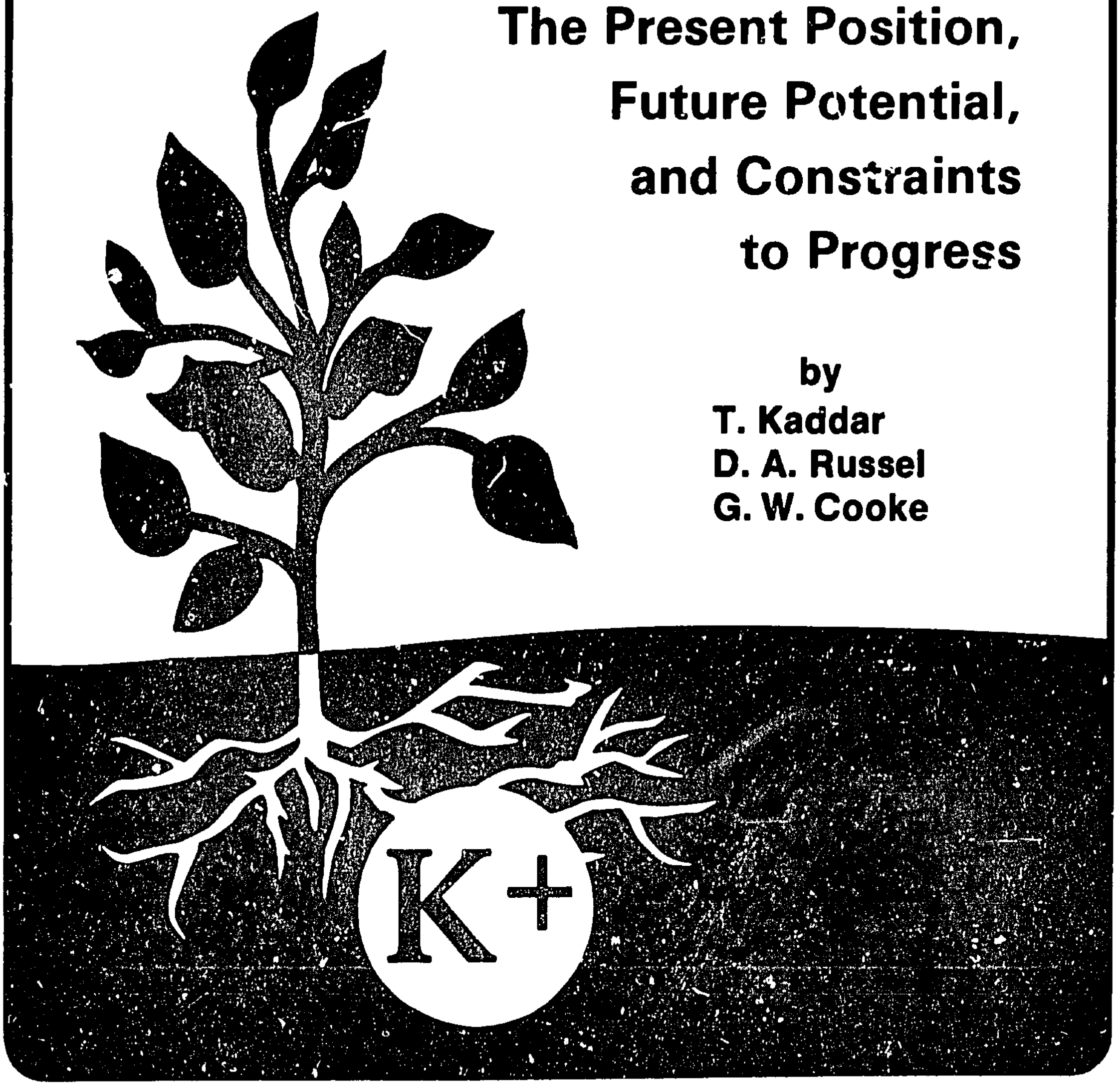
The Vital Role of Potassium Fertilizers in Tropical Agriculture

The Present Position, Future Potential, and Constraints to Progress



by
T. Kaddar
D. A. Russel
G. W. Cooke

International Fertilizer Development Center, Muscle Shoals, Alabama U.S.A.

Abstract

This technical bulletin describes the results of the second study made by the International Fertilizer Development Center (IFDC), with support from the International Potash Institute (IPI) and the Potash and Phosphate Institute (PPI) on the role of potassium fertilizers in tropical agriculture. Specific goals of this study were to:

1. Evaluate the potential for potassium fertilizer use as affected by the sociodemographic factors of developing countries.
2. Identify those constraints to increased use of potassium fertilizers and to suggest how they may be overcome.

Developing countries have greatly increased their use of fertilizers in the past decade and now account for 40% of the nitrogen, 30% of phosphate, but only 15% of the potash used in the world.

In 1981/82 IFDC surveyed 26 countries in the tropics and subtropics concerning their current use of potassium fertilizers. The survey was made by using questionnaires and personally interviewing research workers and specialists familiar with fertilizer use and soil fertility in each country.

Results of the survey showed that an estimated one-fourth of the soils in these regions are deficient in potassium. (In some areas as much as 70% of the land is deficient.) Crop response to applications of potassium fertilizers varied widely with the crop and the type of cultivar used. But in nearly all cases where there was a potassium deficiency, the yield response was great enough to justify the application.

At harvest time all crops contain very large amounts of potash. Depending on the crop and the material taken from the field, this potash may be almost totally removed or, particularly in the case of mechanically harvested grain, left almost entirely in the field. A critical factor in reducing potash loss from the farms is therefore the efficiency with which the farmer recycles crop residues.

Agronomic factors that increase the need for potassium fertilizers are (1) the introduction of high-yielding cultivars, (2) increases in the cropping intensity, that is, growing two or three crops each year, (3) use of new lands for cash or export crops, (4) use of other inputs such as irrigation water and pesticides to increase the yields, and (5) use of potassium to increase the crop's tolerance to saline conditions and to drought.

The present constraints to the use of potassium fertilizers appear to be (1) a lack of knowledge by the farmer, the fertilizer dealer, the demonstration agent, and other government officials about the need for such fertilizers and the benefits derived from them; (2) a lack of research on maximum yields and the role these fertilizers would play; (3) unfavorable crop-fertilizer price ratios; and (4) the limited availability of potassium fertilizers in the marketplace. Specific recommendations for alleviating constraints to the use of potassium fertilizer include the following:

1. Governments should increase research and extension activities designed to identify the need for and, where appropriate, promote the use of potassium fertilizers.
2. Where governments control the availability and price of fertilizers, efforts should be intensified to ensure that farmers have the same physical and economic access to potassium fertilizers as is generally extended to nitrogen and phosphate fertilizers.

The following general recommendations were advanced:

1. Create an effective market structure to dispose of agricultural produce.
2. Avoid establishment of cheap food policies that are maintained at the farmers' expense by setting output prices at low levels.
3. Subsidize the cost of fertilizers whenever low prices must be maintained.
4. Teach farmers how to improve their crop management and water control practices.
5. Give strong support to the agricultural sector with emphasis on strengthening the research and extension services.
6. Establish a national fertilizer program that takes into account all fertilizers necessary to sustain an efficient agriculture.
7. Intensify research on achievable maximum crop yields.

Library of Congress Cataloging in Publication Data

Kaddar, T.
The vital role of potassium fertilizers in tropical agriculture.

Bibliography: p.
1. Potassium fertilizers—Tropics. 2. Potassium fertilizers—Developing countries. 3. Agriculture—Tropics. 4. Agriculture—Developing countries.
I. Russel, Darrell Arden, 1921- . II. Cooke, G. W. (George William), 1916- . III. Title.
S645.K33 1984 338.1'62 84-12971
ISBN 0-88090-051-2

International Fertilizer Development Center
P.O. Box 2040
Muscle Shoals, Alabama 35662

Phone No. 205-381-6600
TWX-810-731-3970 IFDEC MCHL

Edited by E. D. Frederick and E. N. Roth
Illustrations by J. C. Starkey;
layout, J. White; cover design, F. Rudolph

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

Table of Contents

List of Tables

List of Figures

Abbreviations Used in This Report

Organizations

CIAT	International Center of Tropical Agriculture
FAI	Fertiliser Association of India
FAO	Food and Agriculture Organization of the United Nations
IBRD	International Bank for Reconstruction and Development
ICAR	Indian Council of Agricultural Research
IFDC	International Fertilizer Development Center
IPI	International Potash Institute
IRRI	International Rice Research Institute
PPI	Potash and Phosphate Institute
TVA	Tennessee Valley Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization

Other Abbreviations

Ca	calcium
CEC	cation exchange capacity
g	gram (0.035 ounce)
ha	hectare (2.471 acres)
HYV	high-yielding varieties
K	potassium
kg	kilogram (2.2046 pounds)
K_2O	potash (potassium oxide)
meq	milliequivalent (atomic wt/valence/1,000)
Mg	magnesium
MOP	muriate of potash
mt	metric ton (1,000 kg)
N	nitrogen
NPK	fertilizer containing nitrogen, phosphorus, and potassium ($N + P_2O_5 + K_2O$)
P	phosphorus
P_2O_5	phosphorus pentoxide (usually called phosphate)
Rs	rupees
SSP	single superphosphate

Introduction

The population of the world is expected to reach 6 billion by the year 2000 (up from 4.7 billion in 1983). This rapid expansion has created the need for much more food that has to be produced by intensifying existing agricultural systems and by opening up new lands for farming. The crops (which are the basis of nearly all of man's food) take their food, the chemical elements that are essential nutrients, from the soil in which they are rooted. In centuries past the soils supplied enough nutrients to maintain traditional agricultural systems; however, these systems supported only a small population. The need to greatly expand food production in this century could not have been met if we had not been able to provide extra supplies of nutrients for our crops through the development of the fertilizer industry. The three major nutrients provided by fertilizers are nitrogen (N), phosphorus (P), and potassium (K). Fertilizer analyses are usually expressed as percent N, percent P_2O_5, and percent K_2O. The total world consumption of these three nutrients as fertilizers has risen from 9 million metric tons (mt) of N + P_2O_5 + K_2O in 1939 to 114 million mt in 1981/82 (FAO, 1983a).

In the earlier part of this period of over 40 years, nearly all of the expansion in fertilizer use occurred in developed countries. In the more recent period most of the growth in population has been in developing countries, and fertilizer use has expanded rapidly in these countries. Developing countries used 33% of all fertilizers in 1981/82, and the Food and Agriculture Organization of the United Nations (FAO) (1983a) projects that this proportion will reach 37% by 1991/92.

Plants must be supplied with the essential nutrients in needed quantities. The amounts of N and K_2O taken up by crops are roughly equal and are about twice as much as the P_2O_5 taken up. This gives a plant content nutrient ratio of about 2:1:2. Therefore, in examining the use of fertilizers to assess future needs, it is essential to study the ratios of the nutrients applied and to consider whether these ratios match the needs of the crop and the reserves of nutrients in the soils. The amounts of nutrients used as fertilizers in 1981/82 and the ratio of N:P_2O_5:K_2O are given in Table 1. Over most of the world's farmland, the greatest shortage is of nitrogen, and, as Table 1 indicates, N dominates fertilizer use. Although the developing countries use over 40% of the world's nitrogen and 30% of the phosphate, they use only 16% of the world's potash. The quantities of potash used in developing countries, which have a greater area of agricultural land, are very much less than in developed countries.

The ratio of the tonnages of N:P_2O_5 used more closely matches the ratio of these nutrients in crop uptakes in both developed and developing countries than do the N:K_2O ratios. Developed countries use more than half as much K_2O as N, but developing countries use less than one-sixth as much K_2O as N. As was stated above, roughly equal weights of these two nutrients are taken up by crops. This very low N:K_2O ratio in developing countries is therefore a matter of serious concern. Only if soils are rich in potassium will the supply of K for crops be sufficient to match the N that is supplied. We know that in developed countries, where soils are generally richer in all nutrients than they are in the tropics, the present use of potassium fertilizers is generally not sufficient for intensive production of high-yielding crops. Therefore, the situation in developing countries, where fertilizers supply little K_2O relative to the amounts of N supplied and where soils often have lower reserves of K, merits detailed examination. If crops do not receive sufficient K, the full benefit from N and P fertilizers (and from other inputs) will not be obtained, and the goal of growing enough food for the expanding populations of developing countries will not be achieved.

The International Fertilizer Development Center (IFDC), with support from the International Potash Institute (IPI) and the Potash and Phosphate Institute (PPI), conducted a study to determine whether developing countries will have to use much more K fertilizer to achieve their agricultural production targets. The results of the study are summarized in this paper. The four specific objectives of the study were these:

1. Evaluate the K status of tropical and subtropical soils.
2. Summarize crop response to K fertilizers in tropical areas.
3. Evaluate the potential for K fertilizer use as affected by sociodemographic factors.
4. Determine those constraints specific to K fertilizer use and suggest how they may be overcome.

Table 1a.
Fertilizer Consumption in 1981/82

	N	P_2O_5[a]	K_2O	Total	N:P_2O_5:K_2O Ratio
	(million mt)				
World	60.22	30.18	23.93	114.33	1.00:0.50:0.40
Developed countries	35.13	20.95	20.10	76.18	1.00:0.60:0.57
Developing countries	25.08	9.22	3.84	38.14	1.00:0.37:0.15

a. Figures include ground phosphate rock for direct application.

Source: FAO (1983a).

Table 1b.
Fertilizer Application Rates in 1980[a]

	N	P_2O_5	K_2O	Total
	(kg/ha)			
World	41.5	21.7	16.7	79.9
Developed countries	52.9	32.8	30.1	115.8
Developing countries	31.8	12.1	5.2	49.1

a. Kilograms per hectare of arable land and land in permanent crops.

Source: FAO (1982).

The results of studies on objectives 1 and 2 are discussed in detail in *Potassium, Calcium, and Magnesium in the Tropics and Subtropics* (Munson, 1982); the present report focuses on objectives 3 and 4. During the course of this work, 42 countries, representative of the Asian, African, and Latin American regions of the tropics and subtropics, were studied through discussions with local farmers during visits and by questionnaires. The amounts of potash fertilizer used by these countries in 1971 and 1981 and the estimates made by T. Kaddar of likely use of potash in 1985 and in 1990 are given in the Appendix.

The Status of Potassium in Tropical Soils

It is essential to know whether the K available to crops is sufficient for the higher yields that would be made possible by the N and P fertilizers used.

Much of the large increase in food production required in the developing countries must come from land already in production, and most of the soils used have physical and chemical properties that could support higher yields. These soils are generally poor in plant nutrients, and fertilizers, particularly those supplying N and P, are now frequently used to increase crop yields, provided the land is adequately watered by either irrigation or rainfall. Generally, these areas already have an infrastructure that could support increased crop production, given adequate inputs, including more fertilizer N, P, and K as well as lime where needed.

A large amount of land throughout the world can be brought into production. About 40% of the unused land lies in the forest and savanna areas of the tropics. One FAO report, "Agriculture: Toward 2000," indicates that an additional 205 million ha will be brought into cultivation in the developing countries by the year 2000 (FAO, 1979). This assumes that the historical 1% annual rate of expansion will continue. However, given the population growth rate and this low growth rate in land use, the net result will be that available land will decrease from 0.33 ha per capita in 1980 to 0.26 ha per capita in 2000. It is estimated, however, that one-third of the additional food production needed will come from new lands.

The soils of the tropics and subtropics are as variable in physical and chemical characteristics as are those in the temperate zones. Several symposia have included papers on K in tropical soils (IPI, 1974, 1975, 1979, 1980).

Except for soils of recent volcanic or alluvial origin, most tropical soils are highly weathered, and many are acid and low in bases. They have a low cation exchange capacity (CEC) and are unable to adsorb large quantities of K from fertilizers on the exchange complex. Areas deficient in K have been identified by means of soil classification data and agronomic tests. The critical concentrations of exchangeable soil K at which deficiencies occur range up to 0.45 meq K/100 g of soil.[1] The critical levels appear to increase with increased cation exchange capacity of the soil, but they also differ with the crop. In soils with low-base status, the amount of exchangeable K (and of other bases such as calcium and magnesium) decreases with increasing soil depth. The higher amount in the surface soil is due to the slightly higher organic content of that part of the soil and to the recycling of nutrients to the surface by vegetation. Some soils that appear to have adequate reserves may not release the K fast enough to maintain a crop with high K requirements; these same soils would adequately supply a slower-growing crop or one with low K requirements. Often there is little response to K fertilizers under low-yield conditions when water or other nutrients are limiting or if there are toxic substances in the soil. Any of these soils that contain less than 0.15 meq of exchangeable K/100 g soil are invariably so low in available K that they cannot support normal crop growth. Newly-cultivated soils may test relatively high in available K, but with adequate applications of N and P and removal of several crops, a need for K fertilizers will develop. When higher yielding varieties or hybrids are introduced with adequate N and P fertilizers, the more rapid growth markedly increases the rate of K uptake and the potential for response to applied K (Munson, 1982).

Using the FAO-United Nations Educational, Scientific and Cultural Organization (UNESCO) world soil map and a soil fertility capability classification system, North Carolina State University workers have estimated that K is already low in one-fourth of the soils in the tropics and subtropics. The system used provides reasonably reliable estimates of soil productivity in the absence of more precise soil testing information (Buol et al., 1975). The survey covered 3.3 billion ha. The largest continuous areas are in the interiors of Latin America and Africa; there are smaller but important areas in Central America and Southeast Asia (Table 2). Sanchez and Cochrane (1980) estimate that 77% of the acid, infertile soils of tropical America are deficient in K; such soils constitute 70% of the total soil area in tropical America.

In 1981/82 IFDC surveyed 26 countries in the tropics and subtropics concerning their current use of and need for K fertilizers. The survey was conducted by using questionnaires and personally interviewing people familiar with fertilizer and soil fertility in each country. Detailed information was obtained from 19 of the countries (Table 3). Not all the soils reported to be deficient in K are presently being cultivated; however, some of these are expected to be brought into use within the next 20 years. When reporting the K status of soils, respondents to the questionnaire did not distinguish between soils presently in cultivation and those expected to be brought into cultivation.

1. 1 meq = 1 milliequivalent = 1 thousandth atomic weight ÷ valence.

Table 2.
Distribution of Soils With Reserves of K That Are Considered to Be Too Low for Crop Production

	Total Area	K-Deficient Area	% of Area Deficient in K
	(million ha)		
Africa			
Wetland tropics	238.7	2.4	1
Acid savannas	252.5	126.2	50
Steep-land tropics	265.2	23.9	9
Semiarid tropics	402.8	48.3	12
Subtotal	1,159.2	200.8	17
Asia			
Wetland tropics	123.9	13.6	11
Acid savannas	131.0	66.8	51
Steep-land tropics	415.5	128.8	31
Semiarid tropics	299.5	12.0	4
Subtotal	969.9	221.2	21
Latin America			
Wetland tropics	331.6	3.3	1
Acid savannas	142.5	94.1	66
Steep-land tropics	372.0	126.5	34
Semiarid tropics	303.4	106.2	33
Subtotal	1,149.5	330.1	29
TOTAL	3,278.8	752.2	23

Source: Conto, Sanchez, and Buol (1981).

Table 3.
IFDC Study Showing K Status of Soils—Africa, Asia, and Latin America

Country	Identified K-Deficient Areas Very Low	Low
	('000 ha)	
Africa		
Egypt	149	0
Ethiopia	15	0
Ivory Coast	3,434	0
Kenya	272	0
Mauritius	0	77
Morocco	250	2,000
Nigeria	0	2,914
Senegal	2,410	0
South Africa	0	12,200
Sudan	0	794
Zimbabwe	0	28,564
Asia		
Bangladesh	3,187	0
Sri Lanka	687	7,966
Thailand	5,277	13,529
Latin America		
Brazil	309,500	39,485
Chile	0	1,873
Colombia	5,496	11,408
Costa Rica	724	2,174
Peru	0	55,000

Very low K reserve = <0.1 meq exchangeable K/100 g soil.
Low K reserve = 0.1 - 0.45 meq exchangeable K/100 g soil.

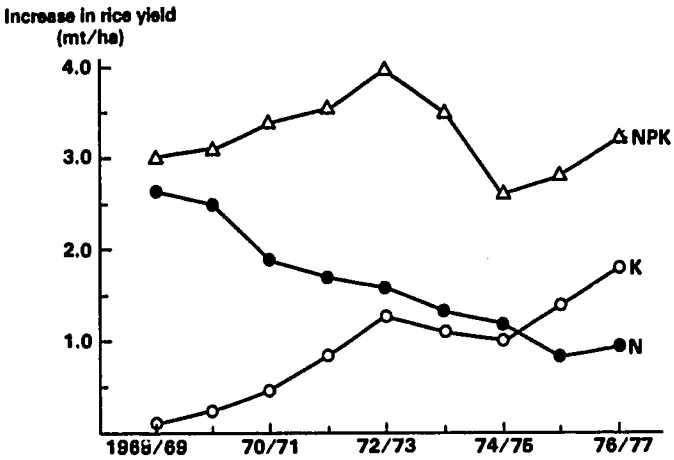
The Response of Tropical Crops to K Fertilizers

When soil reserves of K are insufficient for the needs of the crop, applications of K fertilizers increase yields. These responses are measured in field experiments and assessed against the cost of the K fertilizer and the value of the extra crop produced. The farmers' objective, ultimately, is to achieve the maximum profit per unit area. Thus, once we have a general assessment of the extent of deficiency of available K in soils, we need information on the crop responses to K fertilizers in such soils.

While assessing K fertilization in the tropics and subtropics of Asia, Kanwar (1975) reported on results from the Coordinated Agronomic Trials Project in India. Numerous trials were conducted on cultivators' fields. On soils rated low in available K, an application of 60 kg K_2O/ha increased rice yields nearly 17% in 1971/72. A 15% increase was obtained on fields rated medium in available K. Response data for Latin American and African countries are less numerous but very similar. Munson (1982) cites numerous crop responses to potash fertilization of Latin American soils. He points out that long-term trials are particularly important in developing countries. As already stated, newly cultivated soils may contain relatively high amounts of K; however, with applications of N and P and the removal of several crops, the need for K fertilization eventually becomes apparent when the reserves are depleted. This is shown well by the summary in Figure 1 of the results of long-term fertilizer experiments on rice in the Philippines. The increase in yield from the full NPK fertilizer dressing remained high throughout the 10-year period, varying between about 3 and 4 mt/ha of rice. The response to N fertilizer alone (in the absence of P and K) was nearly as high at the start of the experiment but declined rapidly with time as the supplies of other nutrients were exhausted. The response to K that is shown was measured where N and P fertilizers had been applied. There was very little response to K initially, but the gain from this nutrient rapidly increased as reserves in the soil became depleted.

The Fertiliser Association of India (FAI) has reported on the Indian experiments that show that the economic effects of K fertilizer can be higher than is the case with N and P fertilizers. The following responses and fertilizer prices are given:

Response	Per Kilogram	Price/kg of Fertilizer Nutrient
(kg of grain)		(Rs)
12	of N (urea)	5.1
7	of P_2O_5 (single superphosphate)	5.5
5	of K_2O (muriate of potash)	2.2

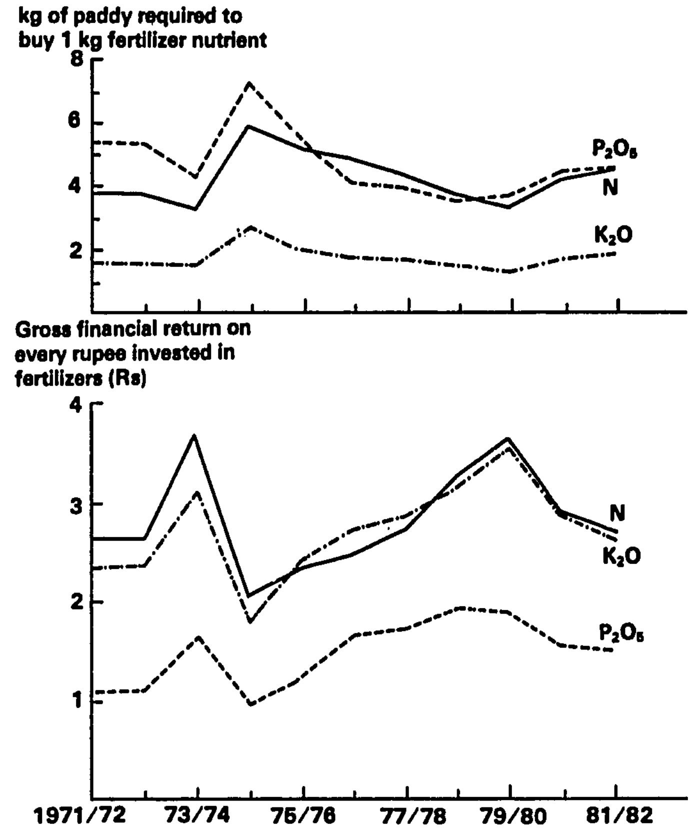


Note: Responses are calculated as follows: NPK = yield with NPK minus unfertilized control yield
K = yield with NPK minus yield with NP
N = yield with N only minus control yield

Figure 1. Response of Rice (in the dry season) to N, P, and K Fertilizers in the Long-Term Fertility Experiment at Maligaya, Philippines (moving two-year averages).

Prices per kilogram of K_2O are lower than those of N and P_2O_5; therefore, less rice is needed to buy 1 kg of K_2O than to buy 1 kg of N or P_2O_5. This leads to a financial return per rupee invested that is as high for potash as for nitrogen. Kanwar et al. (1973) also made an economic analysis of rice responses to fertilizers and used data from 1,573 trials conducted on cultivators' fields from 1967 to 1971. Based on prices of Rs 2.00/kg N, Rs 2.13/kg P_2O_5, and Rs 0.79/kg K_2O, the response in kilogram of rice per rupee spent on fertilizer for the Kharif season was 5.2 for N, 5.7 for P, and 5.9 for K; in the Rabi season the response was 5.2 for N, 8.3 for P, and 10.4 for K.

The relationships for the economics of using fertilizers on rice in India are shown by the data in Figure 2. The cost of K_2O in muriate of potash, expressed in terms of rice needed to buy the fertilizer, remained at less than half the corresponding cost of N and P_2O_5 over a 10-year period. Although the response to 1 kg of K was less than to 1 kg of N or P_2O_5, the relative cheapness of K made it as profitable to use as was N and more profitable than P_2O_5, as the lower part of Figure 2 shows.



Note: The prices and responses assumed are:

	Response, kg paddy per 1 kg of nutrient
N (Urea)	12.0
P_2O_5 (SSP)	7.0
K_2O (MOP)	5.0

Source: FAI, 1982.

Figure 2. The Economics of Fertilizer Use on Rice in India.

Generalizations about the profitability of using K fertilizers are difficult. However, Von Peter (1979), commenting on a summary of the first 10 years of the FAO fertilizer program, said that, with few exceptions, the investment in fertilizer was repaid several times in country after country; returns for K use were more profitable for the root crops (4-5:1) than for the cereals grown in dry areas (0.5-2.5:1).

The Potassium Required by Crops

Before we can finally assess the need for potassium fertilizers in relation to the K status of the soil, we must know how much K is needed by the crop. The yield expected will be affected by the genetic characteristics of the crops, the climate, and the other inputs to the system. Some crops require more K than others do, and some can withstand a deficiency better than others can. Some crops require large quantities of K early in the life cycle; others use it at an almost constant rate. Few crops respond as visibly to K as they do to N although the profitability can be just as dramatic.

The "total K" requirement of the crop has been defined as all the K needed for a crop to produce the highest economic yield under a given set of growth conditions (Mengel, 1979). Oil, sugar, and root crops have high total K requirements compared with those of cereals and cotton. Table 4 illustrates the large variation among crops in terms of harvest removal of K; however, variations between the varieties of a particular crop can be nearly as great as those between crops. For example, Von Uexkull (1968) cites studies by Navasero and Estrada, which showed that the response to K fertilizer of

Table 4.
Nutrients in Harvests of Some Common Tropical Crops

Crop	Yield Per Hectare	N	P	K
		----- (kg/ha) -----		
	Food Crops Grown on Small Farms			
Maize	1,100 kg of grain	17	3	3
Rice	2,200 kg of paddy	26	8	8
Groundnuts	600 kg of kernels	28	2	3
	200 kg of shells	2	0.2	2
Cassava	11 mt of tubers (30% dry matter)	25	3	65
Yams	11 mt of tubers (30% dry matter)	38	3	39
Cacao	600 kg of beans	13	3	11
	600 kg of husks	11	1	25
	Cash Crops Grown on Large Farms			
Oil palm	2.5 mt of oil	162	30	217
Sugarcane	88 mt of cane	45	25	121
Coconuts	1.4 mt of dry copra	62	17	56
Bananas	45 mt of fruit	78	22	224
Rubber	1.1 mt of dry rubber	7	1	4
Soybeans	3.4 mt of grain	210	22	60
Coffee	1 mt of coffee beans	38	8	50
Tea	1,300 kg of dried leaves	60	5	30

Source: Cooke (1982).

different rice varieties grown on the same soil could vary from 3.4 mt/ha for the most responsive variety, which then yielded 4.8 mt/ha, to a response of only 0.2 mt/ha by an older variety, which yielded only 1.9 mt/ha.

Table 5.
Recommended Rates of K_2O Fertilizer for Various Crops Grown in Latin America

Crop	K_2O
	(kg/ha)
Citrus	240
Bananas	180
Tobacco	90
Cotton	90
Sugarcane	60
Cassava	60
Rice	60
Soya	60
Groundnuts	45
Wheat	45

Source: Malavolta and Neptune (1975).

Equally as important as the total K requirement is the amount of K that a crop requires each day to maintain satisfactory growth. A good crop of sugarcane, for example, takes up a total amount of K that is several times the amount taken up by a good maize crop; yet during a short period maize can require six times as much K per hectare per day as does sugarcane (Jansson, 1979; Nelson, 1968; Trocme, 1977). Thus, the ability of a soil to provide K to a crop can greatly influence the type of crop that can be grown. Both the total requirement and the rate requirement must be considered when determining the fertilizer requirement. An example of the variations in recommendations for individual crops is illustrated in Table 5.

The Potassium Cycle

Such large amounts of potassium are essential in producing crops that we must consider how the soil may hold reserves and how some processes can cause serious losses from the agricultural system. We also need to know how crop and animal wastes and residues can restore some of the K removed by crop harvests.

There are many ways that the K originally present in a soil system can be lost. The most obvious is crop removal. Others include leaching by rain water and/or irrigation and soil erosion by wind and/or water. The seriousness and importance of these three causes of loss vary with climatic conditions and changes in farm practices.

Removal of Potassium by Crops

In Table 4, the quantities of K removed in harvests of tropical crops were reported. Harvesting a crop, however, does not necessarily remove all of this K from the soil system. Depending upon how a crop is harvested, quantities of K removed from the soil system will vary significantly.

In subsistence-type agriculture, where the crop is entirely consumed in the home and most of the refuse is returned to the soil, very little K is lost (although it may be shifted from one soil area to another). In densely populated areas, in contrast, crops and their residues usually are removed completely, and almost all the K is lost.

In commercial and plantation agriculture, where the crop is largely exported from the area, losses can be high, and the K should be replaced on a regular basis. The relative proportions vary from the almost complete removal of a sugarcane crop for processing in a factory to the smaller proportion removed when only part of a crop, such as the fruit, is removed. There are great variations among plantation crops. For example, it has been shown that, although the harvest of 1,000 kg/ha of latex from rubber trees removes only 4 kg/ha of K, about 40 kg/ha of K_2O is needed annually to maintain the growth of the trees. At the other extreme, a plantation of oil palm trees may contain about 1,000 kg/ha of K_2O, but nearly two-thirds of this total amount is contained in the fruit. This potassium is removed from the plantation when the fruit is harvested for processing in the factory, and it will be lost to the system unless the residues left after the oil is extracted are returned to the land. Similar questions arise when the disposal of the straw of cereals is considered (straw contains more K than does the grain).

Malavolta and Neptune (1975) have made recommendations for crops in Latin America (Table 5). They report that nearly 4 million mt of K_2O is removed from the fields in Latin America each year; almost one-half of this is contained in crops that are exported from the area, such as sugarcane, coffee, citrus fruits, and tobacco. In 1980 Latin America used 1.9 million mt of K_2O, an amount that does not quite replace the K removed in the exported crops. In addition to the exports, large quantities of food crops are shipped to the cities; nearly 100% of the K contained in such food crops is lost as it passes into sewage systems from which the effluent enters rivers. Almost all the chemical compounds of K in plants and animal bodies are soluble in water. Rain falling on crops washes K from the plant into the soil. Refuse, including human refuse, flushed into modern sewage disposal systems is leached of its K content; this K eventually finds its way to the oceans of the world where it is permanently lost. Mechanization and improvements in agricultural production efficiency already have caused extremely large shifts of population from the rural areas to urban areas in the developed countries. An identical trend has started in the developing countries. World Bank projections show that the urban population of the less developed countries, as a proportion of the total population of these countries, will increase from 30% in 1980 to 43% in 2000 (IBRD, 1971). This can only result in larger and larger shipments of food and fiber crops from the production areas to the urban areas and the consequent increased removal of K from the agricultural system.

Leaching Losses

The soil chemistry of K is distinctly different from that of N or P. Potassium is present in the soil solution as a cation (positively charged ion) and is adsorbed on the soil exchange complex. When so adsorbed, it does not readily leach from the soil provided that the supply of K in the soil does not exceed the capacity of the exchange complex to hold the K. Sanchez (1976) estimates that 4 meq/100 g of effective CEC is adequate to prevent serious leaching losses. Effective CEC has a very high positive correlation with organic matter content. For acid soils with less than 4 meq of CEC, the exchange sites available to adsorb the K are inadequate.

Most temperate soils contain clay minerals with a constitution that permits K ions added as fertilizers to enter the layers of the mineral and to be retained there (termed 2:1 minerals). The K retained in this way is said to be "fixed," and the process has two practical advantages. First, it prevents the loss of K by leaching from temperate soils; second, the fixed reserve of K is slowly released for use by future crops. Many tropical soils are low in organic matter. They contain much smaller reserves of total K and do not contain 2:1 clay minerals; most of the soils contain minerals of a different structure (termed 1:1) that cannot retain potassium. The net result is that most tropical soils commonly have effective CEC values less than 4. Water percolating through such soils, either as rainfall or irrigation, leaches any K not immediately absorbed by the crop to a depth below the root zone. When such soils need to be fertilized with K, small frequent applications are more efficient than single massive applications. Sanchez (1976), quoting the work of various researchers, reported average annual losses of K due to leaching as ranging from 8 kg/ha for a cropped soil in Senegal to 163 kg/ha for a pastured soil in Colombia. A flooded rice soil in the Philippines lost from 16 to 60 kg K/ha.

Erosion Losses

Although soil movement is a normal land-forming process of nature, serious erosion is often a result of cultivation. Many production systems can cause erosion, particularly where shifting cultivation is practiced. Each ton of topsoil lost by erosion contains on average the equivalent of about 12 kg of K_2O, yet the loss of a ton of soil per hectare of land can hardly be detected. Sanchez (1976) reports soil erosion losses from a young coffee plantation in Colombia amounting to 1.8 mt/ha; Mitchell (1965) and Temple (1972) report losses of 30-35 mt/ha for coffee crops in Tanzania. Lal (1980) reports soil losses in tropical countries ranging from negligible to 173 mt/ha, depending upon cropping conditions.

On a more specific basis, Sanchez and Cochrane (1980) categorically state that erosion is the most critical factor affecting crop production on nearly 15% of the land in tropical America. These are the productive, high-base soils that presently support most of the population. In contrast, Moorman and Greenland (1980) minimize the importance of erosion for tropical Africa. Much of that continent is still farmed by traditional and transitional agricultural methods, and these protect soils from erosion. As production intensifies, however, there may be an increase in water erosion of soils. For Southeast Asia, Dent (1980) shows that over 60% of the rice in five countries is planted on rainfed and upland soils where erosion is a serious problem.

Factors That Increase The Need for Potassium

Changes in agricultural practices, in the crops grown, and in the use of cultivable land, which are essential if we are to grow more food, will require the use of more K fertilizer. Several of these changes, already mentioned, are dealt with in the sections below.

Table 6.
Developments in Fertilizer Consumption and the Yields of Rice in Indonesia

	1970/71	1974/75	1977/78	1978/79	1981/82
HYV, as % of total crop	48	56	67	78	79
Rice yield, mt/ha	1.5	1.8	2.1	2.2	2.6
Kilograms N + P_2O_5/ha applied	21	35	55	84	102
Kilograms K_2O/ha applied	0	0	0	0	3.3

Source: Von Uexkull (1983).

The Introduction of High-Yielding Varieties

Table 6 shows the increase in the proportion of high-yielding varieties (HYVs) grown in Indonesia during the period 1971-82. As these varieties formed an increasing proportion of the total crop, the amounts of N and P_2O_5 used were increased (HYVs respond well to N fertilizer), and yields were increased. Although no K fertilizer was used until the end of the period, current projections indicate that K use must increase if high yields are to be maintained.

Increases in Cropping Intensity

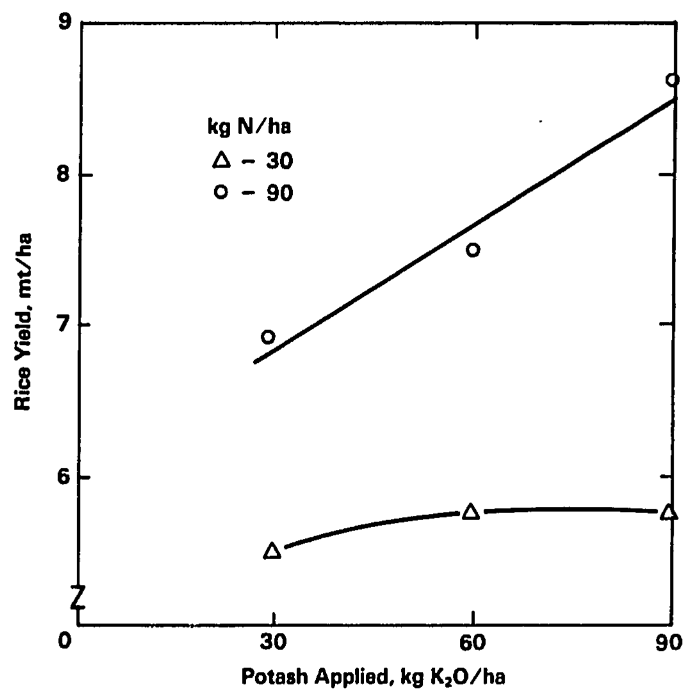
In China, the average number of crops per hectare is 1.6/year. In some areas, up to six vegetable crops are grown per hectare per year. Multiple cropping systems have been practiced in most developing countries for a long time, but only during the last few years have they been investigated by scientists. Large quantities of potassium are taken up by these intensive systems of vegetable production, and to ensure a high yield from such crop sequences, soil fertility has to be maintained at high levels.

The Use of New Lands for Cash and Export Crops

The new lands that are cleared for cash and plantation crops often have soils that are poor in potassium reserves. In the Cerrado region of Brazil, which covers over 180 million ha, large tracts of land are cultivated with soybeans and sugarcane. This area is now being developed at a rate of about 1 million ha/year (Munson, 1982). According to Ritchey (1979), maize yield was 2,328 kg/ha without potash application and 4,372 kg/ha (+88%) with 150 kg K_2O/ha in an experiment on a Cerrado soil. The rain forests in Malaysia and Indonesia have been opened up to grow oil palm and rubber, and these soils are frequently very poor in nutrients, including potassium. Consequently, with well-managed plantations quite high amounts of potash are used.

The Use of Inputs to Build Yields

The way in which input factors interact to increase yield was established in the 1930s. Until then Liebig's "Law of Limiting Factors" was widely accepted. It stated that in any given cropping system the yield level was set by the one factor that was nearest to its minimum; only when this limitation was removed would other inputs have any effect. It is now recognized that all input factors interact at all levels of application to build yields to the maximum. These inputs may be other nutrients, extra water, disease and pest control, improved varieties, and better agronomic practices. A common example is the interaction of N and K fertilizers illustrated in Figure 3; the response of rice to extra N fertilizer was doubled by increasing the K fertilizers applied. With the low level of applied N, there was hardly any increase in yield from an application of more than 30 kg K_2O/ha. But with 90 kg N, there was a linear response to increasing rates of potash, and the yield rose to 8.7 mt/ha when 90 kg/ha each of N and K_2O were applied.



Source: Malavolta, 1978.

Figure 3. Response of Rice to Potash Under Two Levels of Nitrogen.

Interactions (in particular the N x K interaction) have a major effect on crop quantity, but they also influence physiological reactions that help plants to resist environmental stress (such as drought) and also improve crop quality. The effects of K on quality characteristics include effects on oil, starch, and sugar contents; taste; and color of fruits. The interactions between nutrients influence their efficiency, expressed as the extra crop yield produced per kilogram of N, P_2O_5, or K_2O applied. Table 7 provides a summary of various results reported by several authors. It shows for a number of crops and countries the increases in yield produced by 1 kg of N as fertilizer when no K fertilizer was applied and the increases obtained in the presence of the stated amounts of K_2O applied. For all the crops and conditions represented, the efficiency of the N applied was greatly increased by applying K as well.

Table 7.
The Effect of Applying Potassium Fertilizer on the Increases in Yield Given by Nitrogen Fertilizer

	Increase in Yield (kg) Produced by 1 kg/ha of N	
	Without K Fertilizer	With K Fertilizer[a]
Rice		
India	17	23 (60)
Madagascar	3	14 (45)
Wheat		
France	7	9 (80)
Maize		
Nigeria	1	15 (90)
France	10	16 (75)
Cassava		
India	26	41 (100)
Potatoes		
France	18	40 (100)
Oil palm		
Ivory Coast	-23	8 (144)

a. The amount of K_2O applied, in kg/ha, is stated in parentheses.

Other important interactions affect disease control. The incidence of some diseases is diminished when the supply of K to the crop is increased. For example, Chang and Liang, in the People's Republic of China (1978), found that increasing the quantities of K applied together with single superphosphate to cotton decreased the incidence of cotton blight significantly, as is shown in Table 8.

The effects of potassium on plant pests and diseases were summarized in a bibliographical survey by Perrenoud (1977). In a total of over 1,200 observations, a beneficial effect of potash was found in 65% of the cases surveyed and a detrimental effect in 23%; in 12% of the cases there was no change.

Table 8.
Effect of P and K Fertilizer on the Incidence of Cotton Blight

Treatment	kg P_2O_5/ha	kg K_2O/ha	Incidence of Cotton Blight
			(%)
Control (mineral N to all plots)	-	-	21.0
+P	90	-	20.0
+K	-	110	11.0
+P + K	90	110	0.4
+P + 1.5K	90	165	1.5
+P + 2K	90	220	0.5

Source: Chang and Liang (1978).

Tolerance to Salinity and Improved Water Use Efficiency

Large supplies of potassium decrease the detrimental effect of soil salinity and enable plants to grow better under saline conditions. Brag (1972) stated that potassium increases drought tolerance because it has an essential function in the efficient regulation of stomata opening. In order to achieve high efficiency in water use, the potassium content of the leaves should be at least 1.5% of the dry matter. Further studies of water management and soil fertility interrelations are essential for establishing sound fertilizer recommendations under arid conditions.

Conclusions

It will be clear from these very varied examples that potassium has a profound effect on crops through its interactions with other nutrients and with other factors that affect growth. Whenever there are plans for inputs to raise the level of production, consideration must be given to the supply of K. If this is not done and the supply of K from soil is not sufficient for maximum growth, there is a serious risk that other inputs will be inefficient. The result will be lower yields and serious financial loss. Since other nutrients, especially N, are very expensive and will undoubtedly continue to increase as energy prices rise, K levels must continue to be monitored if for no other reason than to ensure optimum efficiency of applied and available nitrogen.

Present Constraints to the Use of Potassium

Fertilizer use constraints have been studied by IFDC, FAO, and many other organizations. There are uncontrollable constraints due to certain climatic, social, political, and economic environments. There are also controllable factors. These include determining the type of fertilizer to sell, the price, availability of the products, and the educational and promotional activities needed to convince the farmer to use the products. An efficient fertilizer marketing system will manage the controllable factors.

Constraints to fertilizer use are not the same for each country. Lee (1980) in describing the stages of fertilizer use development and marketing policy shows that, as the fertilizer industry in various countries matures from the introduction stage to the take-off stage to the maturity stage, the constraints to fertilizer use may be somewhat different. Mathieu and de la Vega (1978) discuss constraints to fertilizer use including (1) nonavailability of fertilizers, (2) lack of credit, (3) inadequate advisory service, (4) poorly informed farmers, (5) nonavailability of high-yielding seed varieties, (6) inadequate water for irrigation, (7) adverse patterns of tenancies, (8) low value:cost ratios, and (9) lack of basic information on the effects of fertilizers on crop yields. Additional constraints listed by others include no ensured place for the farmer to market his produce, nonavailability of other essential and complementary inputs, risks, and farmers' resources that have a higher payoff in other activities. Regardless of the constraints that a particular country may be experiencing, an efficient marketing system will help to overcome most of those listed. The constraints that affect potassium use are essentially the same as those that affect the use of nitrogen and phosphorus.

Lack of Knowledge and Information

The one reason above all others for the limited use of K fertilizers in tropical areas is the lack of farmer demand for this type of fertilizer. Research work on nitrogen and phosphorus and the promotion activities required to induce the farmer to adopt new findings have been much greater than those on potassium, and farmers are therefore less aware of the role of potassium as an essential plant nutrient. Without exposure to K demonstrations using responsive crops on responsive soils, farmers are not likely to learn about this fertilizer. It is the responsibility of research and extension services and/or the fertilizer industry to provide these demonstrations.

The main reason for lack of information advising farmers of the value of K fertilizers is the great shortage in many developing countries of investigations on local soils and particularly long-term experiments on farming systems. It must be emphasized that annual experiments with fertilizers have limited value because a serious shortage of nutrients such as K may not be revealed until several high-yielding crops have been harvested.

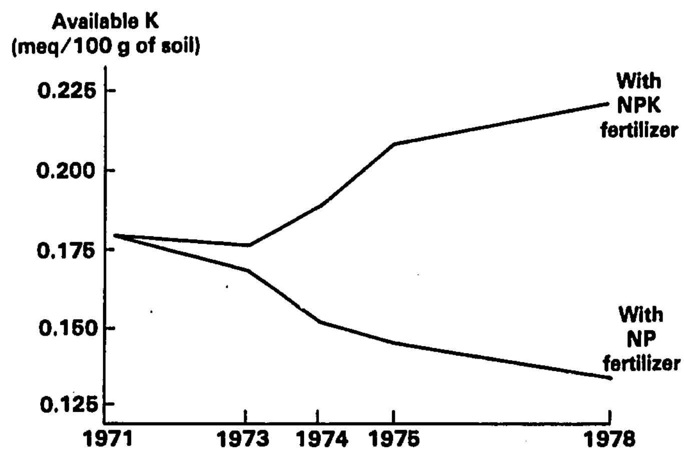
Short-term trials lasting only a year or two rarely show a response to K applications unless the soils have been heavily cropped for a number of years or are very coarse textured. Also, a response may not be apparent if a nonresponsive variety is used as the test crop. If the researchers are not familiar with these limitations or they lack funds to continue the trials, their research may indicate ("prove") that K fertilizer is not needed. There is already a general belief in developing countries that K is not needed. With the pressure to obtain other types of agronomic information, it is easy for researchers to overlook the need to repeat fertility experiments as new varieties are introduced and as rates of application of N and P fertilizer gradually increase. Heathcote (1974), working in Nigeria, has commented:

> Annual trials are of very limited value in predicting fertiliser requirements under intensive and continuous cropping, and may lead to dangerously misleading conclusions. . . . The failure to recognize the need for potassium under intensive cropping is the most striking illustration of their limitations. Long-term trials of the kind described [5-year trials] appear to offer a better means of... identifying specific nutrient requirements.

The need for long-term experiments is illustrated by the example in Figure 4, published by the Indian Council of Agricultural Research (ICAR) in 1980. This figure shows the changes in available potassium during an 8-year period where NPK and NP fertilizers were applied annually for a cropping sequence. From 1971 to 1973 there was very little change in the original value of the analyses for available K. After this preliminary period, with NPK fertilizer available K increased steadily, but where only N and P were applied, the available K steadily decreased. If the experiment had not been continued for more than 3 years, the serious deficiency of K that developed would not have been revealed.

Although good research has a high payoff, it is very expensive. It requires well-trained researchers, support personnel and equipment, and a substantial budget. Poor and inadequate research is even more expensive than good research. It may mislead administrators into a sense of false security about the crop production potential of the land.

Maximum Yield Research—Research on systems for the maximization of yield is essential for further progress in agricultural development. The maximum yield that can be obtained at a site is determined by the solar radiation received and the genetic capacity of the crop grown. In practice many constraints operate to prevent this potential from being achieved. Some constraints are environmental (for example, the water available and the soil physical conditions). Others are concerned with attacks by pests and diseases and competition by weeds; most important are the nutritional constraints caused by inadequate supplies of plant food.



Source: ICAR, 1980.

Figure 4. Changes in Available Potassium in Soils of a Long-Term Fertilizer Experiment in India From 1971 to 1978.

Research is required in all regions to establish the maximum yield potential. This means that all constraints must be identified and experiments must include inputs to overcome these constraints, which do not act individually but interact to reduce yields to the low levels commonly harvested. Correspondingly, inputs interact to build yields, and when all constraints are overcome by inputs that act efficiently, maximum yield will be recorded. Supplies of potassium and other nutrients have an important place because inputs and their interactions with one another must be fully understood to develop improved management systems. Economic examination of the results of such work, and consideration of the farmer's resources and capability will then lead to recommendations for producing *maximum economic yield*, which should be the practical objective of all farmers.

It must be emphasized that the purpose of such research on yield maximization is not academic investigation; it is needed to provide a full knowledge of crop production systems and the hierarchy of limiting factors that now lead to food shortages in many regions. Goedert (1983) has stated, in discussing the management of tropical soils, "Only a multi-disciplinary approach will lead to the development of rational and sustained farming systems for tropical regions." He has appealed to the scientists of developed regions for help in acquiring the fundamental knowledge that is needed to develop the tropics. Progress with work of this kind has been reviewed by Cooke (1982, 1984). Establishing such research and development programs is the best investment that governments can make in implementing policies for agricultural development, for the knowledge acquired of local resources and problems has permanent value despite any changes in economic or social conditions.

The essential role of soil surveys in transferring information from experimental sites to farmers' fields must be stressed. The soil classification and mapping that result from the surveys take into account parent materials, climate, and soil-forming processes, which are the factors that determine the nutrient status of soils in their unimproved condition. Soils that are similarly classified and that have similar past histories will have similar needs for fertilizers.

Unfavorable Crop-Fertilizer Price Ratios

The profitability of using fertilizers is determined basically by (1) the response function for the particular crop, (2) the price the farmer receives for the crop produced, and (3) the price of the inputs, including fertilizers, that are required to produce a crop. The most effective way of increasing food production and also of increasing fertilizer use is to establish crop prices that are favorable relative to the price of fertilizer. This makes the use of fertilizer attractive to the farmer. Examples of these relationships in selected countries in Asia are shown in Table 9. One of the biggest problems in increasing agricultural production in developing countries has been the cheap food policies established by many developing countries in past years. If farmers do not receive a fair price for their agricultural production, eventually they will cease farming and move into the cities. As a result agricultural production declines and the problem is compounded by an increasing urban population.

Governments must recognize that they have a food deficit. The remedies for solving these deficits are within their hands. The surest way to increase agricultural production is to remove the financial uncertainty from farming by establishing crop:price ratios that make it profitable for farmers to use modern agricultural inputs such as fertilizer that research has shown to be necessary to increase production.

Some government actions control the profitability of farmer use of fertilizers including K_2O. Other actions may even prohibit the farmer from obtaining fertilizer or at least limit the amounts that a farmer can obtain. There are many considerations in the development of policies. Preservation of foreign exchange by means of high import taxes can greatly increase the cost of fertilizers because in many tropical countries

Table 9.
Asia: Urea and Rice Price Ratios and Nitrogen Consumption, 1980

Country	Approximate Quantities of Rice Needed to Buy 1 kg of Urea June 1980[a]	Nitrogen Used in 1980/ha of Arable Land and Land in Permanent Crops[b]	Paddy Yield 1980[c]
	(kg)	(kg/ha)	(kg/ha)
Japan	0.26	126	5,128
South Korea	0.43	204	6,438 (1979)
Sri Lanka	0.50	43	2,594
Indonesia	0.67	44	3,293
Malaysia	1.33	32	2,883
India	1.35	21	2,000
Philippines	1.54	23	2,155

a. IFDC unpublished data from monthly price surveys.
b. FAO (1982).
c. FAO Monthly Bulletin of Statistics (March 1983).

Table 10.
Farm Fertilizer Prices and Price Ratios in Developing Countries

Country	Price[a]		Price Ratio, N = 100	
	N	K_2O	N	K_2O
	(US $/nutrient ton)			
North America				
United States	480	225	100	47
Africa				
Egypt	366	135	100	37
Ivory Coast	583	436	100	75
Kenya	917	487	100	53
Madagascar	801	601	100	75
Mauritius	461	368	100	80
Nigeria	153	97	100	63
Senegal	201	154	100	77
Zimbabwe	753	424	100	56
Asia				
Bangladesh	384	199	100	52
Burma[b]	146	186	100	127
China[c]	289	101	100	35
India	498	217	100	44
Malaysia	454	234	100	52
Nepal	442	218	100	49
Philippines	656	446	100	68
Sri Lanka	291	233	100	80
Thailand	606	397	100	66
Latin America				
Brazil	720	388	100	54
Chile	858	668	100	78
Colombia	705	419	100	59
Costa Rica	526	223	100	42
Ecuador[b]	722	647	100	90
Peru	704	377	100	54

a. Prices based on farmer prices for urea and muriate of potash for 1982.
b. Prices are for February 1980.
c. Prices are for late 1981.

fertilizer must be imported. Similarly, the accumulation of funds for government operation through high export taxes limits access to world markets for the export of agricultural commodities produced and limits the amount of foreign exchange that can be generated for fertilizer purchases. If the government insists on maintaining the cheap food policy for the urban population, then farmers must receive a subsidy on some of their production cost, including fertilizers.

Low prices for food crops affect the consumption of potash more than that of nitrogen. Farmers whose available cash is limited in general will minimize the purchase of inputs. They may buy the recommended nitrogen because the response is more visible but save on the purchase of P_2O_5 and K_2O.

The cost of subsidies is causing some countries to abandon or modify their subsidy policy. About two-thirds of the developing countries provide subsidies to enable farmers to purchase nitrogen and phosphate, but potash is not always included. In other cases subsidies are structured in such a way that prices of the various nutrients or products have roughly the same price rather than each nutrient or product being a percentage of the world market price. The normal price ratio of K_2O:N ranges between 40% and 60%. Prices for potash in many countries are higher than this, which tends to discourage potash consumption (Table 10). When a well thought-out fertilizer policy does not exist, this type of inequity readily develops. Without constant surveillance, inequities remain hidden and uncorrected.

Potash also tends to be used less when small quantities of nitrogen are applied. As a result of low food prices, low yields for food crops, and uncertain prices for plantation crops, the profitability of using high rates of nitrogen application may be questionable. In consequence, recommendations are made for low rates of nitrogen application, which also depresses the consumption of potash.

Removing Constraints

The intention in this report has not been to make an exhaustive review of the literature nor even to strike a precise balance between reasons for and against using K fertilizer. This can be done reasonably only by country and best by small region. There are, of course, some general precepts that should be used when reviewing a specific situation. A commitment to improvement is the first requisite.

Sound government policy aimed at removing constraints must be based on a thorough knowledge of (1) which constraints exist and which of these constraints the policy should be aimed toward; (2) how such constraints affect fertilizer use; and (3) how the constraints interact (Amstrup et al., 1977). A considerable amount of information must be collected before it is possible to develop an equitable policy. The collection and especially the interpretation of the information require a multidisciplinary approach. The economist, agronomist, soil scientist, sociologist, lawyer, and administrator must work with the production, importation, and marketing specialists.

Summary and Recommendations

Many situations in the tropical countries cause concern about K fertilizers. New lands being opened for crop production are likely areas for attention. There may be no need for adding K in the first years of cropping, but sustained production and attempts to sustain yields at high levels will usually lead to a deficiency of K and unsatisfactory crop growth. Erosion, which must be controlled in any case, will accentuate the need for K fertilization. Semicommercial and commercial farming, wherein the major portion of a crop is marketed in urban areas or is exported from the country, will quickly lead to the need for K fertilizers unless the soil is unusually rich in native K. The speed at which a deficiency develops depends, to a great extent, upon the crop produced. Some crops have much higher demands for K during growth than others do. Some crops remove large quantities of K from the area when they are harvested; other crops may remove very little K. Given the variability of soils and microclimates within a country, and given the variability in management ability and the crops produced, it is probable that K fertilizers are needed somewhere within each country.

Although the need may exist, this does not always lead to recommendations for the use of K. Economic returns from its use depend on many factors. Among these is the ability of farmers to manage crop production wisely. This includes the use of plant varieties that produce high yields when given the proper inputs. Research, both agronomic and economic, must be conducted to evaluate these factors. The extension service and industry must be aware of this research, and extension representatives must demonstrate to farmers the kinds of fertilizers needed, the amounts to use on various crops, and the economic returns that can be expected. Researchers and extension workers, however, can be successful in their efforts only if the government has a fertilizer policy that permits farmers to make a profit from the use of fertilizer, including K fertilizer when it is needed, and a policy that provides for the fertilizer to be available to the farmer in adequate quantities where and when it is needed.

This report is based on a survey of 42 countries that had increased their total use of potassium fertilizers from 1 million to nearly 3.5 million mt of K_2O over a 10-year period. When South Africa was excluded, the use of K in the countries discussed accounted for 52% of the K_2O used in developing countries in 1971, and this figure had risen to 82% by 1981. These facts indicate the scope and relevance of the study that led to this report. As the Appendix shows, there were great variations in the use of K_2O during the period 1971-81. In some countries there were very considerable increases. Examples were Brazil, China, India, and Indonesia. Such increases were a result of the realization that increased use of K is essential to increase productivity; these examples will have to be followed by other countries as they work to produce more food.

Recommendations—This study leads to the following general recommendations to all those who are charged with the vital responsibility of increasing food production in the developing countries:

1. Cheap food policies maintained at the expense of farmers must be abolished. Agricultural output that is greater than the subsistence needs of farmers will be achieved by creating an effective market structure for agricultural produce; this structure will maintain prices for agricultural produce that encourage the use of modern inputs such as fertilizer. In particular, the fertilizers necessary for improved production must be made available at a reasonable cost.
2. Where low crop prices must be maintained, particularly for grain and other food crops, and where transport costs are high, all fertilizers should be subsidized. The subsidy should be based on units of N, P_2O_5, and K_2O and should reduce farmers' costs for fertilizers without distorting normal market price relationships.

   Price ratios of N, P, and K fertilizers and of crops should be monitored in order to follow developments in fertilizer use and in particular to counteract the impact of changes in the ratio of crop:fertilizer prices on the fertilizers used. For example, an increase in price of N alone could well diminish the amount of K purchased.
3. Improved crop management and water control practices should be taught to the farmers to ensure high and stable yields.
4. Strong support services should be provided for agriculture. These must include research and extension that will provide for the introduction of efficient and up-to-date farm management practices.
5. The national fertilizer program should take into account all three major nutrients—N, P, and K. These programs should be based on the results of long-term experiments, which provide a continuing list of recommendations. Such experiments must be planned to last at least 5 years and preferably longer. They should test N, P, and K fertilizers in appropriate combinations and at a range of levels; they should also make provision for adequate supplies of secondary nutrients and micronutrients. The results should be examined by economists to provide an economic basis for recommendations to farmers. Particular attention should be given to interactions of other nutrients with potassium and to the effects of fertilizers on the health of crops and on quality of produce. The experiments would also serve for the calibration of soil testing on which fertilizer recommendations to individual farmers could be made.
6. The maximum yield research methodology (including tests of the value of potash) should be generally adopted in order to accelerate achievement of high economic yields in developing countries. Maximum yield research needs an interdisciplinary organization that includes economists, as well as agronomists for crops and soils. Other proven methods that have advanced agricultural production and the use of fertilizers are high-yield contests, which proved very effective in Korea and Japan (Von Peter, 1979); packages of improved cultivation methods, which were introduced successfully in Indonesia and India; and credit packages, which include NPK fertilizers, that are extended by financial institutions in India and Egypt.

References

Amstrup, C. R., P. Pinstrup-Andersen, T. P. Hignett, P. J. Stangel, and D. A. Russel. 1977. *Suggested Fertilizer-Related Policies for Governments & International Agencies*, Tech. Bull. No. IFDC-T-10, IFDC, Muscle Shoals, Alabama.

Brag, H. 1972. "The Influence of Potassium on the Transpiration Rate and Stomatal Opening in *Triticum Aestivum* and *Pisum Sativum*," *Physiol. Plant*, 26:250-257.

Buol, S. W., P. A. Sanchez, R. B. Cate, Jr., and M. A. Granger. 1975. "Soil Fertility Capability Classification," IN *Soil Management in Tropical America*, pp. 126-141, Proc. Seminar at International Center of Tropical Agriculture (CIAT), Feb. 10-14, 1974, Cali, Colombia, North Carolina State University, Raleigh, North Carolina.

Chang, I.C., and T. Y. Liang. 1978. "Effect of Potassium Fertilization on Rice and Cotton in Southeast China," Potash Review, Subject 23/58th Suite, No. 9/10, Bern, Switzerland.

Conto, W., P. A. Sanchez, and S. W. Buol. 1981. Unpublished data, Tropical Soil Research Project, Soil Science Department, North Carolina State University, Raleigh, North Carolina (Published with permission).

Cooke, G. W. 1982. *Fertilizing for Maximum Yield*, p. 405, Macmillan Publishing Co., Inc., New York, New York.

Cooke, G. W. 1984. "Developments in Research on Systems for Maximization of Yield." AGS 1-3/1-1/3/38. Proceedings of FAI/FAO Seminar, New Delhi, December 1983.

Dent, F. J. 1980. "Major Production Systems and Soil-Related Constraints in Southeast Asia," IN *Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics*, pp. 79-106, International Rice Research Institute (IRRI), Laguna, Philippines.

FAI. 1982. *Fertiliser Statistics*, 1981/82, FAI, New Delhi, India.

FAO. 1979. *Agriculture: Toward 2000*, FAO, Rome, Italy.

FAO. 1982. *Fertilizer Yearbook, 1981*, FAO, Rome, Italy.

FAO. 1983a. *Current World Fertilizer Situation and Outlook*, FAO, Rome, Italy.

FAO. 1983b. *Monthly Bulletin of Statistics*, March 1983, FAO, Rome, Italy.

Goedert, W. J. 1983. "Management of the Cerrado Soils of Brazil: A Review," *Journal of Soil Science*, 34:405-428.

Heathcote, R. G. 1974. "The Use of Fertilisers in the Maintenance of Soil Fertility Under Intensive Cropping in Northern Nigeria," IN *Potassium in Tropical Crops and Soils*, pp. 467-474, Proc. 10th Colloquium Int. Potash Inst., December 1973, Abidjan, Ivory Coast, IPI, Bern, Switzerland.

ICAR. 1980. *Annual Progress Report 1978-79*, New Delhi.

International Bank for Reconstruction and Development/The World Bank (IBRD). 1971. "Trends in Developing Countries," IBRD, Washington, D.C.

IPI. 1974. "Potassium in Tropical Crops and Soils," Proc. 10th Colloquium Int. Potash Inst., December 1973, Abidjan, Ivory Coast, IPI, Bern, Switzerland.

IPI. 1975. "Potassium Research and Agricultural Production," Proc. 10th Congress Int. Potash Inst., June 1974, Budapest, Hungary, IPI, Bern, Switzerland.

IPI. 1979. "Potassium Research—Review and Trends," Proc. 11th Congress Int. Potash Inst., September 1978, Bern, Switzerland, IPI, Bern Switzerland.

IPI. 1980. Potassium Workshop, Ibadan, Nigeria, October 1980. IPI, Bern, Switzerland.

Jansson, S. L. 1979. "Potassium Requirement of Root Crops," IN *Potassium Research—Review and Trends*, Proc. 11th Congress Int. Potash Inst., September 1978, Bern, Switzerland, IPI, Bern, Switzerland.

Kanwar, J. S. 1975. "Assessment of Potash Fertilisation in the Tropics and Sub-Tropics of Asia," IN *Potassium Research and Agricultural Production*, pp. 261-282, Proc. 10th Congress Int. Potash Inst., June 1974, Budapest, Hungary, IPI, Bern, Switzerland.

Kanwar, J. S., M. N. Das, M. G. Sardana, and S. R. Bapat. 1973. "Economics of Fertiliser Use in Rice in Farmers' Fields," *Fertiliser News*, 18(1):71-88.

Lal, R. 1980. "Soil Erosion as a Constraint to Crop Production," IN *Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics*, pp. 405-423, IRRI, Laguna, Philippines.

Lee, C. Y. 1980. "Fertilizer Marketing Policies in Asian Countries," FAO, Rome, Italy.

Malavolta, E. 1978. "Mineral Nutrition and Fertilization of Irrigated Rice," Department of Chemistry, University of Sao Paulo, Piracicaba, Sao Paulo, Brazil.

Malavolta, E., and A.M.L. Neptune. 1975. "Recent Developments in K Fertilization in Several Countries of Latin America," IN *Potassium Research and Agricultural Production*, pp. 291-310, Proc. 10th Congress Int. Potash Inst., June 1974, Budapest, Hungary, IPI, Bern, Switzerland.

Mathieu, M., and J. de la Vega. 1978. "Constraints to Increased Fertilizer Use in Developing Countries and Means to Overcome Them," The Fertiliser Society of London, Proceeding 173, London, England.

Mengel, K. 1979. "A Consideration of Factors Which Affect the Potassium Requirements of Various Crops," IN *Potassium Research—Review and Trends*, pp. 225-237, Proc. 11th Congress Int. Potash Inst., September 1978, Bern, Switzerland, IPI, Bern, Switzerland.

Mitchell, H. W. 1965. "Soil Erosion Losses in Coffee," *Tanganyika Coffee News*, 5(4):135, 137, 139, 141, 143, 145, 147, 149, 151-152, 155.

Moorman, F. R., and D. J. Greenland. 1980. "Major Production Systems Related to Soil Properties in Humid Tropical Africa," IN *Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics*, pp. 55-77, IRRI, Laguna, Philippines.

Munson, Robert D. 1982. *Potassium, Calcium, and Magnesium in the Tropics and Subtropics*, Tech. Bull. No. IFDC-T-23, IFDC, Muscle Shoals, Alabama.

Nelson, W. L. 1968. "Plant Factors Affecting Potassium Availability and Uptake," IN *The Role of Potassium in Agriculture*, pp. 355-383, Proc. Symposium at National Fertilizer Development Center, TVA, June 18-19, 1968, Muscle Shoals, Alabama, Am. Soc. of Agron., Crop Science Society of America, and Soil Sci. Soc. of Am., Madison, Wisconsin.

Perrenoud, S. 1977. "Potassium and Plant Health," IPI, CH-3048, Bern-Worblaufen, Switzerland.

Ritchey, K. D. 1979. "Potassium Fertility in Oxisols and Ultisols of the Humid Tropics," Cornell Int. Agric. Bulletin 37, 44 pp., Cornell University, Ithaca, New York.

Sanchez, P. A. 1976. *Properties and Management of Soils in the Tropics*, John Wiley and Sons, New York.

Sanchez, P. A., and T. T. Cochrane. 1980. "Soil Constraints in Relation to Major Farming Systems in Tropical America," IN *Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics*, pp. 107-139, IRRI, Laguna, Philippines.

Temple, P. H. 1972. "Measurements of Runoff and Erosion at an Erosion Plot Scale, With Particular Reference to Tanzania," *Geografiska Annaler* 54A:203-220 (cited by Lal, 1980).

Trocme, S. 1977. "Le Potassium dans les plantes," IN *Le Potassium en Agriculture*, pp. 75-92, INA, Paris, France, (cited by Fauconnier, 1979).

Von Peter, A. 1979. "The Economics of Fertiliser Use and Fertiliser Resources," IN *Potassium Research—Review and Trends*, Proc. 11th Congress Int. Potash Inst., September 1978, Bern, Switzerland, IPI, Bern, Switzerland.

Von Uexkull, H. R. 1968. "Potassium Nutrition of Tropical Crops," IN *The Role of Potassium for Agriculture*, pp. 385-421, Proc. Symposium at National Fertilizer Development Center, TVA, June 18-19, 1968, Muscle Shoals, Alabama, Am. Soc. of Agron., Crop Sci.Soc. of Am., and Soil Sci. Soc. of Am., Madison, Wisconsin.

Von Uexkull, H. R. 1983. "Development of Fertilizer Consumption in Rice Fields in Indonesia," (unpublished, personal communication).

Appendix

The amounts of potash fertilizer applied in 1971 and 1981, the estimates made of likely consumption in 1985 and 1990, and the amounts applied to arable and permanent crops in 1981.

Country	1971	1981	Percent Change	Projection 1985	Projection 1990	Use in 1981[a]
	('000 mt K_2O)			('000 mt K_2O)		(kg/ha)
Algeria	26.0	35.8	+37.7	45.0	53.0	4.8
Angola	2.0	3.8	+90.0	5.0	10.0	1.1
Congo	4.0	0.2	-95.0	-	-	0.3
Egypt	1.9	7.5	+294.7	15.0	30.0	2.6
Ethiopia	1.5	0.2	-86.7	1.0	1.0	0
Ivory Coast	11.8	23.5	+99.1	27.0	33.0	6.1
Kenya	3.1	9.0	+190.3	11.0	15.0	4.0
Madagascar	3.9	2.8	-28.2	4.0	5.0	0.9
Mali	0	3.4	+340.0	3.0	4.0	1.7
Mauritius	9.6	13.4	+39.6	21.0	25.0	125.2
Morocco	16.0	40.8	+155.0	45.0	55.0	5.3
Nigeria	1.1	25.0	+2,172.7	35.0	45.0	0.8
Senegal	1.4	5.0	+257.1	15.0	20.0	1.0
South Africa	96.1	139.7	+45.4	158.0	200.0	9.6
Sudan	0	0	-	0	1.0	0
Tunisia	2.1	4.6	+119.0	7.5	10.0	0.9
Upper Volta	0	2.8	+280.0	5.0	7.0	1.1
Zaire	1.2	2.0	+66.7	3.0	3.0	0.3
Zambia	6.1	10.8	+77.0	14.0	18.0	2.1
Zimbabwe	25.0	28.8	+15.2	40.0	50.0	11.6
Costa Rica	6.0	20.0	+233.3	38.0	50.0	40.8
Mexico	25.8	74.8	+189.9	78.0	95.0	3.2
Argentina	7.1	6.0	-15.5	10.0	15.0	0.2
Bolivia	0	1.2	+120.0	1.0	1.0	0.4
Brazil	305.9	1,306.6	+327.1	1,606.0	2,000.0	21.2
Chile	13.2	13.1	-0.8	20.0	30.0	2.4
Colombia	31.8	75.5	+137.4	85.0	94.0	13.5
Ecuador	6.5	17.6	+170.8	22.0	30.0	6.7
Peru	5.0	11.1	+122.0	21.0	24.0	3.2
Venezuela	19.1	50.5	+164.4	60.0	70.0	13.6
Bangladesh	10.7	29.2	+172.9	55.0	82.0	3.2
Burma	1.4	3.1	+21.4	20.0	30.0	0.3
China	29.0	382.8	+1,220.0	770.0	1,250.0	3.9
India	197.7	617.0	+212.1	850.0	1,115.0	3.6
Indonesia	6.5	87.0	+1,238.5	130.0	180.0	4.5
Malaysia	75.7	194.9	+157.5	250.0	300.0	45.3
Nepal	0.2	1.1	+450.0	4.0	8.0	0.5
Pakistan	1.2	9.6	+700.0	25.0	40.0	0.5
Philippines	38.0	55.8	+46.8	78.0	100.0	5.6
Sri Lanka	30.7	46.0	+49.8	50.0	65.0	21.5
Thailand	15.0	35.4	+136.0	40.0	62.0	2.0
Turkey	11.5	49.0	+326.1	55.0	60.0	1.8
42 countries studied	1,050.8	3,446.4	+228.0	4,722.5	6,286.0	
(Without South Africa)	954.7	3,306.7				

a. Per kilogram of arable land and land in permanent crops.

Source: FAO data.