Deep tillage ensured yield increases of about 200 kg/ha and the best preceding crops proved to be peas and wetch mixture.

22. Spain

Wheat is the most important cereal in Spain where it was grown in 1966 on 4.2 million out of its 7.0 million hectares under cereal crops or on 20 percent of the arable area. Barley was grown on 1.3 million hectares while other cereals maize, oats and rye occupied less than 0.5 million hectares each. Spain belongs to the relatively small group of wheat exporting countries since its wheat production, 151 kilograms per capita in 1966, considerably exceeds the domestic consumption. The food use of wheat has been decreasing and in 1966/67 it was 81 kilograms per capita in terms of flour (Int. Wheat Council 1968).

Table 42. Area, production and yield of wheat and fertilizer use - Spain.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4162	3625	870	4	8	2	14
1962-66	4167	4589	1100	18	15	5	38
Incr. (+) or decr. (-)	+ 5	+ 964	+ 230	+14	+7	+3	+24

The area annually under wheat varied relatively little during the last two decades being usually between 4.0 and 4.3 million hectares, and thus also the difference between the averages for the two five-year periods given above is negligible. Therefore, the 27 percent increase in wheat production is a direct consequence of the almost equal increase in hectare yields, which again, at least partly, results from the almost threefold use of fertilizers during the latter period.

Most of the increase in fertilizer consumption consists of nitrogenous fertilizers, the production of which has also been growing rapidly. In 1962 the production met less than half of the consumption but already over 80 percent in 1966. In the case of phosphate fertilizers Spain has been self sufficient and produced 3 to 5 times as much potash fertilizers as is annually consumed within the country.

Except in the Atlantic coast zone in the north, rainfall is insufficient in Spain and water shortage is often the main limiting factor in agricultural production. In addition, annual and seasonal distribution of precipitation is irregular. At present about 2.3 million hectares are irrigated. Wheat is mainly grown in the dry-farming regions where the annual rainfall ranges from 400 to 800 mm. Wheat yields vary with regions and years, the average amounting to 1000 kg/ha in rainfed conditions and 2500 kg/ha under irrigation. Under dry-farming wheat is usually grown after fallow or after a legume crop within the rotation. Winter wheat is more common than spring wheat (Arnaiz and Comhaire 1969).

23. Sweden

Barley and oats are the main cereals produced in Sweden. In 1966 they were grown on 568,000 and 461,000 hectares respectively while the area under wheat was only 191,000 hectares or 6 percent of the arable area. In spite of that Sweden is one of the wheat exporters, partly because of the high yields (fifth highest in the world in 1962-66) and relatively low domestic consumption. The wheat production in 1966 was 576,000 tons. Even though this was the lowest in years and e.g. only 54-55 percent of that in two previous years, it still corresponded to 74 kilograms of wheat per capita while the food use of wheat was 49 kilograms of flour per capita (Int. Wheat Council 1968).

Table 43. Area, production and yield of wheat and fertilizer use - Sweden.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	323	677	2100	19	31	18	68
1962-66	251	856	3410	48	36	31	115
Incr. (+) or decr. (-)	- 72	+ 179	+ 1310	+ 29	+ 5	+ 13	+ 47

In spite of the substantial (22%) decrease in wheat cultivation area from 1948-52 to 1962-66 the production increased by 26 percent because of the simultaneous 62 percent increase in hectare yields. It is obvious that the 69 percent increase in fertilizer use, the bulk of which consisted of nitrogen, has contributed much to the yield increase. During the latter five-year period the production of nitrogenous fertilizers met about one half to two thirds of the annual consumption, phosphate production was about equal to consumption but practically all potash was imported.

An example of the response of spring wheat to fertilizers in the central part of Sweden is given in Fig. 16, showing the effect of N with and without PK fertilizer in soils of three phosphorus levels determined with A-L-method. The results are based on 127 trials.

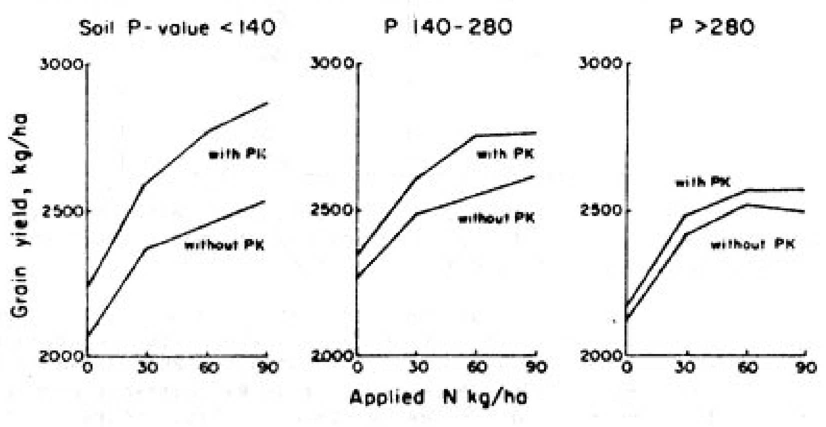

Figure 16. Spring wheat yields as affected by N, P and K fertilization on low (P value < 140), medium (140-280) and high (> 280) phosphorus soils. P_2O_5 and K_2O doses were 39 and 199 kg/ha, respectively (Jönsson 1969).

The effect of nitrogen was highly significant on all soil groups even though the yield increases were rather moderate, not exceeding 30 percent even at the highest nitrogen application (93 kg N/ha) level, and decreased toward soils of highest contents of available phosphorus. Also, the PK effect was significant and decreased with increasing phosphorus value of the soil. The PK effect was ascribed mainly to phosphorus. The crude protein content of grain was raised by nitrogen fertilization from 13.0 (no N) to 14.9 (93 kg N/ha) percent. It also increased with increasing phosphorus value of the soil but was not affected by PK fertilization.

In another study consisting of about 590 trials in the southern and central part of Sweden, nitrogen dressings of winter wheat up to 62 kg/ha were found highly profitable while there was reasonable doubt concerning additional N dressing (Jönsson and Bondeson 1966). Even though splitting up the heavier dressings (93 and 123 kg N/ha) increased the N effect, the profitability of such high doses still remained doubtful. The optimum time of winter wheat N dressing was found to be when growth had started in the spring and the plants had reached a height of about 15 cm.

Nitrogen topdressing was found to be more effective than application prior to sowing. The difference, however, levels out at high application rates. Splitting the dressing often produces the highest yields. The superiority of topdressing is most pronounced on loams and clay soils and on soils low in organic matter. The most common nitrogen fertilizers used in Sweden, calcium nitrate and nitro-chalk, were equally effective when applied prior to sowing, but when given as topdressing to spring or winter wheat calcium nitrate turned out to be more effective (Johansson and Jönsson 1967).

Uneven distribution of nitrogen fertilizer (varying from 0 to 120 kg N/ha in experimental conditions) can cause a yield decrease of 100-150 kg/ha as compared to equal amounts of N (60 kg/ha) distributed evenly (Nilsson and Jönsson 1969).

Due to increasing production and changed production policy, decreasing animal production, straw burning and increased use of concentrated fertilizers the demand for trace element application has also called the attention of soil scientists. In Sweden the primary micro nutrients are manganese, boron and copper. Iron deficiency is to be expected only exceptionally, molybdenum supply seems to be relatively well secured and zinc offers no serious problem so far. Boron is of particular importance for oil-crops and clover seed production and manganese for the production of potatoes (Johansson 1968). An antagonistic effect appears to occur between copper and phosphorus (Table 44).

Table 44. Interaction between phosphorus and copper fertilizers applied to spring wheat in a pot experiment with peat soil, pH 4.9 (Johansson 1968).

Applied superphosphate (grams per pot)		Relative yield (check = 100)		
		First year	Second year	
First year	Second year	without Cu	without Cu	with Cu
0	0	100	56	54
2	1	71	85	100
6	3	1	2	109
8	9	0	0	107

Building up the phosphorus status by P-fertilization on poor soils with potential lack of copper can cause an acute copper deficiency. Risks of copper deficiency are most likely on light soils poor in nutrients, and increase with increasing organic matter content.

A large number of trials with varying seed rates showed that the gross yield increased with increasing seed rate up to 304 kg seed/ha. However, the net yield (gross yield - seed) increased only to about 150 kg seed/ha, remained at almost constant level with 150 to 225/kg/seed/ha and showed a decreasing tendency with higher seed rates. The optimum seed rate was somewhat higher for sites with high yield level, and further, the seed rate adopted seemed to be of less importance at a high yield level than at a low one (Bengtsson and Ohlsson 1966).

24. Switzerland

A considerable share, about 28 percent, of Switzerland's arable land in 1966 was under wheat which is by far the most important cereal in the country exceeding the areas of barley and rye, its nearest competitors, by factors of 3.5 and 7.9, respectively. In spite of this and of the high wheat yields (seventh highest in the world) harvested in Switzerland, the production per capita was as low as 59 kilograms of wheat. When the food consumption of wheat was 71 kilograms per capita in terms of flour (Int. Wheat Council 1968), considerable amounts of wheat have to be imported to fill the shortage.

Table 45. Area, production and yield of wheat and fertilizer use - Switzerland.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	98	260	2660	21	79	38	138
1962-66	108	363	3350	62	121	133	316
Incr. (+) or decr. (-)	+ 10	+ 103	+ 690	+ 41	+ 42	+ 95	+178

Although the average national wheat yield was already high in 1948-52 it was increased by 26 percent by 1962-66. This, together with an increase of 10 percent in wheat area, raised the production by 40 percent. Much of the increase in yield can be attributed to over doubled use of fertilizers during the latter period.

Switzerland's fertilizer consumption per arable hectare is one of the highest in the world. It differs from most European countries in the fact that the share of nitrogen is relatively low in comparison to those of phosphorus and potassium. During the last two decades Switzerland has been producing nitrogenous fertilizers 10 to 35 percent over its own consumption and 20-30% of its phosphate consumption but imports potash fertilizers.

Under conditions in Switzerland crop rotations seem to have a strong effect on yields. Vez (1969 a), for example, reported that in continuous wheat the yield decreased from 4130 to 2590 kg/ha in the third year. This was mainly because of the spreading of diseases (especially Cercosporella herpotrichoides and Ophiobolus graminis). In the fifth year of continuous wheat, only 7% of the crop was free from disease, while 56, 51 and 50% were healthy when following the four-year rotations of:

(a) wheat - wheat - rye - rape
(b) wheat - wheat - potatoes - rape
(c) wheat - wheat - ryegrass - rape, respectively.

Wheat yields after a, b and c rotations were 55.9, 57.4 and 55.6 percent higher, respectively, than in the fifth year of continuous wheat.

Interesting results of the interaction between seed rate and nitrogen fertilization were also reported from Switzerland, where the same grain yield was obtained with 30 kg seed/ha and 115 kg N/ha as with 180 kg seed and 70 kg N per hectare (Vez 1969 b).

25. United Kingdom

Cereal crops covered about a half of the 7.5 million hectares of arable land in the United Kingdom in 1966. Most of it, 2.5 million hectares, were under barley and wheat was grown on 906,000 hectares or on 12 percent of the arable land. In spite of the dense population 63 kilograms of wheat was produced per capita due to the high yields, third highest in the world. The production, however, is not sufficient to meet the domestic consumption, 70 kg per capita in terms of flour (Int. Wheat Council 1968), and considerable amounts of wheat have to be imported.

Table 46. Area, production and yield of wheat and fertilizer use - United Kingdom.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yeild (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	881	2397	2720	28	46	28	102
1962-66	904	3692	4080	85	59	59	203
Incr. (+) or decr. (-)	+ 23	+ 1313	+ 1360	+ 57	+ 13	+ 31	+ 101

The increase of 55 percent in wheat production from 1948-52 to 1962-66 is almost a direct consequence of the 50 percent increase in yields, most of which again is likely to result from the almost 100 percent increase in fertilizer use. An increase of this magnitude in national yield, 1360 kg/ha, is especially worth noticing because it is obtained in conditions of already high yield level.

The consumtpion of fertilizers, seventh highest in Europe and tenth in the world, consists of relatively even distribution of all three nutrients, even though during recent years the increase in the use of nitrogen has been most pronounced. The United Kingdom's fertilizer production meets the domestic consumption of nitrogenous and phosphate fertilizers but potash has to be imported.

Nitrogen is the most important fertilizer for wheat and under most conditions in the United kingdom it must be applied if maximum grain yields are to be obtained.

Table 47. Mean yields of grain for experiments with spring wheat at eight locations over the three years 1959-61. Effects of nitrogen, potassium and application method (Harvey 1964).

Applied fertilizers		K_2O (kg/ha) 0	28	56	Mean
N (kg/ha)		Grain yields (kg/ha) (± 133)			(± 77)
Nil		2910	2890	2875	2890
38	Drilled	3475	3475	3530	3490
38	Broadcast	3605	3590	3580	3590
75	Drilled	3970	4195	4005	4055
75	Broadcast	4230	4065	4095	4130
38 38	Drilled + Broadcast	4095	4205	4155	4155
Mean (± 51)		3715	3740	3705	3715

Yield responses to 38 kg N/ha averaged 650 kg/ha or 22 percent. The extra 38 kg N/ha produced a further 15 percent in yield. Broadcast nitrogen was as effective as drilled nitrogen and there was no response to potash. Similar results were reported by Lessells and Webber (1965 a). They recommend 75 kg nitrogen per hectare for spring wheat following a series of arable crops, but only 50 kg/ha where the crop is sown late, immediately follows grazed kale, or is the first or second crop following a long ley or permanent grass. Late sowing tends to reduce the response to nitrogen (Forbes 1960). Also for winter wheat the optimum rate is around 75 kg N/ha giving a yield response ranging from 700 to 1800 kg/ha (Lessells and Webber 1965b, McClean and Mundy 1965). In some cases, however, like at Terrington, no nitrogen was needed for winter wheat after well fertlized potatoes following peas.

The yield of wheat and the response of wheat to nitrogen also depend largely on the preceding leys affecting the mineralizable nitrogen in the soils (Fig. 17).

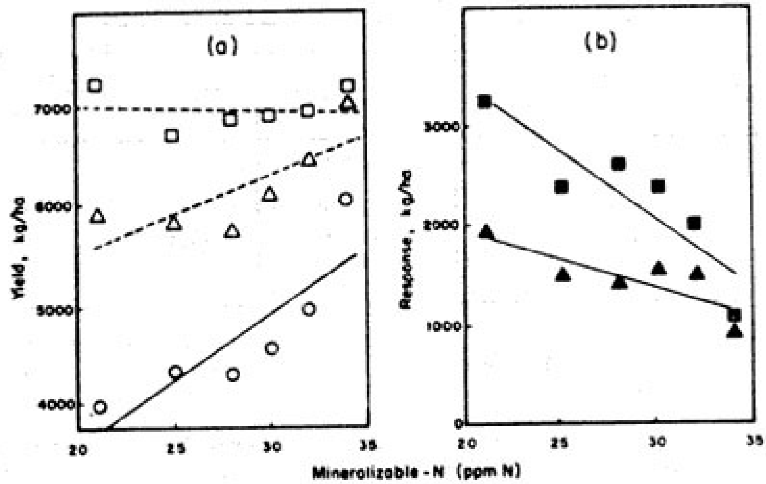

Figure 17. Effects of mineralizable – N in soils under one-year grass/clover or clover leys on (a) grain yields of winter wheat and its (b) response to fertilizer – N. □ = Yield with 126 kg N/ha as fertilizer; ■ = response to 126 kg N/ha as fertilizer; △ = yield with 63 kg N/ha as fertilizer; ▲ = response to 63 kg N/ha as fertilizer; O = yield without fertilizer-N (Gasser 1968).

Without fertilizer-N, wheat yields increased significantly with increasing mineralizable-N in the soil (they were highest after clover ley and lowest after ryegrass ley without fertilizer-N). With 70 kg N/ha as fertilizer (not shown in the graph), yields also showed the same tendency but no longer significantly. With an application of 140 kg N/ha, mineralizable N in the soil had no effect on the yield. Conversely, responses to fertilizer N were significantly negatively correlated with mineralizable N in the soils.

Since fertilizer nitrogen is subject to losses in the drainage over winter, application of this fertilizer should be delayed until spring. The best time for nitrogen top-dressing is just before the flowering stems begin to lengthen. This occurs about the end of March – end of April depending on districts. Earlier top dressings tend to give slightly lower yields, while later top-dressings result in more physical damage to the crop (Holmes 1964).

Yield responses to phosphorus are considerably lower than to nitrogen. For example, the average results of nine experiments on spring wheat in 1958-62 showed a yield increase of only 150 kg/ha for 50 kg P_2O_5 per hectare (Devine and Holmes 1964). It was suggested that a suitable application rate is about 35 kg P_2O_5 per hectare on many soils. On soils with a very low phosphate content twice that rate was recommended if broadcast and 45-50 kg/ha if combine drilled. On some of the rich phosphate soils, or following heavily fertilized root crops on mineral soils, no phosphate may be necessary.

Humpries (1968) quoted several experiments in which the yield of wheat was increased by spraying with CCC although there was no lodging in untreated plots. In an experiment, CCC increased yields by 762 kg/ha on unirrigated plots and 1270 kg/ha on irrigated plots. CCC treated plants had more ears and more grains per ear. It was thought that yield increases are related to the larger root system of treated plants, which counteracts the effect of temporary droughts especially near the time of ear emergency.

26. Yugoslavia

Almost two thirds of Yugoslavia's 8.3 million hectares of arable land were under cereal crops in 1966. Maize was the principal cereal growing on 2.5 million hectares and wheat the next important covering 1.8 million hectares or 22 percent of the arable land. The production of wheat per capita, 233 kilograms, was the third highest in Europe and ninth in the whole world. As in most Mediterranean countries wheat is a staple food in Yugoslavia and its consumption as food, 161 kg per capita in terms of flour, is among the highest in the world (Int. Wheat Council 1968).

Table 48. Area, production and yield of wheat and fertilizer use - Yugoslavia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1821	2171	1190	0.7	1.0	0.4	2.1
1962-66	1979	3885	1960	19.9	16.7	16.8	53.4
Incr. (+) or decr. (-)	+ 158	+ 1714	+ 770	+ 19.2	+ 15.7	+ 16.4	+51.3

From 1948-52 to 1962-66 Yugoslavia's wheat production increased by 79 percent. Most (88%) of this increase was due to 65 percent higher yields during the latter period and the remaining 12 percent due to about 9 percent increase in wheat area.

During the former period only insignificant amounts of commercial fertilizers were used and most of the substantial yield increase since then can be attributed to the considerably higher level of fertilizer use. In the consumption of fertilizers the share of nitrogen slightly exceeds that of the other two nutrients.

Yugoslavia is practically self-sufficient in phosphate fertilizers, producing about a half of the domestic consumption of nitrogenous fertilizers but in the case of potash is dependent upon imports.

IV. b. U.S.S.R. (27)

Wheat is the most important cereal in the U.S.S.R. covering almost 60 percent (1966) of the total cereal area and 29 percent of the arable land. For a long time U.S.S.R. has been the biggest wheat producer among individual countries and since the early nineteen-fifties its wheat production has also exceeded that of Europe and North America. Only Canada and Australia produced more wheat per capita in 1966 than U.S.S.R. (431 kg).

Table 49. Area, production and yield of wheat and fertilizer use - U.S.S.R.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	42633	35759	840	1	2	2	5
1962-66	68014	71000	1045	8	5	6	19
Incr. (+) or decr. (-)	+25381	+35241	+ 205	+ 7	+ 3	+ 4	+ 14

From 1948-52 to 1962-66 the production was almost doubled. About 71 percent of the production increase was due to increased wheat area (from 43 to 68 million hectares), and 29 percent due to an increase in the average national yield (from 840 to 1045 kg/ha). The production in 1962-66 was subject to wide variation because of climatic factors, 1962,64 and 1966 being high production years (1050, 1100 and 1440 kg/ha respectively), while in 1963 and 1965 the average yields were only 770 and 850 kg/ha.

Wheat is grown in U.S.S.R. on soils varying widely in natural qualities. Notwithstanding a number of high mountain ranges (Caucasus, Thien-Shan, Pamirs, Altai, etc.), main agricultural areas are on vast plains: the Russian, the East European, the West Siberian and the plains of Kazakhstan and Central Asia (Guerassimov 1962).

The bulk of the wheat in the U.S.S.R. is grown in the Russian Federation, Kazakhstan and Ukraine, producing e.g. in 1959-62 58.5, 20.5 and 17.0 percent of the total wheat volume, respectively. Spring wheat represented about 61 and winter wheat about 39 percent of the production (Int. Wheat Council 1965). Even though an improvement of cultivation methods, wheat varieties etc. have contributed to raise the average national yield, much of it must be subjected to the fivefold increase in the use of fertilizers which still remains somewhat below the world average. The increase was most marked in the use of nitrogen.

The general effectiveness of fertilizers in the soils of USSR was summarized by Naidin (1964). According to him the largest yield increases with NPK application were usually obtained on dernopodzolic soils and particularly in the north-western and central regions of the USSR non-chernozemic belt. In the European part of the USSR their effectiveness decreases towards south-east and more continental climate (precipitation deficit, higher summer temperature and shorter growing period). In the Asiatic part of the USSR similar general tendency exists from east to west.

Nitrogen fertilizers are more effective on coarse podzolic soils than on soils of steppe regions or on leached and deep chernozems.

Superphosphate is most effective on leached chernozems of the forest-steppe, ordinary chernozems of the Ukrainian northern steppe and on Caucasian chernozems. The effect of superphosphate is smaller on grey forest soils and sandy podzolic soils (due to N deficiency) and chestnut soils and chernozems of the south-east (due to lack of N and water). In the chernozemic belt towards more leached and podzolized varieties of soils the effect of N application increases and correspondingly of P decreases.

In the same soil-climatic zone the effect of fertilizers highly depends on soil texture. N and K fertilizers are more effective on coarser soils, P on the fine-textured soils of a medium cultivation stage and is less effective on loamy sands.

In areas of insufficient precipitation the effect of fertilizers highly depends on a correct combination of fertilizers and application techniques. Heavy fertilization in these regions must be avoided. The determinant condition for high and stable yield gain is the techniques and depth of application that provides for a transformation of nutrient into the lower part of the arable layer, which is more moist during the growing period.

The fertilizer effect, especially of N, increases with irrigation on ordinary, leached and southern chernozems, on chestnut soils and in particular on light-chestnut soils of the south-east of the European part of the USSR as well as on serozems and other soils of Middle Asia and Transcaucasus.

In trials in Kazakhstan yield responses of winter wheat to 30 kg N + 40 kg P_2O_5 per hectare varied from 32 to 82 percent depending on cultivar and those of spring wheat from 22 to 27 percent (Filonov 1968).

On a chernozem soil ploughing to 35 cm depth as compared to 20 cm increased yields of cereals up to 17.8 percent (Stojkovic et al. 1968) and in S.E. Caucasus, field emergence, winter survival and yields of winter wheat were highest when the cereals were grown after clean fallow (85%, 81-86% and 2460-2970 kg/ha respectively), closely followed by wheat grown after legumes. The lowest values (78%, 71-75% and 2100-2390 kg/ha) were obtained from wheat grown after cereals (Rzaev 1968).

In the southern steppe area in Ucraine on chernozem soils urea and ammonium nitrate were equally effective in increasing yield of winter wheat but urea increased the protein content of grain more than ammonium nitrate (Tsvethova 1968). On leached chernozems in Krasnodar region nitrogen increased the yield and protein content of grain. Phosphorus when applied to wheat receiving nitrogen also increased the grain yield but decreased the protein content of the grain. Potassium did not affect either yield or the protein content (Glukhovskü and Poluakova 1969, Turuleva 1969). The amounts of P and K taken up by plants from the soil depended more on the rate of N applied than on the rates of P and K and increased with increasing N applications (Churkin 1969).

IV. c. North and Central America

In 1948-52 North and Central American countries were contributing about 25.6 percent and in 1962-66 19.5 percent of the world's total wheat production. In 1966 the United States and Canada contributed over 97 percent of the total production of the region and most of the rest (2.7%) was produced in Mexico. Approximately 200 kilograms of wheat was produced per capita in this region, exceeding the world average by 110 kilograms. On the average, about 13 percent of the arable land of the region was under wheat. The United States and Canada are the two leading wheat exporters in the world.

28. Canada

Canada ranks as the fourth producer of wheat in the world. In 1966 the total production was 22.5 million tons exceeding considerably that of previous years mainly because of exceptionally high yields (1870 kg/ha) that year. Wheat is the most important crop in Canadian agriculture covering about 12.0 million hectares or 28 percent of its arable land, and 61 percent of the cereal area. Its nearest competitors, oats and barley, were grown on 3.0 and 3.2 million hectares respectively in the same year. Canada produces more wheat per inhabitant (1130 kg in 1966) than any other country and is a leading wheat exporter besides U.S.A.

Table 50. Area, production and yield of wheat and fertilizer use - Canada.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	10507	13443	1280	1	3	1	5
1962-66	11496	18320	1595	4	7	3	14
Incr. (+) or decr. (-)	+ 989	+4877	+ 315	+ 3	+ 4	+ 2	+ 9

About 72 percent of the almost 5 million ton increase in wheat production from 1948-52 to 1962-66 was due to a 25 percent increase in hectare yields and 28 percent due to a 9 percent increase in wheat area. The average national hectare yields have been 290-330 kilograms above the world average but fertilizer consumption per arable hectare corresponded to only half of the world average. Phosphates make up about one half of the total fertilizer consumption but the ratio between the three nutrients has been narrowing. The production of nitrogenous and phosphate fertilizers exceeds their consumption by about 75 and 30 percent respectively and only one twelfth of Canada's potash production was used within the country.

In most years the three Prairie provinces, Saskatchewan, Alberta and Manitoba, produce over 95 percent of Canada's wheat. Over half of the crop is produced in Saskatchewan. Ontario produces about 4 percent and less than one percent is produced elsewhere. The low precipitation is one of the main factors limiting yields. In the Prairie Provinces where the annual precipitation varies approximately from 10 to 20 inches (250 to 500 mm) the average yields in three provinces, e.g. in 1958-62, varied from 1,075 to 1,445 kg/ha while in Ontario receiving 30 to 40 inches (750 to 1000 mm) rainfall the average wheat yield was 2,345 kg/ha during the same period. (Dominion Bureau of Statistics 1964). However, because of the low rainfall the baking quality of wheat produced in the Prairie Provinces is high. About 90 percent of wheat produced in Canada is hard red spring wheat and about 5 percent amber durum wheat (Reitz 1967).

Largely because moisture deficiency has limited crop yields under prairie conditions, depletion of plant nutrients has been slow and the soils are still fertile in spite of having been cultivated for a long time with low fertilization. However, response to fertilizers varies widely from one location to another due to differences in the natural fertility of the soils, moisture supply, soil morphological and topographic factors and due to cultural practices affecting both the physical and chemical properties of soils (Rennie and Clayton 1960, Power et al. 1961, Warder et al. 1963, Spratt 1966, Ferguson and Gorby 1967).

For example, in western Manitoba the response of wheat to phosphorus was found to be related to the topographic position of the soil. At the lowest topographic position, at Brandon, the Calcareous Black (*) soils of the Miniota association to ensure maximum profits from wheat required twice as much phosphate (46 kg P_2O_5/ha) as the better drained Orthic Black soils at higher locations (22 kg/ha) in the Black chernozemic soil catena (Ferguson and Gorby 1967).

In the Griswold-Goodlands area however, the phosphorus requirement was higher for both soils (Fig. 18).

(*) For FAO soil classification see Chapter III, c.

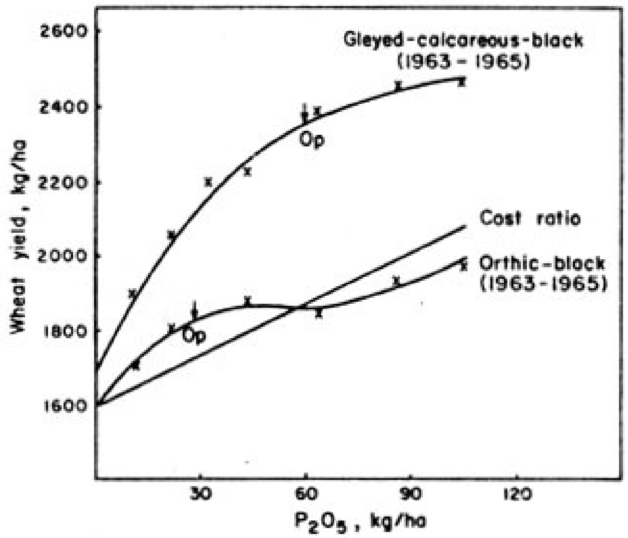

Figure 18. The relationship between actual yield of wheat and rate of phosphorus (Op = max. profit point, curves fitted by hand) (Ferguson and Gorby 1967).

It is generally accepted that forage crops included in long-term rotations will improve, or at least maintain, the desirable chemical and physical properties of the soil. Toogood and Lynch (1959), for example, showed that soil aggregation was appreciably higher when a 5-year rotation including grains and legumes was used instead of a wheat-summer fallow sequence, and considerable difference due to rotation in the response of wheat to fertilizers was reported by Spratt (1966). The results of 1962-65 fertilizer trials established at the Indian Head Experiment Station after two long-term rotations had been carried out continuously since 1911, are given in Table 51. Rotation C consisted of summer fallow-wheat - stubble wheat, and rotation R of summer fallow-wheat - oats as a nurse crop - brome alfalfa for 3 years - intertilled corn - wheat - oats.

Table 51. Average summerfallow wheat grain yields for 1962-1965 from fertilizer trials on two rotations (Spratt 1966). (Average response ratios, kg wheat/kg applied nutrient, are given within parentheses).

Fertilizer treatment, kg/ha			Grain yield, kg/ha		% utilization of applied phosphorus	
N	P_2O_5	K_2O	Rot. C.	Rot. R	Rot. C	Rot. R
0	0	0	2287 (-)	2683 (-)	-	-
5	23	0	2327 (1.4)	2852 (6.0)	11.3	18.3
10	46	0	2321 (0.6)	2744 (1.1)	8.5	12.9
20	92	0	2576 (2.6)	2832 (1.3)		
20	23	0	2536 (5.8)	2791 (2.5)	17.5	21.8
40	46	0	2509 (2.6)	2697 (0.2)	15.1	17.1
5	23	24	2509 (4.3)	2838 (3.0)	12.3	17.4
10	46	24	2489 (2.5)	2805 (1.5)		
40	46	24	2684 (3.6)	2744 (0.6)		
L.S.D. (P = 0.05)			209	N.S.		

The beneficial effect of brome-alfalfa on the rotation was reflected in a higher yield of wheat. The average difference between the unfertilized plots was nearly 400 kg/ha. In general, the response to fertilizer was relatively low. The highest response ratios were obtained at intermediate (20-23-0) fertilizer application level in rotation C and at low (5-23-0) application level in rotation R. Including brome-alfalfa in rotation R also improved physical chemical conditions of the soil, producing higher total porosity, percent of large agregates, hydraulic conductivity, O.M. content, total and nitrate N, total, exchangeable and organic P and exchangeable K and increased the utilization of applied phosphorus.

Large areas of the Prairie region are summerfallowed each year for moisture conservation and/or weed control. In the more arid regions, only two or three tillage operations are required to control weeds and 20 to 40 percent of the seasonal precipitation is conserved (Zingg and Whitfield 1957). In the Black soil zone of Alberta where precipitation is slightly higher, summerfallow is not recommended for moisture conservation, but is used to control persistent weeds. Although four or five tillage operations are normally required to control weed growth, occasionally six to eight operations are used. The study of Dew (1968), however, shows that four tillage operations are adequate for good fallow. With two tillage operations, the yield of wheat was raised from 1970 to 2450 and with four operations to 2800 kg/ha (5-year average at Lacombe Alberta). Additional tillage, up to 12 operations, had no effect on the yield.

Significant yield differences, ranging from 270 to 540 kg/ha, due to different cultural practices in removing crops residues (including various tillage and plowing operations and burning) were obtained during experiments carried out at five experimental locations. Regardless of the cultural methods beneficial and uniform yield responses were obtained at all locations for the rates tested (Table 52). The response to nitrogen on burned or stubble-mulched plots was not different. The highest yields were obtained with the highest N and P rates at all stations, showing that the upper yield limits were not reached with the fertilizer rates used. The response ratios were usually highest at 18-22 kg N + 22 kg P_2O_5 rates.

Table 52. The effect of fertilizer on average yield wheat at five stations, kg/ha (*) (Dawley et al. 1964).

Fertilizer treatment kg/ha		Regina (4 years av)	Melfort (6 years av)	Melita (3 years av)	Indian Head (5 years av)	Lacombe (5 years av.)
N	P_2O_5	Yield Resp. ratio	Yield Resp. ratio	Yield Resp. ratio	Yield Resp. ratio	Yield Resp. ratio
56	22	1420a (3.5)			1440a (6.0)	2630a (7.9)
18	22	1380a (5.7)			1325a (8.7)	2495b (12.1)
56	0	1320b (3.0)			1265c (5.2)	2300c (5.2)
0	0	1150c (-)	1700c (-)	1210c (-)	975d (-)	2010d (-)
6	22		1760b (2.1)	1370b (5.7)		
22	22		1890a (4.3)	1425ab(4.9)		
45	22		1890a (2.8)	1490a (4.2)		

(*) Yields accompanied by the same letter are not significantly different. Average response ratios (kg wheat/kg nutrients) were calculated later and are given within parentheses.

Wind often has a pronounced effect on the growth and development of plants in Canada. During the period 1950-54 an average yield increase of 47 kg/ha and a maximum of 1076 kg/ha for sites close to treed shelterbelts due to windbreaks were obtained in southern Saskatchewan (Staple and Lehane 1955). In most instances these yield increases could be attributed to the effect of additional soil moisture resulting from the accumulation of snow near the hedges. In experiments at Swift Current where the effect of snow accumulation was eliminated, a reduction of 15 to 49 percent in wind travel due to windbreaks led to 12-23 percent decrease in evaporation and to 24-43 percent increase in wheat yields (Pelton 1967).

The importance of the date of seeding of wheat grown on summerfallow in the conditions of northwestern Alberta was clearly demonstrated by Anderson and Hennig (1964). A summary of their results is given in Fig. 19.

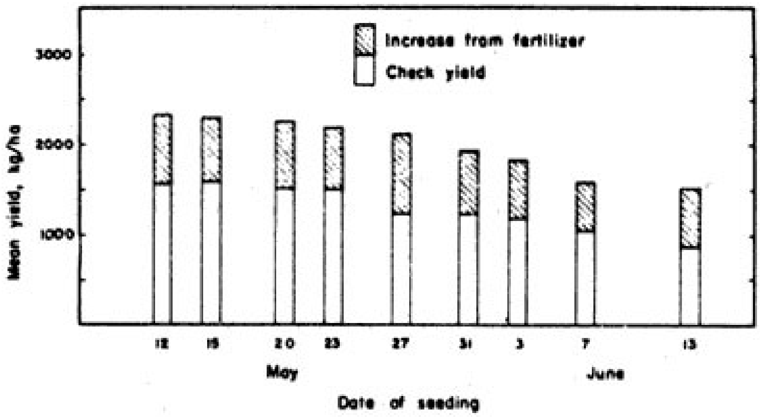

Figure 19. Yields of wheat for nine mean seeding dates, with and without 11-48-0 fertilizer at 39 kg/ha rate during 1951-56, inclusive (Anderson and Hennig 1964).

Reduction in yield from the first to the ninth date for unfertilized and fertilized wheat was 42.6 and 34.9 percent, respectively. The application of 39 kg/ha of 11-48-0 fertilizer increased wheat yields by 51 percent on the average.

The effect of nitrogen on the protein content of wheat seems to vary with locations. In southern Alberta the protein content of wheat was not increased until more than 45 and, in some cases, more than 90 kg N/ha were applied (Russel et al. 1958). In the Black and Dark Brown soil zones of Saskatchewan neither nitrogen nor phosphorus affected the protein content when up to 215 kg N/ha were applied (Rennie 1956, 1958), while in the Brown soil zone an increase in protein (in some cases over 3%) was obtained on both loam and clay soils with 24-40 kg N/ha and 48-69 kg P_2O_5/ha applications (Warder et al. 1963). In Alberta the effect of nitrogen and phosphorus on grain protein content varied in different years, but 3 years averages of protein production (1957-59) closely paralleled the wheat yield results (Fig. 20). Wheat yields were considerably increased by nitrogen and further increased by the

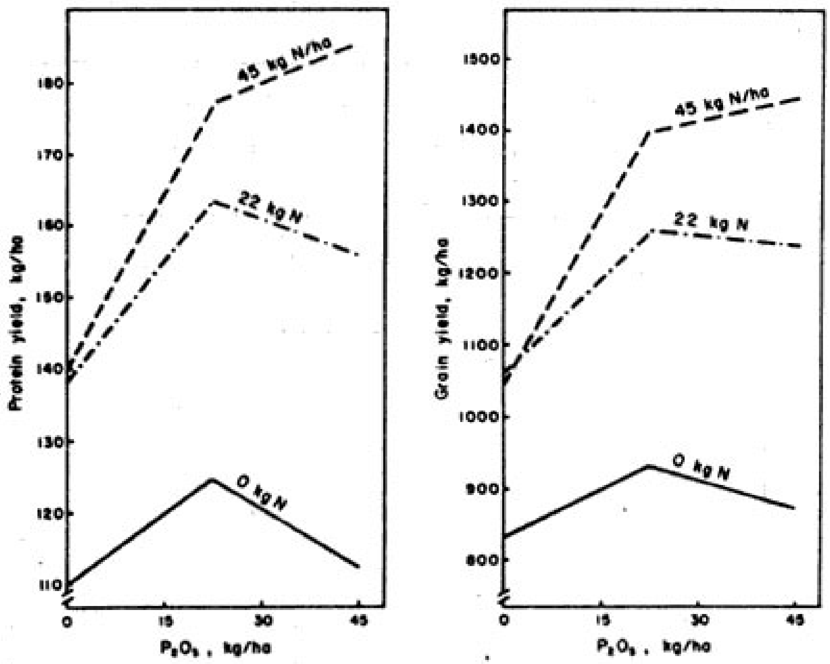

Figure 20. Effects of nitrogen and phosphorus fertilization on protein and grain yields of spring wheat grown on wild-oat infested stubble in Stavely, Alberta 1957-59 (Sexsmith and Russel 1963).

addition of phosphate at the rate of 22 kg/ha. Phosphorus had no measurable effect on the height, straw yield, seed yield, or number of wild-oat plants, but nitrogen increased the number of seed-bearing stems, plant height, straw weight and seed yield, but did not change the wild-oat stand. Therefore, Sexsmith and Russel concluded that in this kind of conditions, fertilizers may be useful for increasing wheat production but only at the expense of production of increased quantities of wild-oat seeds.

In varietal trials in the Prairie Provinces some new Mexican varieties were compared with commercial Canadian varieties. The most promising of the Mexican varieties was Pitic 62. It outyielded Manitou, a widely adopted commercial variety, by 23 to 29 percent. It has some disease resistance but lacks sufficient insect resistance and quality, and showed low phenotypic stability (Walton 1968).

29. Guatemala

Over 90 percent of Guatemala's cereal production consists of maize. Wheat was grown in 1966 on only 40,000 hectares or less than three percent of the arable land area, and the production (35,000 tons) corresponded to about 8 kilograms of wheat per capita.

From 1948-52 to 1962-66 the production of wheat increased by 60 percent, about 27 percent of which was due to 5,000 hectares or 14 percent increase in wheat area and 73 percent due to 38 percent increase in the average wheat yield. In spite of the increase the national yield remained at relatively low level corresponding to less than one half of the average wheat yield harvested in North and Central America. The same is true for fertilizer use. Nitrogen consists of about one half and phosphates about one third of the fertilizers used. For fertilizer supplies Guatemala depends on imports.

Table 53. Area, production and yield of wheat and fertilizer use - Guatemala.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	35	20	580	0.4	0.5	0.3	1.2
1962-66	40	32	800	6.0	3.6	1.8	11.4
Incr. (+) or decr. (-)	+ 5	+ 12	+ 220	+ 5.6	+ 3.1	+ 1.5	+ 10.2

FAO has carried out both fertilizer demonstrations and trials in Guatemala (Table 54).

Table 54. Average results of fertilizer trials in 1965-66 (FAO 1968 a).

Treatment N - P_2O_5 - K_2O kg/ha	Yield kg/ha	Yield increase %	Net Return $/ha	Value/Cost ratio
Control	663	-	(85)	-
100 - 0 - 0	1257	90	+ 47	2.6
100 - 80 - 0	1544	133	+ 61	2.2
100 - 80 - 50	1625	145	+ 61	2.0
100 - 160 - 0	1700	156	+ 58	1.8
200 - 0 - 0	1169	76	+ 6	1.1
200 - 80 - 0	1275	92	- 3	1.0
200 - 160 - 0	1119	69	- 45	0.6
200 - 160 - 100	1513	128	- 16	0.9

Applications of 200 kg N/ha appeared to be too high since they decreased the yields as compared to those with only 100 kg N/ha and nullified the net returns.

The highest yield was obtained with 100-160-0 treatment, while applications of only half as much phosphate gave the highest net returns. Potassium increased the yield but not the net return. The largest net returns were obtained in the West Plateau region.

30. Honduras

As in most Central American countries maize is the most important cereal crop. Wheat area of Honduras has varied between 1,000 and 2,000 hectares during the last two decades and the national wheat yield between 580 and 560 kilograms per hectare. In 1966 only about 0.2 percent of the arable land and 0.4 percent of the cereal area was under wheat the production of which corresponded to less than half a kilogram per capita.

From 1948-52 to 1962-66 the consumption of fertilizers per arable hectare increased from 1.5 to 9.9 kilograms, of which 8.6 kg consisted of nitrogen.

31. Mexico

Almost one third of Mexico's arable land was under maize in 1966. Wheat, the second important cereal crop was grown on 683,000 hectares or on 2.9 percent of the arable area. The production of wheat corresponds to 36 kilograms per capita. Because maize is the main staple food in Mexico, the food consumption of wheat has been low and has shown a further decreasing tendency during the nineteen-sixties. Only 14 kilograms per capita in terms of flour was consumed in 1965-66 (Int. Wheat Council 1968). The decreasing consumption combined with considerably increasing production have turned Mexico from a wheat importer into an exporter.

Table 55. Area, production and yield of wheat and fertilizer use - Mexico.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	604	534	880	0.4	0.4	0.1	0.9
1962-66	750	1702	2270	10.2	2.7	0.5	13.4
Incr. (+) or decr. (-)	+ 146	+ 1168	+ 1390	+ 9.8	+ 2.3	+ 0.4	+ 12.5

Despite the fact that Mexico's wheat cultivation area increased only by 24 percent from 1948-52 to 1962-66, the production in the latter period was over threefold as compared to that in the former period. About 88 percent of the production increase was due to the 158 percent increase in hectare yields and 12 percent due to additional area.

Fertilizer consumption is at a relatively low level consisting mostly (3/4) of use of nitrogenous fertilizers. The average figures for the period 1962-66 do not, however, show the development within the period which is quite substantial. The consumption of N, P_2O_5 and K_2O was increased by factors 2.4, 10.4 and 2.2 respectively from the first to the last year of the period mainly under influence of the new varieties. About one half of nitrogenous and all phosphate fertilizer consumption is met by home production but potash is imported.

The four North Pacific States, especially Sonora, lead both in acreage and yield and produce about half the entire wheat crop. Ten Central Mexican States produce about one third of the crop and the seven Norther States produce most of the remainder (Secr. Agr. Canaderia 1962, ref. Reitz 1967).

The rapid adoption of the semi-dwarf varieties by farmers in Sonora, Baja California and Sinalca, and their culture to the near exclusion of other varieties represents one of the most sweeping changes in variety type in recent times (Borlaug 1965). This phenomenal improvement in wheat production in Mexico was also due to the application of research on soil fertility, irrigation and moisture management, agronomic practices, and the control of diseases, insects and weeds.

Mexican fertilizer trials showed that nitrogen was a miracle food for wheat in many areas and that phosphorus was often a strong booster. In typical experiments on properly irrigates soils in the Bajio, for example, the addition of 140 kilograms of nitrogen per hectare raised the yields more than four-fold, from 600 kg/ha without nitrogen to 2700 with it. Non-irrigated soils yielded only some 550 kg/ha without nitrogen and 1300 kg/ha with it; and when phosphorus was added, yields were often increased five or six-fold. By 1954 many Mexican farmers were getting 3000–4000 kg/ha from lands that had given 650–700 kg/ha before they started fertilizing (Stakman et al. 1967). An example of the excellent responsiveness of the Mexican dwarf varieties to nitrogen is given in Fig. 21. The response ratios for the two varieties, Inia and Ciano, at the 50 kg N/ha rate of fertilization were 35 and 27 and at 200 kg N/ha level still 21 and 15 kg grain/kgN respectively.

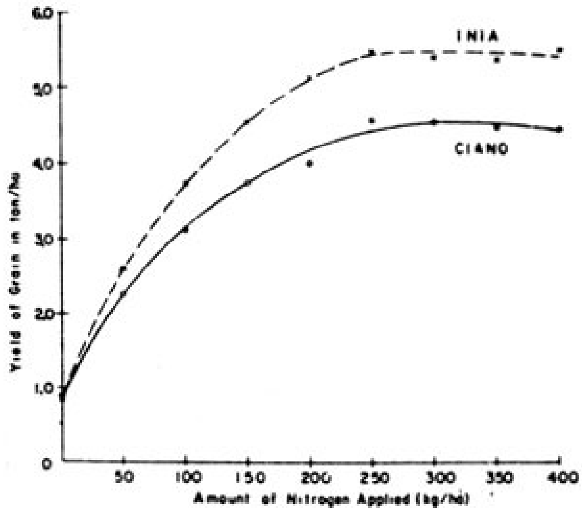

Figure 21. The effect of nitrogen fertilization on grain yields of the Inia and Ciano wheat varieties at the CIANO experiment station, 1969 (CIMMYT 1969).

The record-breaking development in wheat production in Mexico is shown in Fig.22. A short history of the work leading to the developent of high yielding varieties, carried out in Mexico, is given in Chapter II.

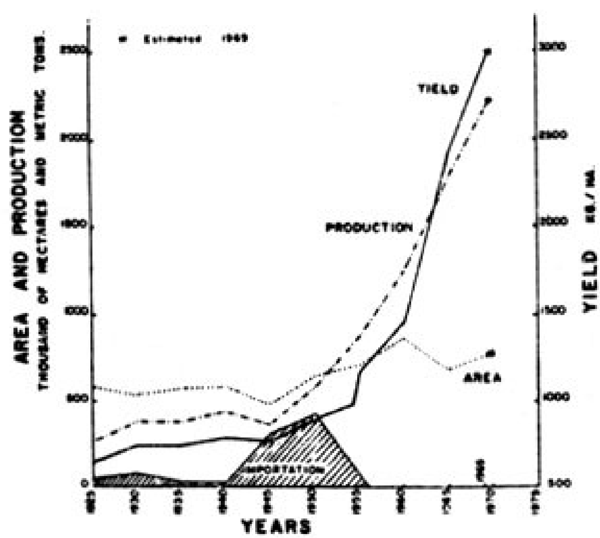

Figure 22. Cultivated area, production and yield of wheat in Mexico, 1925–69 (CIMMYT 1969).

32. United States of America

About one third of the United States 180 million hectares of arable land was under cereal crops in 1966. Maize was the principal cereal growing on 23 million hectares and wheat, the next in importance, on 20.2 million hectares or on 11.2 percent of the arable land. The production corresponded to 181 kilograms of wheat per capita which is about three times as high as the food consumption of wheat, and consequently U.S.A. is a leading wheat exporter besides Canada (Int. Wheat Council 1966, 1968).

Table 56. Area, production and yield of wheat and fertilizer use - U.S.A.

Periods and change	Wheat area (1000 tons)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	27,756	31,065	1,120	7	11	7	25
1962-66	19,294	33,472	1,735	25	19	15	59
Incr. (+) or decr. (-)	- 8,462	+ 2,407	+ 615	+ 18	+ 8	+ 8	+ 34

In spite of the substantial decrease in wheat area due to the acreage control in U.S.A. during recent years the production of wheat was increased by almost eight percent from 1948-52 to 1962-66 resulting from the 55 percent increase in hectare yields. During the same period the consumption of fertilizers more than doubled, over half of the increase consisting of nitrogenous fertilizers. According to U.S. D.A. statistics (Ibach and Adams 1967) on the average 9.5 percent of agricultural consumption of fertilizers (10.4% of N-, 11.4% of P-, and 6.4% of K- fertilizers) were used for wheat crops in 1964. This corresponds to 45 (21+16+8) kilogram nutrients per wheat hectare which was somewhat less than the average use per arable hectare (22+18+14=54 kg/ha) in the same year (FAO 1967 a). U.S.A. produces nitrogenous and phosphate fertilizers over its own consumption while the consumption of potash slightly exceeds the production.

Wheat is a significant crop in 42 states of the U.S.A. (Reitz 1967; Fig.23). In 17 states the production exceeded half a million ton in 1958-62 (USDA, 1964): Kansas (7.0 million tons), North Dakota (3.3), Oklahoma (2.8), Nebraska (2.2), Montana (2.1), Washington (1.8), Texas (1.8), Colorado (1.5), Illinois (1.4), Ohio (1.1), Indiana (1.1), Idaho (1.1), Missouri (1.0), South Dakota (1.0), Michigan (1.0), Oregon (0.7), and Minnesota (0.6). These states contribute over 90 percent of the total wheat production.

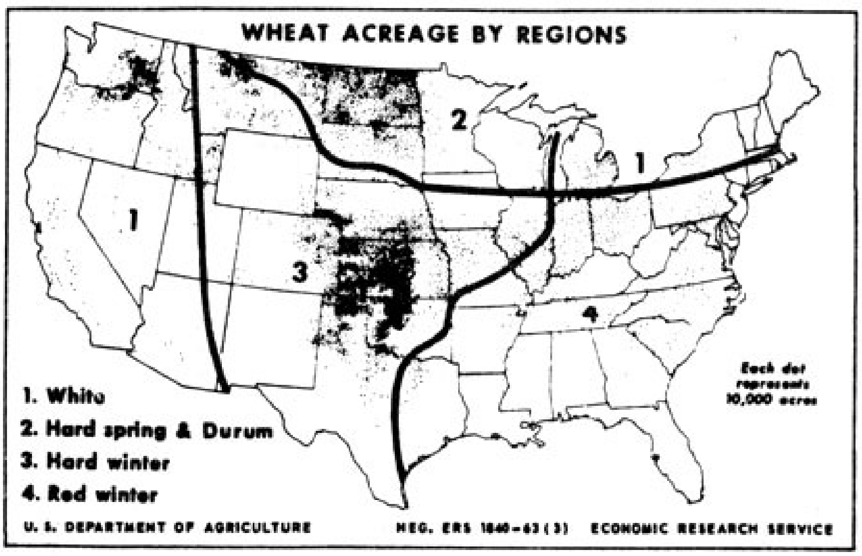

Figure 23. Distribution of wheat in the United States and general boundaries of market classes (Ref. Reitz 1967).

The highest yields, 2000-2500 kg/ha are obtained in the states where rainfall is usually ample (e.g. Ohio, Indiana, Illinois, Michigan) or where irrigation is common (e.g. Washington and Idaho). In states where rainfall is limited the yields usually vary from 1300 to 1800 kg/ha. There are also considerable differences in the average amounts of fertilizers used for wheat crop in different states. E.g. in 1964 less than 10 kg/ha of nutrients were applied for wheat in fertilizers in Colorado, Montana, Nebraska and Dakotas, while in Indiana, Michigan and Ohio the amounts exceeded 100 kg/ha (Ibach and Adams 1967).

Because most of the wheat is produced in areas where moisture is a limiting factor for crop growth, the relations between moisture availability and yield response to fertilizers play an important role in the numerous studies carried out on wheat fertilization.

For example, in North Dakota where there is about 160-200 mm precipitation during the average 85 to 90 days growing season, moisture is usually utilized entirely by plants or otherwise lost. Storage of a reserve moisture supply in nonfallowed soils is then limited mainly to rainfall occuring between harvest and the succeeding spring period.

Table 57. Grain yields in check plots and response to fertilizer in relation to growing-season rainfall and to amounts of stored available soil moisture (0-120 cm depth) at seeding (Bauer et al. 1965).

Rainfall (mm)	Available soil moisture (mm)	Number of trials	Check yield kg/ha	Yield incr. over check (kg/ha) with different N + P_2O_5 (kg/ha) treatments			
				0 + 42	22 + 42	45 + 42	67 + 42
< 100		4	854	-67	94	27	34
100-150		12	1204	215	289	356	242
150-200		21	1305	67	287	377	444
200-250		19	1581	135	383	552	504
> 250		10	1682	161	511	780	821
	< 50	26	1076	141	220	215	195
	50-100	20	1480	148	316	424	377
	100-150	10	1742	-34	504	733	753
	> 150	10	1693	262	531	874	1029

The results shown in Table 57 indicate that average grain yields increased as rainfall increased, both without and with fertilizers. Response, as well as rate of nitrogen fertilizer needed for maximum yields, also increased as rainfall increased. As stored available soil moisture at seeding increased, there was also an increase in the nitrogen (with P) fertilizer rate required to produce the maximum yield response and an increase in the response to a given nitrogen rate. With more stored available soil moisture at seeding, less seasonal rainfall was required to produce profitable responses to nitrogen. The correlation was higher for total moisture (seasonal rainfall + stored available soil moisture) than for either moisture category alone). Total moisture accounted for 46.5% and 40.3% of the yield response to NP and N fertilizer, respectively.

Similarly, Army and Hanson (1960) found that about 66 to 85% of the variation in spring wheat yields in the plains area of Montana was attributable to variations in soil moisture supply at seeding, precipitation, and total daily maximum temperatures during the growing season.

In the Brown soil zone of Northern Great Plains (Huntley) where annual precipitation averages 250 to 330 mm of which less than half falls during the growing season, spring and winter wheat grain yields averaged only about 30 percent of the potential yield with soil moisture removed as a limiting factor. In these conditions, response to fertilizer will nearly always be modified, if not overshadowed, by moisture conditions as the vegetative growth, first accelerated by fertilizer, persisted only until heading then gradually disappeared because of decreased moisture supply (Brown and Cambell 1966).

Under conditions in Oklahoma, soil moisture at seeding, growing season precipitation, soil moisture in the spring and winter wheat yield level were all positively and significantly correlated to yield response to nitrogen fertilizer (Eck and Tucker 1968). It was, however, concluded that soil moisture level at seeding or in the spring is not particularly indicative of yield levels or yield response to nitrogen, and that rainfall distribution is more important than total rainfall. Temperature during the ripening period had no significant effect on yield response to nitrogen while there was a trend toward increasing response to N with decreasing soil organic matter content and with increasing yield level.

The importance of sufficient soil moisture to yield response to nitrogen can also be seen from the results of an irrigation trial (Fig. 24) carried out in Logan, Utah (Singh 1960).

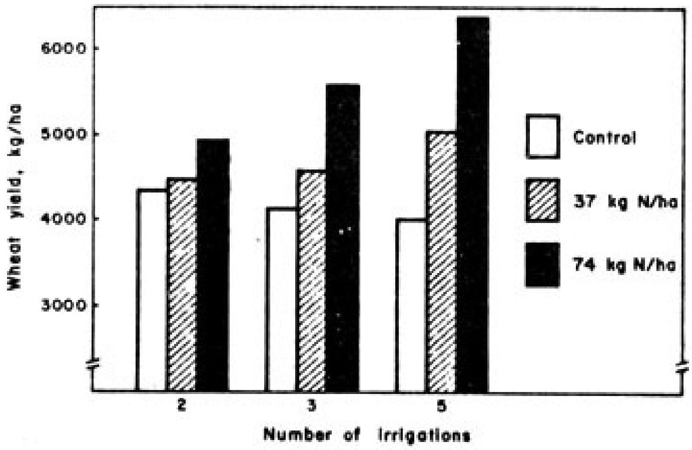

Figure 24. Yield of wheat in relation to moisture and nitrogen fertilization (Singh 1960).

In Illinois, where precipitation is usually high, the relationship between yields of winter wheat and applied nitrogen was nearly linear (up to 67 kg N/ha and about 1200 kg/ha yield increase; aver. 1961–1963), but the response varied widely between years. Spring applied nitrogen was about 50 percent more effective than nitrogen applied in autumn (Welch et al. 1966).

Because of promising results from trials with semi-dwarf varieties, considerable areas are sown to these wheats especially in the southwestern parts of the United States. For example, trials carried out in Utah showed that net dollar returns from semi-dwarf varieties of wheat were nearly double those obtained with tall, hard red spring wheats when both were fertilized with nitrogen (Table 58). Yield increases were primarily due to the production of more tillers. Added phosphorus gave no significant increase in any measured character.

Table 58. Results of four-year trials with tall and semi-dwarf wheat varieties (Woodward 1966).

Character	Variety rating *	Nitrogen used, kg/ha			
		0	45	90	179
Yield, kg/ha	Tall Semi-dwarf	2798 3175	3228 3995	3989 5139	4311 5596
Protein, %	Tall Semi-dwarf	13.2 11.7	11.6 11.9	14.3 11.3	14.6 12.4
Sedimentation, units	Tall Semi-dwarf	33 28	31 29	46 31	42 33
Height, cm	Tall Semi-dwarf	109 81	114 83	117 83	119 91
Lodging, %	Tall Semi-dwarf	18 3	28 0	36 1	40 5
Yield increase kg/ha	Tall Semi-dwarf	0 0	430 820	1191 1964	1513 2421

*/ Pilot, Svenno, Thatcher and W 187-11 rated tall; W 256-3-15, W 212-4-15 and W 212-3-18 (all of Norin 10 origin) rated semi-dwarf.

IV. d. South America

Over 90 percent of South America's wheat production takes place in the three southern countries of the continent, Argentina, Chile and Uruguay. There is important production also in Brazil, Colombia, Peru, Equador and Bolivia, some in Paraguay and Venezuela, while the other countries do not produce wheat to any significant extent. The greater portion of the wheat area lies between 30° and 40° south latitude with only limited acreage south of this area in Chile. North of 30°S wheat is cultivated only at moderate to high altitudes. In 1948-52 South America's wheat production contributed to 4.2 percent and in 1962-66 to 3.7 percent of world's total wheat production.

33. Argentina

Argentina is the most important wheat country in South America and one of the ten leading wheat producers and exporters in the world. In 1962-66 75 percent of the wheat produced in South America came from Argentina.

In 1966 wheat was grown on about 5.2 million hectares or on 27 percent of Argentina's arable land or 47 percent of its cereal area. The areas under its nearest competitors, maize and sorghum, were 3.3 and 1.1 million hectares respectively. The production of wheat per capita was 275 kilograms (seventh highest in the world) in the same year, only less than one half of which, 99 kg in terms of flour, was consumed as food within the country (Int. Wheat Council 1968).

Table 59. Area, production and yield of wheat and fertilizer use - Argentina.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,487	5,175	1,150	0.4	0.3	0.1	0.8
1962-66	4,997	7,509	1,500	1.0	0.3	0.2	1.5
Incr. (+) or decr.	+ 510	+ 2,334	+ 350	+ 0.6	± 0	+ 0.1	+0.7

Wheat yields in Argentina have been relatively high considering the low level of fertilizer use. However, the yearly variation in wheat yields due to climatic conditions is rather marked. During the five-year period of 1962-66, for example, the annual yield varied from 1840 (in 1964) to 1,200 (in 1966) kilograms per hectare. It is likely that with increased use of fertilizers wheat yields could be considerably raised and probably their yearly variation reduced. Among the reasons discouraging the use of fertilizer for wheat are the unfavourable wheat/fertilizer price relations in Argentina (Arens 1966). About one third of the consumption of phosphates and some 13-14 percent of nitrogenous fertilizers are produced in the country but all potash fertilizers are imported.

Much of the land now growing wheat was previously "pampa", fertile long-grass prairie, which was ploughed and taken under cultivation. The cultivation of wheat in Argentina is limited in the north by a combination of high temperature and high humidity in the growing season, in the west by arid desert conditions and in the south by drought and low temperatures. Because of these widely varying conditions of wheat production, a wide variety of hazards to wheat growing are involved. The most serious of these are drought, heat, cold, late frost, hail, strong winds, and diseases including stem, leaf and stripe rusts (Peterson 1965).

Nitrogen proved to be the most effective nutrient for increasing wheat yields in experiments carried out in the wheat areas of the South of the Santa Fé province and the North of the Buenos Aires province (Table 60).

For phosphorus, applications at rates of 40 and 80 kg P_2O_5 per hectare, the yield increases were considerably smaller, 182 and 369 kg/ha respectively, and the response ratio of 4.6 at both rates. Potassium showed only 133 and 163 kg/ha yield increase at rates of 30 and 60 kg K_2O per hectare and response ratios of 4.4 and 2.7, respectively. The ten trials in the provinces of Buenos Aires and Córdoba, reported by Barreira and Lopez Dominguez (1964), showed the highest economic returns for an early (until tillering) application of 50 kg N per hectare.

Table 60. Average results of nitrogen fertilization trials (Caravello and Giannetto 1964).

Nitrogen application kg/ha	Yield kg/ha	Yield increase kg/ha	%	Response Ratio kg grain/kg N
0	1,613	-	-	-
50	2,053	440	27.3	8.8
100	2,245	632	39.2	6.3

In Argentina, the co-operative INTA-CIMMYT-Ford Foundation Programme for the rapid acceleration of both maize and wheat production has been established. During 1968 about 90 advanced genetic lines were included in the official pre-inscription replicated yield tests and compared with the principal commercial wheat varieties. Many of these lines outyielded the best check varieties. Also 33 dwarf durum lines were compared for yield to the tall strawed Argentine commercial durum varieties. Although 19 of the durum dwarfs outyielded the best commercial durum check variety, the yields were 1 ton/ha less than the best experimental bread wheat lines. There is a need to increase both the speed and scope of the wheat breeding programme in Argentina (CIMMYT 1969).

34. Bolivia

Maize and barley are the main cereals grown in Bolivia making up 45 and 24 percent of its cereal area respectively in 1966. The share of wheat was 19 percent of the cereals and 2.9 percent of the arable land area. In spite of some increase in wheat area and yields, the production was only 70,000 tons in 1966 or about 15 kilograms per inhabitant.

Table 61. Area, production and yield of wheat and fertilizer use - Bolivia

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare N	P_2O_5	K_2O	Total
1948-52	61	37	610	0.0	0.0	-	0.0
1962-66	84	67	800	0.2	0.1	0.1	0.4
Incr. (+) or decr. (-)	+ 23	+ 30	+ 190	+ 0.2	+ 0.1	+ 0.1	+ 0.4

The national yield is lower than in most South American countries and the consumption of fertilizers per arable hectare less than in any other wheat growing country of the continent. For all fertilizers Bolivia depends on imports.

Wheat is grown in Bolivia mainly in the mountains at various altitudes up to about 3600 meters. It is grown during the warmest part of the year at these altitudes while at lower altitudes its growing season is during the coolest part of the year. Depending on the altitude some wheat is sown every month but the main months of harvesting are May, June and July (Peterson 1965).

35. Brazil

Almost 30 million hectares or about 39 percent of the arable land of the whole of South America is located in Brazil and 45 percent of it was under cereal crops in 1966. The main cereals, maize and rice, were grown on 8.7 and 4.0 million hectares respectively while the area under wheat was only 717,000 hectares, corresponding to 2.4 percent of Brazil's arable land and 5.3 percent of its cereal area. The wheat production was 615,000 tons or 7 kilograms per capita in the same year. The consumption of wheat as a food is low, only 16 kg flour per capita, but still most of it must be met by importation (Int. Wheat Council 1968). Even in 1968, a year when the domestic wheat crop reached an alltime record, domestic production supplied only about 23 percent of consumption. Wheat was the single most expensive Brazilian import; its value (c.i.f.) was the equivalent of US$182 million, or about one fourth of the coffee export earnings (McDonald 1969).

Table 62. Area, production and yield of wheat and fertilizer use - Brazil.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	671	498	740	0.4	0.4	0.4	1.2
1962-66	751	588	785	2.0	3.0	2.8	7.8
Incr. (+) or decr. (-)	+ 80	+ 90	+ 45	+ 1.6	+ 2.6	+ 2.4	+ 6.6

The 18 percent increase in wheat production from 1948-52 to 1962-66 is mostly (66%) due to expansion in wheat area but also (34%) due to increase in the average national yield. In spite of the sixfold increase in fertilizer use the consumption still remained somewhat below the South American average and was less than one third of the average fertilizer use per arable hectare in the whole world. Brazil's fertilizer production meets about two thirds of its phosphate and one tenth of its nitrogen consumption.

Most of Brazil's wheat production takes place in the three southern states: two thirds in the State of Rio Grande do Sul and about one third in Santa Catarina and Paraná. North of this region, in the forest and savanna lands, long periods of drought in the winter season prevent successful wheat production. In the Amazon valley the combination of high temperature and high humidity is unsuitable for wheat. A rather soft red bread wheat of the spring habit is sown in the autumn or early winter (mainly in June and July) and harvested in November-December (Peterson 1965).

Although many scientists have been working to improve Brazilian wheat yields through investigations into soil fertility, fertilizer use, cultural practices, and development of new high yielding, disease resisting varieties, a breakthrough similar to those in Mexico, India and Pakistan has not yet been achieved. Aluminum toxicity of soils that exists in much of the country is one of the factors preventing the successful growth of imported varieties including those from Mexico. Experiments indicate that this toxicity can be corrected with applications of lime. Brazilian varieties do fairly well even without lime. Research for crossing Mexican and other imported varieties with Brazilian varieties resistant to aluminum toxicity are being carried out (McDonald 1969). Even though rust is fairly well controlled in Brazil, Gibberela and Septoria cause serious problems in Brazilian conditions and different opinions of the possibility of Mexican type breakthrough in Brazil's wheat production have been presented. One of the most optimistic is that of Dr. W.Gibler, Technical Director of the intensified wheat programme that Massey Ferguson is carrying out in Brazil in cooperation with FAO. He believes that within three years Brazil will close much of the gap between domestic production and total requirements and has the capacity within ten years to come much closer to self-sufficiency (McDonald 1969).

36. Chile

As a wheat country Chile ranks second (after Argentina) in South America. In 1966 wheat was grown on 17.4 percent of the arable area and two thirds of Chile's cereal production consists of wheat, the rest being mainly oats, barley and maize. The production corresponded to 133 kilograms of wheat per capita.

Table 63. Area, production and yield of wheat and fertilizer use - Chile.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	777	928	1,190	2.2	4.2	0.6	7.0
1962-66	835	1,222	1,465	8.0	14.7	2.9	25.6
Incr. (+) or Decr. (-)	+ 58	+ 294	+ 275	+ 5.8	+ 10.5	+ 2.3	+ 18.6

Chile's wheat production increased from 1948-52 to 1962-66 by about 32 percent. About three fourths (76%) of this increase was due to the higher yields during the latter period and the rest (24%) was due to increased wheat area. The wheat yields harvested in Chile were some ten percent higher than the average in South America during both periods under comparison. Much of the 32 percent yield increase can be attributed to the increased use of fertilizers.

In terms of the increase in fertilizer use from the former to the latter five-year period and of the corresponding increase in national wheat yield, the response of wheat to fertilizers including other yield factors was about 15 kilograms of wheat per one kilogram of nutrients ($N+P_2O_5+K_2O$) given in fertilizers.

The production of nitrogenous and phosphate fertilizers in Chile shows a decreasing trend while that of potash has been increasing. In 1966-67 about one third of nitrogen and two thirds of potash production was consumed by Chile while the production of phosphate fertilizers contributed less than ten percent of the domestic consumption.

Chile's wheat area extends from 32° to 42° south latitude in the norrow belt of land between the coastal range on the west and the Andes mountains on the east. In the north it is limited by extreme desert conditions and in the south by excessive rain and low temperatures. Most of the wheat produced is common bread wheat of soft texture and low protein but also some durum wheat is grown. About one quarter of the wheat is produced under irrigation (Peterson 1965).

In Chile the response of wheat to fertilizers varies with soils as demonstrated by the results obtained at thirteen experiment stations. At four stations marked increases in yield were obtained with nitrogen; at another five, phosphorus was the most effective plant nutrient; at two other stations both nitrogen and phosphorus were beneficial. At two stations no significant increases were obtained with N, P and K applied either singly or in combination. At one of these two stations the yield of wheat was high, probably indicating high fertility, but at the other the yield was low. In the latter case, lack of response to fertilizers was explained by the existence of other growth limiting factors, lack of moisture and a poor physical condition of the soil (Ignatieff and Page 1962).

37. Colombia

Maize and rice are the main cereals in Colombia making up 67 and 21 percent of its cereal area in 1966 respectively while that of wheat (115,000 ha) was only 8 percent or 2.3 percent of the 5.0 million hectares of arable land. The production of wheat, 94,000 tons, corresponded to five kilograms per capita.

Table 64. Area, production and yield of wheat, and fertilizer use - Colombia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	173	124	715	0.5	1.1	0.9	2.5
1962-66	125	116	930	9.3	9.9	7.3	26.5
Incr. (+) or decr. (-)	- 48	- 8	+ 215	+ 8.8	+ 8.8	+ 6.4	24.0

In spite of a 30 percent increase in hectare yields from 1948-52 to 1962-66 the average annual production fell by 8000 tons or by 6 percent because of a 28 percent reduction in the wheat cultivation area. During the earlier period given above the consumption of fertilizers was, on the average, at the level of that in South America. Since then it has been increased tenfold and in 1962-66 almost three times as much fertilizers per arable hectare were used in Colombia than, on the average, in South America. Much of the yield increase can be attributed to increased fertilizer consumption consisting of approximately equal doses of all three main nutrients. About two thirds of the consumption of nitrogenous and one fifth of that of phosphate fertilizers were produced within the country.

Most of Colombia's wheat is produced in mountains at various altitudes where some of it is sown every month because of the diverse conditions due to different altitudes, but the main harvesting time falls between August-December (Peterson 1965). At low altitudes wheat cannot compete with more remunerative tropical crops.

Wheat has shown good response to fertilizers in trials and demonstrations carried out in Colombia by FAO. An example is given in Table 65.

Table 65. Average results of 14 fertilizer demonstrations in the Narino region (FAO 1970).

Treatments $N - P_2O_5 - K_2O$	Yield kg/ha	Yield increase		Net Return $ / ha	Value/Cost ratio
		kg/ha	%		
Control	1,135	-	-	(165)	-
60 - 0 - 0	1,543	408	36	+ 43	3.7
60 - 90 - 0	1,837	702	62	+ 63	2.6
60 - 90 - 30	1,707	572	50	+ 39	1.9
90 - 135 - 30	1,847	712	63	+ 40	1.6

The highest value/cost ratio was obtained with 60 - 0 - 0 treatment, the highest net return with 60 - 90 - 0, and the highest yield with 90 - 135 - 30 treatment.

Besides the demonstrations shown above, six fertilizer trials were carried out simultaneously in the same region. These also showed positive main effects to nitrogen and phosphorus. The highest yield increase (53%) and net return ($88) were obtained with 90 - 135 - 30 treatment.

38. Ecuador

Wheat was grown in Ecuador on 73,000 hectares or on 2.5 percent of its arable land area in 1966. The three principal cereals of the country, maize, barley and rice, occupied 300,000, 160,000 and 101,000 hectares respectively in the same year. The production of wheat, 73,000 tons, was equal to about 14 kilograms per capita.

Table 66. Area, production and yield of wheat, and fertilizer use - Ecuador.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	55	23	420	0.1	0.1	0.0	0.2
1962-66	73	69	940	2.1	2.0	1.2	5.3
Incr. (+) or decr. (-)	+ 18	+ 46	+ 520	+ 2.0	+ 1.9	+ 1.2	+ 5.1

Ecuador trebled its wheat production from 1948-52 to 1962-66. This was mainly (79%) due to over twofold hectare yields harvested during the latter period and to a lesser extent (21%) due to expansion in wheat area. In spite of the remarkable increase in yields, they still remain well below the South American average.

The ratio between the three main nutrients given in commerical fertilizers corresponds closely to the average ratio in South America but the level of fertilizer use per arable hectare is considerably lower.

The conditions of wheat production are very similar to those in Colombia.

Pertilizer trials with wheat carried out by FAO in 1965-66 in Ecuador showed good response to both nitrogen and phosphorus while responses to potassium were lower (Table 67).

Table 67. Average results of three fertilizer trials in the Sierra, Ecuador in 1965-66 (FAO 1968,a).

Treatment $N - P_2O_5 - K_2O$	Yield kg/ha	Yield Increase %	Net return \$ / ha	Value/Cost ratio
Control	1,331	-	(149)	-
45 - 0 - 0	2,238	68	+ 77	4.1
0 - 135 - 0	2,162	62	+ 52	2.3
0 - 0 - 45	1,467	10	+ 6	1.7
45 - 135 - 0	3,160	137	+ 139	3.1
45 - 0 - 45	2,147	61	+ 57	2.7
0 - 135 - 45	2,101	58	+ 36	1.7
45 - 135 - 45	3,432	158	+ 160	3.1
90 - 270 - 90	3,856	190	+ 132	1.9

The highest value/cost ratio was obtained with 45 N/ha treatment. The heaviest treatment (90 - 270 - 90) gave the highest yield increase while an application of half this dose showed the best net return.

Contrary to the results given in Table 67, potassium was the most effective nutrient in the one trial and in several of the ten demonstrations carried out during the following growing season in the Sierra region (FAO 1969, a). The most complete treatment (NPK) generally gave the highest yield increases and largest net return but these were considerably lower than the year before. Only in one demonstration the net return exceeded \$100/ha and the average of the two next highest was \$72/ha, while in others it was marginal or negative despite good yield increases.

39. Paraguay

Wheat plays only a minor role in Paraguay's agriculture since e.g. in 1966 it occupied only 7,000 hectares or 0.8 percent of the 929,000 hectares of arable land. Maize, the main cereal, was grown on 151,000 hectares in the same year.

From 1948-52 to 1962-66 Paraguay's wheat area increased from about 2,000 to almost 9,000 hectares. With a simultaneous increase in hectare yields, from 670 to 940 kg/ha, the wheat production was raised from a 1,000 ton level to about 8,000 tons. In 1966 the production was about 9,000 tons or four kilograms per capita. No data of fertilizer use were available.

The conditions of wheat production are similar to those in the adjacent areas in Brazil.

40. Peru

As in most South American countries maize is the main cereal crop in Peru where it was grown on 370,000 hectares in 1966. Also the area of barley (175,000 ha) exceeded that of wheat, which was 150,000 ha or 5.6 percent of the arable land area. The production of wheat, 140,000 tons, corresponded to 12 kilograms per capita.

There have been only relatively small changes in Peru's wheat cultivation area, production and hectare yields during the last two decades. The same concerns fertilizer consumption, except nitrogen the use of which has been doubled.

In 1948-52 Peru was practically selfsufficient in all three main fertilizer nutrients but in

Table 68. Area, production and yield of wheat, and fertilizer use - Peru.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	158	146	920	13	9	2	24
1962-66	152	147	970	26	8	3	37
Incr. (+) or decr. (-)	- 6	+ 1	+ 50	+ 13	- 1	+ 1	+ 13

1966 its own production met only three fourths of the consumption of nitrogenous and one half of that of potash fertilizers. The amount of phosphate fertilizers produced exceeded that required for domestic consumption.

In Peru, as in other tropical and subtropical Andean countries, the bulk of wheat is produced in the mountains at various altitudes. The sowing times, depending on the altitude, are distributed throughout the year but the bulk of wheat is harvested in June and July (Peterson 1965).

41. Uruguay

Wheat is the principal cereal in Uruguay where it was grown in 1966 on 380,000 hectares or on 17 percent of the arable land area. The areas of its nearest competitors maize, barley and oats were 213,000, 92,000 and 46,000 hectares respectively.

Table 69. Area, production and yield of wheat, and fertilizer use - Uruguay.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	526	469	890	0.2	0.7	0.1	1.0
1962-66	411	442	1,075	4.2	9.1	2.0	15.3
Incr. (+) or decr. (-)	- 115	- 27	+ 185	+ 4.0	+ 8.4	+ 1.9	+ 14.3

There has been considerable annual variation in Uruguay's wheat area during the past two decades (from 354,000 in 1963 to over 700,000 in 1952-56). The general trend, however, shows a decreasing tendency as indicated by the data given above, so that in spite of an increase (21%) in hectare yields the production has tended to decrease. In 1966 the production, 329,000 tons, corresponded to 120 kilograms per capita which was third highest in South America.

A fourteenfold increase in fertilizer use, even though it is still only 15 kg/ha, raised Uruguay to fourth place as a fertilizer consumer in South America. Most of the consumption consists of phosphates some of which is produced within the country. In 1962-66 the production of phosphate fertilizers equalled 20 to 40 percent (av. 28%) of consumption.

Wheat production in Uruguay is similar to that in the adjacent areas in Argentina.

42. Venezuela

Maize and rice are the principal cereals of Venezuela and wheat was grown there on only 3,000 (less than 0.1%) out of the 5.2 million arable hectares. Wheat cultivation area as well as the production have been decreasing and in 1962–66 were only one fifth of that in 1948–52. Only 0.1 kilogram of wheat per capita was produced in 1966.

Table 70. Area, production and yield of wheat, and fertilizer use – Venezuela

Periods and change	Wheat area (1000 ha)	Weat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	10	5	520	0.3	0.1	0.2	0.6
1962–66	2	1	535	4.1	1.4	1.5	7.0
Incr. (+) or decr. (–)	– 8	– 4	+ 15	+ 3.8	+ 1.3	+ 1.3	+ 6.4

The wheat yields harvested in Venezuela are very low and only a slight increase during the last two decades can be noted. The level of fertilizer consumption is somewhat below the South American average. Over a half of the consumption consists of nitrogenous fertilizers. Most of the nitrogenous and phosphate fertilizer consumption in Venezuela is met by its own production but all potash fertilizers have to be imported.

Most of the wheat produced in Venezuela is grown at high altitudes in the western part of the country.

IV. e. Asia

In 1948–52 Asia contributed to about 21.1 percent and in 1962–66 21.5 percent of the world's total wheat production. Even though rice is the principal cereal crop in many Asian countries, especially in the humid tropics and subtropics, about 62 million hectares (approximately 25 million in Mainland China and 37 million in other countries) or 14 percent of the arable land area were under wheat in 1966. About 90 percent of Asia's total wheat production took place in five countries: Mainland China (27.7 million tons); India (10.4); Turkey (9.7), Pakistan (3.9) and Iran (3.2). The average production of wheat per capita was about 30 kilograms or about one third of the world average.

43. Afghanistan

The main cereal of Afghanistan is wheat the production of which in 1966, for example, contributed to about 59 percent of the total cereal production of the country. Wheat was grown on over 2.3 million hectares or on about 26 percent of Afghanistan's nine million arable hectares and its production, 2,033,000 metric tons, corresponded to 127 kilograms per capita, which after Turkey is the highest figure in the whole of Asia.

Table 71. Wheat area, production and yield – Afghanistan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)
1948–52	2,000	1,700	850
1962–66	2,343	2,158	920
Incr. (+) or decr. (–)	+ 343	+ 458	+ 70

From 1948-52 to 1962-66 the wheat production of Afghanistan increased by 27 percent, two thirds of which was a consequence of expansion in wheat cultivation area and one third due to increased yields. The national wheat yield is close to the average yield harvested in Asia, exceeding it by only 20 kg/ha during both periods given above. Data of fertilizer consumption were not available for the above periods but it has been negligible, since still in 1960 was less than one kilogram per arable hectare used (Tamboli 1970).

Wheat is sown both in autumn (October-November) and in spring (March-April) and about one third of it is grown under irrigation. High yielding Mexican varieties have been compared with local varieties since 1963, and have shown an impressive performance not only in the plains under irrigation but also to some extent in the uplands. In uplands, however, the level of yield and response to fertilizer are lower and varietal differences are relatively small. Lerma Rojo 64 A was the first Mexican variety recommended for Afghanistan, when the accelerated seed production started in 1966. Fertilizer trials conducted on this variety gave good responses to nitrogen (Table 72).

Table 72. Response of Autumn-planted Lerma Rojo 64 A to different doses of nitrogen after basic P_2O_5 (60 kg/ha) fertilization (Tahir 1968)

Doses of N kg/ha	Grain Yield kg/ha	Increase %	Response Ratio kg grain/kg N
0	4,840	-	-
30	5,368	11	17.6
60	5,818	20	16.3
90	6,145	27	14.5
120	6,363	21	12.7

The response to nitrogen was appreciable in all trials while that to phosphorus and potash varied with localities. For obtaining a yield of about 5000 kg/ha, 80 kg N and 60 kg P_2O_5 are recommended for soils of above-average fertility and 120 + 120 kg for soils below-average fertility.

In 1967-68 about 20,000 hectares, planted with Mexican seed, gave very good yields and in 1968-69 the Mexican varieties were planned to cover about 100,000 hectares. The estimated yields of irrigated wheat for 1975 and 1985 given in the IWP Provisional Study were 2000 and 2700 kg/ha respectively, with average applications of 80 and 120 kg N/ha and 40 and 80 kg P_2O_5/ha respectively. Tahir (1968) when revising the IWP Study estimated the respective yields to be as high as 2500 and 3000 kg/ha on the basis of the good results obtained from the Mexican varieties.

During 1968/69 nearly 200 fertilizer trials on wheat were conducted under the FAO Project on Soil Fertility and Fertilizer Use, both under irrigated and dryland conditions. The results were summarized by Tamboli (1969) as follows:

Under irrigation, fertilizer treatments 150 kg N and 150 kg P_2O_5/ha gave the highest yields in seven provinces: Lagman (3197 kg/ha), Nangarhar (3304), Kabul (5420), Kapisa and Parwan (4180), Logar (4769) and Maidan (4900). In the Lagman and Nangarhar Provinces treatments with 75 kg N and 75 kg P_2O_5/ha gave maximum economic return. For every 100 Afganis invested, a farmer would get a net profit of 235 and 248 Afganis, respectively. In the other five provinces the maximum economic return, varying from 304 to 401 Afs. per 100 Afs. invested, was obtained with 150 kg N + 150 kg P_2O_5 treatment. In the case of dryland wheat the highest yield of 1143 kg/ha was obtained by application of 75 kg N and 75 kg P_2O_5/ha, and for every Afs. invested a net return of 193 Afs. was obtained.

44. Burma

Very little wheat was grown in Burma two decades ago. In 1948-52 the 14,000 hectares under wheat comprised only about 0.01 percent of the arable land. In 1962 the wheat area was 36,000 hectares but since then its expansion was very rapid and in 1966 wheat already occupied 152,000 hectares exceeding for the first time the area of millet and maize, 145,000 and 143,000 hectares respectively, in the same year. Even then the wheat area was only 0.9 percent of the arable land while the only important cereal of Burma, rice, covered 4.5 million hectares or 28 percent of the arable land.

Table 73. Area, production and yield of wheat, and fertilizer use - Burma.

Periods and change	Wheat area (1000 ha)	Wheat Production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	14	4	290	0.0	0.0	-	0.0
1962–66	87	55	635	0.3	0.1	-	0.4
Incr. (+) or decr. (-)	+ 73	+ 51	+ 345	+ 0.3	+ 0.1	-	+ 0.4

The increase of wheat production was twice as great as the increase in area because of a more than twofold increase in hectare yields. However, due to low yields, the 1966 wheat production per capita of four kilograms, was still one of the lowest in Asia. Up to the end of the last decade practically no fertilizers were used and even since then their consumption has remained at an insignificant level.

45. China, Mainland

During the last two decades Mainland China has been the world's third greatest producer of wheat (after USSR and USA), with an average annual production output of some 16 million tons in 1948–52 and 24 million tons in 1962–66. No recent data of most crops were available. However, in 1952–56 wheat was second to rice as a food crop. The areas of the main crops were: rice about 30, wheat 21, barley 11, maize 10 and millet and sorghum together 28 million hectares. In 1966 about one fourth of the arable land was under wheat the production was 25.7 million tons, but corresponded only to about 33 kilograms per capita because of the huge population of 780 millions. Sears (1969) estimates the wheat production in 1968 for 21 million tons from an area of 24.5 million hectares.

Wheat is grown in all parts of China even though its cultivation is mainly concentrated in northern China above the east-west line between the Hwang Ho and Yangtze rivers. South of this line rice is the dominating crop. The main wheat producing provinces are Honan, Shensi, Shantung, Hopei, Kiangsu, Shansi, Anhwei, Hupei and Szechwan, while the highest yields are obtained in Szechwan, Kweichow, Kiangsu, Hupei and Yunnan provinces (Reitz 1967).

From the Tsingling Mountains northwards to the Great Wall, winter wheat predominates; beyond the Great Wall, in the North China Plain, and extending into Manchurian Plain, spring wheat is the main crop. Both spring and winter wheats of the northern regions are mostly of fairly hard texture and of moderately good quality for making bread and noodles, while the winter wheats of the south are soft and of lower quality (Peterson 1965).

A considerable effort is being made in China to increase the yield of wheat by traditional means and to extend the cultivation area. Routine expansion has met with many difficulties and failures. Some problems are soil salinity and poor drainage in irrigated areas and soil blowing and drought in rainfed areas. Inadequate management and unsatisfactory plant types have also impeded progress. Moderate success has been reported in variety improvement, insect, smut and rust control (including use of chemicals), and utilization of organic fertilizers. The use of chemical fertilizers has shown less progress (Nash and Tien - Hsi Cheng 1965, ref. Reitz 1967). No data of fertilizer consumption nor production were available.

A general picture of the response of wheat to fertilizers in Mainland China can be obtained from the results of the 108 experiments reported by Richardson (1952). In these experiments when standard rates of nutrients (60 kg of N, P_2O_5 or K_2O per hectare) were applied, the overall means of yield increases were 370, 150 and 15 kg/ha corresponding to response ratios of 6.2, 2.5 and 0.3 for the three nutrients respectively. The response, however, varied considerably with soils. In Table 74 the results are given when the soils were roughly divided into two main classes of pedocals or calcium soils and pedalfers or leached soils.

Both, yields and fertilizer responses were higher on leached than on calcium soils. Limitation of growth by lack of moisture was probably the cause of the difference, but concerning phosphate and potash also the status of these nutrients was lower in the leached soils.

Table 74. Yields and responses (in parentheses) of wheat in 108 fertilizer trials in Mainland China.

Soil	No. of experiments	Mean yield kg/ha	Yield increase (kg/ha) and response ratios due to 60 kg/ha application of:		
			N	P_2O_5	K_2O
Calcium soils	46	1,530	255 (4.2)	105 (1.8)	– 15 (– 0.3)
Leached soils	62	1,605	450 (7.5)	165 (2.8)	20 (0.3)

Calcium soils occur chiefly in the wheat region of northern China which has a relatively dry climate while leached soils occur mainly in the rice region of central and southern China where the rainfall is higher.

46. China, Taiwan

In 1966 about 93 percent of Taiwan's arable area was under cereal crops, 94 percent of which was growing rice, 2.6 maize and only 1.7 wheat. There has been only relatively small changes in the annual wheat area during the past two decades but because of the twofold increase in national wheat yield the production was more than doubled.

Table 75. Area, production and yield of wheat, and fertilizer use – Taiwan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	14	13	960	61	29	8	98
1962–66	14	27	1,930	150	39	45	234
Incr. (+) or decr. (–)	± 0	+ 14	+ 970	+ 89	+ 10	+ 37	+ 136

In spite of the high yields, third highest in Asia in 1966, the wheat production is only a little over two kilograms per capita being one of the lowest in the region. Therefore, the bulk of wheat consumed in Taiwan is imported. The estimates for Taiwan's wheat imports for 1968 and 1969 were 449,000 and 575,000 tons respectively (Goode 1970).

An essential reason for the considerable increase in hectare yields is undoubtedly the increased consumption of fertilizers. In 1966 Taiwan was, after Japan, the second highest consumer of fertilizers in Asia and ninth in the whole world. Over 60 percent of the nutrients given in commercial fertilizers consist of nitrogen. Relatively the increase has been highest in potash and lowest in phosphate fertilizers.

In the early nineteen-fifties only one fifth of nitrogenous and two thirds of phosphate fertilizer consumption were met by Taiwan's own fertilizer industry. Since 1962–64 the country has been self-sufficient in these fertilizers but it still depends on imports of potash.

Stiff-strawed, short, rust-resistant wheats have been found to respond well to dressings of 80–120 kg N/ha, given in split applications at planting and just before tillering, while high nitrogen doses can be harmful for tall or rust-susceptible varieties, because of luxuriant vegetative growth, lodging and spread of rust, induced by high nitrogen supply (De Geus 1970). Wheat also responds well to phosphate fertilizers in various locations of Taiwan. The recommendations of phosphorus and potassium are based on the soil reserves of these nutrients.

47. Cyprus

Wheat was grown in Cyprus on 61,000 hectares or on 14.1 percent of the arable land in 1966. Wheat and barley are the only important cereals of the country and their production, 56,000 and 51,000 tons respectively, constituted together over 99 percent of the total cereal production of Cyprus. The production of wheat per capita, 93 kilograms, was about equal to the world average and over three times as high as the Asian average.

Table 76. Area, production and yield of wheat, and fertilizer use - Cyprus.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	75	48	640	3.2	9.0	0.2	12.4
1962-66	65	65	1,000	19.9	16.9	4.3	41.1
Incr. (+) or decr. (-)	- 10	+ 17	+ 360	+ 16.7	+ 7.9	+ 4.1	+ 28.7

In spite of the 13 percent decrease in wheat cultivation area from 1948-52 to 1962-66 the production increased by 35 percent because of 56 percent increase in the average national yield. The most important reason for the higher yields during the latter period is apparently the over threefold increase in the use of fertilizers in Cyprus. The ratio between the three nutrients given in fertilizers has narrowed (Table 119, p.120) and the share of nitrogen has exceeded that of phosphate, the dominating nutrient two decades ago. Also the share of potash increased from less than two to ten percent of the total consumption of fertilizer nutrients.

48. India

India, with a total land area of 327 million hectares (50% of which is arable) is, after China (mainland), the greatest producer of wheat in Asia and seventh in the whole world. In 1966 12.6 million hectares (7.8% of arable land) were under wheat, producing 10.7 million metric tons of wheat. Due to India's large population (498 millions), however, the wheat production per capita was only 21 kg which is less than one fourth of the world average. The national average yield (820 kilograms per hectare) was somewhat less than the average in Asia (900 kg/ha). Wheat, which after rice is the most important food crop in India, is grown principally in the northern, western and central parts of the country. About one fourth of the wheat fields are furnished with irrigation facilities.

Since possibilities of increasing the area under cultivation in India are very limited, the progressively growing population will have to be fed from practically the same area under cultivation at present. This is possible only through increased yields.

Table 77. Area, production and yield of wheat, and fertilizer use - India.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	9,290	6,087	660	0.4	0.1	0.0	0.5
1962-66	13,355	11,083	830	3.3	0.9	0.5	4.7
Incr. (+) or decr. (-)	+4,065	+4,996	+ 170	+ 2.9	+ 0.8	+ 0.5	+ 4.2

The increase in production (82%) from 1948-52 to 1962-66 is mainly (63%) due to the expansion of wheat cultivation area on the expense of other crops and the remaining 37 percent due to an increase in national yields.

It is generally agreed by Indian soil scientists that the factor which is most responsible for low crop yields in India is the low fertility level of exhausted soils and the slight use of fertilizers. The soils of India, as pointed out by several investigators, are deficient in organic matter and nitrogen in general, and phosphorus in localized areas but are usually rich in potassium. There is also evidence that zinc deficiency might be fairly wide-spread in northern India (Nene at al. 1968, Sharma 1968). Fertilizers provide the quickest means of increasing agricultural production in India (Panse and Khanna 1964). Lack of fertilizers, however, is a factor which limits this development and the demand for fertilizers is rising rapidly. The production figures estimated for 1968–69 were 655,000 tons of N and 320,000 of P_2O_5 while of the estimated consumption was 1,200,000 tons of N, 450,000 tons of P_2O_5 and 180,000 tons of K_2O. By 1973–74 the estimated requirements will be 4.8 and 2.4 million tons of N and P_2O_5 respectively, exceeding sevenfold the present production figures. The food grain target for 1973/74 has been set at 130 million tons. If the response ratio is 15:1 for N used, 400,000 tons of additional N would be required each year for food grains alone, if 10:1, 600,000 tons. (Sahai, ref. CIMMYT 1969). Great effort will be required to advance the fertilizer supply to meet these needs.

The cultural practice of wheat in Indian agriculture usually involves fallow in the "kharif" season for soil moisture conservation and decreasing irrigation requirements. Fallowing, however, does not make full use of land resources. In most wheat areas of India the climatic conditions, however, allow cropping of maize, jowar or bajra in the "kharif" season if sufficient water supply and adequate level of fertilizers for the fallowing wheat crops in the "rabi" season are available (Prashar & Singh 1963).

The high yielding dwarf wheat varieties were first introduced in 1962 under the FAO Near East Wheat and Barley Project in collaboration with the Rockefeller Foundation, and subsequently tested in all the wheat growing states of India. Aware of the excellent performance of Mexican varieties about 2900 ha were planted in 1965 with seed of two well-adapted dwarf varieties Lerma Rojo 64A and Sonora 64. In 1967–68 the high yielding varieties occupied over 18% of the total wheat area and contributed 36% of the total wheat production. It is estimated that just under 4.4 million hectares were sown to high yielding varieties in 1968. The remarkable rise in 1967–69 in wheat production and average yield with the advent of high yielding varieties, together with wider use of fertilizers and increased development of ground water through tube-well drilling is shown in Fig. 25.

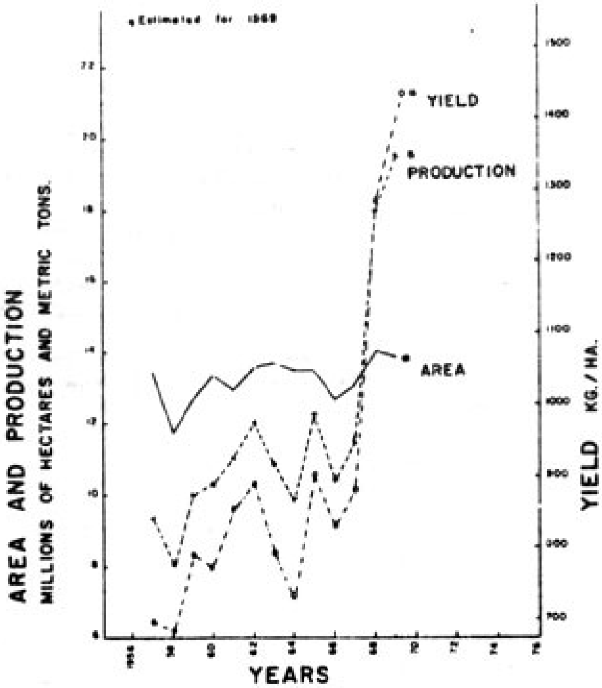

Figure 25. Total area, production and yield of wheat in India, 1957–69 (CIMMYT 1969).

All-India Coordinated Wheat Improvement Project has laid the basis for sound recommendations for proper fertilization, irrigation, seeding rates and dates and depths of planting.

Results of coordinated agronomic trials in India reported by Wright (1968) show the drastic differences between the new dwarf and traditional tall Indian varieties in their agronomic characteristics, necessitating marked changes in cultural practices. There is often a reduction in plant population when planting too deep, e.g. at 8 cm or more (a common practice with tall varieties) because some of the plants do not emerge from the soil due to the short internodia of the dwarfs. In one experiment the reduction was 35 percent when the depth was changed from 4 to 8 cm. It was also observed that when the seeds are placed too deep in the soil, their emergence is in some instances delayed by as much as four to five days. The deepseeded plots in 1967-68 showed also a greater tendency to lodge than the shallow-seeded plots, probably due to poor root development (Wright 1968).

In the early experiments conducted in India, it was apparent that some of the dwarf varieties, particularly Sonora 64 (a short-duration variety) were planted at the wrong time. The results of combined sowing date and fertilizer trials showed that for many dwarf varieties, particularly those of short maturation, the best sowing date is considerably later than for the longer maturing tall varieties. Sowing long-duration varieties too early often encourages greater vegetative growth and subsequent lodging. Fragmentary evidence of greater response to increased levels of nitrogen and increased seed rates at the early planting dates than at the late planting dates were also obtained.

Due to their shortness in stature the dwarf variety can utilize higher rates of fertilizer without premature lodging but are also at lower fertilization levels superior to all varieties in efficiency of fertilizer utilization as can be seen from Figures 26 and 27 and Table 78.

Table 78. Response of Mexican and Indian wheat varieties to different rates of nitrogen. Grain yields are given in kilograms per hectare (Sharma and Singh 1966) - (Average response ratios, kg wheat/1 kg nitrogen, are given within parentheses).

Rates of nitrogen (kg/ha)	0	45	90	135
Sonora 63	2,170	3,232	4,266	3,935
Sonora 64	2,372	3,565	4,585	4,165
Lerma Rojo	1,735	3,889	4,774	4,085
Average, Mexican varieties	2,092	3,562(32.7)	4,542(27.2)	4,062(14.6)
N.P. 876	1,590	2,736	2,797	2,412
N.P. 887	1,617	2,605	2,444	1,019
C. 306	2,034	2,730	2,765	2,032
Average, Indian varieties	1,747	2,690(21.0)	2,569(10.2)	2,121(2.8)

Wright (1968) concluded that for dwarf wheats about 120 kg nitrogen per hectare will be very close to the economic optimum for most soil and climatic conditions. (Under farm conditions the maximum profit point, however, might be nearer to 90 kg N/ha or even below). This level of nitrogen will produce about 20 or more kilograms of grain for every kilogram of nitrogen added, which is a profitable ratio.

The results of Sharma and Singh given in Table 78, show a decline in yields first after 90 kg/ha level for Mexican varieties while the increase of nitrogen application from 45 to 90 kg/ha no more increased the yields of tall Indian varieties.

There is also a marked difference in the response of the two genotypes to phosphorus although both benefit from phosphorus fertilization. At Delhi and Pantnagar areas the optimum rates of P_2O_5 for a dwarf variety Sonolika and a tall variety NP 890 were 60 and 90 kg/ha and the yields 4970 and 3890 kg/ha respectively (Rajat and Mohta 1968).

The results reported by Panse and Khanna (1964) concerning 1916 trials of irrigated and 518 trials of unirrigated wheat in various parts of the country give a good general picture of the average response of Indian wheat varieties to fertilizers (Table 79).

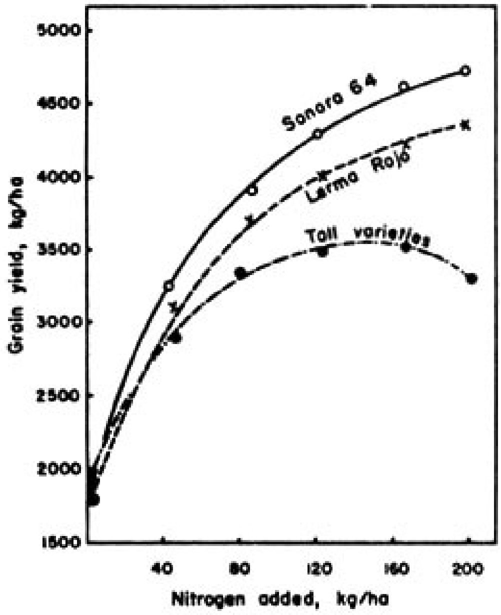

Figure 26. Response of Mexican dwarf and Indian tall varieties to nitrogen (Wright 1968).

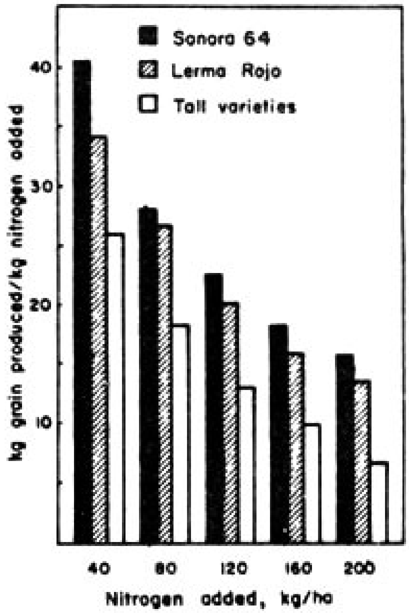

Figure 27. Efficiency of nitrogen utilization of dwarf and tall varieties (Wright 1968).

Table 79. Average increase of yield of wheat (kg/ha) obtained with N, P_2O_5, and K_2O and their combinations. All nutrients applied at 22.4 kg/ha (Panse and Khanna 1964). (Response ratios, kg wheat/1 kg fertilizer nutrient, are given in parentheses).

Treatments	Irrigated wheat	Unirrigated wheat	Average
Average yields of untreated plots	1,300	920	1,110
Average increase in yield due to:			
N alone	370 (16.5)	260 (11.6)	315 (14.1)
P "	230 (10.3)	130 (5.8)	
K "	140 (6.3)	90 (4.0)	
N + P	530 (11.8)	360 (8.0)	445 (9.9)
N + K	440 (9.8)	290 (6.5)	
P + K	340 (7.6)	210 (4.7)	
N + P + K	730 (10.9)	490 (7.3)	610 (9.1)

The difference between the response of irrigated and unirrigated wheat is quite clear. Both the unfertilized yield and responses in dryland conditions correspond to about two thirds of those under irrigation. In both cases the N, NP and NPK treatments gave the highest responses and K and PK the lowest. Also Abraham (1965) found that the responses of unirrigated wheat were about one third less than those under irrigation and in addition the response curves of unirrigated wheat showed greater rates of diminishing return at high nitrogen application levels. The results given in Fig. 28 show the effect of timing of irrigation on the wheat yields.

The response of potash varies considerably with soils. In 336 trials (Raheja et al. 1970) the highest response ratios (5.2–7.0) for irrigated wheat was found on Alluvial soils and lowest (2.5–5.0) on Desert soils. For unirrigated wheat the corresponding response ratios were 5.4–7.4 on Sub-Montane soils and 1.0–1.3 on Deep black soils. Prasad and Mahapatra (1970) reported net profits from Rs. 12 on Sub-Montane soils to Rs. 218 on Red and Yellow soils to an application of 30 kg K_2O per hectare.

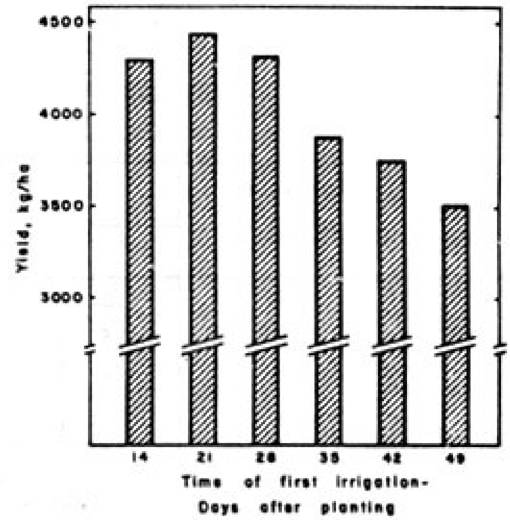

Figure 28. Yield of dwarf wheats as affected by timing of first irrigation (Wright 1968).

Forms of fertilizers have certain effects on responses. When comparing different nitrogenous fertilizers, Panse and Khanna (1964) draw the conclusion that the new fertilizers being manufactured or proposed to be manufactured in India are generally more effective than ammonium sulphate, with which the Indian farmer is most familiar. In particular, ammonium sulphate nitrate was found to be most responsive on several crops.

Chandnani (1954) obtained increased yields with farmyard manure only when applied in large quantities, the optimum dose being 25–37 tons per hectare or about 110 N/ha applied 7–8 weeks before sowing. Green manuring gave 20 to 40 percent increase depending on soil conditions and was the cheapest source of nitrogen for wheat. Ammonium sulphate, ammonium nitrate, Chilean nitrate and urea all proved to be good carriers of nitrogen. Urea, however, showed slightly lower trends. In general, the presence of sufficient doses of phosphorus increased the efficiency of nitrogen.

Also in Gautam's (1961) experiments 43 percent higher yields were obtained with ammonium sulphate than with farm compost on equal nitrogen dose basis.

The results of Mehrotra (1966) indicate that there is hardly any difference in the responsiveness of rock phosphate in comparison to superphosphate under the upland soil conditions of Gangetic alluvial soils. Thus, the finely ground rock phosphate could very safely supplement the supply of superphosphate in meeting the total requirements of phosphate fertilizer for the upland soils of Uttar Pradesh. Saolapurkar et al. (1968), however, state that although rock phosphate is as effective as superphosphate on some acid paddy soils and for plantation crops like tea, coffee and rubber, it is not an effective source of P for most cereals.

In trials of wheat, nitrophosphate was more effective than single superphosphate in the case of red and yellow soils but in all other soils single superphosphate was either equal to or better than nitrophosphate (Raychaudhuri 1965).

Due to the quick and spectacular effect of nitrogen in increasing crop yields, the emphasis in fertilizer use has been mainly on nitrogen use. Use of phosphate and potash has received comparatively less attention in the agricultural development programmes. Because of this, local depletions of soil fertility have been noticed and recently several authors have pointed out the importance of research in increasing agricultural production and soil productivity through balanced fertilization. (Anonymous 1970, Prasad and Mahapatra 1970, Raheja et al. 1970, Ramamoorthy and Bajaj 1970).

49. Iran

Wheat is the main crop in Iran where it was produced on 4.2 million out of Iran's 11.6 million arable hectares in 1966. The share of wheat area of the arable land, 36 percent, was higher than that in any other country of the world. The corresponding percentage for barley and rice, the next important cereals of Iran, were 10 and 3 percent respectively. Wheat production per capita, 125 kilograms, was third highest in Asia.

Table 80. Area, production and yield of wheat, and fertilizer use - Iran.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	2,085	1,879	900	0.0	-	0.0	0.0
1962–66	3,980	2,898	730	1.6	1.1	0.2	2.9
Incr. (+) or decr. (-)	+ 1,895	+ 1,019	- 170	+ 1.6	(+ 1.1)	+ 0.2	(+ 2.9)

Between the five-year periods given above the area of wheat cultivation almost doubled. Because of a simultaneous 19 percent decrease in average wheat yields, the wheat production, however, was increased only by 54 percent. This is apparently due to taking more marginal soils under cultivation.

The use of commercial fertilizers was still practically unknown to Iranian farmers in the nineteen-fifties, but from the beginning of the last decade their consumption began to increase. In 1966 4.0 kilograms per arable hectare were used, two thirds of which consisted of nitrogen.

Wheat is one of the major parts of the Iranian peasant's diet and also one of the most secure crops that can be grown under the dry climate characteristic of the country. Normally it is grown in rotation with fallow but, depending on the availability of water, it may be rotated with other crops like oil seeds or legumes. Wheat can be grown year after year under irrigated conditions or, as is often practiced, it can be grown once in every two to seven years depending on the availability of irrigation water (Dewan and Famouri 1964).

According to "Agricultural Statistics 1339", corresponding to years 1960-61 (ref. Dewan and Famouri 1964) winter wheat was grown on about 85 percent and spring wheat on 15 percent of the total wheat area of Iran. The yields of winter wheat were over 60 percent higher than those of spring wheat in dryland farming and over 30 percent higher under irrigated conditions. The average yields of irrigated winter wheat (1245 kg/ha) and spring wheat (945 kg/ha) exceeded those under dryland conditions (585 and 360 kg/ha respectively) by factors 2.1 and 2.6 . Somewhat less than one third of the wheat area was irrigated in 1960-61 and at the end of the latter five-year period given above, the irrigated wheat area consisted of about 1.4 million hectares (Tahir 1968). Some 300,000 hectares wheat land was in areas receiving over 500 mm rainfall, about 2 million hectares in 350-500 mm precipitation areas and 300,000 hectares received less than 350 mm rain. The yields in the last two areas mentioned are normally about 500 and 300-400 kg/ha respectively and expansion of wheat in these arid areas may be partly responsible for the decrease in average national yield.

The best practices for dryland wheat production will not be the same in all areas of Iran. Until results of experiments on best cultural practices in Iranian conditions become available, Olson (1968) recommends growing wheat continuously or with infrequent fallow in large areas of western Iran receiving an average of more than 500 mm precipitation per year. For continuous wheat, it is then necessary that the first tillage be given immediately after harvest.

Under conditions of low precipitation, the principal means of conserving moisture is through fallow. However, fallowing practices presently used by most farmers in Iran do not include early ploughing and therefore cause wastage of much moisture and increase weed populations. Therefore, it is recommended that farmers should be encouraged to control weeds on fallow land.

The high yielding Mexican and Colombian varieties (Pitic 62, MexiPak, Penjamo 62, Nairuni, Inia 66) are well adapted to the Caspian zone and to Khuzistan (about 400,000 ha) and can yield 2-3 tons per hectare under irrigation and good farming conditions but without fertilizer. With 90 kg N and 45 kg P_2O_5 fertilizer the yields obtained in demonstration plots or at progressive farms have been 4 tons per hectare and with 120 kg N + 60 kg P_2O_5/ha 6 tons per hectare. An example of the responses of the high yielding and local varieties to fertilizers is given in Table 81.

Table 81. Response of Mexican and local wheat varieties to nitrogen and phosphorus at Ahwaz, Khuzistan in 1966-67 (Tahir 1968).

$N + P_2O_5$ kg/ha	Grain yield, kg/ha		
	Mexican var.	Local var.	Incr. over Local var.
0 + 0	2,850	2,250	600
60 + 30	3,850 (11.1)*	2,600 (3.9)	1,250
90 + 60	4,200 (9.0)	2,900 (4.3)	1,300

*) Figures within parenthesis = response ratios (kg grain/kg fert. nutrient).

Under good farming conditions and application of 90 kg N and 45 kg P_2O_5/ha, an average yield of 3000 kg/ha can be anticipated in these two zones for 1975, and with 120 kg N + 60 kg P_2O_5/ha it might be further increased to 3500 kg/ha by 1985. This would require introduction of resistance to stripe rust to which Mexican varieties are somewhat susceptible in this area. Because of very low winter temperature the present Mexican varieties are not suitable for most of the irrigated and much of the assured rainfall areas. Some of the newly developed local varieties give economic response to 60 kg N and 30 kg P_2O_5/ha in these areas (Tahir 1968).

An accelerated wheat production programme was initiated in 1967-68 under the Dezful Pilot Project in Khuzistan through large scale planting of Mexican (mainly MexiPak) varieties. In 1968 about 1500 tons of Penjamo 62 seed was imported and 70 tons produced locally. This seed would cover 20,000 hectares and local high yielding varieties about 630,000 hectares in 1968-69. Total wheat area to be fertilized in 1968-69 with about 90 kg N and 45 kg P_2O_5/ha was estimated to be 50,000 hectares, which come under an Impact Programme started that season. This programme is supposed to cover half a million hectares of irrigated land and another half a million hectares of land in good rainfall areas by 1972-73 (Tahir 1968).

50. Iraq

Two decades ago barley was the main cereal of Iraq and its production exceeded that of wheat by over 60 percent in spite of almost equal areas under the two crops. Since then the wheat area has been increasing and in 1966 wheat occupied over 1.7 million hectares or 23 percent of the arable land while the area under barley was somewhat less than 1.2 million hectares. The production of the two crops is now at the same level, 826,000 and 832,000 tons respectively, contributing together 83 percent of the total cereal production of Iraq. Wheat production per capita (99 kg) was fifth highest in Asia.

Table 82. Area, production and yield of wheat, and fertilizer use - Iraq.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	936	448	480	0.0	-	-	(0.0)
1962-66	1,673	842	505	0.3	0.1	0.0	0.4
Incr. (+) or decr. (-)	+ 737	+ 394	+ 25	+ 0.3	(+0.1)	(± 0)	(0.4)

The 88 percent increase in production from 1948-52 to 1962-66 was almost entirely (94%) due to a 79 percent increase in wheat cultivation area while the slight increase in average national yield contributed only 6 percent to it. *The average annual yields harvested in Iraq are among the lowest in Asia partly because of severe climatic conditions and partly because of poor soil and crop management,* including insignificant fertilizer consumption.

The main wheat regions of Iraq are the Northern Uplands and Lower Mesopotamian Plains where wheat is grown in winter. The bulk of wheat is produced in the north where it depends essentially on rainfall. For example, because of an exceptionally high precipitation in 1956 the wheat production in Northern Iraq was 780,000 tons, while in two previous years of lower rainfall it had been only 213,000 and 520,000 tons respectively (Buringh 1960).

The traditional cropping system on farms growing winter grains is: one year wheat or barley followed by one uncropped year, "idle" or fallow. During the idle year the soil is not ploughed nor tilled while fallowing includes these.

The region of Lower Mesopotamian Plains has an arid climate and profitable cultivation is only possible if the soils are irrigated.

High yielding Mexican varieties can be profitably grown only in irrigated areas, about half a million hectares, or in areas where the rainfall exceeds 500 mm, some 375,000 hectares (Tahir 1968). In some irrigated areas there is the problem of salinity, requiring urgent remedial measures. Out of the remaining wheat area about a quarter of a million hectares have a rainfall of 400-500 mm and the rest less than 400 mm. In large parts of the wheat areas in the north, with less than 400 mm rainfall, the land could be better utilized for livestock production. A rotation of wheat followed by 3-4 years pasture will help in restoring soil fertility and in accumulating organic matter in the soil. Tahir has summarized the results of variety trials conducted between 1965 and 1968 (Table 83).

Table 83. Yields of MexiPak and local varieties in different growing conditions in Iraq.

Variety	Under irrigation with fertilizer (80 kg N + 40 kg P_2O_5/ha)	Under irrigation without fertilizer	Under dry farming without fertilizer
MexiPak	3440 kg/ha	-	990 kg/ha
Local	2570 kg/ha	1680 kg/ha	690 kg/ha

Benefit cost ratio was 8.0 for MexiPak and 5.9 for local variety when both were similarly irrigated and fertilized.

When the Government of Iraq first obtained five tons of seed of MexiPak for further multiplication and also for distribution to progressive farmers, the results were so outstanding that the farmers who received the seed on loan refused to give back the seeds to the Government (Hafiz 1968). In addition to local multiplication of Mexican seed, Iraq has imported 800 tons of MexiPak seed from Pakistan. This would cover 10000 hectares of wheat area in 1968-69.

According to the plan of the Government, 300,000 hectares of irrigated and 150,000 hectares of rainfed (over 500 mm rainfall) would be covered by Mexican varieties by 1970-71. This would require 36,000 tons of N and 18,000 tons of P_2O_5. The remaining 200,000 hectares of irrigated area and some 225,000 hectares under sufficient rainfall would be covered by 1975 (Tahir 1968).

According to the Provisional IWP Report the average yield of irrigated wheat (900 kg/ha) would be 1,500 and 2,500 kg/ha for 1975 and 1985 respectively. This naturally provides that fertilizer requirements shown by the trials and measures of salinity control will be met.

51. Israel

Wheat is the main cereal crop grown in Israel, where it occupied 76,000 hectares or 19 percent of the arable land and 58 percent of the cereal area in 1966. During the same year barley, the second most important cereal of the country, was grown on 49,000 hectares. Israel's wheat production, 101,000 tons, corresponded to 38 kilograms per capita while its consumption as food was about three times as high or 100 kilograms per capita in terms of flour (Int. Wheat Council 1968).

Table 84. Area, production and yield of wheat, and fertilizer use - Israel.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	35	23	670	15	17	4	36
1962–66	61	97	1,590	56	27	8	91
Incr. (+) or decr. (-)	+ 26	+ 74	+ 920	+ 41	+ 10	+ 4	+ 55

In 1962-66 more than four times as much wheat was produced as in 1948-52. About 35 percent of the increase was due to 74 percent increase in the wheat area but considerably more than that, or 65 percent of the increase, was contributed by the 137 percent increase in the average national wheat yield. In respect to highest yields this increase raised Israel from fifteenth to fifth place among Asian countries.

Much of the yield increase can be attributed to the 150 percent increase in fertilizer consumption consisting mostly of nitrogenous fertilizers. In 1948-52 Israel imported over 60 percent of the nitrogenous, about 45 percent of the phosphate and all of the potash fertilizers consumed in the country. In 1962-66 it was self-sufficient in nitrogenous fertilizers, produced 48 percent over its own consumption of phosphates and about 65 times as much potash fertilizers as it used itself, being the only noteworthy potash producer in Asia.

In the southern region of Israel as well as in other arid regions, wheat and other field crops are often badly damaged or even completely desiccated due to a prolonged drought in the middle of the rainy season. Therefore, the results reported by Israeli scientists (Plaut and Halevy 1966) on the subject of regeneration of wheat plants after wilting as affected by growth regulators are mentioned here. It was found that growth regulators (CCC or B-995) had no effect on yield when wheat plants had been subjected to wilting for one day. With plants exposed to two droughts each causing wilting for 5-6 days, both compounds greatly increased grain and dry matter yields compared with untreated plants. This was attributed to the increased ability of the plants to regenerate shoots when watered after wilting. Wilting for 10-12 days killed all the plants irrespective of prior treatment. The authors felt that their results may be of practical importance in arid regions.

52. Japan

Rice is by far the most important crop in Japan where it was grown on about 3.3 million hectares in 1966. Wheat ranks second, but the acreage was only 421,000 hectares corresponding to 10 percent of the cereal area and 7 percent of the total arable land. Somewhat less land (338,000 ha) was under barley. As a wheat producer Japan ranked sixth in Asia with its production of over one million tons, but because of its high population only 10 kilograms of wheat per capita was produced in 1966. Rice being the main food crop the consumption of wheat as food is as low as 31 kilograms per capita in terms of flour (Int. Wheat Council 1968) but this is still high enough to make Japan a considerable wheat importer. In 1969 4.3 million tons wheat was imported about 52 percent of which came from the United States (Jean 1970).

Table 85. Area, production and yield of wheat, and fertilizer use - Japan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	745	1,375	1,850	64	37	23	124
1962–66	526	1,180	2,245	126	88	99	313
Incr. (+) or decr. (-)	- 219	- 195	+ 395	+ 62	+ 51	+ 76	+ 189

From 1948-52 to 1962-66 the annual wheat cultivation area decreased by 29 percent and wheat production by 14 percent. A similar trend seems to continue since in the end of the latter period (1966) the area was only 421,000 ha and production 1,024,000 tons.

The hectare yields harvested in Japan are the highest in Asia. During 1962-66 the national yields varied from 2430 to 2700 kg/ha with the exception of the year 1963 when the yield was as low as 1230 kilograms per hectare because of unfavourable weather conditions. In spite of that the average yield in 1962-66 was 21 percent higher than that in 1948-52. The over 150 percent increase in fertilizer use is likely to be the most important reason for the yield increase. Tokunaga (1968) draw a similar conclusion when analysing the factors contributing to the wheat yield increase during the past decade. About two-thirds of the increase was attributed to the improvement of fertilization and cultural techniques and one third to improved wheat varieties. Because farmers' cultural techniques for wheat had not made any remarkable progress except in labour saving, the effect of fertilizers was considered as the greatest contribution to the increase in wheat production. Japan's consumption of fertilizers per arable hectare was highest in Asia and sixth highest in the world. She is self-sufficient in phosphates and produces twice its own requirements of nitrogenous fertilizers.

Depending on climatic conditions three types of cropping upland crops have been practiced in Japan; single cropping a year, three croppings in two years and two croppings a year. Under these types of cropping wheat, barley, rice, potatoes and legumes are grown as main crops and maize is also cultivated as a forage crop. The highest yields are produced in the KantoTosan region and in the Pacific area of the Tohoku region because of favourable weather conditions. The percentage of wheat area of the cultivated land is higher in Kanto-Tosan than in other regions and two croppings a year, often wheat and upland rice (or groundnut), are carried out.

If the upland soils are roughly divided into volcanic ash soils and non-volcanic ash soils (mainly mineral soils), the former soils are occupying about 70 percent (prevalent in the Hokkaido, Kanto-Tosan and Kyushu regions) and the latter about 25 percent (prevalent in Tokai region) of the upland fields. The response of wheat to nitrogen is lower in the volcanic ash soils, than in the mineral soils. The volcanic ash soils have a low content of available phosphorus. Therefore, there is a considerable difference in the response of wheat to phosphorus between the two groups of soils, an example of which is given in Table 86.

Table 86. Response of wheat to phosphate fertilizer on a volcanic ash soil in Nagano prefecture and on a mineral soil in Aichi prefecture (Tokunaga 1968).

P_2O_5 applied kg/ha	Volcanic ash soil		Mineral soil	
	Yield kg/ha	Response ratio kg grain/kg P_2O_5	Yield kg/ha	Response ratio kg grain/kg P_2O_5
0(check)	1350	-	5470	-
50	3370	40.4	5430	−0.8
100	3860	25.1	5520	2.0
150	4740	22.6	5790	2.1
200	4890	17.7	5640	0.9
300	5080	12.4	5450	−0.1
400	5330	10.0	5720	0.6

Even if the examples given above represent extreme conditions, it is apparent that the differences in the phosphorus requirement of various soils are of essential importance. Compound fertilizers are increasingly used and especially for volcanic ash soils fertilizers of high phosphorus content are recommended.

In some Japanese soils, especially in the northern districts, wheat was suffering from copper deficiency. Since this was discovered in 1957, and response to copper sulphate recognized, the problem has largely been overcome (Tokunaga 1968).

53. Jordan

Wheat is the principal cereal crop in Jordan where it was grown on 214,000 hectares in 1966 covering 75 percent of the cereal area and 19 percent of the total arable land. The production, 101,000 tons, corresponded to 50 kilograms of wheat per capita. Half of the domestic requirement is imported.

Table 87. Area, production and yield of wheat, and fertilizer use - Jordan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	182	128	700	0.4	0.1	-	(0.5)
1962-66	256	172	670	1.0	1.0	1.5	3.7
Incr. (+) or decr. (-)	+ 74	+ 44	- 30	+ 0.8	+ 0.9	(+1.5)	(+3.2)

The comparison of the averages of two five-year periods given above shows over 40 percent increase in wheat area, 34 percent in production and a slight decrease in hectare yields. In Jordan, more than in most countries, wheat cultivation has been a subject of wide annual variation because of variation in annual rainfall ranging between 250 and 600 mm. For example, in two successive years, 1963 and 1964, the figures for wheat area were 206,000 and 297,000 hectares, yields 370 and 990 kg/ha and production 76,000 and 297,000 tons respectively. The precipitation decreases sharply towards the rocky desert areas in the eastern part of the country as well as from north to south. Most of the wheat is grown under rainfed conditions and about one fifth in areas of less than 300 mm average rainfall. In general, the hectare yields have been low and only relatively insignificant amounts of fertilizers have been used. No fertilizers are produced.

A recently released local variety, Deir Alla-1 has yielded 3000-3500 kg/ha in trials under irrigation and 2000-3000 kg/ha under good rainfall and fertilization. Some Mexican varieties have also given satisfactory results in better areas. Average yields could be raised to 1100 and 1500 kg/ha for 1975 and 1985, respectively in view of the fact that modern moisture conservation techniques are being developed by UNDP/SF and also better varieties have become available (Tahir 1968).

54. Korea, North

Wheat is of relatively little importance in North Korean agriculture. In 1965 it was grown on only 160,000 hectares or 6 percent of the cereal area while maize and rice, the principal cereals, occupied some 820,000 and 700,000 hectares respectively. About seven kilograms of wheat per capita was produced. The area under wheat in 1948-52 was about the same (162,000 ha) as in 1964-65 (160,000 ha) but production fell from 104,000 to 85,000 tons because of the decrease in national wheat yields from 640 to 530 kilograms per hectare. No data of fertilizer consumption were available.

55. Korea, Republic of

Cereals play a dominating role in South Korean agriculture, rice and barley being the principal crops. In 1966 about 153,000 hectares or six percent of the cereal area was occupied by wheat, the third important crop of the country, the production of which was 315,000 tons or 11 kilograms per inhabitant.

From 1948-52 to 1962-66 the production of wheat was more than doubled. About 60 percent of the increase was due to expansion in wheat cultivation area and the rest, 40 percent, due to a 35 percent increase in the average national wheat yield. During the latter period the second highest wheat yields in Asia were harvested in South Korea where also the third highest amounts of fertilizers were used per arable hectare. Over one half of the nutrients given in commercial fertilizers in 1966 consists

Table 88. Area, production and yield of wheat, and fertilizer use - South Korea.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	95	139	1460	32	11	2	45
1962-66	144	284	1970	88	50	17	155
Incr. (+) or decr. (-)	+ 49	+ 145	+ 510	+ 56	+ 39	+ 15	+ 110

of nitrogen, which is the only nutrient produced in the country on a large scale. Its production met about one third of the consumption. Phosphate production, 1700 tons, corresponds to less than two percent of consumption.

Wheat is generally grown as an upland crop in conditions where irrigation facilities usually do not exist. The yields of wheat without fertilizer are almost twice as high in the central and southern part of the country as in the north, but are subject to more annual variation than in the north. In spite of the differences in wheat yield levels the response of wheat to fertilizers does not appear to be affected by the location of fields as indicated by the results of trials carried out by FAO/UNDP projects. As shown in Table 89 average yield increases of 1660-1940 kg/ha were obtained with 100-130 kg N/ha corresponding to about 200% in the northern and 100% in the central and southern regions.

Table 89. Average regional wheat yields (kg/ha) at different nitrogen application levels and response ratios (kg grain/kg N) in 1964-65 — 1968-69 field trials in South Korea (FAO 1970, b).

Region	Applied N (kg/ha)	0	70	100	130
North	Yield Response ratio	860 -	2,360 21.4	2,600 17.4	2,620 13.5
Centre	Yield Response ratio	1,700 -	3,030 19.0	3,360 16.6	3,510 13.9
South	Yield Response ratio	1,840 -	3,400 22.3	3,650 18.1	3,780 14.9

The optimum level of nitrogen application was somewhat lower (about 100 kg/ha) in the north than in the other two regions (about 130 kg/ha). Phosphorus and potassium were most effective in the northern region.

Due to the interaction between the three nutrients, the highest net profits (40,000 - 56,000 W = US$ 129 - 180 per hectare) were usually obtained with combinations of 100 - 130 kg N, 75 - 100 kg P_2O_5 and 60 - 80 kg K_2O per hectare giving a value/cost ratio from about 4 to 6 (FAO 1970, b).

56. Lebanon

Wheat is the principal cereal crop in Lebanon where it was grown on 68,000 hectares in 1966 covering 76 percent of its cereal acreage and 23 percent of the arable land. The production of 70,000 tons corresponded to 28 kilograms of wheat per capita. Wheat imports of Lebanon have ranged between 200,000 tons and 240,000 tons in recent years.

Table 90. Area, production and yield of wheat, and fertilizer use - Lebanon.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg /ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	70	51	730	5	2	4	12
1962-66	68	64	945	33	22	7	62
Incr. (+) or decr. (-)	- 2	+ 13	+ 215	+ 28	+ 20	+ 3	+ 50

From 1948-52 to 1962-66 the average national wheat yield increased by 29 percent. This increase compensated for the small decrease in wheat area and brought the production up by 25 percent. Much of this can be attributed to the fivefold increase in fertilizer use, raising Lebanon up to fifth as a fertilizer consumer in Asia. Over half of the nutrients given in fertilizers consist of nitrogen while the share of potash is only 11 percent. Somewhat over half of the consumption of nitrogenous fertilizers was met by home production in 1966 and only one half of the phosphate production was consumed within the country. Potash fertilizers are imported. About half of the wheat area is irrigated. Hard (durum) wheat occupies about 45 percent of the area.

The results of the demonstrations with irrigated wheat in 1961-63 carried out by FAO (FAO 1966) showed good yield responses and economic returns to fertilizers. The most complete treatments 60-60-30 and 40-40-0, gave the highest yields (3744 and 3005 kg/ha) and also the largest monetary returns ($126 and 101 per hectare, respectively) while the highest value/cost ratio (8.2) was obtained with 30 kg N/ha alone.

With dryland wheat there were a number of treatments that showed economic returns. The best results were obtained in North Lebanon with the treatment 60-60-0 which gave a yield increase of 1837 kg/ha (94%), a net return of $131/ha and a value/cost ratio of 5.1 . In Bekaa region the treatment 60-60-30 showed the largest yield increase, 1334 kg/ha (72%) and also the highest net return, $81, and a value/cost ratio of 3.2.

Variety trials have shown that under irrigation some of the Mexican varieties give considerably higher yields than local varieties (e.g. in the 1966-67 trials the best Mexican variety yielded 4100 kg/ha on the average while the yield of the best local variety was 2800 kg/ha). In areas of high rainfall the average yield of Mexican varieties was about 2000 kg/ha (Tahir 1968).

In a single trial on calcareous soil in Bekaa an extremely high grain yield of Mexican variety Pitic 62 (9050 kg/ha) was reported by Fuehring (1969) indicating considerable potential for wheat as an irrigated crop in the area. Application of nitrogen increased yields up to about 400 kg N/ha, but most economic returns (yields from 6000 to 8000 kg/ha) were obtained with about 300 kg N/ha.

In 1967-68 12 tons of seed of MexiPak and Indus 66 were imported and grown during 1967-68 on government farms for multiplication. Ford/Rockefeller Foundations have established a wheat breeding programme in Lebanon. Yield estimations of soft wheat in 1975 are 3000, 1800 and 1000 kg/ha for irrigated, high rainfall and low rainfall areas, respectively, and 3500, 2100 and 1200 kg/ha in 1985 (Tahir 1968).

57. Mongolia

Two decades ago wheat was a relatively unimportant crop in Mongolia where some 10,000 tons were produced on about 10,000 hectares in 1948-52. In 1952-56 the average annual production was still only 12,000 tons but since then a tremendous increase in wheat cultivation has taken place. During the five-year period of 1962-66 the average area annually under wheat was 314,000 hectares and production was 302,000 tons. In 1966 it was grown on 320,000 hectares or on nine percent of the 3,5 million hectares of Mongolia's arable land area and the production, 325,000 tons, corresponded to 285 kilograms of wheat per capita, which figure was second highest in Asia (after Turkey) and sixth highest in the world.

The national wheat yields have been varying from about 900 to 1000 kilograms per hectare. No data on fertilization were available.

58. Nepal

Rice and maize are the principal crops of Nepal where they were grown on 45 and 19 percent of arable land respectively in 1966. In the same year, wheat, the third important cereal, occupied 118,000 hectares or 5 percent of the arable area.

The wheat cultivation area has been relatively constant during the past two decades. For example, the averages for the five-year period of 1948-52 and 1962-66 were 128,000 and 129,000 hectares respectively. However, because of about a 21 percent increase in hectare yields (from 910 to 1100 kg/ha) the average annual production increased from 117,000 to 142,000 tons. In 1966 the production was 147,000 tons corresponding to 14 kilograms per capita (FAO 1967a), but increased to 227,000 tons in 1969 (Parker 1970). In the latter year about one third of the wheat area was planted to the new high yielding varieties. Many farmers received free seed of Mexican varieties from the research station near Katmandu. Wheat varieties popular in the middle hills include Lerma 52 and Pitic 62, while Lerma Rojo and S227 have done well in the Terai (Parker 1970). The consumption of nitrogen fertilizer was still in 1966 less than one half kg N per arable hectare. No data on other fertilizers were available.

59. Pakistan

In spite of the fact that rice is the chief crop grown in Pakistan and occupies twice as large an area (10.5 million ha in 1966) as wheat (5.3 million ha) Pakistan is the fourth biggest wheat producer in Asia. The area under wheat corresponded to 19 percent of the arable land and the production, 3.9 million tons, to 34 kilograms of wheat per capita.

Table 91. Area, production and yield of wheat, and fertilizer use - Pakistan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,218	3,685	870	0.2	-	-	(0.2)
1962-66	5,160	4,207	815	4.0	0.5	0.2	4.7
Incr. (+) or decr. (-)	+ 942	+ 522	- 55	+ 3.8	(+0.5)	(+ 0.2)	(+ 4.5)

The half a million ton (14%) increase in annual wheat production from the five year period of 1948-52 to 1962-66 is totally due to the expansion (22%) in wheat cultivation area, because of the simultaneous 6 percent decrease in hectare yields. One of the reasons for the unfavourable development concerning the yields is apparently the low level of fertilizer use, corresponding only to somewhat more than one third of the Asian average in 1962-66. During this period, however, a clear increasing trend can be noted since from 1962 to 1966 the consumption of fertilizers was almost trebled including increases from 2.3 to 6.1, 0.4 to 1.1 and 0.1 to 0.5 kilograms per arable hectare in the consumption of N, P_2O_5 and K_2O respectively. Somewhat over one half of the consumption of nitrogenous but less than three percent of that of phosphate fertilizers were met by Pakistan's own fertilizer production in 1966. All potash fertilizer has to be imported.

High yielding varieties were first introduced in Pakistan during 1964-65 when Mexican varieties were tested in over 300 microplots. Lerma Rojo 64 and Penjamo 62 were found suitable for local conditions and the following year 350 tons of seed were imported, multiplied into 17000 tons and during 1966-67 about 120,000 hectares were sown with this seed. Through further multiplication of the seed of these two varieties and importing an additional 40,000 tons of seed of MexiPak 65 and Indus 66 from Mexico, Pakistan was able to sow about 1.2 million hectares with seed of the high yielding varieties in 1967-68. The farmers were supplied with fertilizers at subsidized rates, and a large number of demonstration plots were laid out. As a result of this accelerated programme the target of 5.4 million ton production fixed for 1968 was exceeded by 1.1 million tons, making the country almost self-sufficient in its wheat requirements (Hafiz 1968). It is further estimated (CIMMYT 1969) that about 2.6 million hectares were under Mexican varieties in 1968–69 representing about 45% of the total area (54% of irrigated and 18% of rainfed area) sown to wheat, and 65–70% of the production.

Table 92. Estimated 1969 Pakistan wheat crop (CIMMYT 1969).

Item	Irrigated		Rainfed		Total
	Mexican	Local	Mexican	Local	
Estimated area sown, mill. ha	2.3	2.0	0.3	1.3	5.9
Estimated aver. yield, kg/ha	2177	970	672	336	1275
Calculated production, mill. tons	5.12	1.93	0.19	0.42	7.6

Mexi Pak 65, Indus 66 and Penjamo 62 contributed to about 80, 10 and 5 percent of the acreage of dwarf wheats, respectively.

The experimental data from previous years (Qureshi and Narvaez 1966, 1967) indicate that the dwarf wheats show at least double the fertilizer response of that of the tall wheats. However, special cultural practices are required to obtain the maximum benefit from dwarf wheats. Such are: 1) better moisture conditions in the seedbed, 2) shallow seeding (less than 2½ inches), 3) higher seed rate (up to 112 kg/ha), 4) higher fertilizer level (up to 169 kg N + 56 kg P_2O_5/ha), and 5) more irrigations (5–6 instead of 3–4). Also deep ploughing (8–10 inches instead of 4–5) and drill sowing were found to be beneficial. The results of fertilizer trials with Mexi Pak 65 carried out in West Pakistan in 1967–68 are summarized in Table 93.

Table 93. Average regional yield data (kg/ha) and response ratios (kg grain/kg fertilizer nutrients, in parentheses) from 171 fertilizer trials with Mexi Pak wheat in West Pakistan during the rabi season 1967–68 after kharif (K) and after summer fallow(S) (Munshi et al. 1968).

Region	No. of trials	N – P_2O_5 – K_2O treatment, kg/ha			
		0–0–0	103–0–0	103–56–0	155–56–0
Central	39 K	1,736	3,271 (15)	4,237 (16)	4,423 (13)
North	34 K	2,555	3,670 (11)	4,187 (10)	4,842 (11)
South	26 S	1,844	3,643 (17)	4,658 (18)	5,110 (15)
		0–0–0	77–0–0	77–56–0	103–56–0
Central	61 S	1,970	3,424 (19)	4,173 (17)	4,402 (15)
North	11 S	2,529	3,191 (9)	3,723 (9)	4,561 (13)

The impact of dwarf wheats on the wheat production in West Pakistan during the recent years can be seen from Fig. 29.

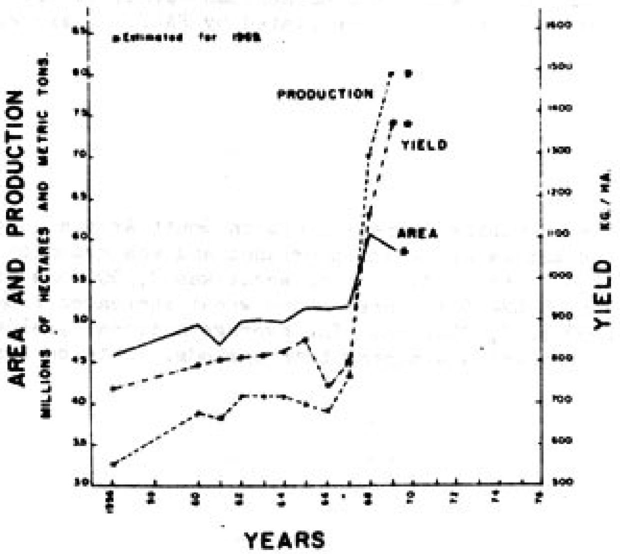

Figure 29. Cultivated area, production and yield of wheat in West Pakistan, 1956–69 (CIMMYT 1969).

The widespread use of high-yielding fertilizer-responsive dwarf wheat and rice varieties has revolutionized the use of fertilizer in Pakistan over the past three years. An estimated 115,000 tons of nutrients were applied to wheat crops in 1968-69 corresponding to nearly 20 kilograms per hectare. However, more than half of the farmers who use fertilizer only apply nitrogen and those who do use phosphates apply less than is needed for optimum economic yield. The current recommended fertilizer application for dwarf wheat under irrigation is 120-60-0. Nevertheless, the proportions of nitrogen to phosphorus used on the 1967-68 and 1968-69 wheat crops were 14:1 and 6:1, respectively. The Government of Pakistan is importing considerable amounts of diammonium phosphate and other mixed fertilizers high in phosphate to correct this crop production bottleneck (CIMMYT 1969).

60. Saudi Arabia

Wheat is the most important cereal of Saudi Arabia where it was grown on about 100,000 hectares in 1966 covering 54 percent of the cereal area and 27 percent of the total arable land. Other cereal crops, sorghum, barley and millet, occupied 45,000, 25,000 and 15,000 hectares respectively. In that year 149,000 tons of wheat (34 kg per capita) was produced and about five times as much was imported.

Table 94. Area, production and yield of wheat, and fertilizer use - Saudi Arabia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	39	49	1,370	-	-	-	-
1962-66	95	137	1,440	4.3*	3.0*	1.7*	9.0*
Incr. (+) or decr. (-)	+ 59	+ 88	+ 70	-	-	-	-

* Average of the last two years of the period.

Since 1948-52 the wheat production has increased considerably being 2.8 times as high in 1962-66 as in the earlier period. This was mainly because of expansion of the wheat area by a factor of 2.5 and the rest was due to increase in the average national yield. No data of commercial fertilizer consumption during the first period were available but apparently only negligible amounts were used.

About 80 percent of the wheat is grown under irrigation. New varieties were introduced, Giza 144, Penjamo 62, Pitic 62 and Mexico 8156, which gave twice the yield (3,000 kg/ha) of local varieties. The Government has planned to import 50 tons of seed of Mexican varieties from Pakistan for the 1968-69 season. The average yields for 1975 and 1985, estimated by FAO/IWP, are 2,300 and 3,000 kg/ha respectively (Tahir 1968).

61. South Arabia, Federation of

Millet and sorghum are the principal cereal crops in South Arabia covering 38,000 hectares or 88 percent of the cereal area. Wheat is of minor importance and was grown on about 4,000 (1.6%) of its 252,000 arable hectares in 1966. The production of wheat was 9,000 tons or 8 kilograms per capita in the same year. From 1948-52 to 1962-66 the area under wheat increased from about 2,000 to 4,000 hectares and production from 3,000 to 8,000 tons. The average national yields, 1640 and 1840 kg/ha respectively, were among the highest in Asia during both periods. Data on fertilizer use were not available.

62. Syria

Syria is an important wheat producer. In 1966 wheat was grown there on 858,000 hectares or on 70 percent of its cereal area and on 14 percent of the arable land. About one tenth of the wheat area is irrigated. The production in that year, 559,000 tons or 101 kilograms per capita, however, was only about a half of that in the previous four years because of a smaller cultivation area and a lower yield.

Table 95. Area, production and yield of wheat, and fertilizer use - Syria.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	994	761	770	0.1	0.1	0.0	0.2
1962-66	1,305	1,053	805	1.9	0.7	0.1	2.7
Incr. (+) or decr. (-)	+ 311	+ 292	+ 35	+ 1.8	+ 0.6	+ 0.1	+ 2.5

The average annual wheat production increased by 38 percent from the five-year period of 1948-52 to that of 1962-66 mainly (87%) because of about a 31 percent increase in wheat area, the rest (13%) being due to higher yields. Syria is self-sufficient in wheat in most years and exports the surplus in good years.

The consumption of commercial fertilizers varies considerably from year to year but has remained generally at a low level. About two thirds of the consumption consists of nitrogenous fertilizers. All fertilizers are imported.

About 75 percent of the wheat area is under hard (durum) wheat and 25 percent under soft bread wheat. Most of the wheat (90-95%) is grown in the northern part of the country under rainfed conditions. About 61,000 ha wheatland is irrigated. There is an urgent need not only for high yielding varieties but also for a properly organized seed production and distribution programme (Tahir 1968).

High yielding varieties were introduced in 1963 and have given very promising results as shown in Table 96.

Table 96. Mean yields (kg/ha) of Mexican and local varieties in 1964-65 and 1965-66 (Tahir 1968).

	Irrigated		High rainfall	Low rainfall	
1964-65:					
NP fertilization (kg/ha)	100 + 35	40 + 35	40 + 35	20 + 17	
No. of places	1	2	4	3	
Mexican varieties, yield	6,095	4,062	4,009	2,162	
Local soft varieties, "	4,883	2,874	2,791	1,769	
Local hard varieties, "	4,333	1,670	2,616	1,899	
1965-66:					
NP fertilization (kg/ha)	80 + 70	80 + 70	80 + 70	40 + 35	40 + 35
No. of places	2 (Exp.Stns)	3 (Farmers fields)	4*	2 (Exp.** Stns)	2 (Farmers fields)
Mexican varieties, yield	4,682	4,256	2,596	1,951	1,325
Local soft varieties, "	4,179	2,456	1,902	1,577	947
Local hard varieties, "	3,068	3,550	1,760	1,519	665

* Three places had medium (400-500 mm) rainfall. ** One place had high (>500 mm) rainfall.

In four irrigated trials in 1966-67 the best Mexican variety gave average yields of 3930 and 4690 kg/ha under low (NP 40 + 35 kg/ha) and high (NP 80 + 70) fertilization respectively while the corresponding yieldsof tall variety (Florence Aurore) were 2825 and 3311 kg/ha. In high rainfall areas the yields of Mexican and local varieties were 3150 and 2565 kg/ha respectively with NP fertilization of 40 + 35 kg/ha. It is obvious that the Mexican varieties give appreciably higher yields and respond better to fertilizers than local varieties both in irrigated and rainfed conditions. The Syrian Government has shown interest in a larger scale production of Mexican varieties (Tahir 1968).

63. Turkey

Turkey is one of the ten leading wheat producers in the world. In 1966 wheat was grown there on 8.1 million hectares covering 62 percent of Turkey's cereal area and 32 percent of the arable land. The production (9.7 million tons) corresponded to 295 kilograms per capita which figure was fifth highest in the world. Turkey is not only a considerable wheat producer but also a marked consumer since wheat is the staple diet in Turkey. The consumption of wheat as food, 218 kilograms per capita in terms of flour in 1966-67, by far exceeds the respective figure for any other country (Int. Wheat Council 1968).

Table 97. Area, production and yield of wheat, and fertilizer use - Turkey.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,770	4,770	1,000	0.2	0.1	0.1	0.4
1962-66	8,004	9,101	1,135	2.3	2.2	0.1	4.6
Incr. (+) or decr. (-)	+ 3,234	+ 4,331	+ 135	+ 2.1	+ 2.1	± 0.0	+ 4.2

From 1948-52 to 1962-66 Turkey's wheat production almost doubled because of a 68 percent increase in the wheat cultivation area and 13 percent in the average annual yield. Consequently wheat imports have decreased. For example in 1960-62 the wheat import amounted to $42 million and in 1968 only to $1.6 million (Kurtzig 1970).

Fertilizer consumption is low but increasing rapidly. In the beginning of the latter five-year period the production of nitrogenous and phosphate fertilizers almost satisfied the domestic consumption. Since then consumption has increased much more rapidly and in the end of the period consumption exceeded the production by a factor of about 2.5. Only negligible amounts of potash have been used, all of it imported.

Over two thirds of Turkey's wheat supply comes from the Anatolian Plateau area and Eastern Turkey. Production in the Plateau area is very unstable due to low (aver. about 300 mm) and unreliable rainfall, soil erosion and extensive farm practices. The rest is produced mainly in the high rainfall (600-1200 mm), low altitude and mild winter areas of the coastal region, and in the areas of intermediate rainfall and moderate winter surrounding the Anatolian Plateau.

FAO carried out 3425 dryland wheat demonstrations in Turkey during the three-year period 1961/62 - 1963/64 (FAO 1966). On the average 0-60-0 (kg/ha N - P_2O_5 - K_2O) treatment was best in the lower rainfall areas of the Anatolian plateau, and 40-40-0 treatment in the higher-rainfall areas of the plateau and in other regions. The response to both treatments above the check-plot yield (about one ton/ha) was just over 50 percent, and the value/cost ratios were 2.6 and 2.0, respectively for the two treatments. All fertilizer treatments on irrigated wheat were economic and the heaviest treatments, 60-60-60 increased the yields 72-97 percent, and the net returns by more than 50 percent. Corresponding results for 1965-66 are summarized in Table 98.

Under irrigated conditions in eastern Anatolia returns from P or N, if applied alone, were not as high as if applied together in the fall (Ross et al. 1968).

High yielding Mexican varieties were first introduced in Turkey when some progressive farmers of the Cukurova region imported 60 tons of seed of Mexican varieties (mainly Sonora 63 and 64) for plan-

Table 98. Average results of the fertilizer demonstrations carried out in 1965-66 (FAO 1968, a).

Treatment $N - P_2O_5 - K_2O$ kg/ha	Yield kg/ha	Yield Increase %	Net return $/ha	Value/Cost ratio
	Non - irrigated wheat			
Control	906	-	(77)	-
0 - 40 - 0	1,208	33	+ 14	2.2
40 - 40 - 0	1,636	81	+ 37	2.5
40 - 40 - 40	1,908	111	+ 52	2.6
	Irrigated wheat			
Control	1,499	-	(126)	-
60 - 60 - 0	2,317	55	+ 32	1.9
60 - 60 - 60	2,676	79	+ 51	2.1

ting during 1966-67. Noting the good performance of these varieties the government imported about 22,000 tons of seed of Mexican varieties, which was multiplied at the Government State Seed Farms as well as distributed to some of the farmers during 1967-68 with very encouraging results, yield averages between 3500 and 4000 kg/ha as compared to 1000-1500 kg/ha from local wheat. In 1968-69 Mexican wheats were planted on about seven percent of the total wheat land and it is likely that within a few years the Mexican seed will be grown on much of the southern and western coastal wheatlands, or on about 15 percent of Turkey's total wheat acreage (Hafiz 1968; FAO 1969,b). The Mexican wheats seem to be adapted to the warmer coastal areas. The Turkish programme for the expansion of acreage in these wheats developed very rapidly with little preparation (Agency Int. Develop. 1969).

64. Yemen

Wheat is the only important cereal of Yemen, where it was grown on 21,000 hectares in 1965. The production, 26,000 tons, corresponds to five kilograms per capita. From 1948-52 to 1962-65 the wheat area increased by 50 percent (from 14,000 to 21,000) and production somewhat more (from 14,000 to 25,000 tons), because of a simultaneous increase in hectare yields from 1030 to 1200 kilograms per hectare. No data of fertilizer use were available.

IV. f. Africa

Africa's wheat production was only 2.4 percent of the world's total production in 1948-52 and 2.2 percent in 1962-66. About 74 percent of the production (1966) came from four North African countries: Algeria, Morocco, Tunisia and UAR, 12 percent from South Africa and 14 percent from other countries. On the average only 2.9 percent of the total arable land in Africa was under wheat and the production per capita, 15 kilograms, corresponds to only one sixth of the world average. The average wheat yields harvested in Africa as well as the consumption of commercial fertilizers per arable hectare are lower than those of any other continent.

65. Algeria

Wheat is the most important cereal of Algeria, where it was grown on 1,475,000 hectares covering 22 percent of the arable land and 78 percent of the cereal area in 1966. In the same year 391,000 hectares were under barley, the next most important cereal of the country. Wheat production, 627,000 tons, corresponded to 53 kilograms per capita, which was the fourth highest in Africa. However, during the preceding years the wheat area had been around two million hectares and the annual production about twice as high as in 1966. As in most North African countries, the national yield in 1966 was exceptionally low, only 430 kg/ha.

The influence of the year 1966 is quite significant in the average figures for 1962-66 given below. In spite of this the average annual production was 25 percent higher than in 1948-52.

Table 99. Area, production and yield of wheat, and fertilizer use - Algeria.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1,597	996	620	0.9	2.8	1.6	5.3
1962-66	1,927	1,242	645	2.4	3.4	2.1	7.9
Incr. (+) or decr. (-)	+ 330	+ 246	+ 25	+ 1.5	+ 0.6	+ 0.5	+ 2.6

About 84 percent of the production increase was due to 21 percent increase in the wheat area and 16 percent due to a four percent higher average national yield. Algeria produced about three fourths of the phosphate fertilizers consumed in the country in 1966 but other fertilizers had to be imported.

Wheat is cultivated primarily along the coastal region extending about 300 kilometers inland, where the annual precipitation is usually from 500 to 1000 mm but varies considerably. The summer is hot and dry but the winter season is mild and rainy. South of this region the climate becomes too dry for wheat. The acreage of durum wheat exceeds that of common wheat by a large margin and it is mainly used for macaroni manufacturing.

66. Angola

Maize is the principal crop of Angola, where it was grown in 1966 on about 500,000 hectares out of Angola's 900,000 hectares of arable land while wheat occupied only some 20,000 hectares. Wheat grows relatively well on the high plateau of Angola and the average yields, around 1,100 kg/ha in 1965-66, are considerably higher than the African average. About 4 kilograms of wheat per capita was produced in 1966. The consumption of nitrogenous fertilizers was negligible in 1948-52, about ½ kg N/ha in 1962 and 4 kg/ha in 1966. Data on other fertilizer nutrients were not available.

67. Burundi

Only about one percent or 12,000 hectares of Burundi's 1.1 million hectares of arable land was under wheat in 1966. Other cereals, sorghum, maize and millet were grown on 119,000, 110,000 and 32,000 hectares respectively.

During the past two decades Burundi's wheat cultivation area has been varying annually from 11,000 to 14,000 hectares, production from 7,000 to 9,000 tons and average yield from 600 to 700 kilograms per hectare. In 1966 the production, 8000 tons, corresponded to somewhat over two kilograms of wheat per inhabitant. No data of fertilizer use are available.

68. Ethiopia

Teff (Eragrostis abyssinica L.), millet, sorghum, barley and maize are the principal cereals in Ethiopia (Pinto 1969). Wheat was grown on 432,000 hectares or 3.4 percent of the arable land in 1966. About 14 kilograms of wheat per capita were produced in this year.

Table 100. Wheat area, production and yield - Ethiopia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)
1948-52	360	179	500
1962-66	397	285	715
Incr. (+) or decr. (-)	+ 37	+ 104	+ 215

From 1948-52 to 1962-66 the average average annual production increased by 58 percent. About 81 percent of this increase was due to increased national yield and the rest (19%) due to expansion of wheat area. Data on fertilizer use were not available.

High altitude cultivation of wheat is typical for Ethiopia, where most of it is grown at altitudes of 2,000 to 3,000 meters. Wheat in Ethiopia consists mainly of a mixture of indigenous tetraploid forms, generally suitable for making unleavened bread and paste products. Bread wheats comprise less than 10 percent of the wheat under cultivation and domestic production does not at present satisfy the demand of the rapidly increasing population of cities and towns (Pinto 1969). Imports of such wheat and of wheat flour were valued at almost US$1.5 million in 1967 (Imp. Eth. Gov. 1967). As very little expansion in the cultivated areas of the Central Highlands is possible, the internal cereal requirements could best be met through raising yields and also increasing the area sown to wheat whilst decreasing that sown to teff and barley (Pinto 1969).

69. Kenya

Over 97 percent of Kenya's 1.7 million arable hectares were under cereal crops in 1966. The main crops were maize, millet and sorghum. Wheat was grown on 122,000 hectares or on 7.2 percent of the arable area and its production, 127,000 tons, corresponded to 13 kilograms per capita.

Table 101. Area, production and yield of wheat, and fertilizer use - Kenya.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	95	101	1,070	0.2	2.8	0.1	3.1
1962-66	108	121	1,120	5.6	5.5	0.6	11.7
Incr. (+) or decr. (-)	+ 13	+ 20	+ 50	+ 5.4	+ 2.7	+ 0.5	+ 8.6

The 20 percent increase in wheat production from 1948-52 to 1962-66 was mainly (75%) due to expansion in wheat cultivation area. The contribution of increased hectare yields was 25 percent. Both hectare yields and consumption of fertilizers considerably exceed the African averages. About five percent of the phosphate fertilizer consumption is met by Kenya's own phosphate production.

In spite of Kenya's location on the equator, wheat can be successfully grown at high elevations ranging from 1700 to 2700 meters, mainly in the Rift Valley Province. Because of the location there are no distinct seasons comparable with those in temperate zones, but only rainy and dry seasons. Depending on the pattern of seasonal rainfall, wheat is seeded in April-June or October-November, or both. All of the wheat is of the common hexaploid species (Reitz 1967).

In Kenya six of the eight soil types tested gave responses to superphosphate with wheat, the response being inversely related to the pH of the soils (Ignatieff and Page 1962). In general, phosphorus seems to be of dominant importance in wheat monoculture in the Kenya highlands whereas nitrogen and phosphorus are of less importance.

Depending on basic soil fertility and previous cropping history, 9-23 kg N/ha and 56-67 kg P_2O_5 per hectare are recommended for wheat growing in Kenya (De Geus 1970). Higher N doses are recommended for continuously cropped land on which wheat or maize has been grown at least two years previously and the lower N recommendation is for newly broken grass or virgin land, which is generally rich in organic matter and on which response to nitrogen is likely to be low. Higher nitrogen doses than those given above should be applied only to strong-strawed varieties. For very fertile soils, in order to maintain the natural fertility of the soil, the recommendation for P_2O_5, is 16 to 20 percent less than given above. On these soils nitrogen is not likely to give an economic response.

Stem rust is serious over the entire wheat area, leaf rust in lower altitudes and strip rust in higher altitudes. Therefore, adequate rust resistance is the first requirement for a successful wheat variety in Kenya (Evans 1969). Breeding programmes are in progress.

70. Lesotho

Almost 80 percent of Lesotho's 353,000 hectares of arable land was under cereal crops in 1966. Maize, the principal crop of the country, was grown on 140,000 hectares and wheat, the second in importance, on 70,000 hectares or on 20 percent of the arable land. Wheat production corresponded to about 46 kilograms per capita, which is relatively high in African conditions.

Table 102. Area, production and yield of wheat, and fertilizer use - Lesotho.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	49	50	1,010	-	0.3	-	(0.3)
1962-66	70	43	615	0.1	0.1	-	(0.2)
Incr. (+) or decr. (-)	+ 21	- 7	- 395	(+ 0.1)	- 0.2	-	(-0.1)

In spite of over 40 percent expansion of wheat area from 1948-52 to 1962-66 the production of wheat decreased by 14 percent because of the considerably lower wheat yields during the latter period. One reason for the decreasing yields is apparently the insignificant use of fertilizers.

Most of the crop is produced in mountains where wheat is sown in the spring, while in lowlands the sowing takes place in the autumn.

71. Libya

Barley is the main cereal grown in Libya where it was grown on about 400,000 hectares in 1966. Wheat area in the same year was 180,000 hectares or 12 percent of the arable land, and production about 40,000 tons or 24 kilograms per inhabitant.

From 1948-52 to 1962-66 wheat cultivation area increased from 124,000 to 164,000 hectares, wheat production from 11,000 to 40,000 tons and yields from 90 to 245 kilograms per hectare. Data of fertilizer consumption were not available. In Libya wheat is grown in the coastal region having less precipitation than other North African countries. Drought is the main factor limiting the yields to an extremely low level.

Durum wheats are predominantly cultivated in the heavy clayey soils of the plateaux of Cyrenaica and Tripolitania, characterized by relatively high rainfall (500-700 mm), and cooler and longer growing seasons. Principal varieties are Mahmoudi and Hamera. Common wheats are in general grown on lighter soil either under rain-fed conditions in the coastal plains and the semi-desert areas, or under irrigation in the oases. Varieties grown in the semi-desert areas are highly drought resistant, early maturing, but have a low yield potential. The principal variety is Ithkair. All varieties are highly susceptible to rusts(Al-Jibouri 1966).

72. Morocco

Over 50 percent of Morocco's arable land was under cereal crops in 1966. The two principal cereals, barley and wheat, were grown on 1,775,000 and 1,635,000 hectares occupying 22.6 and 20.8 percent of the total arable land respectively. Wheat production, 814,000 tons, corresponded to 61 kilograms per capita, which was second highest in Africa, but as in most other North African countries, the production in 1966 was considerably lower than in preceding years due to an exceptionally low yield of only 500 kilograms per hectare.

Table 103. Area, production and yield of wheat, and fertilizer use - Morocco.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	1,287	786	610	0.3	1.4	0.6	2.3
1962-66	1,586	1,153	730	2.2	2.5	1.2	5.9
Incr. (+) or decr. (-)	+ 229	+ 369	+ 120	+ 1.9	+ 1.1	+ 0.6	+ 3.6

From 1948-52 to 1962-66 Morocco's wheat production increased by 47 percent because of almost equal relative increases in both wheat area and wheat yield.

The consumption of fertilizers is somewhat higher than the average in Africa. The most important increase in fertilizer use has been that of nitrogenous fertilizers. Phosphates are the only fertilizers produced by Morocco itself. Up till 1964 phosphate production was about equal to domestic consumption but since then production has substantially increased and already in 1966 over five times as much was produced as consumed.

Wheat cultivation is mainly concentrated in the coastal region of Morocco. The acreage of durum wheat has been somewhat larger than that of common wheat.

Morocco's first experience with Mexican dwarf varieties began during the 1967-68 crop season with excellent results. During the next season a total of 5,000 ha of Mexican dwarf wheats were grown with mixed results because this season was affected by twice the usual amount of rainfall, and as a result of the continuous cloudy and rainy weather a very serious epidemic of septoria leaf and glume blotch developed on both Mexican and local varieties. Especially Siete Cerros, which during the previous season had outyielded all other varieties, appeared to be hyper-susceptible to this disease. The yield results of the Mexican and local varieties from the demonstration site at Sidi Kacem, in the area of severe Septoria epidemic, were as follows (CIMMYT 1969):

Mexican varieties (*):		Local varieties (*):	
Penjamo 62	3,316 kg/ha	BT 3597 (Mara)	2,951 kg/ha
Tobari 66	3,272 "	BT 908	2,932 "
Inia 66	2,895 "	BT 2511	2,673 "
Norteño 67	2,696 "	BT 2306	2,502 "
Siete Cerros	1,950 "		

(*) Fertilized with 40 kg N and 27 kg P_2O_5 at planting and 46 kg N per hectare at tillering.

In general, Tobari 66, Penjamo 62, and Inia 66, produced satisfactory to good yields of grain in most locations, especially when adequately fertilized. Considerable observation at evidence indicates that fields that were top-dressed with nitrogen before heading withstood Septoria much better than those that were deficient in nitrogen, or wherever nitrogen uptake was reduced by waterlogged soil. In southern parts of the rainfed region where there was less rain, Tobari, Inia, Penjamo and Norteño produced good to excellent yields, and outperformed the local varieties by a good margin. Siete Cerros should be grown only in the south under dry conditions and irrigation where its yields were excellent (CIMMYT 1969). Research for developing more disease resistant varieties for Moroccan conditions is in progress both in Tunisia and Morocco.

73. Mosambique

Wheat plays a relatively small role in Mosambique's agriculture where only 14,000 out of the 2.6 million arable hectares were under wheat in 1966. The main cereals, maize and rice, were grown on 163,000 and 45,000 hectares respectively. Somewhat less than one kilogram of wheat was produced per capita.

Table 104. Area, production and yield of wheat, and fertilizer use – Mosambique.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	n.a.	n.a.	630	0.3	0.1	0.0	0.4
1962–66	5	5	980	1.6	0.4	0.6	2.6
Incr. (+) or decr. (–)	n.a.	n.a.	+ 350	+ 1.3	+ 0.3	+ 0.6	+ 2.2

In spite of some increase in the use of fertilizers their consumption is still at a low level.

74. South Africa

Over one half (6.8 million ha) of South Africa's 12 million arable hectares was under cereal crops in 1966. Wheat occupied slightly over one million hectares (8.5% of arable land) and maize, the principal cereal of the country, almost five times as much. Wheat production, 567,000 tons, was fourth highest in Africa but corresponded only to 31 kilograms per capita. The food consumption of wheat was about 48 kilograms per capita in terms of flour (Int. Wheat Council 1968).

Table 105. Area, production and yield of wheat, and fertilizer use – South Africa.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	928	555	600	0.9	8.4	0.6	9.9
1962–66	1,178	779	660	7.5	12.9	5.2	25.6
Incr. (+) or decr. (–)	+ 250	+ 224	+ 60	+ 6.6	+ 4.5	+ 4.6	+ 15.7

About 73 percent of the 224,000 ton increase in the average annual wheat production shown above was due to a 27 percent expansion in wheat area, and the rest, 27 percent, was due to the ten percent increase in hectare yields.

The amount of fertilizers used per arable hectare is third highest in Africa after UAR and Zambia but still slightly below the world average. In 1948–52 phosphates made up 85 percent of fertilizer consumption. Since then its proportion has decreased to about 50 percent in 1962–66. About two thirds of South Africa's nitrogen consumption was met by its own production in 1966. The annual production and consumption of phosphate fertilizers have been about equal during the past two decades.

The importance of nitrogen for the production of wheat is emphasized by the results of the experiments carried out under conditions of 434 mm average rainfall (Table 106).

Differences between yields of the two phosphate treatments, with or without nitrogen, were not significant and potash had no noticeable effect on the yield of wheat. An application of 93 kg P_2O_5 per hectare (as superphosphate) resulted in a grain yield of 950 kg/ha. This increased to 1800 kg/ha when 50 kg N per hectare (as ammonium sulphate) was added. With an additional 50 kg N/ha, the yield

Table 106. Average results of five-year fertilizer experiments at Vaalhartz Agricultural Research Station (Wessels and Pretorius 1953).

Fertilizer treatment (kg/ha) N - P_2O_5 - K_2O	Grain yield kg/ha	Relative yield (Treatment 0-93-0=100	
		Grain	Straw
0 - 93 - 0	950	100	100
0 - 187 - 0	1,005	106	106
50 - 93 - 0	1,750	184	202
50 - 93 - 112	1,785	188	206
50 - 187 - 0	1,855	195	208
100 - 187 - 0	2,540	267	323

was further increased to 2,540 kg/ha. The effect of nitrogen on the straw yield was even more marked than on the grain yield.

In another experiment an increase of 145 percent over the grain yield with 93 kg P_2O_5/ha treatment was obtained from an application of 23 tons of kraal manure per hectare. Even this effect was attributed primarily to the nitrogen factor (Wessels and Pretorius 1952).

Considerable climatic differences between different parts of the country impose the adoption of wheat cultivation practices and fertilizer use methods varying from one locality to another. For example, the effect of time of nitrogen application on nitrogen uptake, growth and grain production of wheat at Langgewens area receiving an average annual rainfall of about 330 mm diverged markedly from that at Elsenburg, where the average annual rainfall is more than double, about 690 mm (Wassermann and Eksteen 1962).

On a sandy soil at Elsenburg leaching of nitrogen occurs easily and disappointing results were obtained when nitrogen was applied at seeding time. Here the application in the early stooling stage, i.e. 30-40 days after seeding, gave the highest yields, while low yields resulted from nitrogen dressings in the late stooling stage. Under conditions at Langgewens, nitrogen applications at seeding time and N top dressings up to the full stooling stage gave equally good results as regards N uptake, increase in dry weight of plants, and grain yield. The period between early piping and heading was the one of maximum growth intensity and therefore the plants must be well supplied with N from the start of piping but the time of top-dressing can be extended up to the late stooling stage, i.e. 60-70 days after seeding. In these experiments the use of ammonium sulphate and ammonium nitrate gave slightly stronger plant growth and higher grain yield than urea, but the differences were not significant.

75. Sudan

Wheat was grown on 57,000 hectares or on less than one percent of the 7.1 million hectares of Sudan's arable land area in 1966. The main cereals, sorghum and millet, occupied 1,341,000 and 548,000 hectares respectively, and some maize (18,000 ha) was grown mainly in the southern parts of the country where there is more moisture available. The area and production of wheat have been rapidly increasing and in 1966 the production was 69,000 tons corresponding to 5 kilograms of wheat per capita.

Table 107. Area, production and yield of wheat, and fertilizer use - Sudan.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	13	15	1,180	0.7	-	-	(0.7)
1962-66	35	44	1,260	3.6	0.1	0.8	4.5
Incr. (+) or decr. (-)	+ 22	+ 29	+ 80	+2.9	(+0.1)	(+0.8)	(+3.8)

During both periods given above the wheat yields were over 50% higher than the average harvest in Africa. Nitrogen plays a dominating role in the fertilizer consumption but the rates used are still low. However the situation is rapidly changing and over the five-year period 1962-66 they rose from less than the African average consumption per arable hectare to 40 percent above average.

The wheat area of Sudan is expanding very rapidly. In 1967-68 it was already about 100,000 hectares, most of it in Gezira and Khashm El Girba. Almost all the wheat is grown under irrigation. The growing season is short and unless the crop is sown before the end of October an appreciable reduction in yield occurs. The majority of farmers still grow wheat very late which apparently lowers the national yield level. Giza 144 and 148, the most common varieties, are capable of producing a yield of 2,500 kg/ha on a large scale. Some farmers get 3,000-4,000 kg/ha by carrying out recommended cultural practices and by application of 100 kg nitrogen per hectare and copious irrigation. The effect of planting time on yield is illustrated below (Tahir 1968):

Date of sowing	Yield kg/ha	
17.9	2,760	A trial in Gezira;
1.10	3,100	Variety Giza 144:
15.10	3,120	Nitrogen application
29.10	3,180	80 kg/ha at sowing
15.11	2,670	

After mid-November yields decline even more sharply. Some early maturing Mexican varieties have given promising results.

76. Tanzania

Only 34,000 (0.3%) out of Tanganyika's* 11.6 million arable hectares were under wheat in 1966. The main cereals were maize, millet and sorghum, but the area of rice was also over three times larger than that of wheat.

Table 108. Area, production and yield of wheat, and fertilizer use - Tanganyika.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	15	9	560	0.0	0.0	0.0	0.1
1962-66	29	26	895	0.2	0.1	0.1	0.4
Incr. (+) or decr. (-)	+ 14	+ 17	+ 335	+ 0.2	+ 0.1	+ 0.1	+ 0.3

From 1948-52 to 1962-66 wheat production increased threefold. About 61 percent of the increase was due to expansion of the wheat area and 39 percent due to higher yields. A similar trend seems to be continuing and in 1966 the production was 39,000 tons.

Only insignificant amounts of commercial fertilizers have been used. The conditions of wheat production are somewhat similar to those in Kenya.

When studying the effect of soil and cultivation history on responses of wheat to fertilizer in Northern Tanzania, Anderson et al. (1966) obtained economic responses to 125 kg of ammonium sulphate nitrate per hectare in 13 out of 17 experiments. There was a response to phosphorus only in cases where wheat was grown on soils brought under cultivation by ploughing native grassland. It was concluded that grass/legume leys were the best means for maintaining high productivity of the Northern Tanzanian soils.

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* Data for Zanzibar not available.

77. Tunisia

Tunisia is one of the five leading wheat producers in Africa. In 1966 wheat was grown on 845,000 hectares or on 19.5 percent of the arable land and two thirds of the ceral area. Barley, the second important cereal of Tunisia, occupied 377,000 hectares in the same year. Tunisia is the only African country where wheat production per capita, 96 kilograms, exceeded the world average. Consumption of wheat as food was 92 kilograms per capita in terms of flour (Int. Wheat Council 1968).

Table 109. Area, production and yield of wheat, and fertilizer use – Tunisia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948–52	917	452	490	0.1	2.2	0.1	2.4
1962–66	1,013	548	540	1.3	3.0	0.7	5.0
Incr. (+) or decr. (-)	+ 96	+ 96	+ 50	+ 1.2	+ 0.8	+ 0.6	+ 2.6

From 1948–52 to 1962–66 wheat production increased 21 percent, half of which was due to a 10 percent expansion in wheat area and half due to a 10 percent increase in average national yield. The wheat yields harvested in Tunisia are among the lowest in Africa. Two decades ago phosphates were practically the only commercial fertilizers used but since then some nitrogenous and potash fertilizers have also been applied. In spite of the over two-fold increase in fertilizer consumption since 1948–52 the level of fertilizer use is still very low, about equal to African average, but less than one fifth of the world average. Both nitrogenous and potash fertilizers have to be imported but the production of phosphates exceeds domestic consumption by a factor of ten.

As in Algeria durum wheat is the most extensively cultivated wheat in Tunisia.

The recent improvement in the standard of living, however, has resulted in greater consumption of bread wheat to the detriment of durum wheat.

Over four fifths of Tunisia's wheat production takes place in the northern part of the country and the rest is produced in the central and southern regions. Further, by dividing the country into modern and traditional sectors, following general set-up has been prepared (USAID/Tunis, 1969):

Table 110. Wheat production and yields in different sectors of Tunisia.

	Wheat area (1000 ha)	Wheat production (1000 tons)	Yield (100 kg/ha)
North:			
Modern Sector	365	365	10
Traditional Sector	300	120	4
	665	485	7
Centre and South:			
Modern Sector	52	13	2.5
Traditional Sector	310	62	2
	362	75	2
TOTAL:	1,027	560	5.4

The yields of the modern sector are considerably higher because of more advanced cultivation methods, including higher level of fertilizer use, while the differences between the northern and other regions depend mainly on weather conditions. The South is a large area where wheat growing remains hazardous because of insufficient rains. Instead, it would be more profitable to set up rangelands and encourage extensive stock breeding, dry tree culture and secondary cereals such as barley (USAID/Tunis 1969).

In 1967-68 the Tunisian Extension Service started to carry out, with USAID's assistance, a large production demonstration programme. The results were very encouraging. The Mexican varieties yielded 30 to 50 percent more than the Florence-Aurore wheat which was introduced as a check variety. In the region of Beja, Inia yielded 5,300 kg/ha under dryland conditions and near Sidi Bou Zid the best Mexican variety, Tobari, gave a yield of 6,900 kg/ha under irrigation. The overall average yields (kg/ha) and average yields under irrigated farming for the six varieties included in the demonstration (with 45 to 89 kg nitrogen per hectare) were as follows:

	Overall	Irrig.		Overall	Irrig.
Inia *)	2,840	3,650	Florence-Aurore	1,760	2,860
Sonora *)	2,300	3,310	Mahmoudi	1,270	1,700
Iaral *)	2,100	2,840			
Tobari *)	2,200	3,640			

*) Varieties of Mexican origin.

For 1969-70 the commercial production goals for growing Mexican or short-stemmed wheat varieties are 140,000 hectares.

In Tunisia low rainfall is a limiting factor of wheat production in many areas. During the cropping season 1968-69, the rainfall was exceptionally low, especially in the Bou Rebia, Pont du Fahs, Zaghouan, El Aroussa and Siliana regions where yields from dryland production were in the range of 100-1000 kg/ha. The rainfall data and experimental population yield means for five experimental areas of 1968-69 trials (CIMMYT 1969) are compared below:

Farm-Location	October-May rainfall, mm	Wheat yield kg/ha
Amel - Pont du Fahs	200	350
Azima - Medjez el Bab	250	1,260
Aissa - Pont de Bizerte	310	3,120
Marja II - Bou Salem	340	3,760
Bakhria-Mateur	377	3,840

As a result of the moisture shortage there was no positive response of wheat to nitrogen at Amel and Azima, while at Aissa, where the best treatment gave 68 percent increase over the check, the results were very informative as shown in Table 111.

Table 111. Results of fertilizer trials at Aissa 1968-69 (USAID/Tunis 1969).

Treatment N, P_2O_5, K_2O (kg/ha)	Yield * (kg/ha)	Treatment N, P_2O_5, K_2O (kg/ha)	Yield (kg/ha)
0 - 0 - 0	2,130 e	135-45-96	3,240 a
45 - 45 - 96	2,590 de	45-45-48	3,280 a
45 - 90 - 48	2,680 cd	90-45-96	3,330 a
135 - 90 - 96	3,040 abc	135-90-48	3,380 a
45 - 90 - 96	3,160 ab	90-90-48	3,490 a
90 - 45 - 48	3,180 ab	90-90-96	3,580 a

* Yields followed by same letter do not differ significantly from each other.

The data indicate that 45 kg P_2O_5 per hectare was sufficient since there was no significant response to the addition of 90 kg/ha. No response to potassium was obtained and 90 kg N/ha was the optimum since 135 N/ha caused a slight, although insignificant, yield depression.

On the basis of information taken from both experimentation and production fields the general fertilizer recommendations for dryland wheat vary from 22 to 100 kg N/ha and 45 to 67 kg P_2O_5/ha depending on both the cereal and seasonal distribution of moisture and on the preceding crop. For irrigated wheat 112 kg N/ha (45 kg at seeding and 67 kg at tillering) and 67 kg P_2O_5/ha (before or at seeding) are recommended. Potassium was not recommended generally for wheat.

78. United Arab Republic

UAR is the biggest producer of wheat in Africa. In 1966 its production corresponded to one third (34%) of the continent's total wheat production.

Within the country, however, wheat covered only the second largest area (after maize) under cereal crops and its production was exceeded also by that of rice. The cultivation areas and production of these three principal crops were: Maize 661,000 ha and 2,358,000 tons, wheat 605,000 ha and 1,620,000 tons, and rice 486,000 ha and 2,000,000 tons respectively. The wheat area corresponded to 22 percent of the toal arable land and wheat production to 54 kilograms per capita.

Table 112. Area, production and yield of wheat, and fertilizer use - UAR.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	605	1,113	1,840	29.0	6.4	0.3	35.7
1962-66	580	1,561	2,690	87.7	17.4	0.4	105.5
Incr. (+) or decr. (-)	- 25	+ 448	+ 850	+ 58.7	+ 11.0	+ 0.1	+ 69.8

In spite of the 25,000 hectares decrease in the average wheat cultivation area from 1948-52 to 1962-66, United Arab Republic's wheat production increased by 40 percent, because of 850 kg/ha (46%) higher yields harvested during the latter period. These yields are by far the highest in Africa and are exceeded outside of Europe only by those of New Zealand. Exclusion of UAR would decrease the average wheat yield of Africa from 825 to 660 kg/ha or by 20 percent.

The bulk of the 850 kilograms increase in hectare yields is apparently due to the threefold increase in fertilizer use. Over 80 percent of the total consumption of fertilizers consists of nitrogenous fertilizers, while the use of potash is negligible.

UAR's fertilizer industry produced about 68 percent of Africa's total nitrogen production in 1966-67 but only 65 percent of its domestic consumption. About 85 percent of UAR's phosphate consumption was met by its own production. Potash fertilizers were imported.

Wheat is grown as a winter crop on the alluvial soils of the Nile Valley and Delta, where the annual flooding of the Nile provides irrigation. The main hazards to wheat production are the three rust diseases (stem, leaf and stripe rust) in the northern part of the country, and insect attacks, both in the field and in storage, in all parts of the country. Lodging of the heavier crops is also a great problem (Peterson 1965).

Thus, increase of wheat yield in the UAR means continuous fight against races of rust. Three varieties (Giza 144, 147 and 150) developed since the early nineteenfifties occupy three fourths of the wheat area. A new variety Giza 155 released in 1967-68 has resistance to all the Egyptian races of the three rusts and competes favourably with the Mexican varieties giving a yield of 5,000 kg/ha with 75 kg N and 45 kg P_2O_5 per hectare. Although some of the Mexican varieties have outyielded Giza 155 in variety trials by 1,700 kg/ha under high doses (135 kg/ha) of nitrogen, they are not fully resistant to all the rusts (Tahir 1968). The IWP Provincial Study has estimated yield levels of 3,500 and 4,200 kg/ha for 1975 and 1985 respectively, provided that other targets of improvement (fertilizer and pesticide use, management etc.) are met.

79-86. Other African countries

In addition to the countries described above wheat is grown in limited areas of several other African countries; however, these only make a small contribution to Africa's total wheat production.

In the following eight countries: Chad, Congo-D.R., Mali, Niger, Rwanda, Sth. Rhodesia, S.W. Africa and Zambia wheat was grown in 1966 on less than 0.3 percent of the arable land, its acreage varying from about 4,000 hectares in Congo D.R., and Sth. Rhodesia, 3,000 in Mali and 2,000 in Chad to 1,000 hectares or less in the other four countries. The production of wheat was about 9,000 tons in Sth. Rhodesia, 3,000-4,000 tons in Chad, Mali and Congo D.R. and around 1,000 tons in the other four countries. In Sth. Rhodesia and S.W. Africa the production corresponded to about two kilograms per capita, while in the other six countries it was only one kilogram or less.

The development of wheat yields from 1948-52 to 1962-66 differs considerably from one country to another. In Sth. Rhodesia and Zambia the national yields increased most, from 780 to 2,120 and 710 to 1,875 kg/ha respectively. Also in Chad, Mali and Niger the increases were quite substantial, from 1,230 to 1,565, 1000 to 1,450 and 480 to 1,210 kg/ha respectively while in S.W. Africa the average yield decreased from 1,270 to 1,210, in Congo D.R. from 870 to 720 and in Rwanda from 790 to 700 kilograms per hectare.

The 164 percent yield increase in Zambia is obviously, at least partly, a consequence of more than tenfold use of fertilizers from 2.9 (1.9 kg N, 0.7 kg P_2O_5 and 0.3 kg K_2O) kilograms to 39 (19, 10, 10) kilograms per arable hectare. The same applies to Mali where practically no fertilizers were used before the turn of the last decade but in 1962-66 7.3 (1.0, 1.3, 5.0) kilograms per arable hectare were applied on the average. Only negligible amounts of fertilizers have been used in Chad and Congo D.R. and no data for the other four countries were available. In these countries there is fertilizer production only in Zambia where in 1962-66 somewhat over 80 percent of its phosphate consumption was met by its own phosphate production.

IV. g. OCEANIA

Over 97 percent of Oceania's 39 million hectares of cultivated land area was located in Australia (37.15 million ha) and in New Zealand (0.82 million ha) in 1966. These two countries also produced practically 100 percent of the wheat of this region (Australia 97.7 and New Zealand 2.3%). In 1948-52 Oceania contributed about 3.0 percent and in 1962-66 3.6 percent of the world's total wheat production.

87. Australia

Australia ranks fifth as a producer of wheat in the world, with 12.6 million tons on 8.2 million hectares in 1966. The area under wheat corresponds to 74 percent of Australia's cereal area and 22 percent of the total arable land. The production per capita, 1089 kilograms, was second highest (after Canada) in the world and the consumption of wheat as food 75 kilograms in terms of flour (Int. Wheat Council 1968). Australia is one of the leading wheat exporting countries.

Table 113. Area, production and yield of wheat, and fertilizer use - Australia.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	4,620	5,161	1,120	0.4	8.8	0.2	9.4
1962-66	7,175	9,391	1,310	1.6	21.4	1.6	24.6
Incr. (+) or decr. (-)	+ 2,555	+ 4,230	+ 190	+ 1.2	+ 12.6	+ 1.4	+ 15.2

From 1948-52 to 1962-66 the average annual wheat production increased by 82 percent. About 76 percent of the increase was due to a 55 percent expansion of wheat area and the rest, 24 percent, due to the 17 percent increase in the average national yield. The wheat yields have been somewhat above the world average.

Wheat is grown mainly in the southern part of the continent in the so called wheatbelt area which appears to have become stabilized within the areas that receive between 9 and 15 inches (23-38 cm) of rain during the period May to October (Fig.30). The combination of topography, temperature, and heavy winter rainfall makes the regions with May-October falls of more than 15 inches better suited to pastures than to wheat growing. In Southern Australia, which has a predominantly winter rainfall, the rainfall during the growing period largely determines the yield; this does not apply so much to northern New South Wales and Queensland, where moisture conserved from summer rains is more important (Callaghan and Millington 1956). Only a small portion of wheat fields are irrigated.

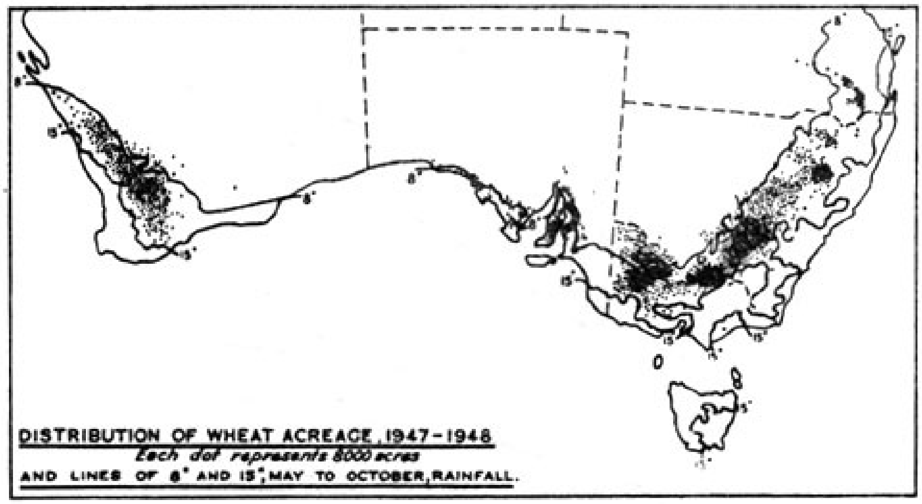

Figure 30. Australia's wheatbelt (Callaghan and Millington 1956).

The level of commercial fertilizer consumption in Australia is relatively low as compared with other developed countries. About 87 percent of the total amount of nutrients given in fertilizers comprises phosphate and the rest is equally distributed between the other two nutrients. The soils in the semi-arid environment of the Australian wheatbelt are usually rich in potassium and the nutrients most responsible for limitation of wheat yields are phosphorus and nitrogen. Their deficiency in Australian soils has been known for a long time (Valder 1897, Cobb 1898). The deficiency of phosphorus for wheat production has been widely corrected with superphosphate fertilizer while for nitrogen deficiency, which is also believed to be widespread, there has been a general correction through nitrogen fixation only since about 1950, when the value of crop rotation with subterranean clover pasture was recognized (Colwell 1963). Rixon (1966), for example, reports a 66 percent difference in wheat yields grown after Wimmera ryegrass (2,554 kg/ha) and white clover (4,235 kg/ha) pastures.

The results of series of experiments to examine the influence of different nitrogen levels on the yield of wheat in South Australia are given in Table 114.

Table 114. Response of wheat to nitrogen in the cereal areas of South Australia. Average results of 1956-61 trials (Russel 1967).

Ammonium sulphate applied kg N/ha	Grain yield kg/ha	Yield increase kg/ha	Response ratio kg grain/kg N
0	1,237	—	—
13	1,350	113	8.7 ± 1.4
26	1,423	186	7.2 ± 1.4
52	1,500	263	5.1 ± 0.9

These mean values are lower than those reported for other more humid wheat growing areas but there were conditions where the responses were at a comparable level. Increases exceeding 10 bushels/ac

(672 kg/ha) were obtained at six out of 52 sites and those over 5 bushels at 22 sites. Significant positive linear trends were recorded at 27 sites and significant negative linear trends at four sites. All the major soil groups were represented, but since there was considerable range of difference in soil profile characteristics within the soil groups, no clear differences of responses between the soils were reported. The seasonal effects on the response to nitrogen were marked (Fig. 31) and apparently only little response is to be expected at locations receiving less than 100-150 mm of May-October rain (Russell 1967).

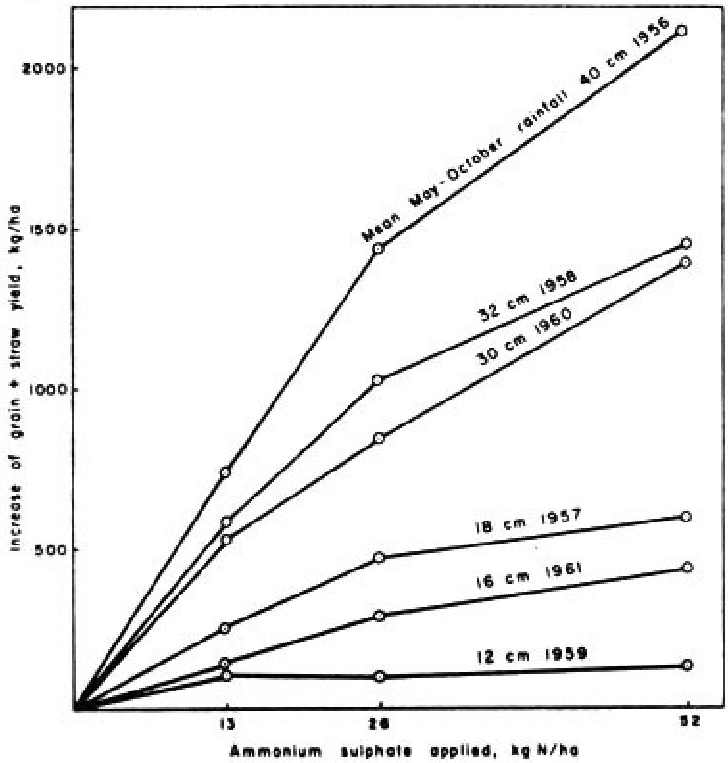

Figure 31. Mean responses of yield to nitrogen of four locations in six years of different rainfall levels (Russell 1967).

The results of Littler (1963) indicate that there is a marked response of wheat to nitrogen fertilizer (urea) on older cultivations, especially if applied at sowing time. As the stage of growth advanced, the effect of urea on yield decreased (Fig. 32). Urea also improved grain protein, to a lesser extent baking quality and the number of mottled grains was reduced with increasing rates of urea applications. The residual responses in yield were quite substantial indicating a sufficient carry-over of nitrogen in Pampas area and supporting the findings of Cuthbertson (1959) in New South Wales.

In several Australian trials of nitrogen fertilization no response or even yield decreases have been obtained especially in dry seasons and in dry areas.

Adequate water supply seems to be essential for responsiveness to nitrogen. Swartz and White (1966) noted that production per inch of water used rose to a peak at the most favourable water/nitrogen availability balance and even when neither was limiting the crop growth, a luxury supply of one reduced the efficiency of grain production per unit of water used.

A significant nitrogen/variety interaction was obtained for wheat grain yield in experiments conducted by Barley and Naidu (1964). The factors contributing to this interaction were tiller survival and grain weight. Therefore the authors feel that more attention should be given to these factors in the selection of varieties for soils rich in nitrogen, or for areas where moisture stress is likely to occur at the end of the season.

Because of the generally low available phosphorus status of Australian soils the response of wheat to phosphatic fertilizers is usually more pronounced than to nitrogen. The results of field trials located in ten districts and representing most of the wide diversity of growing conditions in the southern wheatbelt of New South Wales, reported by Colwell (1963), are summarized in Table 115.

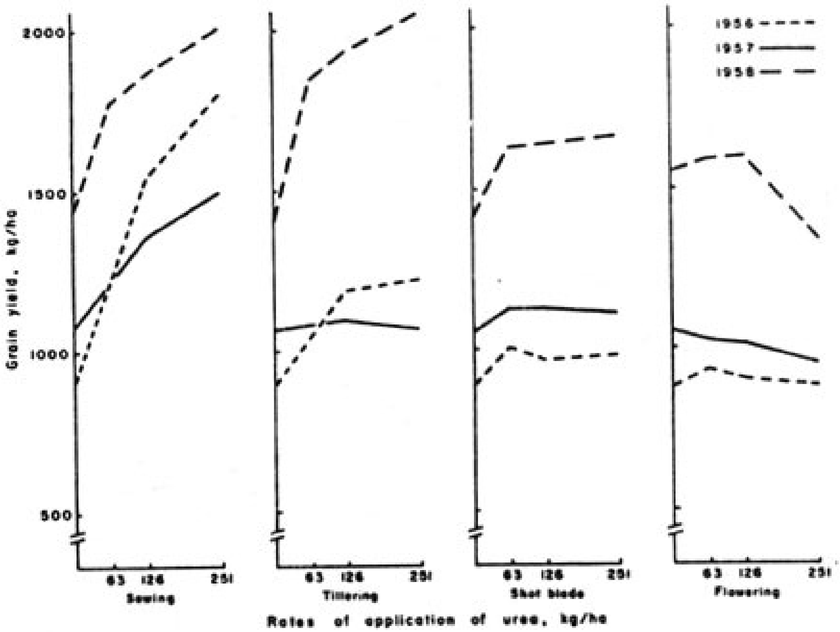

Figure 32. Effect of time of urea application on wheat yield on an Australian Black Earth soil (Littler 1963).

Table 115. Response of wheat to phosphorus in New South Wales. Average results of 22 trials.

Superphosphate applied kg P_2O_5/ha	Aver. Yield kg/ha	Yield increase kg/ha	Response ratio kg.grain/kg P_2O_5
0	1,701	—	—
25	2,224	523	20.9
99	2,408	707	7.1

The experiments included also urea treatments but the average response to urea was small (5 significant responses) compared to that of phosphorus (18 significant responses). The most economic rate of superphosphate application varied largely with locations, the average being 180 kg/ha (36 kg P_2O_5/ha).

Because of the repeated applications of superphosphate to wheat crops in most parts of southern Australia for a long period, the residual phosphorus has become important in determining yield responses. In an experiment over a period of 26 years, approximately 56 percent of the response obtained at 34 kg/ha superphosphate application level was attributed to residual phosphorus. The corresponding percentage at 67 and 101-135 kg/ha application levels were 71 and 61 respectively (McClelland 1968). On the basis of 102 "Rate of Superphosphate on Wheat" trials in the 12 to 20 inch rainfall areas of West Australian wheatbelt in 1952-1966, Cox (1968) has estimated the requirement of superphosphate for five main soil groups of the district in relation to previous superphosphate applications (Fig. 33).

The use of semi-dwarf varieties in Australian wheat breeding programmes is increasing as high-yielding types with good grain quality become available. In comparison with representative Australian varieties Heron and Olympic the semi-dwarf varieties Mexico 120 and Chile I3 yielded somewhat more grain but there was no difference between the responses of the four varieties to nitrogen fertilizer (Syme 1967).

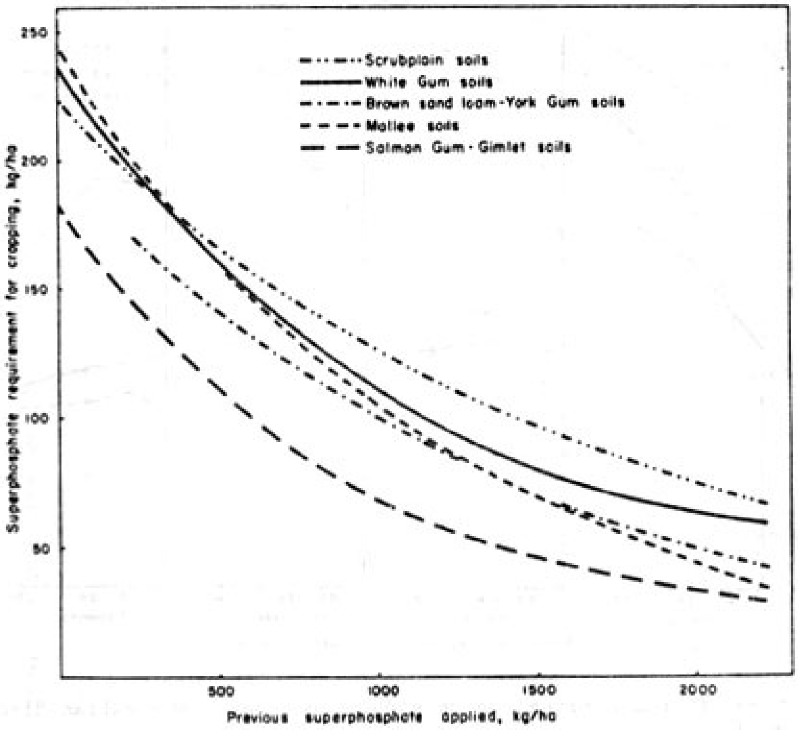

Figure 33. The effect of previous superphosphate applications on superphosphate requirements of cereal crops on five soils (Cox 1968).

88. New Zealand

Wheat is the principal cereal crop in New Zealand where it was grown on 81,000 hectares in 1966 covering about 60 percent of its cereal area and 10 percent of the arable land. Because of the increase in production New Zealand has become self-sufficient in wheat. In 1966 the production corresponded to 109 kg grain per capita and the food consumption of wheat was 84 kilograms in terms of flour respectively (Int. Wheat Council 1968).

Table 116. Area, production and yield of wheat, and fertilizer use - New Zealand.

Periods and change	Wheat area (1000 ha)	Wheat production (1000 tons)	Aver. nat. yield (kg/ha)	Use of fertilizers kg/arable hectare			
				N	P_2O_5	K_2O	Total
1948-52	51	139	2,730	2	167	9	178
1962-66	81	256	3,160	7	376	102	485
Incr. (+) or decr. (-)	+ 30	+ 117	+ 430	+ 5	+209	+ 93	+ 307

Annual wheat production increased by 84 percent from 1948-52 to 1962-66. About 74 percent of the increase was due to an enlarged wheat growing area and 26 percent due to increased national yield. The highest annual production, 292,000 tons, was obtained in 1966 corresponding to an average yield of 3610 kg/ha, which was the fourth highest in the world.

The total use of commercial fertilizers, 485 kilograms of nutrients per arable hectare, was the third highest in the world after the Netherlands and Belgium (584 and 490 kg/ha respectively). There are, however, essential differences in the proportion of various fertilizers used in different countries (Table 119). New Zealand is the greatest consumer of phosphatic fertilizers (mainly superphosphate) using 376 kg P_2O_5 per hectare which is more than twice the amount used by any other country and 40 times the world average. Also high doses of potassium (aver. 102 kg/ha) are characteristic of New Zealand's agriculture, while only 7 kg N/ha (less than world average, 11 kg/ha) were used. As apparent compensation for the low nitrogen doses is obtained from the general inclusion of nitrogen fixing clover pastures in rotations which was typical also for Australia. Further, it is apparent that considerably more nitrogen fertilizer than the average use per arable hectare has been used for wheat and correspondingly less for pastures where the nitrogen requirement can be met essentially by nitrogen fixation. New Zealand's phosphate fertilizer production meets the consumption but fertilizers containing the other two nutrients have to be imported. The response of average national wheat yield to increased use of fertilizers is very low (Fig. 37) as can be expected in a country where high doses of fertilizers have already been used and high yields obtained.

A large number of trials has been carried out to find out the best rate of fertilizer for wheat. On most wheat soils of North Island, the biggest increase in yield is generally to the first hundredweight per acre (125 kg/ha) of superphosphate. On low-fertility paddocks twice that amount may be necessary, but seldom more. Trials with potash and nitrogen in the forms of sulphate of ammonia or nitrolime, have shown little effect on wheat yields even on soils known to respond to potash when in pasture (McEwan and Burgess 1967).

The fertilizer trials with winter wheat in North Otago (Douglas 1968) showed an overall average yield increase of three bushels/acre (about 200 kg/ha) to one cwt. of superphosphate per acre during the period 1930-1950. Since then the situation has changed in the 1950-1965 period the corresponding average increase in yield was only half a bushel to the acre (34 kg/ha). This can be explained by the greater use of phosphate fertilizers on pasture in recent years, leading to a build-up of soil phosphate sufficient to support autumn-sown wheat without additional fertilizer. In some trials, however, 200-340 kg/ha yield responses to 125 kg/ha of superphosphate were obtained, especially when a wheat crop was sown in soil ploughed from unfertilized pasture.

In the same area nitrogen fertilizers showed significant responses in seven out of 18 trials during the 1930-1950 period and in five out of 21 trials in 1950-1965. Response to nitrogen is most likely to be attained where some fertility depletion has taken place with successive crops of wheat or where autumn sown wheat shows "spring yellows" symptons of nitrogen deficiency. Yield increases of one to three bushels wheat per acre (67 - 202 kg/ha) would be required to cover the cost of one cwt. per acre (126 kg/ha) (Table 117).

Table 117. Approximate marginal wheat yield increases* to cover the costs of fertilizers (Douglas 1968).

Fertilizer	Cost of fertilizer $ per cwt. (51 kg)	Cost of fertilizer $ (per kg)	Yield increase to cover cost of one cwt. fertilizer bushel (27 kg)	Yield increase to cover cost of one kg fertilizer kg
Superphosphate	1.15	0.023	1	½
Amm. sulphate	2.78	0.055	2-3	1-1½
Nitrolime	3.12	0.061		
(Harvesting costs not deducted)				

*) 1 bushel wheat = $1.45; 1 kg wheat = $0.054

The few trials with gypsum, lime, molybdenum and manganese indicate that these are not beneficial in most circumstances.

V. WHEAT YIELDS IN RELATION TO USE OF FERTILIZERS

V. a. Regional yields and fertilizer use

The world consumption of commercial fertilizers was over three times greater in 1966 than in 1948-52. The regional development of fertilizer consumption is illustrated in Fig. 34,A. During the given period the greatest increase, 79 kilograms per arable hectare, took place in Europe. The corresponding figures for other regions were: North America 39, Oceania 27, USSR 21, Latin America 14,

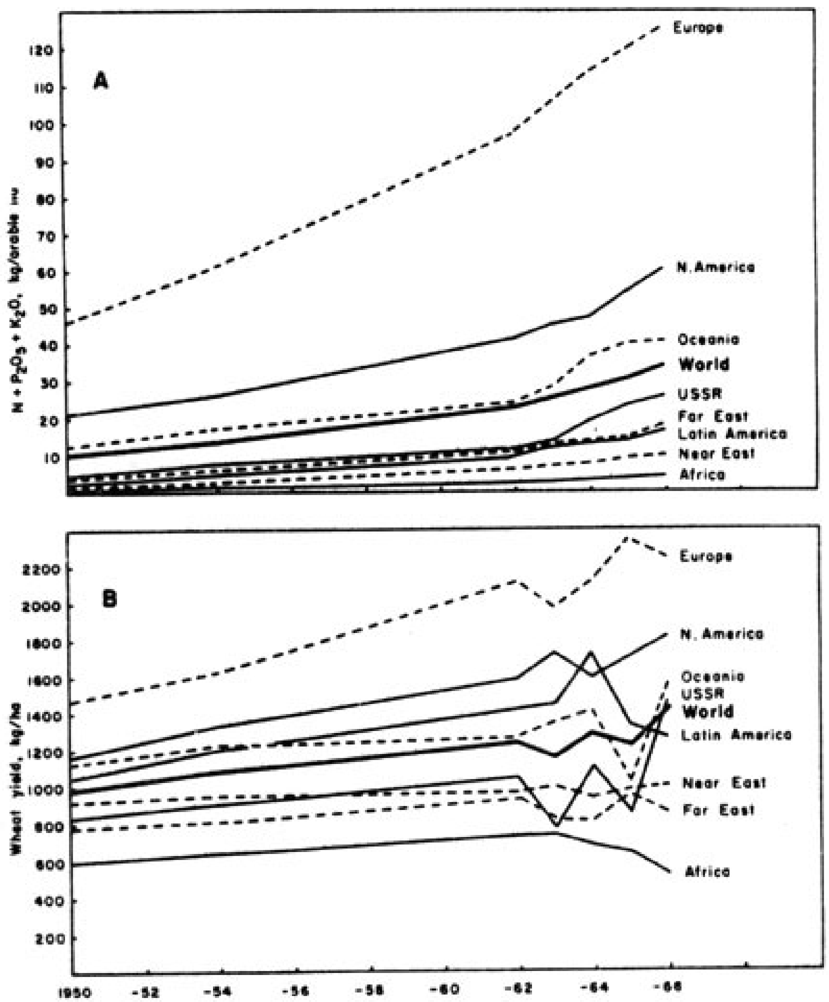

Figure 34. Development of wheat yields and consumption of commercial fertilizers in different regions of the world.

x) Five-year average.

Far East 14, Near East 8 and Africa 3 kg/ha. In spite of a more rapid relative increase in fertilizer use in developing than in most of the developed regions, the changes have led to increased differences between the developed and developing regions. A similar tendency can also be seen in the development of average regional wheat yields (Fig. 34, B). The highest yields were obtained in Europe and the lowest in Africa. In 1948-52 the European yields were about two and a half times as high as those in Africa. Since then the difference has increased and in 1962–66 the average wheat yields per hectare harvested in Europe were more than three times those in Africa.

The annual variation of wheat yields in different regions had relatively little influence on the average wheat yield of the whole world. For example, the low yields in Europe and USSR in 1963 were mostly compensated by relatively high yields in North America and Oceania and the low yields in Oceania, USSR, Latin America and Africa in 1965 were again compensated by the higher yields in other regions.

The resemblance of the curves showing the regional fertilizer use and those of yields given in Fig. 34 A and B is obvious. The relationship between these variables and their development is summarized in Fig. 35, giving the figures for two five-year periods, 1948–52 and 1962–66.

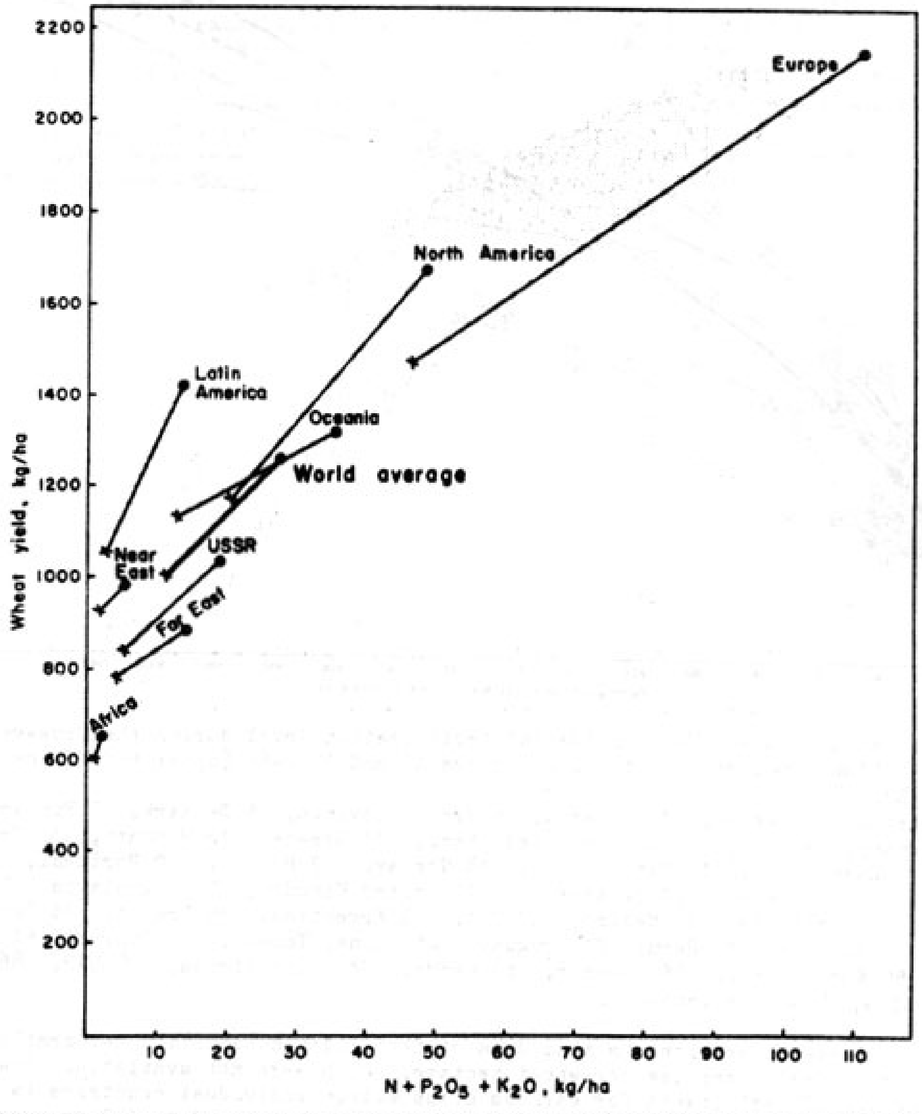

Figure 35. Relation between wheat yields and consumption of fertilizers per arable hectare in different regions of the world. Averages of two five-year periods of 1948–52 (x) and 1962–66 (•).

V. b. National yields and fertilizer use

The relationships between national wheat yields and use of fertilizers are given in Fig. 36, where also the regressions for both periods are shown:

Curve A (1948–52) : $\text{Log } Y = 2.9568 - 0.0893 \text{ Log } X + 0.1285 (\log X)^2$; $R = 0.81$, $F = 41.8^{***}$

Curve B (1962–66) : $\text{Log } Y = 3.0982 - 0.2059 \text{ Log } X + 0.1485 (\log X)^2$; $R = 0.80$, $F = 41.1^{***}$

where Y = wheat yield (kg/ha) and X = use of fertilizers (kg/ha).

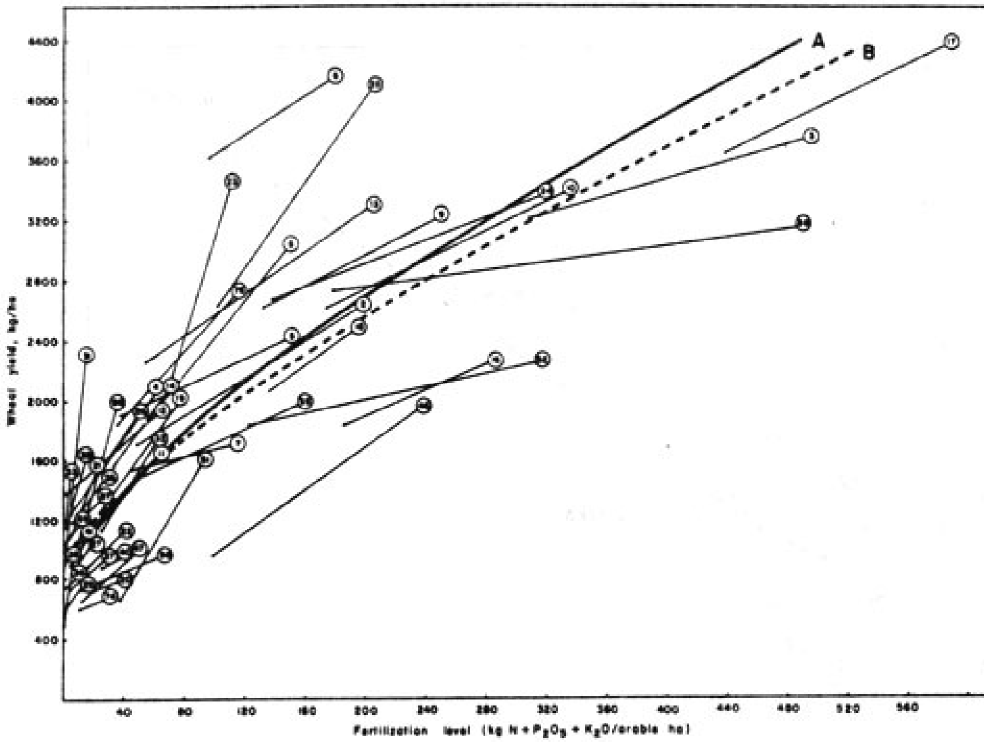

Figure 36. Relationship between wheat yields and fertilization level during the five-year periods of 1948–52 (lower end of each line, and curve A) and 1962–66 (upper end of the line and curve B).
2 Austria, 3 Belgium, 4 Bulgaria, 5 Czechoslovakia, 6 Denmark, 7 Finland, 8 France, 9 Germany, Eastern, 10 Germany, Fed. Rep., 11 Greece, 12 Hungary, 13 Ireland, 14 Italy, 15 Luxembourg, 17 Netherlands, 18 Norway, 19 Poland, 20 Portugal, 21 Romania, 22 Spain, 23 Sweden, 24 Switzerland, 25 United Kingdom, 26 Yugoslavia, 27 USSR, 28 Canada, 29 Guatemala, 31 Mexico, 32 USA, 33 Argentina, 35 Brazil, 36 Chile, 37 Colombia, 38 Ecuador, 40 Peru, 41 Uruguay, 46 China, Taiwan, 47 Cyprus, 51 Israel, 52 Japan, 55 Korea, Rep., 56 Lebanon, 69 Kenya, 74 South Africa, 78 UAR, 86 Zambia, 87 Australia, 88 New Zealand.

A limitation of these regressions is that data of fertilizer consumption per arable hectare are used instead of data of fertilizer use per wheat hectare, which were not available. However, the difference between the use of fertilizers for various crops within individual countries is considered very small in comparison to fertilizer use in different countries varying from 1–2 to over 500 kilograms per hectare.

It must also be understood that fertilizers alone are not responsible for the total increase in yield but their consumption per arable hectare is evidently a reliable index of the extent to which modern agricultural methods have been adopted. Similarly, wheat yields in the correlations given above can be considered as indexes of the level of productivity and its development in individual countries.

In spite of these limitations the significance of the correlations between the two variables are considerably high. On a world-wide basis, representing a full range of climatic, soil and other environmental factors these correlations may provide helpful general information in estimating the contribution of fertilizers to increasing crop production and give a general picture of the quantity of fertilizer required to attain or maintain a desired level of production.

However, comparisons of the general data on a country basis presented in this chapter with results obtained from individual fertilizer trials in different countries given in Chapter IV, are essential to obtain a more detailed and reliable picture of the response of wheat to fertilizers in different conditions.

It can be seen from Figure 36 that all 48 countries have used more fertilizers during the latter period, have also attained higher wheat yields, and thus have moved more or less in parallel up the curves. The close relationship between the two regressions calculated on the basis of data from the two five-year periods, 1948-52 and 1962-66, should be noted. The position of some countries are relatively distant from the regression lines, and the slopes of some country lines differ from those of the general regression lines. For example, in Denmark the yields have been considerably higher than in other countries on the corresponding level of commercial fertilizer consumption. One of the reasons is that Denmark is a dairy country and besides using advanced methods of farming brings about equal amounts of nutrients into the soil in farmyard manure as in commercial fertilizers (Landbrugsraadet 1967). The exceptionally high increase of wheat yields in Mexico is mainly a result of balanced use of fertilizers, improvement in soil-water management, and adoption of new high yielding wheat varieties. The divergence of other countries from the curve is due to exceptional climatic, soil or other environmental conditions.

V. c. National responses of wheat to fertilizers

The general pattern of the regression lines in Figure 36 indicates the effect of the law of diminishing returns. This can be seen more clearly from Figure 37 where the response of wheat to fertilizers is plotted against the fertilization level in individual countries. An example: In France an average of 51 kg nutrients per arable hectare were annually applied in 1948–52 and 147 kg/ha in 1962–66, increase 96 kg/ha (see X-coordinate). Simultaneously the national wheat yield increased from 1,830 to 3,010 kg/ha or by 1,180 kg/ha. The increases in yield and in fertilization level thus correspond to a response ratio of 1,180/96 = 12 kg wheat/kg fertilizer nutrients (see Y-coordinate).

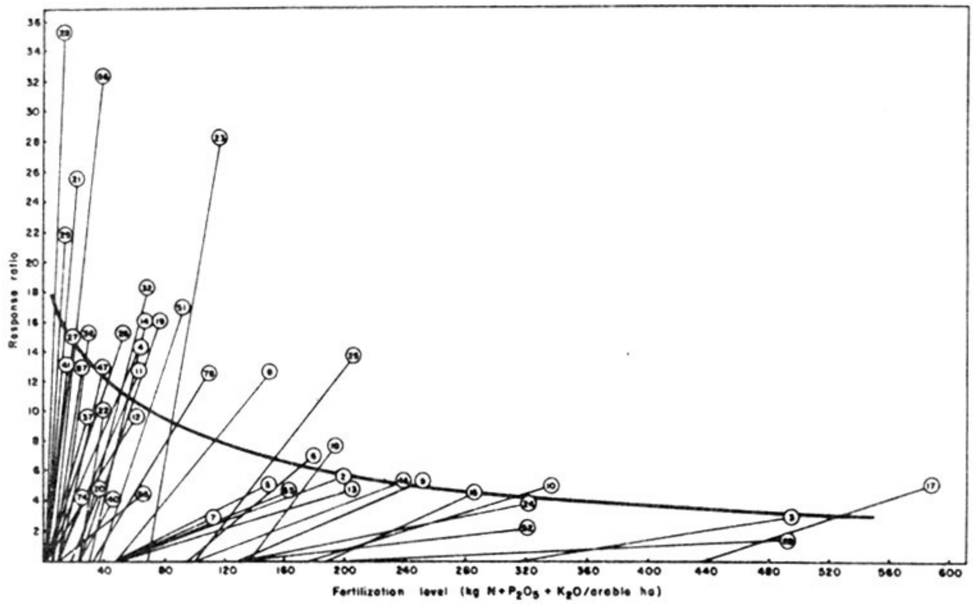

Figure 37. Changes of fertilization levels in 43 countries from the five-year period 1948–52 (Lower end of lines) to period 1962–66 (O and X-coordinate) and the response of wheat to increased fertilization (O and Y-coordinate). The regression curve indicates the overall relation between the response ratio and fertilization levels.
2 Australia, 3 Belgium, 4 Bulgaria, 5 Czechoslovakia, 6 Denmark, 7 Finland, 8 France, 9 Germany, Eastern, 10 Germany, Fed. Rep., 11 Greece, 12 Hungary, 13 Ireland, 14 Italy, 15 Luxembourg, 17 Netherlands, 18 Norway, 19 Poland, 20 Portugal, 21 Romania, 22 Spain, 23 Sweden, 24 Switzerland, 25 United Kingdom, 26 Yugoslavia, 27 USSR, 28 Canada, 29 Guatemala, 32 United States, 36 Chile, 37 Colombia, 40 Peru, 41 Uruguay, 46 China, Taiwan, 47 Cyprus, 51 Israel, 52 Japan, 55 Korea, Rep., 56 Lebanon, 59 Kenya, 74 South Africa, 78 UAR, 86 Zambia, 87 Australia, 88 New Zealand.

It must be understood that beside fertilizers other input factors, such as improved cultivation methods, increased pest, disease and weed control, more responsive varieties etc. have affected the response ratio. The given ratio, therefore, includes also the effects of improvement in these input factors, the extent of which, however, is difficult to quantify.

The regression line

$$\text{Log } Y = 0.9706 + 0.4478 \text{ Log } X - 0.2302 (\text{Log } X)^2; \quad R = 0.63; \quad F = 13.2^{***}$$

where Y = the response ratio (kg wheat/kg fertilizer nutrients)
and X = fertilization level (kg/arable ha)

indicates the response ratio as a function of fertilization level, based on national yield responses to increased fertilization from the five year period 1948–52 to that of 1962–66 in 43 countries.

The regression shows considerably higher potential of response in countries of low fertilization level (mainly developing countries) than in those already using heavy doses of fertilizers. Further, the regression line gives the response level at various fertilizer use levels in average environmental conditions. Deviation of an individual country from this line may be due to resource or natural factors such as soil and climatic conditions. However, for many countries the input factors mentioned above and the extent of their improvement between the two periods may be more important than resource factors in determining the response and thus, the position of a country in relation to the regression line. These factors are discussed in Chapter III and IV.

The regression curve enables one to make theoretical calculations of the response to be expected in a country on a certain level of fertilizer use. For example, if a country using now 20 kg fertilizers per hectare is planning to increase its fertilizer consumption to 60, 100 or 150 kg/ha, the response likely to be obtained from this increase would be 11, 9 or 7 kg wheat per kg fertilizers, respectively, in average environmental conditions.

The slopes of the country lines in Figure 37 also contribute to an estimation of divergence from average conditions.

The relationship between response ratio and yield level (Fig. 38) is similar to the relationship between response ratio and fertilization level, even though the correlation remains at a lower level of significance. The regression curve shows that the average potential of response is considerably higher in countries where the yield level is low (mostly developing countries) than in countries al-

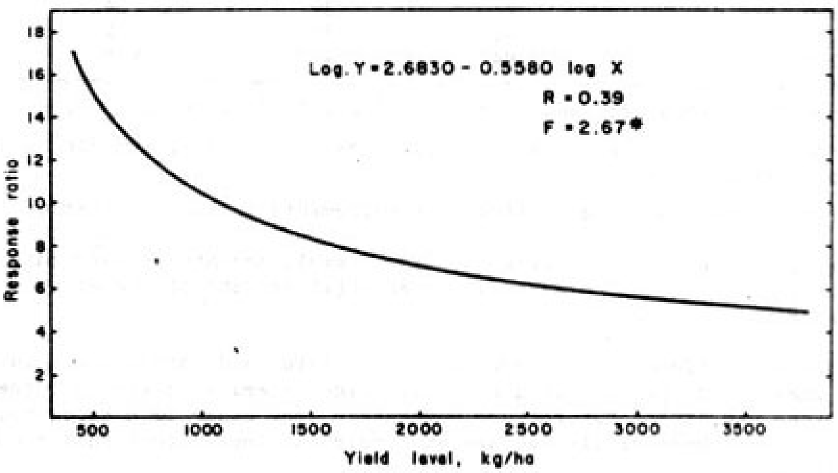

Figure 38. Relationship between response ratio (kg wheat/kg fertilizer nutrient) and the level of wheat yield. Regression is based on national yields (1948–52) in 43 countries and on increases in yield/fertilizer use from 1948–52 to 1962–66.

ready harvesting high yields. For example, countries with national wheat yields at 750–1000 kg/ha level are likely to obtain an average yield increase of 12 to 10 kg for each additional kilogram of fertilizer nutrients applied per hectare, while in countries with national yields of 2,500 kg/ha or more the response would only consist of half that amount.

V. d. Wheat and fertilizer use in relation to soil nutrient balance in different world regions

Fertilizer application and nutrient removal by crops are only two factors affecting the nutrient balance of soils. The extent of the effects of these, however, is possible to quantify with more accuracy than that of most other factors such as various chemical and physical processes in soil releasing or fixing nutrients, nitrogen fixation from air, leaching, erosion, flooding, etc.

The amounts of nutrients removed from the soil by eight commonly grown crops are compared in Table 118.

Table 118. Removal of nutrients from soil by eight commonly grown crops. Average data from different sources (1) are used and converted to correspond to world average crop yields in 1962-66

Crop	World average yield in 1962-66 kg/ha	Nutrients removed (2)			
		N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Total kg/ha
Wheat	1265 grain	33	19	26	78
Oats	1496 "	37	16	27	80
Barley	1528 "	39	16	36	91
Rice	2036 "	33	13	45	91
Potatoes	12100 tubers	45	18	70	133
Soybeans (3)	1166 grain	77	30	34	141
Maize	2212 "	63	33	71	167
Sugarbeets	24240 roots	94	47	148	289

1) Sources: Bear 1965, Ignatieff and Page 1958, Russell 1961, Shell 1960.

2) For grain crops both grain and straw, for potatoes only tubers, and for sugarbeets both roots and tops are included.

3) Legume crops may obtain all their nitrogen requirements through N fixation from the air.

Even though wheat is a crop which removes relatively small amounts of nutrients from soil in comparison to other crops, its extensive cultivation area (15 percent of the world's total arable area) increases its importance in relation to other crops.

There are considerable differences in regional wheat yields and consequently in the amounts of nutrients removed by wheat in different world regions. Since there is a strong correlation between the yields and fertilizer use, these two factors compensate each other to a large extent. An estimation of the effects of these single factors and their combined effect on the nutrient balance of soil is shown in Figure 39.

Following aspects concerning the data presented in Fig- 39 should be noted:

- the general purpose of the estimation is to show some relative differences between the seven world regions.
- for nutrients applied in mineral fertilizers and removed by wheat, FAO data and average data from sources given in Table 118 are used.
- all nutrients in wheat grain are assumed to be removed from the soil.
- no attempt is made to estimate the effects of different straw management practices (burning, ploughing in, use for animal bedding, feeding, etc.) on the nutrient balance. Instead, two balances (with and without removal of nutrients in straw) are given;
- nutrients applied into soil in farmyard manure and through nitrogen fixation from air are excluded.

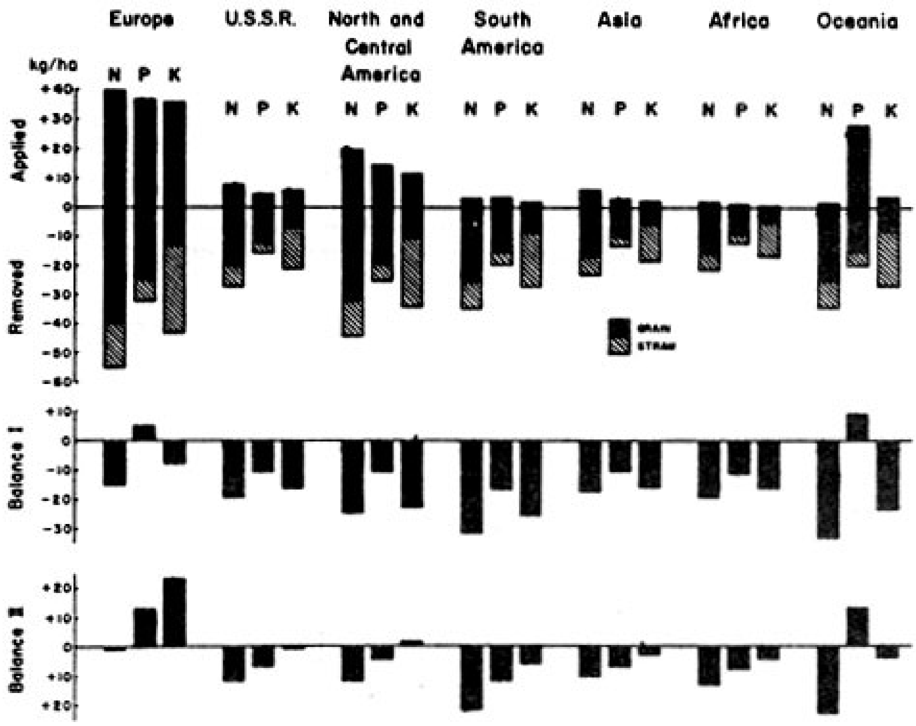

Figure 39. An estimation of the effects of annual fertilizer application and of nutrient removal by wheat yields on the nutrient balance of soil in different world regions. Balance I is calculated assuming the nutrients in both grain and straw to be removed from the soil. In balance II the nutrients in straw are assumed to remain in the soil. The estimation is based on data on average regional fertilizer consumption and average regional wheat yields in 1962-66. For sources of nutrient removal, see Table 118 (P and refer to P_2O_5 and K_2O).

The balances are in general more positive (or less negative) in the developed than in developing regions in spite of the higher yields accompanied by heavier removal of nutrients in the farmer regions. An exception to this general trend, is the strongly negative nitrogen balance in Oceania. This balance, however, may be the most misleading one among the balances given, because an apparent compensation for the low nitrogen fertilizer use in Australia and New Zealand is obtained from the general inclusion of nitrogen fixing clover pastures in rotations.

The exclusion of the effect of farmyard manure on the nutrient balance is not only because of lack of reliable data on total manure production in different regions but mainly because of difficulties in estimating how much of the produced manure would be applied to the arable land and how much nutrients are lost through bad manure handling, through manure use as fuel etc. It is apparent, however, that the difference between developed and developing regions would increase if the effect of manure on soil nutrient balance is taken into account.

A rough example: it could be estimated on the basis of average nutrient content of manure of different domestic animals, annual manure production per animal and number of various domestic animals (Ensminger 1955, FAO 1967, a) that the total manure production of Europe would correspond to about 50-60 kg N, 20-25 kg P_2O_5 and 40-50 kg K_2O per arable hectare. For Africa the figures would be only about one third of those or 15-25, 5-10 and 12-18 kg/ha, respectively. Further, if estimated that in European conditions of intensive agriculture 30-50 percent of the total of nutrients in manure would reach the arable fields, for Africa the respective estimation would hardly exceed 5-10 percent. Thus, the contribution of the nutrients in manure to the nutrient balance of soil would be substantial in Europe while in Africa it would be rather negligible, and thus the difference between the European and African soil nutrient balances (Fig. 39) would considerably increase for the benefit of Europe.

V. e. Mutual ratios of nutrients in fertilizer use

The data of fertilizer use given above relate mostly to the total consumption of the three main nutrients N, P_2O_5 and K_2O per arable hectare. However, there are considerable differences in the ratios in which these nutrients have been applied to soil in different countries. Most of these differences are due to dissimilarities in the nutrient requirement of soils established by extensive fertilizer trials, chemical analyses and experience. In some cases, however, secondary or circumstantial factors including the production, trade, transportation and price of fertilizers, may make certain fertilizers more abundantly available for farmers than the others, and thus affect the choice of fertilizers to be used. Inadequate knowledge of farmers combined with insufficient extension work or lack of cooperation between agricultural experts and persons responsible for the fertilizer trade may also be the cause of unbalanced use of fertilizers.

The ratios ($N: P_2O_5 : K_2O$) in which the nutrients were used in different countries and regions in 1948-52 and 1962-66 are given in Table 119.

In general, a trend of increasing use of nitrogen is obvious in most countries as aslo indicated by the change of world average ratio of $N : P_2O_5 : K_2O$ from 1 : 1.4 : 1.0 in 1948-52 to 1 : 0.8 : 0.7 in 1962-66. A similar tendency is true for different regions except for South America, Oceania and Asia, where the relative use of potassium as compared to the other two nutrients was increased.

In spite of the considerable quantitative increase in the world's total use of P_2O_5 from about 6.1 to 13.3 million metric tons or from 4.2 to 9.3 kilograms per arable hectare, its relative proportion in fertilizer consumption has essentially decreased. The corresponding figures of the other two nutrients N and K_2O for the periods mentioned above increased from 3.0 to 11.0 and 3.1 to 7.7 kg/ha, respectively.

The ratio between the three nutrients varies considerably from one country to another even though a trend toward narrower ratios from the former to the latter period can be noticed. For example, the number of countries (Table 119) using at least 50 percent more P_2O_5 than N was 26 in 1948-52 and only 14 in 1962-66. Correspondingly, 14 countries consumed over 50 percent more K_2O than N in 1948-52 and only 6 countries in 1962-66. To what extent this kind of development can be considered a sign toward "balanced use of fertilizers" cannot be stated because the conception of balanced use of fertilizers cannot be uniformly defined and may vary from one location to another according to nutrient resources of soils and climatic and environmental conditions. In addition, input factors like previous history of fertilizer use, adoption of rotations with nitrogen fixing legumes (e.g. in Australia and New Zealand) may have an effect on the requirement of various nutrients. From the general point of view, all the nutrients taken from soil by crops should be replaced, and those nutrients limiting the growth should be applied in excess to improve the soils. Balanced use of fertilizers, therefore, involves the application of all three main nutrients in a ratio which may vary from time to time, but in the long run results in a balance related to that of crop requirement. Factors like leaching and fixation of nutrients, besides repeated fertilizer trials, have to be taken into account in estimating the best use of fertilizers. More attention should also be paid to the accelerated removal of secondary and trace nutrient by increased yields in order to avoid the exhaustion of soils of these nutrients.

The ratios given in Table 119, especially if divergent from those of other countries with similar conditions and higher yields, may suggest to the agricultural scientists concerned the need for further studies.

Considerable changes have taken place, not only in the relative consumption of various nutrients, but also in the forms of fertilizers in which the nutrients have been applied to the soil. Especially the trend toward more concentrated products has been marked. FAO data on the forms of nitrogenous and phosphate fertilizers production (Cooke 1969) show this general trend (Table 120).

Table 119. **RELATIVE** CONSUMPTION OF THE THREE MAIN NUTRIENTS IN DIFFERENT COUNTRIES AND REGIONS OF THE WORLD (N = 1)

Country and Region	1948–52 N	1948–52 P_2O_5	1948–52 K_2O	1962–66 N	1962–66 P_2O_5	1962–66 K_2O
Albania	–	–	–	1	1.9	0.5
Austria	1	1.5	1.2	1	1.5	1.8
Belgium	1	1.1	1.5	1	0.9	1.2
Bulgaria	1	0.2	0.0	1	0.7	0.0
Czechoslovakia	1	1.2	1.5	1	1.0	1.4
Denmark	1	1.3	1.7	1	0.7	1.0
Finland	1	3.6	1.8	1	1.4	1.1
France	1	1.6	1.4	1	1.5	1.1
East Germany	1	0.4	2.0	1	0.8	1.5
Fed. Rep. Germany	1	1.1	1.8	1	1.0	1.4
Greece	1	0.8	0.2	1	0.8	0.1
Hungary	1	8.3	0.7	1	0.6	0.3
Ireland	1	5.1	2.2	1	3.2	2.6
Italy	1	1.9	0.2	1	1.0	0.4
Luxembourg	1	1.6	1.1	1	1.1	1.2
Netherlands	1	0.8	1.0	1	0.4	0.4
Norway	1	1.1	1.4	1	0.8	0.9
Poland	1	1.0	1.8	1	0.8	1.1
Portugal	1	1.7	0.2	1	0.7	0.2
Romania	1	0.6	0.7	1	0.8	0.1
Spain	1	1.9	0.5	1	0.9	0.3
Sweden	1	1.6	0.9	1	0.8	0.7
Switzerland	1	3.9	1.8	1	2.0	2.2
United Kingdom	1	1.7	1.0	1	0.7	0.7
Yugoslavia	1	1.4	0.5	1	0.8	0.8
Europe (average)	1	1.3	1.3	1	0.9	0.9
USSR	1	1.5	1.5	1	0.7	0.8

Country and Region	1948–52 N	1948–52 P_2O_5	1948–52 K_2O	1962–66 N	1962–66 P_2O_5	1962–66 K_2O
Canada	1	3.2	1.7	1	1.6	0.7
Guatemala	1	1.3	0.8	1	0.6	0.3
Honduras	1	1.8	0.2	1	0.1	0.1
Mexico	1	0.9	0.2	1	0.3	0.0
USA	1	1.7	1.1	1	0.8	0.6
N. and C. America (av.)	1	1.7	1.1	1	0.8	0.6
Argentina	1	0.9	0.2	1	0.3	0.2
Bolivia	–	–	–	1	1.0	0.8
Brazil	1	1.1	1.1	1	1.5	1.4
Chile	1	1.9	0.3	1	1.8	0.4
Colombia	1	2.2	1.8	1	1.0	0.8
Equador	1	1.5	0.5	1	1.0	0.6
Peru	1	0.6	0.1	1	0.3	0.1
Uruguay	1	3.8	0.5	1	2.1	0.5
Venezuela	1	0.4	0.6	1	0.3	0.4
S. America (av.)	1	1.0	0.4	1	1.0	0.6
Australia	1	20.9	0.5	1	13.3	1.0
New Zealand	1	107.4	5.7	1	56.9	15.4
Oceania (av.)	1	26.8	0.9	1	15.8	2.1
World (av.)	1	1.4	1.0	1	0.8	0.7

Country and Region	1948–52 N	1948–52 P_2O_5	1948–52 K_2O	1962–66 N	1962–66 P_2O_5	1962–66 K_2O
Burma	1	1.0	–	1	0.2	–
China (Taiwan)	1	0.3	0.1	1	0.3	0.3
Cyprus	1	2.8.	0.1	1	0.8	0.2
India	1	0.2	0.1	1	0.3	0.1
Iran	–	–	–	1	0.7	0.1
Iraq	–	–	–	1	0.3	0.1
Israel	1	1.2	0.3	1	0.5	0.1
Japan	1	0.6	0.4	1	0.7	0.8
Jordan	1	0.3	–	1	0.8	1.2
Korea, Rep.	1	0.3	0.1	1	0.6	0.2
Lebanon	1	0.5	0.8	1	0.7	0.2
Pakistan	–	–	–	1	0.1	0.0
Syria	1	0.3	0.1	1	0.4	0.1
Turkey	1	0.7	0.3	1	1.0	0.0
Asia (average)	1	0.5	0.2	1	0.5	0.4
Algeria	1	3.0	1.8	1	1.2	0.9
Kenya	1	11,8	0.3	1	1.0	0.1
Mali	–	–	–	1	1.5	5.5
Morocco	1	5.5	2.5	1	1.1	0.5
Mozambique	1	0.3	0.1	1	0.2	0.4
South Africa	1	9.2	0.6	1	1.7	0.7
Sudan	–	–	–	1	0.0	0.2
Tanganyika	1	0.3	0.8	1	0.3	0.6
Tunisia	1	31.3	1.7	1	2.3	0.5
UAR	1	0.2	0.0	1	0.2	0.0
Zambia	1	0.4	0.1	1	0.5	0.5
Africa (average)	1	1.4	0.3	1	0.6	0.3

Table 120. Changes in forms of nitrogenous and phosphate fertilizers produced.

Forms of Fertilizers	Percentages of world total 1952/53	1959/60	1966/67
Nitrogenous fertilizers:			
Ammonium sulphate	32	26	17
Ammonium nitrate	22	28	27
Sodium nitrate	5	2	-
Calcium nitrate	6	4	2
Calcium cyanamide	6	3	2
Urea	-	-	13
Other forms solid	7	18	17
Solutions	13	18	21
Phosphate fertilizers:			
Single superphosphate	64	51	42
Concentrated superphosphate	9	14	16
Basic slag	13	16	8
Other products (*)	13	19	34

(*) Includes "other phosphate fertilizers", "complex fertilizers" and "organics".

Ammonium sulphate, which in early fifties was the most used nitrogenous fertilizer comprising one third of the total of nitrogenous fertilizers, makes only one sixth of the total in 1966/67. This trend can be considered favourable, for it is a dilute fertilizer increasing the acidity of soils more than most other nitrogenous fertilizers. Ammonium nitrate has maintained its position, but urea, which is much more concentrated than ammonium nitrate, has emerged as an important fertilizer with an eighth of the total production. The production of liquid fertilizers, mainly anhydrous and aqueous ammonia, has increased to one fifth of the total N-fertilizer production, even though the use of these materials is limited to a few countries.

Changes to more concentrated fertilizers can be noted also in the diminished importance of single superphosphate and basic slag and in the increased production of concentrated superphosphate and "other products". The latter were not specified but are believed to consist mainly of ammonium phosphates, which are concentrated and versatile ingredients of compound fertilizers.

Most of the world's potassium fertilizers are supplied as potassium chloride (60% K_2O) and change from this form is not likely for the sake of concentration (Cooke 1969).

The development toward more concentrated fertilizers is highly desirable especially from the point of view of developing countries, where the costs of fertilizer transportation are often unduly high because of difficult transport situation.

In the future, fertilizers with new dimensions, including trace elements, are needed to match the new developments in agriculture that have already raised potential yields greatly (Cooke 1969). Further advances are inevitable as better varieties are obtained, as more pests, diseases and weeds are controlled, and new methods of cultivation are developed.

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