PROCEEDINGS OF THE IFPRI/FAO WORKSHOP ON PLANT NUTRIENT MANAGEMENT, FOOD SECURITY, AND SUSTAINABLE AGRICULTURE: THE FUTURE THROUGH 2020

Viterbo, Italy

May 16-17, 1995

Edited by P. Gruhn, F. Goletti, and R. N. Roy

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FOREWARD

Thirty percent of the Earth's population, about 1.1 billion people in the developing world, live in absolute poverty. Twenty percent, or 800 million people, do not have access to the food necessary to live a healthy and productive life. Although high-yielding, nutrient-responsive modern varieties improved access to food in many parts of the world since the 1960s, the pressure on agriculture is beginning to show. For example, the growth in cereal yields has begun to slow; the over-application of inorganic and organic fertilizers in developed countries has been linked to environmental pollution, and poor soil management and continuous cropping, without the replenishment of nutrients, has led to a decline in soil fertility and more general soil degradation in many developing countries.

In order to develop an action plan for the eradication of hunger and malnutrition while protecting the environment by the year 2020, the International Food Policy Research Institute (IFPRI) led an international initiative entitled A 2020 Vision for Food, Agriculture and the Environment. In support of the 2020 Vision, IFPRI, in collaboration with the Food and Agriculture Organization of the United Nations, sponsored a workshop in Viterbo, Italy in May 1995 on Plant Nutrient Management, Food Security, and Sustainable Agriculture: The Future through 2020. The workshop and these edited proceedings are part of our effort to further the debate and encourage action by individuals, groups, and governments to realize the 2020 Vision.

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WELCOMING ADDRESS

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May 16-17, 1995, Viterbo, Italy

Gentlemen,

I do not know whether the decision to choose Viterbo to host this important meeting was based mainly on the amenities of the region or reflects the fact that Viterbo is home to a Faculty of Agriculture which, though of recent foundation, is active in the areas to be discussed in the workshop.

Naturally, as head of the Faculty, I prefer to think that the latter is the case. The presence among the rapporteurs of Professor Liano Angeli, one of our distinguished professors, seems to support this hypothesis. This is why I wish to say a few words outlining some of the commitments of my Faculty to the great task of ensuring a proper role for agriculture in the difficult phase that society is facing.

Our Faculty, largely because of our Rector's, Professor G.T. Scarascia Mugnozza's impulse, has been a participant in many research programs of the CGIAR network, mainly in the areas of genetics and biodiversity; we are active members of Italian and international consortia managing rural and agro-forestry development programs; we have the main responsibility for a cooperation program with the Faculty of Agriculture of the University of Maputo; and most of our staff are directly engaged in research, teaching, and consultancies with international organizations involved in agricultural development. Our contribution is less than we would like, because our present charter makes it almost impossible for us to specialize in agricultural development. Nevertheless, we hope to strengthen our experience in this area, and to become a permanent member of your club.

I understand that, during the next few days, you will be engaged in that most serious game of crystal-ball gazing, of building scenarios, and of suggesting strategies for coping with them. I can imagine the blend of knowledge, dedication, and imagination needed to make this particular game fruitful. I know that the personal experiences of the people around this table and the ongoing commitment of the organizing agencies will ensure, in this case, a valuable result. I hope Viterbo will contribute by creating a friendly atmosphere.

1. INTRODUCTION

by Peter Gruhn, Francesco Goletti, and Rabindra N. Roy

In the next 25 years, the challenge for agriculture will not only be to meet the food needs of Earth's expanding population, but also undertake it in a manner that is sustainable for present and future generations. The challenge for agriculture is immense. By 2020, the population of Earth is projected to approach eight billion, an increase of some 2.3 billion from 1995. Although world population growth rates will slow and approach zero in the more developed regions, population growth is projected to increase by over two percent in Africa and just under one percent in Asia around the year 2020. Already during the early 1990s, 95 percent of world population growth occurred in the less developed regions (United Nations 1993, United Nations 1995). Baseline projections by the International Food Policy Research Institute (IFPRI) indicate that world cereal production will need to expand to 2.6 billion tons by 2020, an increase of 56 percent from production levels in 1990. The majority of the increase in world cereal production growth is projected to occur in developing countries, with cereal production forecast to rise by 70 percent in Asia and by 140 percent in Sub-Saharan Africa (Rosegrant et al 1995). As land constraints become increasingly binding, the synergy generated by genetic engineering and plant nutrients will be necessary to maintain and boost crop yields.

Tremendous quantities of nutrients are required to produce the food necessary to feed the world in any given year. Poor management of these nutrients in many parts of the world has led to environmental pollution and the degradation of this resource base, particularly in the developing world. To meet agricultural production and sustainable intensification goals over the short- and long-term, plant nutrients and soils need to be managed properly. In a joint effort, IFPRI and the Food and Agriculture Organization (FAO) of the United Nations have collaborated to increase awareness of the vital need to maintain and enhance high crop yields for present and future generations by effectively and efficiently managing soils in an environmentally benign manner.

The genesis for these proceedings was a workshop on *Plant Nutrient Management, Food Security, and Sustainable Agriculture: The Future to 2020* held in Viterbo, Italy from 16-17 May 1995, organized by IFPRI and FAO. The workshop was part of an international initiative led by IFPRI entitled, *A 2020 Vision for Food, Agriculture, and the Environment*. The initiative seeks to a) develop a vision and an action plan for eradicating hunger and malnutrition by the year 2020 while protecting the environment, and b) to generate information and encourage debate by national governments, non-governmental organizations, the private sector, and international development institutions to take action to realize the 2020 Vision. In essence, the 2020 Vision is "a world where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective, low-cost food systems that are compatible with sustainable use of natural resources." In order to realize the 2020 Vision, sustained action is called for in the areas of a) strengthening the capacity of developing country governments, b) enhancing social services, c) strengthening agricultural research and extension services in and for developing countries, d) promoting sustainable agricultural intensification and sound management of natural resources, e) developing efficient, effective, and low-cost agricultural input and output markets, and f) expanding international cooperative and assistance, and to improve its efficiency and effectiveness. (see IFPRI 1995).

As part of the 2020 Vision to promote sustainable agricultural intensification and sound resource management, the Viterbo workshop brought together experts from a wide variety of fields and institutions including fertilizer industry groups, universities, non-governmental organizations, research institutes, and governmental institutions, to examine the role of fertilizers and other plant nutrient sources in contributing to the food security of developing countries using sustainable methods over the next 25 years. At the workshop, the presentations, discussions, and working groups examined low input use and productivity issues in Africa, the decreasing efficiency of plant nutrient supplies in Asia, and the integration of various inputs for sustainable intensification. In the final workshop session, the participants developed a set of recommendations to help foster sustainable and environmentally benign intensification. The participants list and the workshop conclusions and recommendations are presented in the appendix.

Each of the papers in these proceedings helps to make the case that agricultural intensification can be sustainable, without degrading the environment. To sustain high crop yields and soil fertility for future generations, nutrients will need to be returned to the soil, particularly in sub-Saharan Africa where soil structure is often poor and fertilizer use is low, and in parts of Asia where nutrient imbalances and deficiencies are beginning to affect crop yields. To bring this about, the use of inorganic fertilizer has and will continue to play an important role, albeit not the only one. Organic fertilizer applications, soil conservation measures, and the integrated management of all plant nutrient sources (IPNM) will all be a necessary part of the program. Only through an integrated approach can all nutrient sources and conservation practices be tapped to make all plant nutrients (the primary nutrients - N, P, and K, the secondary nutrients - S, Ca, and Mg, and the micro-nutrients) available in the correct absolute and relative quantity and at the right time, place and price for high crop yields to be realized, agriculture to be sustained, and food security improved through the year 2020 and beyond.

IPNM will be the means through which the long-term fertility of the soil will be assured and contamination of the environment minimized. Yet, IPNM alone will not be sufficient to bring this about; farmers need to adopt effective and efficient crop, pest, soil, and water management techniques as well. Governments also have an important role to play to promote effective and environmentally sound management of plant nutrients, improve research, monitoring, participation, and extension of effective plant nutrient management, and to support complementary measures to lower costs, recycle urban waste, secure land tenure, and increase production capacity, to improve transport and communication infrastructure, and to establish an effective institutional environment conducive to the efficient functioning of nutrient, other input and output markets.

The proceedings are grouped into three broad sections: sustainable intensification and plant nutrient management, 1) globally, 2) in Africa, and 3) in Asia. The first paper in Section 1 by Gruhn, Goletti, and Yudelman summarizes many of the nutrient related points raised in the workshop including the growth of inorganic fertilizers use over the past thirty-five years, the impediments that have limited its application in certain regions, and environmental problems related to the over and under application of plant nutrients, with special reference to Sub-Saharan Africa. The paper stresses a) the importance of the integrated management of plant nutrients through soil conservation methods and the application of inorganic and organic fertilizers, to help maintain and enhance soil fertility, high crop yields, and sustain agriculture; and b) the contribution of knowledge and technology dissemination to help farmers effectively, efficiently, and inexpensively maintain soil fertility in a sustainable manner; and c) the important role government can play to support better management practices.

The next paper by Angé identifies the adoption of agriculture intensification and economic development as key factors in the campaign against hunger and poverty. The paper goes on to describe the use of and various limitations to the application of mineral fertilizers in Africa and Asia, with special reference to China, and the requirements for greater mineral fertilizer use in semi-arid Africa. The last paper in Section 1 by Pretty comprehensively examines sustainable intensification. Pretty first briefly describes the current debate on the appropriate pathways to the modernization of agriculture in order to meet future food requirements and the challenge of sustaining agriculture. Next he reviews many of the environmental and health problems associated with the over-use of fertilizers and examines alternative nutrient sources and management practices for the sustainable intensification of agriculture. Lastly, he identifies and expounds upon the role of learning and participation in sustaining agricultural intensification.

Section 2 of the proceedings examines fertilizer use and plant nutrient management in Africa. In his paper, Mwangi first reviews inorganic fertilizer use in Africa and its effect on soil fertility. He then goes on to describe the various demand, supply, pricing, infrastructural and government policy factors that have limited greater application. The paper by Negussie undertakes a very comprehensive review of crop production, fertilizer use, the influence of modern seed varieties, soil conservation methods, and their impact on farming and agricultural output in Ethiopia. He goes on to describe how farming practices are influenced by the environmental, technological, and policy constraints faced by farmers in Ethiopia, and how they in turn contribute to land degradation. Lastly, Negussie proposes and details various nutrient management and sustainable intensification practices that can be employed to improve crop yields.

Section 3 of the proceedings examines fertilizer use, plant nutrient management, and sustainable intensification in Asia. The paper by Hossain and Singh gives a general overview of the region, including fertilizer consumption trends, and the various factors, such as yield response, agro-climatic conditions, and fertilizer distribution and pricing policies, that have affected fertilizer demand. The authors conclude their chapter with a description of the challenges for agriculture and the role that sustainable intensification could play to help achieve food security in Asia by 2020.

The remaining three papers in the section examine aspects of integrated nutrient management and sustainable intensification in China, Pakistan, and India. In their paper, Jin Jiyun and Zhang Guilan review fertilizer use, plant nutrient management, and crop yield growth in China in general, before taking a closer look at nutrient balances, crop rotation and nutrient management in Henan state to illustrate the need for balanced application of organic and inorganic fertilizer in sustainable intensification. The next paper by Majid details the objective, strategy, and impact of the Aga Khan Rural Support Programme to mobilize farmers and village organizations to increase agricultural productivity and to manage resources sustainably. The last paper by Tandon, describes the cropping systems, the use of fertilizer and other nutrient sources, and the effect of these inputs on nutrient balances and crop yields in India, and in Uttar Pradesh province in particular. Lastly, the paper discusses the policy and resource requirements necessary for sustainable intensification.

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SECTION 1: SUSTAINABLE INTENSIFICATION AND PLANT NUTRIENT MANAGEMENT: THE GLOBAL ENVIRONMENT

2. FERTILIZER, PLANT NUTRIENT MANAGEMENT, AND SUSTAINABLE AGRICULTURE: USAGE, PROBLEMS AND CHALLENGES

by Peter Gruhn, Francesco Goletti, and Montague Yudelman

INTRODUCTION

Agriculture will be heavily burdened to feed a world population projected to exceed eight billion by the year 2020. The synergy between the application of inorganic fertilizer and the development of nutrient-responsive modern seed varieties was in no small part responsible for the phenomenal growth in crop yields and food supplies in developed countries over the past thirty-five years. The ability of agriculture to provide for food needs to the year 2020 and beyond is becoming increasingly difficult however. In developed countries, over-application of inorganic and organic fertilizers has led to environmental damage, while in developing countries, population pressures, land constraints, and the decline of traditional soil management practices have led to a decline in the fertility of the soil. The integrated management of plant nutrient resources through soil conservation practices and the widespread and responsible use of organic and inorganic fertilizers offers the opportunity to sustain agriculture over the long-term and to maintain and enhance soil fertility, while minimizing any environmental damage. For Integrated Plant Nutrient Management (IPNM) to be successful at the field level, the farmer must have the knowledge, tools, and support necessary to effectively manage his fields, crops, and soil to their maximum potential.

This paper is divided into four sections. Section 1 illustrates the growth in the production and use of fertilizer over the past thirty-five years and briefly examines some of the major impediments that have limited fertilizer application, particularly in Sub-Saharan Africa. Fertilizer-related environmental problems in many developed countries and the decline in soil fertility in developing countries is described in Section 2. Section 3 details how IPNM can be used to maintain and enhance soil fertility, while minimizing environmental damage. Lastly, the conclusion details the role of government to establish an enabling environment and provide the necessary support for IPNM to be successful in sustaining agriculture through the year 2020 and beyond.

FERTILIZER USE AND PRODUCTION

World Fertilizer Use and Production

Global fertilizer use increased from 26 million metric tons (mmt) in 1958 to 145 mmt by 1988. Political and economic upheaval and reform in Eastern Europe and the former Soviet Union beginning in 1989, has, however, led to a temporary reduction in overall global fertilizer use. Consequently global fertilizer consumption fell steadily from 1989 to 121 mmt by 1993, before recovering somewhat to 130 mmt in 1995. Of the 26 mmt of inorganic fertilizer used in 1958, 8.7 mmt (34 percent of total world consumption) was nitrogen (N) fertilizer, 9.1 mmt (35 percent) phosphorus (P) fertilizer, and 7.9 mmt (31 percent) was potassium (K) fertilizer (FAO 1965). By 1988, 79.5 mmt (55 percent of total world consumption), 37.6 mmt (26 percent) and 28 mmt (19 percent) was N, P, and K fertilizers, respectively (IFIA 1997). The dominance and relative growth of N fertilizer is in large part a consequence of the adoption of nutrient-responsive, high yielding modern varieties by farmers in the developed world and in Asia. While consumption of fertilizer has stagnated in developed countries in recent years, use of inorganic N, P, and K fertilizers in developing countries increased to 48. 3 mmt (62 percent of world consumption), 19.0 mmt (61 percent), and 9.0 mmt (43 percent), respectively, for a total of 76.3 mmt in 1995.

Production of NPK fertilizer grew from 26.0 mmt in 1958 to 156 mmt by 1988 (FAO 1965, IFIA 1997). While production in developed countries grew three fold over the period to 110.3 mmt of NPK fertilizer, production in the developing countries jumped 24 fold from 2.0 mmt in 1958 to 48.5 mmt by 1988. Unlike the developed world where production, especially in the transforming economies has declined, NPK fertilizer production continued to grow in developing countries to 59.6 mmt by 1995, with N fertilizer production increasing to 43.1 mmt (54 percent of world production) (FAO 1965, IFIA 1997).

Fertilizer use, production, and trade in Asia and Africa

Fertilizer use in Asia was over 16 times greater than in Africa in 1995. While African consumption rose from 0.6 mmt in 1958 to 3.9 mmt (5.5 times greater) by 1995, use in Asia skyrocketed from 2.4 mmt in 1958 to some 62.7 mmt (25.1 times greater) by 1995. In 1995, Asia as a region accounted for just under 50 percent of world fertilizer consumption and 82 percent of the developing world’s use. In the thirty five years to 1995, total fertilizer production in Asia rose to 45.2 mmt from 1.1 mmt in 1958 (FAO 1965, IFIA 1997). Production incentives received a boost from the nutrient requirements of the high yielding modern varieties, the willingness of various donors to support fertilizer plant construction projects, and investments by oil and natural gas abundant Asian countries in fertilizer production capacity where fertilizer use is low (Bumb and Baanante 1996). The adaption of inorganic fertilizer has been less successful in Africa, with inorganic fertilizer production of 4.3 mmt in 1995, sufficient inorganic fertilizer was produced to meet all African consumption demand. Geography and poverty, however, have conspired to keep consumption of African produced fertilizer low at only 0.3 mmt consumed in SSA and 0.8 mmt in Southern Africa.

The large difference between fertilizer consumption and production in developing countries necessitates an active trade in fertilizer between Asia and Africa and the rest of the world. In Asia, net imports of 17.5 mmt of fertilizers (28 percent of total consumption) were required to make up the difference between use and production. Africa, a net importer of fertilizers until 1980, exported some 2.6 mmt of fertilizer in 1995. North Africa, which accounted for 74 percent of African production, was chiefly responsible for the reversal as both Egypt and Libya became major nitrogenous fertilizer producers, and Morocco and Tunisia major phosphate fertilizer exporters. Sub-Saharan Africa (SSA) by contrast, was a net importer of some 1.0 mmt (77 percent of SSA's total fertilizer consumption) in 1995. Further, in 1990 of the 40 countries in SSA, 22 received all of their fertilizers as aid and another 7 countries received over 50 percent of their fertilizer imports as fertilizer aid (FERTECON 1993).

High costs contribute to the low level of fertilizer use in SSA. While a kg of fertilizer costs the typical Asian farmer 2 - 3 kg of grain, it costs his/her African counterpart between

6 to 11 kg of grain (Isherwood 1996). Correspondingly fertilizer use in Africa is low with only 20 kg of NPK fertilizer applied per hectare of arable land in 1994, whereas over 142 kg/ha was used on average in Asia. In SSA, only 14 kg/ha was applied overall in 1994, and in countries such as Ghana and Niger, overall NPK fertilizer application was even lower with only 4.3 and 1.4 kg per hectare of arable land, respectively (FAO 1996a, FAO 1996b). Production and local marketing of fertilizer in SSA is constrained by high production, transportation and investment costs, and a relatively inexpensive and plentiful supply from foreign sources. Fertilizer imports are often also constrained by foreign exchange shortages, inefficient and ineffective marketing boards, and by high prices arising from small procurement lots (tenders for less than 5,000 tons are common), weak bargaining power, and high freight and international marketing costs. Special mixes tailored for typical African needs or the addition of nutrients such as sulfur or boron, can each add an additional $15 - $20 per ton to the cost of importing fertilizer (Coster 1991).

Structural Adjustment Programs

Further limiting the application of inorganic fertilizer in SSA and other countries has been the adoption of Structural Adjustment Programs (SAPs). SAPs have been instituted in many countries at the behest of the International Monetary Fund and the World Bank, with the long-term goal of reallocating resources, so as to improve economic efficiency and social welfare. The programs have included reforming exchange rate, fiscal, monetary and trade policies, as well as promoting liberalization, the withdrawal of subsidies, and privatization of state owned enterprises. Through exchange rate devaluation, imports--such as fertilizers--are more expensive. This in turn has reduced the profitability of using these fertilizers to increase production, mostly food grains for domestic consumption. At the same time though, farmers growing export crops, who have benefitted from the restructuring of currencies, have increased their fertilizer use. Given the vast acreage under food crops compared with the modest areas devoted to export crops, it would appear that the revaluation of currencies has militated against increased application of imported fertilizers--at least in the short run.

The SAPs have also frequently induced countries to phase out fertilizer subsidies. While proponents argue that subsidies encourage fertilizer application by reducing the cost to farmers, opponents by contrast, argue that subsidies strain foreign exchange reserves and government budgets, that in turn leads to delayed and rationed supplies, which prevent the farmer from obtaining the necessary fertilizer at the right time and in the right quantity to aid crop growth. Evidence, in Africa at least, is mixed. In Ghana and Senegal, for example, fertilizer use clearly declined as subsidies were withdrawn (Jebuni and Seini 1992; Shepard 1989), while in Tanzania and Malawi, the removal of large subsidies eased supply constraints and resulted in a slight increase in fertilizer use, even though prices rose (World Bank 1993).

CURRENT PROBLEMS

Environmental Damage

Inorganic fertilizers are not without their share of problems. The over-supply of nutrients from inorganic and organic sources in excess of plant needs and in the absence of a mechanism to bind the nutrients to the soil, can lead to environmental contamination. Soil nitrate concentrations in excess of plant absorption needs, for example, allow the soluble nitrate to be carried away in ground water to contaminate surface waters and underground aquifers. Consumption of water high in nitrate (and nitrite) has been linked to “blue baby syndrome,” goitre, birth defects and heart disease, and may be involved in the creation of carcinogenic compounds within the body that can cause stomach, liver and esophageal cancers (Conway and Pretty 1991). Leaching and run-off of nitrogen and phosphorus into rivers, lakes, and inlets, can cause eutrophication--an excess accumulation of nutrients in water that promotes algal over-production. This algal over-production damages the marine environment as it starves plant and animal aquatic life of both the light necessary for photosynthesis and the oxygen needed to breath. When in excess to plant needs, nitrogen also escapes into the atmosphere as nitrogen gas and various nitrous oxides. In the upper atmosphere, nitrous oxides react to form acid rain which can be damaging to crops, acidifies soil and water, and contributes to property damage. Further, cumulative application of ammonia-based fertilizers often leads to soil acidification, which in turn requires redress through the application of lime or dolomite to forestall soil degradation. Coupled with ammonia fertilizer production that is both energy intensive and pollutive of the environment, the potential exists for the over-application of inorganic and organic fertilizers to cause substantial environmental damage.

Because of high application rates, frequently well in excess of fertilizer recommendations, fertilizer related environmental damage is most often observed in the developed world. For example, some 1.6 million people in the U.K. are supplied with water with nitrate levels that exceed guidelines, Danish, Dutch and German coastal regions exhibit signs of eutrophication (Bockman *et al.* 1990), and according to the USDA, nearly two-thirds of the pollution in U.S. rivers has been attributed to agriculture with close to 60 percent of the pollution in lakes caused by runoff from excess plant nutrients (NRC 1993). Thus, although fertilizer nutrient applications are necessary for plant growth, to maintain soil fertility and to sustain agriculture over the long-term, over-application is wasteful as it does not increase crop yields and contributes to environmental damage.

Decline of traditional management practices

While over-application of fertilizers has contributed to environmental damage in developed countries, under-application and the decline of traditional soil fertility management practices, by contrast, have contributed to environmental damage in developing countries. Traditional techniques employed in Africa, such as slash-and-burn and fallowing, are no longer a feasible option. Population induced food needs are such that land can no longer be taken out of production for substantial periods of time to allow for natural processes to replenish nutrients, nor is the incorporation of crop residues and animal manures sufficient to rebuild soil nutrient stocks. Further, with the promotion of rural non-agricultural development, crop residues are increasingly in demand as a source of fodder, fuel, and raw materials for artisanal activities to generate additional income, rather than as a natural amendment to the soil. Insecure and crumbling tenure arrangements have contributed to declining soil fertility as well. Communal rights to graze land without any effort to maximize long term returns, has led to serious over-grazing in Africa and other regions of the world. In addition, ill-defined property rights and insecure tenure arrangements have reduced the incentive for farmers to undertake longer-term, profit-inducing, soil fertility enhancing investments (see Hopkins *et al.* 1995). Lastly, declining commodity prices during the 1980s reduced the incentive for agriculture related investment, which in turn led farmers to further draw down soil nutrient reserves.

Soil degradation

The reduction in the incentive to invest in agriculture, coupled with the general breakdown of traditional soil fertility management practices and insufficient application of inorganic fertilizers, has led to substantial nutrient mining of the soil. Nutrient mining of nitrogen, phosphorous, potassium, magnesium and calcium was estimated at 7 m metric tonnes in 1993 for the low-income countries of Bangladesh, Indonesia, Myanmar, Philippines, Thailand and Vietnam (Mutert 1996). In Sub-Saharan Africa net nutrient depletion has been estimated at 22 kg N/ha, 2.5 kg P/ha, and 15 kg K/ha per annum over the 1982/84 period, and was expected to increase to 26, 3, and 19 kg/ha of nitrogen, phosphorus, and potassium, respectively per annum by the year 2000 (Stoorvogel *et al.* 1993). Such soil mining has resulted in the loss of over 8 mmt of nutrients annually in SSA (Stoorvogel and Smaling 1990). Oldeman *et al*. (1990) have estimated that over 128 m ha of land in Africa, Asia and South America has been damaged as a result of human-induced soil degradation.

Despite the cumulative effect of negative nutrient balances and the degradation of some 45 m hectares of land in Africa (Oldeman *et al*. 1990), overall yields on this continent increased somewhat between 1960 and the mid-1990s. The mobility of the SSA farmer has been a major factor in the modest improvement of crop yields. Between 1973 and 1988, arable and cropped land increased by 14 m ha, forest and woodland area fell by 40 m ha, and pasture land remained stable. The difference (26 m ha) has been lost to desertification or abandoned. Thus the effect of reduced soil fertility is hidden as farmers abandon nutrient depleted land to clear and farm heretofore uncultivated, marginal land (Vlek 1993). Once the land constraint becomes binding, such as the Mossi plateau in Burkina Faso (Vlek 1993), or affected areas in Malawi (Mwangi 1995) and Senegal (Bationo and Mokwunye 1991b), and soil fertility has sufficiently declined, yields and production will fall.

Projecting into the future, continued nutrient mining will put in danger the long-term sustainability of agriculture. By the year 2020 it is projected that global net primary nutrient removal will reach 366 mmt per annum. With world inorganic NPK fertilizer production in the year 2000 estimated at only 157 mmt, inorganic fertilizer production will need to increase 209 mmt (or 10 mmt / year) by the year 2020 in order to maintain soil nutrient balances at current levels, without taking into account the need to redress current cumulative negative nutrient balances in lightly and moderately degraded soils (Bumb and Baanante 1996). Projected supply and demand of inorganic fertilizers by 2020 will however, fall well short of meeting nutrient replenishment needs.

FUTURE CHALLENGES AND INTEGRATED PLANT NUTRIENT MANAGEMENT

Fertilizer outlook

The increased application of inorganic fertilizers is necessary to help to sustain agriculture in the future. Over the thirty year period to 2020, global fertilizer demand is projected to grow at an average rate of 1.2 percent to 208 mmt. With expected world supply capacity in 2000 of 157 mmt, the world will need to produce an additional 51 mmt of inorganic fertilizer to meet demand by 2020, to say nothing of the additional quantity required to maintain soil nutrient balances. At a minimum, additional production of 29 mmt of N, 15 mmt of P, and 8 mmt of K fertilizer will be required to meet expected demand (Bumb and Baanante 1996).

Because of expected population, cereal and income growth, and the fertilizer requirements necessary to meet those needs, fertilizer demand is projected to increase by 2.2 percent annually in developing countries. With Asian demand projected to reach 100.7 mmt of nutrients, fertilizer supply (production and imports) in Asia would need to increase by 46.2 mmt (22.3 mmt of N, 16.0 mmt of P and 8.0 mmt of K), almost double the amount of fertilizer used in the region in 1990. Fertilizer demand in Africa is projected to grow at an even faster rate to 9.3 mmt by 2020, over 2.6 times the quantity of fertilizer applied in 1990 (Bumb and Baanante 1996).

Is more fertilizer enough?

The application of inorganic fertilizer will not be sufficient, however. First, while it is conceivable that world fertilizer production can increase by an additional 51 mmt to meet projected demand by 2020, an increase of 209 mmt of fertilizers to meet the amount removed annually by negative nutrient balances, will be much more of a challenge. Second, fertilizer application may not be environmentally benign. As noted previously, ammonia-based inorganic fertilizers increase soil acidity, are highly volatilizable, have been linked to global warming and acid rain, are costly and pollutive to manufacture, and when applied in excess of crop nutrient needs can contaminate ground and surface water through leaching and erosion. Third, heavy application of inorganic NPK fertilizers does not replace secondary and other micro-nutrients removed by harvested crops, crop residue and erosion, nor do they directly improve soil organic matter content and structure. For agriculture to be sustainable, an integrated approach to the management of plant nutrients will be necessary, in which inorganic fertilizer application needs to be used as a supplement to other nutrient conservation and augmentation practices.

Integrated Plant Nutrient Management (IPNM)

Integrated plant nutrient management (IPNM) is an important component of sustainable agricultural intensification, as well as crop, pest, soil, and water management. IPNM centers on the management of soils in their capacity to be a storehouse of plant nutrients that are essential for vegetative growth. The goal of IPNM is to integrate the use of all natural and man-made sources of plant nutrients, so as to increase crop productivity in an efficient and environmentally benign manner, without diminishing the capacity of the soil to be productive for present and future generations.

IPNM incorporates many technologies including soil conservation, nitrogen fixation, and organic and inorganic fertilizer application. Soil conservation practices prevent unnecessary losses of nutrients from the field through wind and water erosion. Organic fertilizers play an important role in the improvement of soil structure and organic matter content. They are also often a good source of the secondary and micro-nutrients necessary for plant growth, and contribute a modest quantity of the primary nutrients (nitrogen, phosphorus, and potassium) to the soil. Biological nitrogen-fixation by leguminous plants and by cereals, whereby bacteria-nodules on the roots of the plants synthesize nitrogen for the plant, offer the future potential for plants themselves to meet some of their nutrient needs. Inorganic fertilizers are most desirable and effective when application coincides with the major growth spurts of the plant--when the primary nutrients are needed most intensively--and where necessary to make up for secondary and tertiary nutrient deficiencies in the soil (Benneh 1997). Further, by enhancing crop growth, inorganic fertilizer application has the added benefit of increasing the biomass of crop residues, which can in turn be reincorporated into the soil as a green manure to improve the structure and organic mater content of the soil. Nutrient application from organic and inorganic sources should thus be at the absolute and relative level required for optimal crop growth and yield, taking into account crop needs, soil nutrient balances, agro-climatic considerations, and improved soil characteristics, while minimizing negative externalities.

Often under-emphasized, nutrient conservation is a critical component of IPNM. First, practices such as terracing, bund building, alley cropping, and no or low till farming, alter the local physical environment of the field and thereby prevent soil and nutrients from being carried off the field through leaching and erosion. Second, mulch application, cover crops, inter-cropping, and biological nitrogen-fixation, act as a physical barrier to the destructive effects of wind and water erosion, and help to improve soil characteristics and structure. Lastly, organic manures aid in soil conservation as they contribute to improved soil structure, as well as replenish secondary and micro nutrients. As the cost of investment is often high, governments can play a key role in the promotion and adoption of soil conservation measures. The ultimate success of these measures and the continued maintenance of the investment, however, is often dependent on the support and full participation of farmers.

If used appropriately, the recycling of organic waste from urban to rural areas is a potential, largely-untapped source of nutrients for farm and crop needs. For example, through irrigation, environmentally undesirable wastewater can be utilized to return nutrients and organic matter to the fields and to improve water quality (see Tandon 1992). Organic household and commercial waste can also be collected and composted to form a safe, nutrient-rich, soil structure improving amendment for application on local farms and gardens. Urban waste needs to be treated and its application monitored to be used safely, however. Untreated sewage used for irrigation can put pathogens in contact with fruit and vegetables. Currently, effective utilization of urban waste is hampered by its high water content, bulkiness, its distance from rural areas, and high, labor- intensive handling, storage, transport and application costs. However, given the cost and the lack of availability of inorganic fertilizers in some areas, and the relative abundance and benefit of waste as an organic soil amendment, the effective utilization of urban waste may yet become an important soil and nutrient amendment in different parts of the world where the economics of waste disposal and conversion are attractive.

Because of low primary nutrient content and thus the need for large applications per unit area, farmers and policy makers are often reluctant to adopt and promote the use of organic fertilizers. Although the positive effects of organic matter on the physical properties of the soil is accepted (see Box 2.1), all its benefits are not sufficiently quantified through research. More hard data is needed on the direct and indirect benefits of greater soil organic matter content, improved physical properties, better buffering of soil acidity, replenishing of secondary and micro nutrients, and the reduction of environmental externalities. Information, education, and quantity and quality standards on pH, nutrient, moisture, and organic matter content also need to be made available so that farmers can better evaluate the cost/benefit of organic fertilizer applications.

Box 2.1: Plant Nutrient Management

Classical field experiments at the Rothamsted Experimental Station in England have provided a wealth of information on the yields of crops grown continuously and in rotation using a variety of soil fertility amendments. Continuously cropped wheat, without the benefit of organic and inorganic fertilizers, typically has yields of only 1.2 tons/ha. Yields where wheat is grown in rotation or with potato / fallow rotations did not improve greatly. Substantial increases in wheat yields (6-7 tons/ha), were only possible on organic and inorganic fertilized fields. Wheat yields were highest (9.4 tons/ha) on the fields where IPNM techniques were used most extensively, specifically in this case on manured fields that grew wheat in rotation and were topped up with inorganic nitrogenous fertilizers.
Source: Rothamsted 1991.

Alternative and additional sources of inorganic fertilizers will also be required, particularly in parts of Africa where soils would benefit from recapitalization, and where costs and supply constraints limit fertilizer application. For example, many parts of SSA have phosphorus deficient soils, where phosphate fertilizer applications of 15-20 kg/ha could substantially improve crop yield. Cost effective technology needs to be developed to bring into production and distribution fertilizers from phosphate rock reserves in Senegal, Mali and Niger (Bationo and Mokwunye 1991a).

The choice for sustaining agriculture through 2020 and beyond is not simply one of either inorganic fertilizer, organic fertilizer, or soil conservation. Inorganic and organic fertilizers and soil conservation are not substitutes, but rather complements to each other. It is the synergy created by using the most appropriate mix of these technologies that will help to sustain agriculture. Effective and efficient management of these resources and technologies, by farmers specifically through integrated plant nutrient management practices, will help to make it possible.

Knowledge and technology

Knowledge and technology are key for the farmer to manage soil fertility to benefit present and future generations. First, farmers need to know the condition of their soils. Widespread soil testing needs to be undertaken to gather data on the nutrient cycle and nutrient balances in representative areas. Second, once the condition of the soil is known, the farmers can then select the most appropriate mix of technologies to manage soils and yields in the short- and long-term, while minimizing environmental externalities, and taking into account their particular financial and resource circumstances. Here researchers and extension service providers have a role to play in making farmers aware of the various technology options and their relative cost and effectiveness. To be used effectively, researchers and extension service providers will need to have developed the local knowledge necessary to make appropriate recommendations. Some of this knowledge can be obtained through interaction with farmers--often the local technology and agricultural condition experts. Through their interactions with farmers, researchers have the opportunity to learn and evaluate traditional soil management techniques, and have the responsibility to disseminate the knowledge about the most cost effective and nutritionally beneficial practices for a particular farmer's situation in a variety of regions. Third, the farmer needs to have the knowledge and technology to test soils and plant nutrients in order to monitor the condition of her fields and crops, and to intervene when appropriate to improve yields when crops would otherwise suffer from hidden hunger or fail. As soils are dynamic systems and different crops use different nutrients in different quantities, soil testing and regular monitoring will help ensure that an environment conducive for optimal plant growth and crop yield can be established through nutrient application and conservation, and soil reclamation where necessary. Once the base knowledge has been acquired, other techniques can be implemented by farmers to boost efficiency, such as precision farming practices that use the Global Positioning System, in conjunction with soil sampling, the physical characteristics of the field, and monitoring yields, to maximize crop yields, reduce costs and minimize environmental damage by reducing nutrient over-application within a field.

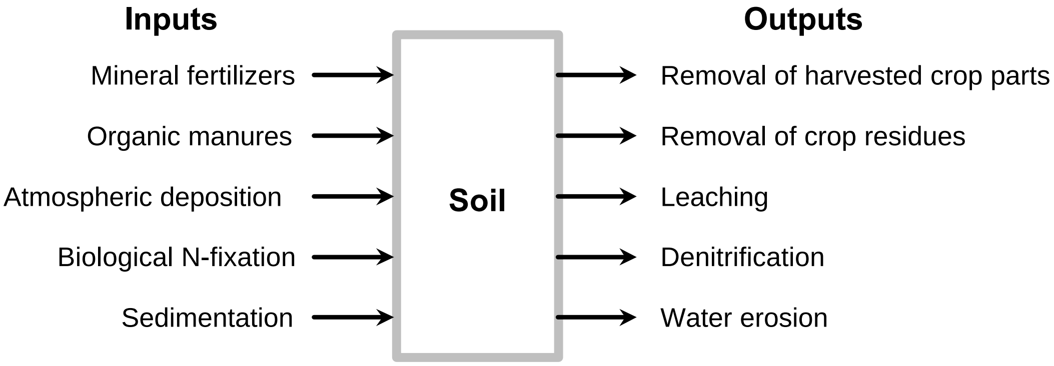
CONCLUSIONS

In the period since Nobel Chemistry Prize winners Fritz Haber and Karl Bosch developed the process that made the synthetic production of ammonia an economically viable reality, world nitrogen fertilizer production skyrocketed from a mere four thousand metric tons in 1914 to 73 mmt by 1994. The explosion in the use of inorganic fertilizers--particularly nitrogenous fertilizers, was in part a consequence of the adoption of nutrient-responsive, high-yielding modern seed varieties by farmers in the developed world and parts of Asia. Together, this potent combination made a significant contribution to the increase in world food production. In many developed countries however, fertilizer over-application and poor soil management has led to erosion and leaching induced environmental pollution. In many developing countries, by contrast, the decline in traditional soil fertility management practices coupled with insufficient fertilizer application, has resulted in the mining of soil nutrients, a reduction in soil fertility and environmental pollution. With 366 mmt of nutrients projected to be mined from global soils annually, soils will need to be managed more effectively and efficiently for agriculture to be sustained through the year 2020 and beyond.

The widespread and responsible application of inorganic fertilizers will play a critical role in helping to replenish these nutrients. Yet, to help meet the expected nutrient replenishment shortfall and for agriculture to be sustainable over the long-term and recognizing the poor socio-economic conditions in many countries, use of relatively expensive inorganic fertilizer will have to be accompanied by other measures for nutrient requirements to be managed effectively. *First*, soil conservation practices will need to be further adopted to prevent the unnecessary loss of nutrients from the field through leaching and erosion. *Second*, greater use will need to be made of organic fertilizers such as organic manures, cover-crops, and underdeveloped urban waste resources to improve soil structure, rebuild secondary and micro-nutrients, and provide a minimum quantity of the primary nutrients. *Third*, inorganic fertilizers will need to be applied to provide both the primary nutrients at critical plant growth periods and to remedy secondary and tertiary nutrient deficiencies. *Lastly*, genetic engineering offers the potential in the future for the plants themselves to meet some of their nutrient requirements. Together, these nutrient conservation and replenishment methods need to be managed - reflecting the farmer's particular bio-physical and socio-economic situations, in such a way as to provide a cost effective and appropriate level of nutrients to maximize yields and sustain agriculture, without polluting the environment. Furthermore, by sustaining agricultural intensification, effective and efficient nutrient management reduces the need to cultivate and degrade marginal lands.

Governments have both an active and supporting role to play in the adoption and success of IPNM. *First*, because the private sector often does not have a very large incentive to undertake research on technologies that conserve nutrients or more effectively use organic nutrients, governments must provide the financial support. *Second*, for improved soil management, governments a) need to support the establishment of testing and monitoring systems to gather data on the nutrient cycle and nutrient balances in representative areas, b) develop and disseminate the recommendations to farmers and extension service providers, c) encourage closer cooperation and coordination between farmers and researchers and other farmers to exchange, evaluate and disseminate information and technologies, and d) transfer knowledge and technology to farmers to test and monitor soil and plant nutrients. *Third*, at the institutional level, governments have a role to play in the establishment of an efficient market for the productive distribution and use of inorganic and organic fertilizers. In establishing such an environment, governments need to invest in infrastructure, establish property rights, withdraw from the procurement and distribution of goods and services when the private sector can more efficiently undertake these functions, and when necessary encourage fertilizer use through appropriate price incentives.

Figure 2.1--The plant nutrient balance system



Source: Smaling, 1993.

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3. PLANT NUTRITION MANAGEMENT IN THE FARMING SYSTEMS OF SEMI-ARID TROPICS IN AFRICA AND IN ASIA: CONTRASTS AND CHALLENGES FOR SUSTAINABLE AGRICULTURE

by A.L. Angé

INTENSIFICATION AND DEVELOPMENT

Today more than one billion, seven hundred million people (34 percent of the world's population) have access to less than 2,300 kilocalories per day from their food. The average daily caloric intake from food in developing and developed countries is 2,470 kilocalories and 3,400 kilocalories respectively. The proportion of the world's population suffering from insufficient access to food has decreased during the last 25 years (down from 57 percent in 1970). However, the overall number of people suffering from hunger has not declined during this period. The World Bank, in 1990, estimated the number of poor in the world to be 1.116 billion people, 16.1 percent of whom lived in Sub-Saharan Africa (47 percent of the population of the region) and 71 percent in Asia. Fifty-five percent of the population of India is still below the poverty level, against 20 percent of the population in China, representing 37.6 percent and 18.8 percent of the world's poor, respectively. There is a close relationship between the geographic distribution of the poor and the distribution of malnutrition. While the most significant proportion of rural poor is still in Asia, the total number of these poor has decreased significantly during the last 20 years, with the exception of India. In Sub-Saharan Africa, the number of rural poor and of dramatically malnourished people has increased during this period.

In Asia, the average arable land per head decreased from 0.162 hectares to 0.135 hectares (-16.4 percent) between 1980 and 1990. In Africa, the average arable land per head decreased from 0.388 hectares to 0.296 hectares (-23.7 percent) during this period. In both cases, arable land was not expanded. However, there are major contrasts between the various macro-ecological zones in both continents and according to the level of economic development in Asia. In Africa, in 1980, the availability of arable land per inhabitant was quite high and comparable to the situation prevailing in the developing countries of northwest Asia. In India, there were still on average 0.244 hectares per head, while in China there were 0.102 hectares per head, three times the availability of land in Japan. In 1990, in Africa, the availability of arable land was still nearly three times higher than in Asia. In India, the arable land per head was only 0.200 ha, while in China there were only 0.084 hectares per head, which is still 2.5 times the availability of arable land per head in Japan. Thus, in Sub-Saharan Africa, the proportion of poor is comparable to the proportion in India, while the availability of arable land is much higher in Africa than in India. The proportion of poor in Sub-Saharan Africa is more than double that of China, while the availability of arable land in 1990 was three times higher in Africa than in China. The intensification of cropping systems and the general level of economic development largely explain such contrasts.

The World Bank estimates that by 2000, only 44 percent of the world's poor will live in South Asia (26 percent of the population of the region) and 8.5 percent in East Asia (14 percent of the population of the region). Thus, the poor in Asia will decrease from 790 million people to 435 million people in the course of ten years, in spite of an average population growth of 30.3 percent. The forecast low development of agricultural intensification and of the national economies in Sub-Saharan Africa could increase the number of poor from 180 million to 265 million people (47 percent), while the total population will increase by 60.5 percent between 1990 and 2000.

The progress of agricultural production through the intensification of cropping systems has had a significant role in reducing the proportion of the poor in Asia. However, the improvement in the Gross Agricultural Product (GAP) per head has been quite different among Asian countries during the last 20 years. The greatest progress has occurred in Japan (from US$2,043 to US$5,094), caused by the combination of strong intensification of agriculture and steady support to agricultural commodity prices guaranteed by tight protectionism. Important progress has also been registered in Malaysia (from US$550 to US$1,429), through the development of industrial crops with high economic value (rubber, palm oil, cocoa, coconuts) and the steady improvement in the yields of these crops, as well as through the impact of general economic progress on the profitability of food crops. Important progress has also occurred in the Republic of Korea (from US$602 to US$1,369), mostly caused by the intensification of agriculture. In these three countries, even though the food intake was already high in the early 1970s, food consumption increased by 16 percent in the course of the past 20 years. Further, the considerable increase in Gross National Product (GNP) per head during the last 20 years (88 percent in Japan, 124 percent in Malaysia, 246 percent in the Republic of Korea) has also boosted progress in agriculture.

Compared to the above three countries, progress in Gross Agricultural Product per head during the last 20 years has been modest, but important, in relation to the prevailing situation in the 1970s, in China (from US$147 to US$258), in Thailand (from US$189 to US$331), and in Indonesia (from US$167 to US$309). Gross National Product per head in these countries also improved considerably during this period (176 percent, 135 percent, 119 percent, respectively), but the corresponding values have been modest compared to those of the first group of countries. Progress in the availability of kilocalories from food per inhabitant has been very high (32 percent, 26 percent and 25 percent, respectively), and the present caloric intake situation is satisfactory (2,600 to 2,900 kilocalories per head per day). General economic progress has not been sufficient, however, to boost progress in agriculture to the level observed in the developed countries and in the intermediate countries of the region.

In India, Laos, Myanmar, Pakistan, the Philippines, and Vietnam, the Gross Agricultural Product per head has improved modestly (22 percent, 58 percent, 83 percent, 24 percent, 36 percent, 82 percent, respectively), albeit only at low or very low levels. In these countries, the Gross National Product per head is also low and has not improved much during the last 20 years. Industrialization is marginal in these countries, and the general progress of the economy has not raised the intensification of the cropping systems in an efficient way. However, in all these countries, the availability of food per inhabitant improved from 1970 to 1990 (10 percent in India, 24 percent in Myanmar, 16 percent in Pakistan, 39 percent in the Philippines), with the exception of Vietnam (1.5 percent). The availability of kilocalories from food per inhabitant per day remains modest (2,400 to 2,900) for the most part, albeit low in Vietnam (2,120 kcal/person/day).

In Afghanistan, Bangladesh, Mongolia, and Sri Lanka, progress in the Gross Agricultural Product per inhabitant has been limited, and has decreased in Cambodia, Iran, Nepal, and Papua New Guinea. In all these countries, except Bangladesh and Sri Lanka (where GAP has always been very low) the Gross National Product per head has stagnated or decreased. Similarly, the availability of food per inhabitant has also decreased or stagnated (-2 percent in Afghanistan and Mongolia, -9 percent in Bangladesh, -18 percent in Cambodia, -2 percent in Nepal, and -4 percent in Sri Lanka). However, in Iran and Papua New Guinea where income from oil and ore has been available to governments, important investments have improved agricultural production, resulting in a significant increase in the available food per head (32 percent in Iran and 18 percent in Papua New Guinea).

Therefore, economic progress in Asia (mostly resulting from progress in mining, industry, and services, and which has improved the average income of the population) has certainly had an important role in increasing agricultural production per inhabitant. The development of national markets, induced by higher average incomes, has supported the intensification of agriculture. The negative impact of the reduction of arable land on the availability of agricultural products per inhabitant at last has been overcome.

In Africa, the combination of a generally low development of the industrial and mining sectors, as well as services, coupled with a rapid population increase, has resulted in a widespread decrease in the Gross National Product per head. In most countries, the Gross Agricultural Product per head has also decreased, with the exception of Botswana, South Africa, and Swaziland. In South Africa, the strong development of Gross National Product from 1970 to 1990 created a favorable environment for the improvement in the Gross Agricultural Product per head in the whole area. In Benin and Kenya, in spite of modest overall economic results, Gross Agricultural Product per head improved significantly (39 percent and 11 percent, respectively). Cameroon is the only non-industrial country in which the Gross Agricultural Product per rural inhabitant and the Gross National Product per inhabitant improved from 1970 to 1990 (22 percent and 97 percent, respectively).

On average, in the Sahelian countries (Botswana, Cape Verde, Djibouti, Mauritania, Namibia, Niger, Somalia, and South Africa), the Gross Agricultural Product per rural inhabitant decreased by 12 percent during this period (from US$342 to US$300). In the Sahelo-Sudanian zone (encompassing Burkina Faso, Chad, Ethiopia, the Gambia, Mali, Senegal, Sudan, and Zimbabwe), the prevailing situation in Ethiopia has been particularly dramatic with the Gross Agricultural Product per rural inhabitant decreasing from US$71 to US$59. In the other countries of the area, the Gross Agricultural Product per rural inhabitant decreased from US$194 to US$162. In the Sudanian zone (Angola, Benin, Guinea Bissau, Kenya, Lesotho, Mozambique, Sierra Leone, Swaziland, Tanzania, and Zambia), Gross Agricultural Product per rural inhabitant decreased dramatically in Lesotho and in Mozambique, from US$132 to US$62. In the other countries of the area, however, the Gross Agricultural Product per rural inhabitant increased slightly, from US$156 to US$169. In the Sudan-Guinean zone (Central Africa, Guinea, Ivory Coast, Madagascar, Malawi, Nigeria, and Togo), and in Malawi (the poorest country in the zone), the Gross Agricultural Product per rural inhabitant is still very low (US$78-85), but in all other countries the GAP is decreasing (from US$332 to US$255) because of falling commodity prices. Within the Guinean zone (Burundi, Cameroon, Comoro Islands, Congo, Gabon, Ghana, Liberia, Mauritius, Rwanda, Seychelles, Uganda, and Zaire), the Gross Agricultural Product per rural inhabitant decreased (from US$255 to US$232). This unfavorable trend holds also for Uganda (from US$1,187 to US$846) in spite of the quite exceptional quality of the natural resources, and in Gabon (from US$615 to US$312) in spite of heavy subsidies in agriculture. This depreciation is also related to the decrease in commodity prices.

In fact, the Gross Agricultural Product per rural inhabitant is quite comparable in the Sudanian-Guinean and in the Guinean countries of Sub-Saharan Africa and in some Asian countries (China, India, Myanmar, Pakistan), where the GAP is at a moderate level. Thus, the GAP alone cannot explain the considerable difference in agricultural intensification levels between the African countries on the one hand and some Asian countries on the other. Agricultural intensification is, of course, not homogeneous in Asia, and a small proportion of the cropped area is relatively highly intensified, while a large proportion of the cropping systems is extensive. Accordingly, there are ample variations in income from agriculture between the regions in each Asian country being considered. Nevertheless, without doubt, the contrast between the agricultural policies in Asia and in Sub-Saharan Africa, in particular for investment in agriculture, largely explains the differences in productivity and production increases between the two groups of countries. The availability of arable land in Africa, as compared to the prevailing situation in most Asian countries, is certainly not a positive factor for agricultural intensification.

The development of urban population is also an important factor in favor of the development of crop production. This development varies greatly between Africa and Asia and from one country to another within each region. In fact, because of the migration of rural people to cities, in many countries the decrease in the average available arable land per rural inhabitant has been lower than the decrease in the arable land per head. During the last ten years, the arable land per rural inhabitant has decreased by 17.1 percent in Africa, while it has only decreased by 8.6 percent in Asia. As a consequence, the population supplied with food by every rural inhabitant has increased during this period. In 1980, in Africa, 10 rural people produced food for 14 people in total; whereas in 1990, 10 rural people produced food for 15 people in total. Thus, the surplus required from each producer has not increased very much, but the available arable land to produce such a surplus has decreased considerably. In 1980, in Asia, 10 rural people produced food for 15 people in total (on 2.49 hectares compared to 5.37 hectares in Africa); whereas in 1990, 10 rural people produced food for 17 people in total (on 2.27 hectares compared to 4.95 hectares in Africa). The surplus required from each producer increased greatly because of the combination of the increased consumption per inhabitant with the increased number of consumers for each producer and because the arable land to produce this surplus has decreased quite significantly. These ratios between producers and consumers of food are very low compared to European standards (10 rural people produced for 79 inhabitants in 1980 and for 117 inhabitants in 1990). However, it underlines the urgent need for the intensification of cropping and farming systems in Africa and in Asia.

FERTILIZERS USE IN AFRICAN AND ASIAN COUNTRIES

The consumption of agricultural inputs within farming systems has had an important impact on the intensification of cropping systems, on the increase in food production per head, and on industrial crops grown per head in developing countries. The consumption of mineral fertilizers has had a particularly important impact on crop yields in Asia, while fertilizer consumption in Sub-Saharan Africa has remained limited.

In Africa, in the course of ten years, food production per inhabitant has decreased by 19 percent and industrial crop production per inhabitant has declined by 23.5 percent. By contrast in Asia, food production per inhabitant increased by 19.5 percent, and industrial crop production per inhabitant grew by 25.8 percent between 1980 and 1990. Indeed, food production per inhabitant in Asia is ten percent higher today than food production per inhabitant in Africa, in spite of the very limited availability of arable land in Asia. In countries where industries and services are important and expanding, industrial crops provide a substantial contribution to GNP. These crops, however, no longer play the main role in economic growth and in the development of domestic agricultural markets (Malaysia: palm oil, rubber and cocoa; Thailand: rice). However, in countries with modest industrial and mining activities, industrial crops represent most of the exports (Ivory Coast: cocoa, coffee, and cotton; Uganda: coffee) and provides most of the hard currency that supports the imports of agricultural inputs. Thus, in many countries, the intensification of the whole farming system should be led by the intensification of commercial crops, which will induce the intensification of food crops. The decrease in the production of industrial crops per inhabitant in Africa is an important factor within the complex systems of constraints hampering the intensification of the farming systems and the increased use of farm inputs in this continent.

Table 3.1 presents the evolution of crop production in Africa and in Asia from 1980 to 1990. As far as food crops are concerned, the production of paddy, coarse grains, roots, and tubers increased at a faster rate than the population growth in Africa, but the production of wheat, maize, pulses, oilseeds, fruit, and vegetables did not match the population growth rate. Thus, the diversification of food crops failed. In Asia, however, the increase in root and tuber production was much lower than the population growth rate, and the production of coarse grains decreased. This decline in production was largely compensated for by considerable progress in the production of wheat, rice, and maize. The production of oilseeds has increased tremendously during the last decade in Asia and the production of fruit and vegetables has also increased significantly. Thus, in Asia, the diversification of food crop production has been successful and has been achieved within a framework of considerable progress in food production. In Asia, all industrial crops, except coconuts, increased at a higher rate than population growth. Huge progress was achieved in the production of cocoa, palm oil, and tobacco, and considerable progress was registered for coffee, sugarcane, sugar beets and cotton. In Africa, increases in the production of tea, cotton, rubber, coconuts, and tobacco exceeded the population increase, but in all other sectors progress was low compared to Asia and could not match the population increase.

Table 3.2 presents the evolution of fertilizer use and food crop yields in Asia and in Sub-Saharan Africa. Crop yields in 1980 were much higher in Asia than in Africa. The gap increased greatly for all crops, with the exception of sugarcane. In fact, while most Asian sugarcane is produced by small-scale farmers, most of the sugarcane in Africa is produced by large industrial estates using large quantities of inputs. The limited development of irrigated land in Africa compared to the prevailing situation in Asia is responsible for the difference in yields between the two regions both in 1980 and in 1990. However, during this period, progress in irrigation was low on both continents, while the yield gap grew as a result of progress in Asian agriculture. Consequently, irrigated land increased by 23.8 percent in Asia (from 3.4 percent of arable land in 1980 to 4 percent in 1990), while it increased by only 16.4 percent in Africa (from 26.5 percent of arable land in 1980 to 29.5 percent in 1990). The development of the use of mineral fertilizers combined with further progress in the use of high-yielding varieties explains the widening of the yield gap much better than does the development of the irrigated land.

In Asia, cropped area represented 86.5 percent of arable land in 1980 and 84.9 percent of arable land in 1990. Further cropping intensity, resulting from the number of crops cultivated each year on the same land, exceeds one and may even reach two in some agricultural regions of Asia. Consequently, more than 70 percent of arable land is cropped each year. Since cropped area increased by only 2.87 percent between 1980 and 1990, the increase in crop production is thus mainly related to the intensification of the cropping systems. In Sub-Saharan Africa, cropped area represented only 53.5 percent of arable land in 1980 and 59.3 percent of arable land in 1990. Cropping intensity is low, and two crops per year may only be harvested in the Sudan-Guinean and Guinean areas where two rainy seasons occur each year. Between 1980 and 1990, the cropped area increased by 16.04 percent and led to over 50 percent of the increase in food crop production on the continent. The strategy of most farmers in Africa is based on expanding the cropped area and mobilizing plant nutrients from the soils and the natural vegetation. Thus, the consumption of mineral fertilizers has not developed significantly during the last decade and remains low. By contrast, in the developing Asian countries, consumption of mineral fertilizers increased by 91 percent between 1980 and 1990.

In Asia, the present average consumption of mineral fertilizers varies greatly from one country to another. Figures 3.1 and 3.2 present the evolution of the availability of arable land per head and of fertilizer use per hectare in Asian countries, grouped by agro-ecological zones. Consumption of mineral fertilizers increased rapidly in the humid north Asian countries (China, Democratic Republic of Korea, Republic of Korea), and where consumption in 1990 was already high or very high (Figure 3.1). Consumption in south-equatorial Asia (Indonesia and Malaysia) started in the early 1970s and is today quite important (Figure 3.2).

In Sri Lanka, fertilizer use grew during the 1970s. Since 1980 however consumption has not improved harmoniously because of the general economic crisis within the country. In the Indian sub-continent, mineral fertilizer consumption also started during the early 1970s, but growth has been relatively moderate--70-100 kilograms applied per hectare. Consumption of mineral fertilizers also started in the early 1970s in the Philippines and Vietnam, while in Thailand, it began only in 1985, increasing rice exports. In dry northern Asia, the availability of gas boosted the consumption of mineral fertilizers in Iran since 1980, while consumption is still low in the Himalayan range and in Mongolia. In the south Asian region, with a long dry season, the consumption of mineral fertilizers remains low.

In fact, the comparison between the development of the use of mineral fertilizers and the decrease in the arable land per inhabitant from 1960 to 1990 shows that in northern Asia the consumption of mineral fertilizers started when the available arable land was less than 0.3 hectares per person, and it progressed very rapidly when the arable land was less than 0.15 hectares per person. This first use of mineral fertilizers took place even with a higher threshold of available arable land in Iran (0.4 hectares per head). In China, Nepal, and the Republic of Korea, the consumption of mineral fertilizers started when the availability of arable land was less than 0.15 hectares per inhabitant, which is certainly related to intense transfers of plant nutrients from non-cropped areas (hills and mountains) to cropped areas in these countries.

In southern Asia, mineral fertilizer use has been relatively high since 1960 in Malaysia, when the available arable land per head still exceeded 0.2 hectares, because of the importance of high-value perennial crops in this country. In Thailand, with more than 0.35 hectares of arable land per head, the use of mineral fertilizers was boosted from 1980 in support of rice exports. In the Philippines, the consumption of fertilizers started in the late 1960s with 0.2 hectares of arable land per head, but the increase in consumption was slow, up to the moment when the arable land per head was close to 0.125 kilograms (in 1985), then, consumption increased rapidly. In Bangladesh, Indonesia, and Vietnam, consumption of mineral fertilizers began when the arable land per head decreased to 0.15 hectares and really took off when the arable land per head was lower than 0.125 hectares. In Sri Lanka, the development of fertilizer consumption has been slow, in spite of the scarcity of the land, which could explain the important degree of poverty in rural areas in this country. The ready availability of land has not favored the intensification of the cropping systems in Cambodia, Laos, and Myanmar, as has been the case in Afghanistan, in northern Asia, and in Mongolia.

Thus, from the driest regions of Asia to the most humid parts of the continent, land scarcity has pressed farmers to increase the use of mineral fertilizers. The threshold level of arable land per inhabitant in Asia from which the consumption of fertilizers started is increasing regularly, from 0.125 hectares in the southeast to 0.15 hectares in the east and south; from 0.3 hectares in the Indian sub-continent to 0.4 hectares in western Asia.

It is interesting to compare the evolution of arable land per inhabitant and fertilizer consumption in Sub-Saharan African countries with that of Asian countries. In the semi-arid countries of Africa, South Africa, Swaziland, and Zimbabwe, heavy fertilizer use is related to the relatively high development of the economy and to the export of agricultural products. In Ethiopia, the Gambia, Lesotho and Mozambique, the consumption of mineral fertilizers started, like in India and in Pakistan, when the availability of arable land per head was close to 0.3 hectares. However, the development of fertilizer use was much lower when the scarcity of land increased in these African countries than in the dry Asian countries. In Kenya and Tanzania, the consumption of mineral fertilizers began when the arable land per head was lower than 0.2 hectares. However, the development of fertilizer use failed when the arable land became increasingly scarce. Thus, in Angola, Benin, Burkina Faso, Guinea Bissau, Mali, and Senegal, the availability of the land is still high compared to India and Pakistan and this situation does not favor the intensification of the cropping systems, with the exception of specific situations, where commodity markets (rice, maize, cotton) are expanding. In Cape Verde, Ethiopia, the Gambia, Kenya, Lesotho, Mauritania, Mozambique, Sierra Leone, Somalia, and Tanzania, mineral fertilizers use is insufficient by Asian standards. In Botswana, Chad, Namibia, Niger, Sudan, and Zambia, land is still readily available and fertilizer use should be limited to the irrigated or to the most humid areas.

In the humid countries of Sub-Saharan Africa, fertilizer consumption began early on a limited scale in Ivory Coast and Nigeria, but consumption growth has been slow, since the price of cash crops has not been favorable for 15 years. In Malawi and Togo, the consumption of mineral fertilizers took off when the availability of arable land per head was lower than 0.22-0.25 hectares, which fits with Asian standards in corresponding climatic conditions. However, the same evolution stopped in Ghana in the early 1970s and in Liberia in the late 1970s, which created a different situation for food self-sufficiency in these countries. In Burundi and in Madagascar, access conditions for arable land should have favored the take off in fertilizer use for at least the past five to ten years, thus following the favorable development observed in Malawi and Togo. In Zaire, no development in fertilizer use occurred during a period of ten years, during which time the take off in fertilizer consumption should have begun. The extremely low development of mineral fertilizer use in Guinea and Rwanda has certainly played an important role in the present shortage of food in these countries. By Asian standards, the actual average consumption should be about 25 kilograms per hectare in Rwanda and 60 kilograms per hectare in Guinea. In Congo, from 1960 to 1970, the development of the use of mineral fertilizers was remarkably comparable to the evolution registered in Bangladesh and Indonesia, where 50 kilograms per hectare was applied when the arable land per head was under 0.11 hectares. However, unfavorable economic conditions rapidly reduced the profitability of fertilizer use, and today the country imports more than 60 percent of food. In Cameroon and Central Africa, land is readily available and the conditions required for the use of mineral fertilizers are limited to specific situations. In Gabon and Uganda, arable land is still readily available and fertilizers are hardly profitable.

In conclusion, in many African countries, the availability of arable land is not a limiting factor forcing farmers into agricultural intensification, even if climatic and ecological risks and low productivity of human labor limit the availability of food to low levels. In some humid African countries with high population pressures, mineral fertilizer use should be rapidly increased in order to significantly improve the food demand and supply balance. Moreover, in these countries, the climatic conditions are favorable for a high fertilizer use efficiency. In most semi-arid countries of Sub-Saharan Africa, the population density on arable land has already created or will soon create a strong demand for fertilizers, as evaluated through the comparison with Asian standards. However, the lack of irrigation and the vagaries of rainfall create unfavorable conditions for good fertilizer use efficiency in these countries. In addition, improper economic policies and weak domestic markets have deterred farmers from producing surpluses.

FERTILIZER USE AND NUTRIENT MANAGEMENT IN CHINA

The contrasts between the development of agricultural intensification in northern Asia and in semi-arid Sub-Saharan Africa are very important. The analysis of the development of mineral fertilizers use and of agricultural production in China shows how a process of on-farm plant nutrient recycling has been monitored.

From 1960 to 1990, the population of China increased by 74 percent (less than 1.9 percent per year on average). However, through urbanization and land degradation, the total arable land decreased by 16.8 percent during the same period (0.52 percent per year). During this period the cropped area decreased by 5.5 percent and the cropping index went up from 1.24 to 1.41, in particular through the development of irrigated areas (from 28.6 percent to 45.2 percent of the arable land). Cereal production increased by a factor of 2.5 during the period, and the total production of equivalent grains grew by a factor of 2.3. Thus, in spite of the population growth, the availability of agricultural products per inhabitant increased 32 percent, from 330 kilograms to 436 kilograms in equivalent cereal terms. These results were made possible, in particular, by a steady increase in the use of mineral fertilizers. Fertilizer consumption rose from 1.45 million tons in 1960 to 29.15 million tons in 1992. Table 3.3 illustrates the sharp rise in crop yields registered in China during the period.

Traditionally, in China a large part of the plant nutrients in crop residues are recycled, either directly or through manures. In addition, a substantial proportion of grain is consumed by domestic animals (pigs), which contributes to the production of manure. Moreover, a significant proportion of domestic and human wastes have traditionally been recycled in agriculture as well. Although this source of plant nutrients is not accounted for here, it is possible, from available data on crop production and animal population, to estimate plant nutrient balances.

Of course, the data presented depends greatly on the calculations and estimates that have been developed. Much of the data requires checking through accurate surveys and studies in the country. However, this modeling exercise has the merit of highlighting the main problems in improving the efficiency of plant nutrient management in Chinese agriculture. It is thus possible to estimate the role of the various sources of each nutrient in the total supply, and to compare their balance with the balances observed where only mineral fertilizers are accounted for, and where no fertilizers are applied.

As indicated above, reference values have been used to estimate the plant nutrient content of the various sources presented in Table 3.4. Table 3.5 indicates the supply of N, P_2O_5, and K_2O from the main local sources and from fertilizers during the period 1949 to 1990, and the corresponding dose per hectare of cropped land of supplied nutrients.

The total supply of nitrogen (N) per hectare of cropped area grew by a factor of 2.5 between 1949 and 1970, and by a factor of 3.9 between 1970 and 1980. N fertilizer supply per hectare was negligible in 1949. By 1970, it represented 41 percent of the total supply of N, and reached 70 percent of total supply in 1990. The supply of N per hectare of cropped area from local sources increased by 50 percent between 1949 and 1970, and by 94 percent between 1970 and 1990. This reflects a change in nutrient supply annual expenditures on mineral fertilizers to nutrients recycled from crop residues, manure and N fixation. Since 1985, total N supply has been high compared to the average yields in cereals, but the share of the various sources of N has not altered significantly, while the total supply of N has increased by 66 percent.

The total supply of phosphate (P_2O_5) per hectare of cropped area increased by a factor of 2.15 from 1949 to 1970, and by a factor of 3.83 from 1970 to 1990. Phosphorus (P) fertilizers represented only 29 percent of the total supply in 1970, and 61 percent in 1990. The dose of P_2O_5 supplied per hectare of cropped area from local sources increased by 55 percent between 1949 and 1970, and by 111 percent between 1970 and 1990, reflecting a transfer from annual fertilizer expenditure to nutrients sources from crop residues and manure. The dose of P_2O_5 from such recycling was low in 1990. This is the result of a continuing imbalanced supply of N and P since the beginning of fertilizer use. The optimal N/P_2O_5 ratio from all sources is close to 2.4 for an average cerearl yield of 1.5 tons per hectare, to 2.5 for average cereal yields between 1.5 and 2.5 tons per hectare, to 2.6 for average cereal yields between 2.5 and 3.5 tons per hectare, and to 2.7 for average cereal yields between 3.5 and 4.5 tons per hectare. Therefore, in order to take the best advantage of the total N supply, the supply of all sources of P_2O_5 should have reached 2.385 million tons in 1966 against the actual 2.109 million tons, 3.153 million tons in 1970 against 2.669 million tons, and 3.8 million tons in 1975 against 3.48 million tons. Soil reserves may have provided a large part of the complementary phosphorus (1.9 kilograms per hectare per year in 1966, 3.3 kilograms per hectare in 1970, and 2.2 kilograms per hectare in 1975), representing an average mining of 23 kilograms of P_2O_5 per hectare just to compensate for excessive N application during these ten years. Since 1975, fertilizer supply imbalances have been severe. The supply of all sources of P_2O_5 should have reached 6.89 million tons against 5.34 million tons in 1980; 7.97 million tons against 5.90 million tons in 1985; and 10.21 million tons against 9.62 million tons in 1990. The required corresponding supply from soil reserves was 11 kilograms per hectare of P_2O_5 in 1980, 15.7 kilograms per hectare of P_2O_5 in 1985, and only 4.3 kilograms per hectare of P_2O_5 in 1990. The theoretical corresponding mining of soil P_2O_5 reserves was 32 kilograms per hectare between 1975 and 1980, 90 kilograms per hectare between 1980 and 1985, and 43 kilograms per hectare between 1985 and 1990, with a total of 145 kilograms per hectare of P_2O_5 during the last 15 years. Such a supply has certainly been impossible, even if a certain amount of phosphorus may have been transferred each year from reserves not available to the crops to reserves available to the crops. Thus, crops have certainly been deficient in P_2O_5, which in turn has reduced the yields from what they might have been.

Therefore, losses of nitrogen from excessive N fertilizer supply have certainly been enormous since 1975. If soil reserves are able to provide sustainably one kilogram of P_2O_5 per year without jeopardizing the fertility of the soil, it can be estimated that 0.81 million tons of N were wasted in 1970, that no N fertilizers were over-supplied in 1975, that 3.65 million tons of N were over-supplied in 1980, that 4.4 million tons of N were over-supplied in 1985, and that only 1.24 million tons of N were over-supplied in 1990, thanks to a sharp increase of the consumption of phosphate fertilizers.

The total supply of potash (K_2O) per hectare of cropped area meanwhile increased by a factor of 1.59 between 1949 and 1970, and by a factor of 2.2 between 1970 and 1990. However, the supply of K_2O from K fertilizers remained below ten percent of the total supply in 1990. The P_2O_5/K_2O ratio has regularly decreased since 1949. The ratio has been close to two to one only since 1990. Thus, the availability of potash has probably not been a limiting factor on crop yields, at the national level until recently. Potash deficiency is present in the tropical zone of China in high intensification conditions, while no deficiency has been registered in the temperate part of the country where moderate agricultural intensification has occurred. Improved management of crop residues and manure could increase the availability of potash for crops.

Analysis of the components of the plant nutrient supply to cropped areas in China indicates that while the consumption of mineral fertilizers has been increasing sharply since the mid-1970s, in 1990 the share of organic sources in the total supply of potash was still over 80 percent, the corresponding share of phosphorus supply was still close to 40 percent, and the share of N supply was close to 25 percent of the total supply. Thus, the recycling of crop residues and waste continue to play a major role in potash recycling and the balance of plant nutrient supply, as mineral fertilizers mainly supply nitrogen and to a lesser degree phosphorus. As manuring has been a traditional practice in China, the important role of livestock in the farming system explains the importance of manure in plant nutrient supply. Since 1990, there has been a shift in plant nutrient supplies from mineral fertilizers to crop residues and manure (up to 30 percent of the nutrient supply). The Chinese example thus shows how effective management of all nutrient sources (mineral fertilizers, animal and green manures, and crop residues) can provide sufficient levels of nutrients for high crop yields. The efficiency of the livestock channel for recycling nutrients is poor with enormous losses, which may to a large extent explain the pollution problems related to nitrate leaching in China. Improvements in waste recycling would probably save a sizeable quantity of the nutrients, but the logistics of supplying the bulky source of nutrient could exacerbate the country's existing transport infrastructure and facility problems.

The recycling of crop residues and animal waste cannot fully compensate for the increased demand of nutrients for the intensification of cropping systems and nutrient losses. The supplies of N and P fertilizers in the system are imbalanced, which in turn deteriorates the N/P_2O_5 and P_2O_5/K_2O ratios. Thus, the supply of potash (and sulphur) to crops through mineral fertilizers is increasingly required. This is costly for China, which does not have any significant potash supplies. The effect could however by minimized through the adoption of more efficient recycling processes.

Agriculture in China has become increasingly productive, thanks to the increase in plant nutrient supply from all available sources, which increased from 84 kilograms per hectare in 1960 to 406 kilograms per hectare in 1990. Up to 1975, the productivity of the supplied nutrients was 11.25 kilograms of cereal equivalent grain per kilogram of fertilizer (N, P_2O_5, K_2O). with an acceptable ratio of N/P_2O_5 ratio around 2.84 and a P_2O_5/K_2O ratio of 0.34. Between 1975 and 1980, the productivity of the supplied nutrients fell to 3.26 kilograms of cereal equivalent grains per kilogram of fertilizer (N, P_2O_5, K_2O) which resulted from an excessive increase in the supply of N fertilizers compared to P fertilizers. The situation improved between 1980 and 1985, possibly through new generations of high yielding varieties using the supplied nitrogen more efficiently, because the N/P_2O_5 ratio was even worse (11.9 kilograms equivalent cereals per kilogram of supplied $N+P_2O_5+K_2O$). Since 1985, the productivity of the supplied nutrients has fallen again in spite of an improvement in the N/P_2O_5 and P_2O_5/K_2O ratios. At the present level of plant nutrient supply, the losses of plant nutrients are certainly high, a fact which is mainly related to the losses of nitrogen within the crop residues + grains - livestock - manure system prevailing in China (4.4 kilograms equivalent cereals per kilogram of supplied $N+P_2O_5+K_2O$).

The problems related to the falling efficiency of the supplied plant nutrients with the increase in the dose of supplied nutrients have been underlined in an FAO/AGLN publication on fertilizer use and rice production. Chronograms of rice yields versus fertilizers in all Asian countries indicate a series of segments of curves corresponding to the importance of the use of high yielding varieties and of irrigated areas. Using data from all Asian countries, between 1960 and 1990, a response curve of rice to fertilizer supply at the national level was proposed, with various levels corresponding to the importance of irrigated crops compared to lowland crops and rainfed crops. The curve indicated that the low productivity of fertilizers in China between 1975 and 1980 and between 1985 and 1990 was largely due to the stagnation of rice yields.

REQUIREMENTS FOR INCREASED FERTILIZER USE IN SEMI-ARID AFRICA

Data (BDPA) for the period 1955 to 1982 on the evolution of crop yields for millet, groundnuts, sorghum and maize in semi-arid countries of western Sub-Saharan Africa indicate that for millet grown without fertilizer in Burkina Faso, Mali and Niger, average yields are greatly affected by the vagaries of rainfall. Yield levels did not decrease during the 27 years. Thus, models indicating heavy mining of plant nutrients in these areas have overestimated plant nutrient losses. However, sorghum yields in Niger were badly affected by the drought in 1970, where sorghum is mainly grown in the very dry zone through water harvesting techniques. In Senegal, fertilizers were supplied on the millet-groundnut system with two periods of crop intensification. During the first period, groundnut yields were improved by the supply of fertilizer, while during the second period, both groundnut and millet yields were improved by the supply of mineral fertilizers. In Burkina Faso, groundnuts have been grown without fertilizer supply and yields have always been much lower than in

Senegal. In Mali, the yields of groundnuts were also significantly improved through fertilizer use. Finally, in Mali, while millet yields have not improved in the traditional non-intensified cropping systems, maize yields have greatly improved since 1969, and particularly since 1980, through the use of fertilizers. The FAO Fertilizer Program in Burkina Faso, Ethiopia, the Gambia, Guinea Bissau, Senegal, Somalia, and Sudan has assessed the agronomic value of the sound use of mineral fertilizers in the semi-arid areas of Sub-Saharan Africa for over 35 years.

To illustrate the potential of agricultural intensification, the possible impact of the development of fertilizer use in the Gambia is presented here as an example (Table 3.6). In this country, since 1980, the production of cereals and groundnuts per inhabitant has been decreasing, while fertilizer use has been stagnant. Two scenarios are proposed for improving the welfare of the population and the corresponding fertilizer use requirements estimated from the response curves of the crops to fertilizer supply. In the Gambia, the availability of non-cropped arable land is already limited, with 184,000 hectares of cropped land in 1990. This cropped area should reach 190,000 hectares by 2000, and 200,000 hectares by 2010. In the low growth scenario, the production of cereals per inhabitant was projected to be stable at 120 kilograms from 1995, thanks to the expansion of cropped area from 50 percent to 67 percent between 1990 and 2015 and to the improvement in average yields. Population was estimated at 861,000 people in 1990, and it is projected to reach 1,717,000 people in 2015. The total production of groundnuts was 75,000 tons in 1990 and should be stable at 95,000 tons from 1995 onwards. Under these conditions, the consumption of mineral fertilizers should increase from 4,141 tons in 1990 to 15,438 tons in 2015 (from 22.6 to 75.3 kilograms per hectare $N+P_2O_5+K_2O$). In the high growth scenario, the production of cereals per inhabitant is projected to improve steadily up to 160 kilograms in 2015, and the production of groundnuts to increase to 156,000 tons in 2015, which will maintain production per head close to the present level and, thus, farmers' incomes. In this scenario, fertilizer consumption will reach 27,647 tons in 2015. In both scenarios, the rate of improvement in crop yields is within the farmers' reach and average yields are achievable. However, in order to realize these scenarios, radical change is needed in the fertilizer policies of the government and in the economic environment and education of the farmers to encourage investment in agriculture.

CONCLUSIONS

While considerable progress in crop production has been made in Asia through the rapid increase in the use of mineral fertilizers, especially in the countries where the shortage of arable land has made further enlargement of the cropped area difficult, in Africa, the availability of food for the population has not improved and the consumption of mineral fertilizers has not been developed. In many Sub-Saharan African countries the present average availability of arable land per head does not favor the intensification of the cropping systems when commodity prices are low and markets poorly organized. However, precise comparisons between African and Asian countries in comparable ecological conditions indicate that many African countries should have already increased their consumption of mineral fertilizers to support the improved welfare of the population.

Mineral fertilizers in U.S. dollars at the farmgate are in general much more expensive in Africa than in Asia. However, while in Asia most of the national currencies have been devalued compared to the U.S. dollar from 60 percent to 100 percent, the price of food crops has been systematically adjusted to international markets. In Africa, many national currencies have been devalued at least fivefold, but the prices of food crops have not been adjusted accordingly. Thus, African farmers, having less improved cropping techniques than most Asian farmers, have been severely affected by the unfavorable development in the ratios of crop prices to fertilizer prices. In addition, commercial channels are less efficient in Africa than in Asia.

The development of sustainable and correctly intensified agriculture to meet the growing demand of the populations requires sound strategies for the development of plant nutrition management and of the use of mineral fertilizers. These strategies should be supported by adequate social and economic policies, realities which require the adoption of complex regulations and incentives.

Table 3.1--Evolution of crop production in Asia (excluding West) and Sub-Saharan Africa, 1980 - 1990

Crop production	Africa			Asia		
	1980	1990	Progress	1980	1990	Progress
	(million tons)		(percent)	(million tons)		(percent)
Industrial crops						
Cocoa (beans)	1.04	1.34	28.8	0.06	0.41	583.3
Coconut (copra)	0.18	0.25	38.9	3.71	4.23	14.0
Coffee (green)	1.19	1.23	3.4	0.63	1.08	71.4
Palm oil	1.34	1.71	27.6	3.45	8.79	154.8
Rubber	0.20	0.28	40.0	3.55	4.60	29.6
Sugarcane	52.59	60.92	3.9	294.56	438.15	48.7
Sugar beets	-	-	-	22.21	35.07	57.9
Tea	0.20	0.32	60.0	1.48	1.99	34.5
Cotton lint	0.65	1.02	56.9	5.32	8.40	57.9
Tobacco	0.29	0.39	34.5	1.90	4.12	116.8
Food crops						
Wheat	3.38	4.11	21.6	115.33	174.98	51.7
Paddy rice	6.12	9.70	58.5	359.75	476.38	32.4
Maize	25.15	29.75	18.3	84.71	122.59	44.7
Other coarse grains	22.59	36.47	61.4	48.63	46.06	-5.3
Roots and tubers	72.88	102.14	32.9	216.90	230.63	6.3
Pulses	4.62	5.87	27.0	20.57	23.49	14.2
Oilseeds	7.64	9.40	23.0	44.89	74.30	65.5
Fruits	29.71	36.03	21.3	70.54	96.73	37.1
Vegetables	12.28	15.29	24.5	172.33	231.91	34.6
Total cereals	56.94	70.38	23.6	608.42	820.00	34.8
Total industrial	64.08	67.46	5.3	336.87	506.84	50.5
Total food crops	184.37	248.76	34.9	1,033.65	1,477.08	42.9
Arable land (million hectares)	148.61	155.34	1.0	428.26	448.75	0
Total population (million)	382.50	526.30	35.5	2396.8	2867.1	19.6
Arable land/head (hectares)	0.338	0.296	-23.7	0.162	0.135	-16.4
Production industrial crops/head (kilograms)	167.5	128.2	-23.5	140.5	176.8	25.8
Production food crops/head (kilograms)	482.0	472.7	- 1.9	431.3	515.2	19.5

Source: FAO Production Yearbook, vol. 45, 1991.

Table 3.2--Evolution of fertilizer use and food crop yields in Asia and in Sub-Saharan Africa, 1980-1990

	Africa				Asia (developing countries)			
	1980		1990		1980		1990	
Consumption of mineral fertilizers (t)	2,120,000		2,046,000		25,799,000		49,259,000	
Average fertilizer dose (kg/ha)	14.3		13.5		60.2		109.8	
Arable land (ha)	148,612,000		155,342,000		428,257,000		448,752,000	
Irrigated land (ha)	4,994,000		6,185,000		113,443,000		132,161,000	
	Yield	Cropped area	Yield	Cropped area	Yield	Cropped area	Yield	Cropped area
	(kg/ha)	(1,000 ha)	(kg/ha)	(1,000/ha)	(kg/ha)	(1,000 ha)	(kg/ha)	(1,000 ha)
Millet	666	11553	750	13393	683	22841	855	18454
Sorghum	868	13528	736	15063	954	19854	1088	16693
Maize	1472	17088	1451	19623	2330	36364	3307	39313
Rice	1349	4548	1595	5763	2753	125855	3566	131023
Wheat	1192	2838	1313	2897	1701	67439	2457	72190
Barley	1231	990	1078	1114	1447	5840	1659	5333
Groundnuts	710	6280	790	5866	1018	10833	1239	12946
Soybeans	695	311	907	419	1060	9560	1315	12503
Pulses	548	8416	518	11309	609	33611	694	33064
Cassava	6869	7185	7966	8484	11645	3788	12957	3918
Yams	7744	1378	9869	2012	2555	8	3971	7
Potatoes	6882	399	7697	466	11172	3687	12354	4530
Sweet potatoes	5407	1002	4912	1428	13322	9317	15499	7301
Sugarcane	62	847	55	1106	52	5662	59	7384
Cottonseed	605	3,080	828	3,242	940	15,596	1,492	16,209

Source: FAO Production Yearbook, vol. 45, 1991 and FAO Fertilizer Yearbook, vol. 41, 1991.

Table 3.3--Crop yields in China (official statements corrected in 1985, and modeling the correction from 1960 to 1985)

Crop	1949	1960	1966	1970	1975	1980	1985	1990
				(kilograms per hectare)				
Cereals								
Wheat	690	882	929	1046	1419	1872	2951	3194
Barley	1119	1270	1250	1212	1820	2420	2854	3125
Rye	650	850	900	1071	1340	1591	1429	1385
Oats	762	852	860	971	1071	1500	1250	1071
Maize	1444	1974	2130	2556	2999	3238	3546	4522
Millet	550	710	1095	1323	1390	1458	1702	1974
Sorghum	800	1183	1500	2002	2300	2607	2842	3576
Sugar crops								
Sugarcane	35200	53400	58800	53734	57800	54170	58199	58846
Sugar beets	11,830	20,122	20,000	22,039	27,627	19,106	21,800	21,679
Root tubers								
Potatoes	6346	8411	8358	9083	10346	10847	11376	11322
Sweet potatoes	6369	8411	8571	7986	9489	8231	10018	10000
Cassava	12500	13250	12500	12062	15036	13061	15732	13920
Taro	11,290	11,806	11,875	11,667	12,105	12,666	11,822	13,808
Pulses								
Dry beans	631	674	703	695	843	1008	1153	1281
Dry peas	910	890	912	1114	1022	1080	1188	1362
Dry broad beans	985	1,019	1,016	1,009	1,133	1,161	1,353	1,500
Oilseeds								
Soybeans	810	800	820	842	853	1042	1426	1455
Groundnuts	1150	1150	1192	1108	1306	1574	1902	2186
Cottonseed	390	493	618	634	1000	1030	1566	1613
Linseed	383	369	400	416	444	648	742	813
Rape seed	302	338	364	425	486	769	1129	1264
Sesame seed	360	380	410	410	422	324	768	701
Sunflower seed	1200	1250	1250	1270	1276	1375	1597	1879
Castor beans	310	370	490	500	585	609	795	1,055

Source: FAO Production Yearbook, various issues.

Table 3.4--Plant nutrient content by nutrient source

Plant nutrient source	Plant nutrient content			
	N	P_2O_5	K_2O	Total
	(kilogram/ton)			
Crop residues				
Cereals	9.7	6.1	27.0	42.8
Roots and tubers	2.6	0.9	2.6	6.1
Oilseeds and pulses	13.9	4.0	21.9	39.8
Sugar crops	3.2	0.9	6.3	10.4
Manure	10.0	5.0	20.0	35.0
Rain and dust	2.0	1.0	3.0	6.0
Irrigation water	5.0	0	20.0	25.0

Source: Compilation of various sources.

Table 3.5--Supplied dose of plant nutrients on the cropped area in China

Source of nutrients	1949	1960	1966	1970	1975	1980	1985	1990
	(kilograms per hectare)							
N								
Crop residues	4.6	2.4	3.9	5.7	6.7	8.8	13.6	17.3
N fixation	3.4	3.8	4.0	4.3	4.5	4.4	7.1	6.5
Rain and dust	1.7	1.7	1.7	1.7	1.8	1.5	1.5	1.4
Irrigation	1.0	1.3	1.3	1.4	1.5	1.6	1.7	1.8
Manures	9.8	13.9	14.3	17.6	20.6	24.7	30	32.6
Total local sources	20.5	23.1	25.2	30.7	35.1	41.0	53.9	59.6
Fertilizers	0.3	6.5	13.7	21.5	29.8	85.6	103.7	142.6
Total supply	20.8	29.6	38.9	52.2	64.9	126.6	157.6	202.2
P_20_5								
Crop residues	2.7	1.4	2.7	3.4	4.0	5.3	8.1	10.4
Rain and dust	0.8	0.8	0.8	0.8	0.9	0.7	0.7	0.7
Manures	4.9	7.0	7.2	8.8	10.3	12.0	15.1	16.3
Total local source	8.4	9.2	10.7	13.0	15.2	18.4	23.9	27.4
Fertilizers	0.1	2.7	3.7	5.4	8.5	19.4	21.0	43.1
Total supply	8.5	11.9	14.4	18.4	23.7	37.8	44.9	70.5
K_20								
Crop residues	12.2	6.2	10.9	15.1	17.7	23.6	36.3	46.3
Rain and dust	2.5	2.4	2.5	2.6	2.6	2.2	2.2	2.1
Irrigation	4.0	5.3	5.4	5.6	5.8	6.4	6.9	7.0
Manures	19.5	27.9	28.6	35.1	41.5	49.4	60.0	65.3
Total local source	38.2	41.8	47.4	58.4	67.6	81.6	105.4	120.7
Fertilizers	0	0.8	1.5	2.2	2.8	3.4	3.3	12.5
Total supply	38.2	42.6	48.9	60.6	70.4	85.0	108.7	133.2
Total N + P_20_5 + K_20	67.5	84.1	102.2	131.2	159.0	249.4	311.2	405.9

Source: Compilation from various sources and estimates.

Table 3.6--Scenarios for the development of crop production in the Gambia

Scenario	1980	1985	1990	1995	2000	2005	2010	2015
Low growth								
Cereals								
Kilogram/head	123.7	155.8	104.8	120	120	120	120	120
Yield (kg/ha)	1,186	1,085	1,102	1,214	1,293	1,350	1,414	1,503
Acreage (1,000 ha)	64.4	93.6	91.5	97.7	105.3	115.8	126.9	137.1
Groundnuts								
Kilograms/head	93.9	101.7	86.5	98.2	83.7	72.9	63.5	55.3
Yield (kilograms/ha)	730	1,150	809	1,111	1,122	1,200	1,300	1,400
Acreage (1,000 ha)	82.5	65.9	92.1	87.3	84.7	79.2	73.1	67.9
Fertilizers								
Consumption (t)	3,041	3,849	4,141	7,223	8,423	10,282	12,688	15,438
Dose (kilograms/ha)	20.7	24.1	22.6	39.0	44.3	52.7	63.4	75.3
High growth								
Cereals								
Kilogram/head	123.7	155.8	104.8	125	130	140	150	160
Yield (kg/ha)	1,186	1,085	1,102	1,300	1,447	1,673	1,934	2,233
Acreage (1,000 ha)	64.4	93.6	91.5	95.0	102.0	109.0	116.0	123.0
Groundnuts								
Kilograms/head	93.9	101.7	86.5	108.0	103.4	99.1	94.9	90.8
Yield (kilograms/ha)	730	1,150	809	1,186	1,334	1,501	1,690	1,902
Acreage (1,000 ha)	82.5	65.9	92.1	90.0	88.0	86.0	84.0	82.0
Fertilizers								
Consumption (t)	3,041	3,849	4,141	6,470	10,592	14,719	20,137	27,647
Dose (kilograms/ha)	20.7	24.1	22.6	35.0	55.7	75.5	100.7	134.9

Source: Modeling done in Plant Nutrition Management Service, FAO using data from FAO Production Yearbooks.

Figure 3.1--Fertilizer use and arable land per head in northern Asia, 1960-90

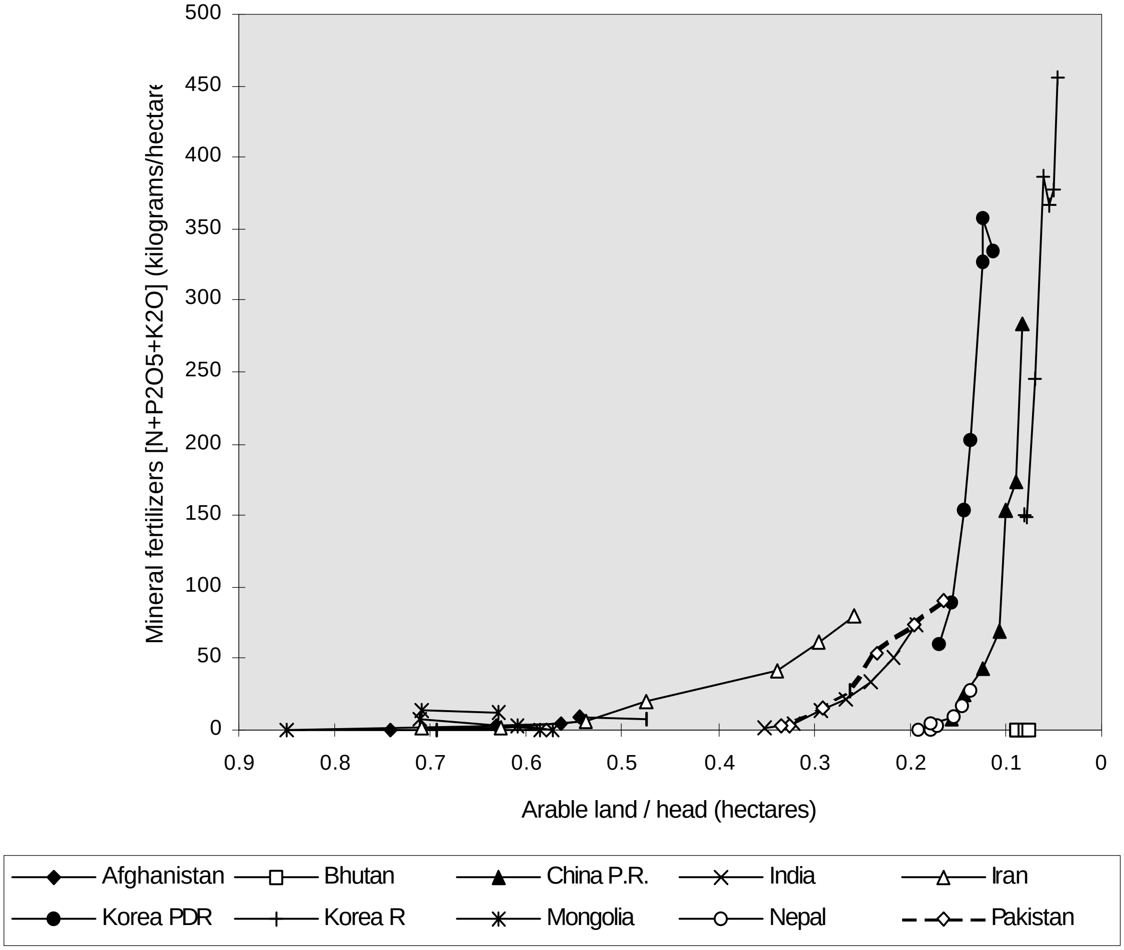
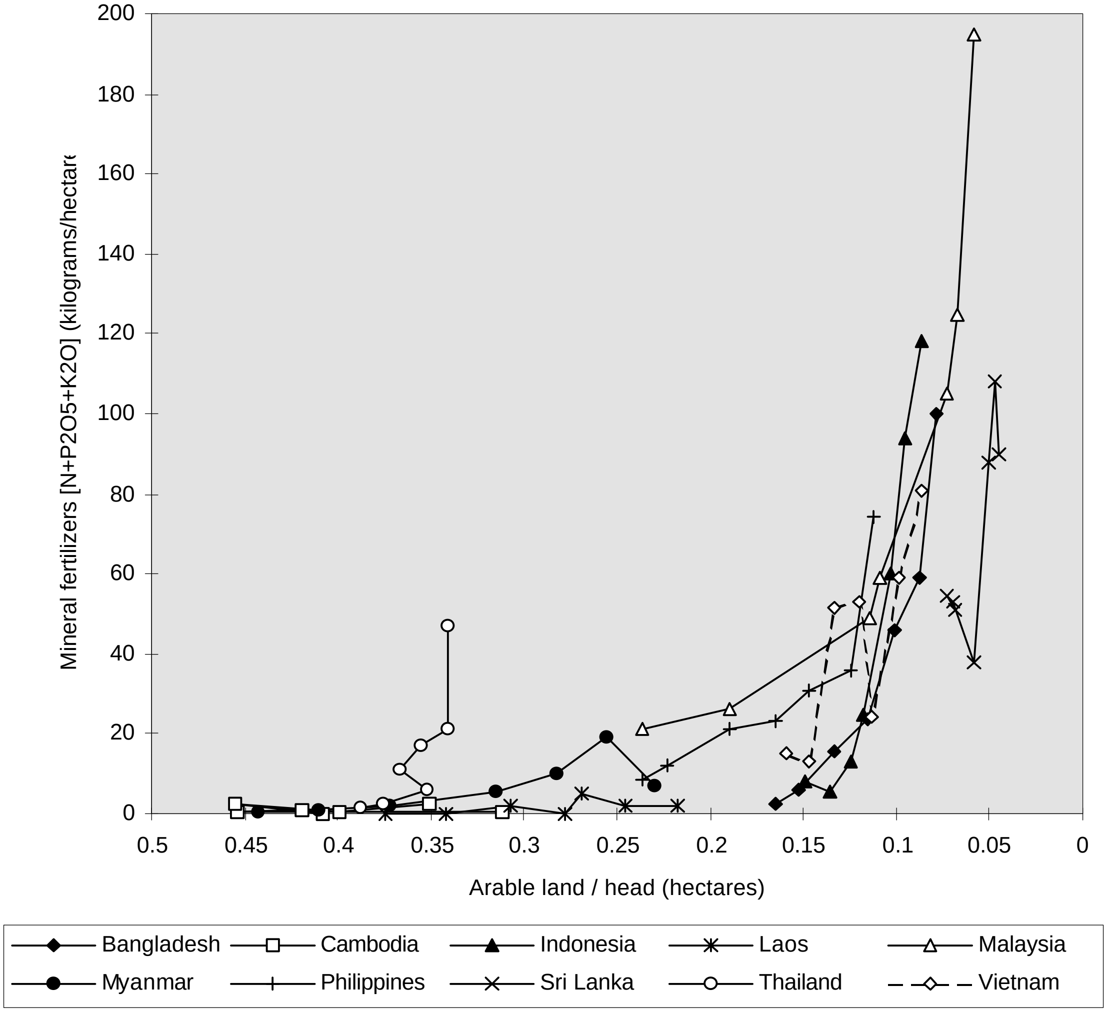


Figure 3.2--Fertilizer use and arable land per head in southern Asia, 1960-90



4. INTEGRATED CROP NUTRITION FOR SUSTAINABLE AGRICULTURE: TECHNOLOGY AND POLICY CHALLENGES

by Jules N. Pretty

THE SCALE OF THE IMMEDIATE CHALLENGE

> *"And the soil said to man: take good care of me or else, when I get hold of you, I will never let your soul go"* Kipsigis proverb, as told by Mr. Arap Keoch, Chemorir, Kenya, 1990.

Farmers and others involved in agricultural development face some extraordinary challenges over the next quarter century. By the year 2020, the world will have some 2.5 billion more people and cereal demand is expected to double to 2 billion tons annually in the Third World. Farmers will have to find ways of producing this extra food from current agricultural land, as any expansion into marginal lands would cause unacceptable environmental damage. This will also have to be done while protecting the environment, as so many “modern” practices and technologies have damaged natural resources.

This growth will be difficult. Although we produce enough food in aggregate to feed everyone in the world, some 700 million people do not have access to sufficient food. Hunger is common, even though world food prices have been falling in recent years. Some 1.1 billion people live in poverty, and 180 million children are underweight and suffer from malnutrition. Further, yield growth in cereals is declining; neither wheat nor rice yields have increased in the past five years. Current estimates suggest a global shortfall in cereals of 250-525 million tons by 2020-2025 (McCalla 1994; Pinstrup-Andersen and Pandya-Lorch 1994; Harris 1995).

The key question is, where is all this food going to come from? Or are we on course for an unprecedented Malthusian disaster, with agricultural production reaching and passing ecological limits? There are four different sets of views on how we should approach these challenges (see McCalla 1994; Hazell 1995; Pretty 1995a for summaries). These vary from the downright pessimistic to the overly optimistic.

The *pessimists* suggest that ecological limits to growth are being approached (Harris 1995); are soon to be passed (Kendall and Pimentel 1994); or have already been reached (Brown and Kane 1994). It is said that populations are too great; yield growth has slowed, and will slow more, stop or even fall; no new technological breakthroughs can occur; and that environments have been thoroughly degraded. We are now, it is said, about to exceed the world's carrying capacity.

The *business-as-usual optimists* say there is no problem on the supply side, and that recent growth in food production will continue alongside reductions in population growth (Mitchell and Ingco 1993; FAO 1993; Simon and Kahn 1983). Technological innovations combined with more land under cultivation will keep food growth rising.

The *industrialized world to the rescue* lobby believes that the Third World will never be able to feed itself, for all sorts of ecological, institutional and infrastructural reasons, and so the food gap will have to be filled by modernized agriculture in the North (Avery 1995; Carruthers 1993). Increased production in large, mechanized operations will allow small and marginal farmers to go out of business, so protecting natural resources in zoos and wildernesses. The large producers will then be able to trade their food with those who need it, or have it distributed by famine relief.

The last two groups believe that biological yield increases are possible on current land, though they are fundamentally divided over what is the most appropriate approach. A strong lobby, the *"new modernists",* argues that growth can only come from high-external input farming, either on the existing Green Revolution lands, or expanded to the high-potential lands that have been missed by the past 30 years of agricultural development (Borlaug 1992, Borlaug 1994; Sasakawa/Global 2000 1993b; Sasakawa/Global 2000 1994; Paarlberg 1994; World Bank 1993; Waggoner 1994). This group firmly believes that many farmers use too few fertilizers and pesticides. These inputs are said to be the only way to improve yields and so keep the pressure off natural habitats. It is also commonly argued that resource-conserving technologies are low-input and so will always be low-output.

An alternative lobby, the *sustainable productionists* , believe that substantial growth is possible in currently unimproved or degraded areas whilst protecting or even regenerating natural resources (Pretty 1995a; Hazell 1995; McCalla 1994, McCalla 1995; Scoones 1994). Emerging empirical evidence is indicating that low-input agriculture can be highly productive, provided farmers participate fully in all stages of technology development and extension. This evidence also suggests that the concept of a fixed carrying capacity should be replaced by more plastic alternatives, with potential productivity being more a function of human capacity and ingenuity rather than simply of biological and physical processes.

Where most agree is that feeding another 2.5 billion will not be easy. It will require huge reforms in investment, institutions and policies.

DIVERGENT APPROACHES IN AGRICULTURAL DEVELOPMENT

If we set aside both the business-as-usual optimists and the total pessimists, most agree that agricultural production in the Third World will somehow have to grow substantially, probably by as much as 2 percent per year.

The difficulty will be determining which of the two divergent approaches should prevail. The "new modernists" suggest that the only way to achieve this growth is to continue to emphasize the use of external resources and inputs, particularly on the so-called "high-potential" lands. This modernized approach is what succeeded so well in the Green Revolution. The "sustainable productionists" indicate that there is now good evidence to show that significant yield growth is possible on formerly "unimproved" and "low-potential" lands using sustainable technologies. Some argue that these two are incompatible; others that they could be complementary.

MODERNIZED AGRICULTURE

The impact of modern agriculture has been remarkable. About half of the rice, wheat and maize areas in Third World countries are now planted to modern varieties. Farmers have intensified their use of external resources: nitrogen consumption increased from 2 to 75 million tons in the last 45 years; pesticide consumption in many individual countries has increased by 10-30 percent during the 1980s alone; and the area under irrigation grew from 100 to 170 million ha between 1960 and 1990. As a result, food production per capita has since the mid-1960s risen by 7 percent for the world as a whole, with the greatest increases in Asia (FAO, various). Between 70-90 percent of these increases in production have been due to increased yields, and the remainder to expanded area under agriculture (World Bank 1993).

There however have been two major problems with this external input centered approach: (1) access to inputs and to products and (2) adverse environmental and health impacts.

Modern agriculture begins on the research station, where researchers have access to all the necessary inputs at all the appropriate times. But when the package is extended to farmers, even the best performing farms cannot match the yields the researchers get. For high productivity per hectare, farmers need access to the whole package of modern seeds, water, labor, capital or credit, fertilizers and pesticides. But many poorer farming households simply cannot adopt the whole package. If one element is missing--the seed delivery system fails or the fertilizer arrives late, or there is insufficient irrigation water--then yields may not be much better than those for traditional varieties. Even if farmers want to use external resources, very often delivery systems are unable to supply them on time.

As a result, many people have missed out on the benefits of modern agriculture, and hunger still persists in many parts of the world. In Africa, for example, food production per capita fell by 20 percent between 1964-1992. Even though there is sufficient food produced worldwide to feed everyone, about 1.1 billion people are living in poverty and 700 million do not have access to sufficient food.

For the second problem, where production has been improved through modern technologies, all too often there has been adverse environmental and health impacts. These effects are a direct result of an increasingly intensive and specialized agriculture. For comparison, the mixed farm can be an almost closed system, generating few external impacts. Crop residues are fed to livestock or incorporated in the soil; manure is returned to the land in amounts that can be absorbed and utilized; legumes fix nitrogen; trees and hedges bind the soil and provide valuable fodder and fuelwood and habitats for predators of pests. In this way the components of the farm are complementary in their functions.

Over the last half century, many such highly integrated systems have disappeared. Farms have become more specialized with greater use of external inputs. These inputs, though, are never used entirely efficiently by the receiving crops or livestock. As a result, residual inputs are lost to the environment. Some 30-80 percent of applied nitrogen and significant but smaller amounts of applied pesticides are lost to the environment to contaminate water, food, fodder, and the atmosphere (Conway and Pretty 1991). Water is often also wasted or used inefficiently, leading to groundwater depletion, waterlogging, and salinity problems.

Many environmental problems have increased dramatically in recent years. These include:

- Contamination of water by pesticides, nitrates, soil and livestock wastes, which cause harm to wildlife, disruption of ecosystems, and health problems in drinking water;
- Contamination of food and fodder by residues of pesticides, nitrates, and antibiotics;
- Damage to farm and natural resources by pesticides, which cause harm to farmers and the public, disruption of ecosystems, and harm to wildlife;
- Contamination of the atmosphere by ammonia, nitrous oxide, methane and the products of burning, which play a role in ozone depletion, global warming, and atmospheric pollution;
- Overuse of natural resources, which cause depletion of groundwater and loss of wild foods and habitats, and of their capacity to absorb wastes, causing waterlogging and increased salinity;
- The tendency in agriculture to standardize and specialize by focusing on modern varieties, which displace traditional varieties and breeds;
- New health hazards for workers in the agrochemical and food-processing industries.

These costs of environmental damage are growing, and are dispersed throughout many environments and sectors of national economies (Conway and Pretty 1991).

SUSTAINABLE AGRICULTURE

During the past fifty years, agricultural development policies have been remarkably successful at emphasizing external inputs as the means to increase food production. These external inputs have, however, substituted for natural control processes and resources, rendering them more vulnerable. Pesticides have replaced biological, cultural and mechanical methods for controlling pests, weeds and diseases; inorganic fertilizers have substituted for livestock manures, composts and nitrogen-fixing crops; information for management decisions comes from input suppliers, researchers and extensionists rather than from local sources; and fossil fuels have substituted for locally-generated energy sources. The specialization of agricultural production and the associated decline of mixed farming have also contributed to this situation. What were once valued internal resources have often now become waste products.

The basic challenge for sustainable agriculture is to make better use of these internal resources. This can be done by minimizing the external inputs used, by regenerating internal resources more effectively, or by combinations of both. Sustainable agriculture, therefore, is any system of food or fiber production that systematically pursues the following goals:

- A more thorough incorporation of natural processes such as nutrient cycling, nitrogen fixation, and pest-predator relationships into agricultural production processes;
- A reduction in the use of those off-farm, external and non-renewable inputs with the greatest potential to damage the environment or harm the health of farmers and consumers, and a more targeted use of the remaining inputs used with a view to minimizing variable costs;
- A more equitable access to productive resources and opportunities, and progress towards more socially-just forms of agriculture;
- A greater productive use of the biological and genetic potential of plant and animal species;
- A greater productive use of local knowledge and practices, including innovative approaches not yet fully understood by scientists or widely adopted by farmers;

- An increase in self-reliance amongst farmers and rural people;
- An improvement in the match between cropping patterns and the productive potential and environmental constraints of climate and landscape to ensure long-term sustainability of current production levels; and
- Profitable and efficient production with an emphasis on integrated farm management and the conservation of soil, water, energy and biological resources.

When these components come together, farming becomes integrated, and resources are used more efficiently and effectively. Sustainable agriculture, therefore, strives for the integrated use of a wide range of pest, nutrient, soil and water management technologies. These are integrated at the farm level and tailored to the biophysical and socioeconomic conditions of the individual farms. In this way sustainable agriculture aims for increased diversity of enterprises within farms, combined with greater linkages and flows between them; the use ofby-products or wastes from one enterprise as an input for another; and reduced effects on the environment, as natural processes increasingly substitute for external inputs.

RECENT IMPACTS OF SUSTAINABLE AGRICULTURE

Emerging evidence suggests that regenerative and resource-conserving technologies and practices can bring both environmental and economic benefits for farmers, communities and nations (Figure 2.1). The best evidence comes from countries in Africa, Asia and Latin America, where the concern is to increase food production in the areas where farming has been largely untouched by the modern packages of externally-supplied technologies. In these complex and remote lands, some farming communities adopting regenerative technologies have substantially improved agricultural yields, often only using few or no external inputs (Bunch 1991, Bunch 1993; GTZ 1992; UNDP 1992; Lobo and Kochendörfer-Lucius 1992; Krishna 1993; Shah 1994; SWCB 1994; Balbarino and Alcober 1994; Pretty 1995a).

These are not however the only sites for successful sustainable agriculture. In high-input and generally irrigated lands, farmers adopting regenerative technologies have maintained yields whilst substantially reducing their use of inputs (Bagadion and Korten 1991; Kenmore 1991; van der Werf and de Jager 1992; UNDP 1992; Kamp *et al.* 1993; Pretty 1995a). And in the very high input lands of the industrialized countries , farmers have been able to maintain profitability, even though input use has been cut dramatically, such as in the USA (Liebhart *et al.* 1989; NRC 1989; Hanson *et al.* 1990; Faeth 1993; NAF 1994); and in Europe (El-Titi and Landes 1990; Vereijken 1990; Jordan *et al.* 1993; Pretty and Howes 1993; Reus *et al.* 1994).

All of these successes have elements in common (Figure 2.2). Farmers have made use of resource-conserving technologies, such as integrated pest management, soil and water conservation, integrated plant nutrition, regeneration and recycling, multiple cropping, water harvesting, and waste recycling. There has also been action by groups and communities at local levels, with farmers becoming experts at managing farms as ecosystems, and at collectively managing the watersheds or other resource units of which their farms form part. As well, there have been supportive and enabling external government and/or non-government institutions, often working in new partnerships with new participatory methodologies, which have reoriented their activities to focus on local needs and capabilities.

Most successes, though, are still localized and are simply islands of success. This is partly because favorable policy environments are missing. Most policies still actively encourage farming that is dependent on external inputs and technologies. It is these policy frameworks that are one of the principal barriers to a more sustainable agriculture (Pretty 1995a).

It is also partly because many scientists and policy makers still argue vigorously that the most certain way to feed the world is by increasing the adoption of modern varieties of crops and breeds of livestock, fertilizers, pesticides and machinery. Table 2.1 contains examples of the types of perspectives brought to the debates on the future of agricultural development. All make the point that the route to food security is through modern agriculture and external inputs. Some, such as the Nobel Laureate, Norman Borlaug, do so by vigorously putting down all alternatives, suggesting that unrealistic claims are made on behalf of alternative or sustainable agriculture. Others predict that if widespread starvation is to be averted, then *"soil fertility management based on anything other than increased chemical fertilizer would lead to massive increases in food imports"* (Vlek 1990). The FAO has estimated that over 50 percent of future gains in food crop yields will have to come from fertilizers.

At the same time, traditional agriculture is presented as environmentally destructive, so needing to be modernized; or as efficiently-managed systems which have hit a yield ceiling, so again needing modern technologies. Even where there have been recent shifts in emphasis, both in rhetoric and substantive policy, the Green Revolution model tends to be widely believed to be the *"only way to create productive employment and alleviate poverty"* (World Bank 1993).

Some of these perspectives clearly arise because the empirical evidence for the alternatives is not well understood, while others result from a diminution of the environmental and health costs of modern inputs.

ENVIRONMENTAL AND HEALTH PROBLEMS ASSOCIATED WITH FERTILIZERS

Fertilizers are not directly toxic either to wild animals and plants or to ourselves. Under certain conditions, though, they play an important role in chemical reactions in the environment that result in significant pollution.

Fertilizer losses to the environment

Fertilizers are contaminants of the environment rather than pollutants. Under certain conditions, however, they can give rise to eutrophication of rivers, lakes and coastal waters that cause environmental harm. Contamination arises because not all the fertilizer applied is taken up by crop plants. Fertilizer use has grown dramatically in recent years with average rates in the industrialized countries of 120-550 kg N/ha. Elsewhere, average rates are a great deal lower: about 30 kg N/ha in Asia, 15 kg N/ha in Latin America and only 4 kg N/ha in Africa. Much land receives no inorganic fertilizer at all.

Various factors, including rainfall, irrigation, soil and crop type, the mode of application, and the nature of the fertilizer added, affect the efficiency of fertilizer nitrogen uptake. Early sowing, for example, increases recovery in temperate cereal crops by extending the opportunity for nitrogen uptake. It also increases if early growth is vigorous, if rainfall and therefore leaching is low, or if there is little nitrogen already present in the soil. Recovery rates are lower in the tropics. Maximum recovery in rainfed crops is 50-60 percent of applied nitrogen, but seldom more than 30-40 percent for rice (de Datta 1986; Conway and Pretty 1991). The unique anaerobic conditions of paddy fields result in heavy losses of nitrogen, particularly though volatilisation as ammonia. Even under highly controlled conditions and with the best agronomic practices, recovery remains low.

Overall, these figures suggest that a high proportion of the applied nitrogen fertilizer can end up as an environmental contaminant. For industrialized countries, it is probably over 50 percent. It is likely to be higher in Third World countries (Conway and Pretty 1991). It is important, however, to appreciate that not all the nitrogen lost from crop fields is derived from fertilizer. A significant proportion also comes from natural stores of organic nitrogen in the soil, as well as following the application of manures and sewage effluents (Addiscott and Powlson 1989).

Much depends on local circumstances. If fertilizer rates are optimal and other conditions are favorable, then fertilizer may contribute little to nitrate leaching. Excessive applications however, can directly result in heavy losses, especially when rainfall, soils, and the absence of plant growth are conducive to high nitrate leaching.

Fertilizer contamination of surface and ground water systems

There is widespread evidence of progressively rising nitrate concentrations over the past three decades in both surface and groundwater. This is particularly true in regions of intensive agriculture in industrialized countries. In the UK and the USA, many rivers have concentrations approaching 50 mg of nitrate per liter.[1] In tropical and subtropical rivers, there are few reports of serious nitrate contamination, though this may merely reflect a lack of investigation. Ten of the major rivers of Asia, for example, average only 3.1 mg of nitrate per liter with a maximum of just 10 mg per liter. In India, a nationwide survey of 350 rivers did not find any with nitrate concentrations greater than 10 mg per liter. Where there are high concentrations in surface waters, such as in Sri Lanka, Zambia and Zimbabwe, contamination is mainly from sewage effluents (Conway and Pretty 1991).

Of greater consequence is nitrate contamination of groundwater. In many localities, both in industrialized and Third World countries, levels are high and rising fast (Conway and Pretty 1991). In the UK, at least 1.5 million people in eastern and central England receive water that exceeds 50 mg per liter. The problem will almost certainly get worse. Profiles from boreholes reveal "a nitrate front" some 3-8 meters below the surface, which is moving downward at about one meter per year. One source has been the ploughing up of grassland with consequent mineralization of organic soil nitrogen. High nitrogen levels are also present in profiles under land which has been continuously cultivated to arable crops. In this case, increased fertilizer applications appear to be the main source.

In the USA, high risks occur in many intensive agricultural regions across the whole country. A wide range of well surveys have shown many contaminated to levels that exceed

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[1] In Europe, the drinking water standard for nitrate is 50 mg NO_3 per liter; in the USA, it is 45 mg per liter. Some sources use nitrate-N as a measure: the equivalent standards are therefore 11.3 mg NO_3-N per liter and 10 mg NO_3-N per liter.

45 mg per liter. These include the Geological Survey, which found 7900 above 45 mg per liter out of 124,000 wells; and the American Water Works Association with 364 of 1583 wells (Conway and Pretty 1991; Nielson and Lee 1987). Shallow drinking wells present the greatest risk because of infrequent intermixing within aquifers which results in high nitrate concentrations in the surface layers. In Illinois, Arkansas and Wisconsin, about a quarter of shallow wells are contaminated, but only 2 percent of deep wells. Most hot spots of nitrate are linked to fertilizer use, particularly under intensive vegetable and fruit crops. In some places, though, livestock wastes are important, particularly in semi-arid areas where there are large feedlots.

There are increasing reports of contamination of groundwater in the tropics but, as with surface waters, the causes are usually other than fertilizers. In India, a nationwide survey of 3000 wells found that 20 percent had nitrate concentrations in excess of 50 mg per liter, and 3 percent with concentrations over 100 mg per liter (Handa 1983). In some cases, individual wells had concentrations of more than 1500 mg of nitrate per liter. At all sites, though, concentrations are greater in wells in villages compared with those in the fields, suggesting than contamination comes mainly from domestic wastes. In one study of an Indian village, a nitrate plume containing 900 mg/l was discovered. It was centered on the village, and stretched out in the direction of the groundwater flow. To the north, concentration fell to 45 mg per liter within 50 m; but to the south, the direction of the flow, these levels were not reached for 500 m (Cook and Das 1980).

Although fertilizers are rarely to blame for nitrate contamination in the Third World, there are examples of where they can cause serious problems under tropical conditions. In the Canary Islands off the coast of Africa, many groundwater supplies below agricultural lands are seriously contaminated because of the poor volcanic soils which require both irrigation and heavy nutrient applications (Custodio *et al.* 1984). In Gran Canaria, 12 percent of the groundwater supplies exceeded 60 mg per liter, with the most serious problems under banana groves which received some 600 kg N/ha/year.

The nutrients contained in fertilizers will not only promote the growth of crops but also of wild plants, including weeds in fields, wild flowers, shrubs and trees in nearby hedgerows, as well as algae and aquatic plants in rivers, lakes, estuaries and the sea. In general, levels of nutrients in excess of those normally present in natural ecosystems will result in considerable disturbances to plant and animal communities. Damage usually results from nitrogen and phosphorus in excess; there does not seem to be any undesirable effects of potassium in the environment.

The effects of added nutrients are most apparent in the aquatic environment. Algae are a particularly good indicator of the nutrient supply of lakes and rivers: the higher the level of nutrients, the greater is the algal population. The addition of fertilizers or sewage effluent greatly accelerates this process of nutrient enrichment or eutrophication. Algae multiply, producing a dense population that reduces light to the aquatic plants beneath, which may then die. In turn, invertebrates, fish and birds that depend directly and indirectly on the plants for food starve and may disappear. In deep stratified lakes the dense algal populations may sink to the lower layers. As they decomposed microbially, they remove the oxygen from the water, which in turn can lead to a rapid decline in fish populations, and under extreme conditions, make the body of water virtually lifeless (Moss 1988).

Serious cases of eutrophication have occurred in the USA and UK, and in a number of tropical rivers and lakes. Various coastal waters, including the Chesapeake Bay in the USA and parts of the North Sea, have also experienced massive growths of algal populations. Coral reefs are particularly at risk from increased nutrients, but coral dieback in Jamaica and Hawaii has mostly occurred from sewage wastes rather than fertilizers. Many harbors have become lifeless, again mainly from urban wastes.

Agriculture as a global polluter

Agriculture is also a major source of atmospheric pollution, producing significant amounts of methane, carbon dioxide, nitrous oxide and ammonia. About 45 percent of global methane emissions come from paddy fields, the guts of livestock and the burning of vegetation. Methane contributes to increased tropospheric ozone, the destruction of ozone in the stratosphere and to global warming (Sass 1994; Conway and Pretty 1991). Carbon dioxide is produced directly by agricultural practices that involve burning, and indirectly by energy-intensive practices and technologies. Ammonia arises mostly from volatilisation of nitrogen in livestock wastes, but also in small part from fertilizers. Ammonia losses are particularly high from fertilized paddy fields in the tropics and subtropics, usually 5-15 percent, but sometimes reaching 40-60 percent, of applied nitrogen (Fillery and Vlek 1986). Ammonia depositions can damage plant growth, and on a wider scale, contribute to acid rain (Conway and Pretty 1991).

Nitrous oxide (N_20) is the most significant atmospheric pollutant from fertilizers. N_20 is produced naturally by the action of bacteria in soils and water and by the burning of biomass and fossil fuels containing nitrogen. Up to 2 percent of nitrogen when applied as ammonium and urea compounds can be liberated as N_20, though the average loss from all fertilizers is lower. Atmospheric N_20 concentrations have steadily increased in the past 100 years, from 280 ppb to 310 in the mid-1990s. The current annual increase is mostly driven by fertilizer use. Estimates vary over how much fertilized land contributes to the total annual production of 14-20 million tons of N_20-N, but it would appear to be between 0.4-4 million tons (Mosier 1994; Watson *et al.* 1992; Duxbury and Mosier 1993; Bouwman 1994).

N_20 is important as it is converted in the atmosphere to nitric oxide, which contributes to the depletion of stratospheric ozone. Although it is not the only destroyer of ozone (molecules containing chlorine, bromine and hydroxide are more powerful), its impact is still significant: a 20 percent increase in N_20 concentration would result in a 2 percent reduction in stratospheric ozone (Conway and Pretty 1991). N_20 is also 250 times better at absorbing radiation than carbon dioxide, and it currently accounts for about 2-4 percent of total global warming potential. This could rise to 10 percent in the future (Dickinson and Cicerone 1986; Mosier 1994).

Fertilizers and human health: Blue-baby syndrome

Nitrate is not toxic to humans because when ingested in food and water it is quickly absorbed and excreted. However, if the conditions are right, nitrate can be reduced by bacteria in the gut or mouth to produce nitrite, which is capable of disrupting vital physiological processes. In particular, it is well established that nitrite is a cause of methaemoglobinaemia, or blue-baby syndrome. In this disease, the capacity of the blood to carry oxygen is lessened, and affected people, usually infants, exhibit a slate-blue discoloration (cyanosis) of the skin.

Infants are particularly susceptible for a variety of reasons. Their gastric juice is less acidic so encouraging bacterial conversion of nitrate to nitrite and they consume relatively large quantities of fluid. Most recorded cases of methaemoglobinaemia have involved infants given milk formulations prepared with water rich in nitrate. Methaemoglobinaemia has been a serious problem in some regions of the industrialized countries but, while fertilizer nitrate is an important factor, of at least equal importance is bacterial contamination of the drinking water. The condition is also commonly associated with diarrhoea. Infants suffering from diarrhoea usually have a less acid stomach than normal infants (Marriott *et al.* 1933). As some strains of acutely pathogenic organisms can reduce nitrate, this means that diarrhoea can create the conditions for nitrite production (Lee *et al.* 1986; Hegesh and Shiloah 1982).

Since methaemoglobinaemia was first recognized (Comly 1945), most reported cases have been associated with water containing more than 90 mg/l, but also contaminated with coliform bacteria. Almost all cases in the USA have been linked to private water supplies, despite the fact that many public supplies are routinely in excess of 45 mg per liter. One study in California showed, even with concentrations in public well water up to 130 mg per liter, clinical methaemoglobinaemia is absent, though methaemoglobin levels were raised, particularly in infants with diarrhoea. The crucial factor is bacterial contamination (Shearer *et al.* 1972). The most recent incidents occurred in the 1980s in Spain, Hungary and the USA. An infant died in South Dakota in 1986 following drinking water containing 650 mg per liter; and in Hungary, there were 21 deaths and 1353 cases between 1976-1982 (Johnson *et al.* 1987; WHO 1985).

For several reasons, there may be a greater risk in tropical countries. Infants drink more because of the high ambient temperatures, diarrhoea is very common, and diets are poor in vitamin C (which protects against bacterial conversion of nitrate). Nonetheless, there are few records of the condition, probably because it is not recognized. There is only the one account: high incidence in infants from a rural area of Namibia (Super *et al.* 1981). About 8 percent of some 500 infants were found to contain sufficient methaemoglobin in their blood to produce clinical signs of the condition. More than 40 percent of infants drank water in excess of 90 mg per liter, but the source of nitrate was unknown.

Despite the lack of evidence, methaemoglobinaemia may be more prevalent than is supposed. It could be that its presence is masked by far higher incidence of diarrhoea, which currently accounts for some 5-10 million deaths each year. Infants may be dying from diarrhoea well before severe methaemoglobinaemia manifests itself.

Fertilizers and human health: Cancers

Far more problematic is the role of nitrate in the production of cancer, especially gastric cancer. In the laboratory and in human volunteers nitrate may be converted to nitrite, which is then combined with amines and amides to produce N-nitroso compounds. These are known to be carcinogenic. However, the link between nitrate in the diet or drinking water and the incidence of gastric cancer has not been established epidemiologically. Although nitrate intake per capita and national rates of gastric cancer are correlated, in certain regions of the world, such as Chile and Colombia, with high nitrate intakes or high fertilizer use, the correlations do not survive detailed analysis (Mirvish 1983; Armijo *et al.* 1981; Cuello *et al.* 1982).

In most countries gastric cancer rates are declining despite rapid increase in fertilizer use (Conway and Pretty 1991). High rates occur in central Chile and the Nariño region of Columbia. In the former, there is an association with overall fertilizer use, but not with nitrate concentrations in the drinking water. In the latter, there is an association with drinking water, but this does not seem to be related to fertilizer use (Armijo and Coulson 1975; Armijo *et al.* 1981; Cuello *et al.* 1976). It seems that other factors, in particular the nature and content of the diet, are considerably more important. High intake of fresh fruit and vegetables suppresses the reduction of nitrate to nitrite (Conway and Pretty 1991; Fontham *et al.* 1986).

For bladder cancer, which is particularly prevalent in Egypt, and for esophageal cancer, common in northern China, there is an association with the presence of N-nitroso compounds and possibly with nitrate in the drinking water or diet but, again, there are several complicating factors (Hicks 1983; Hicks *et al.* 1982; Lu *et al.* 1986; Chen *et al.* 1987). In Egypt, infection with the parasitic worm, *Shistosoma*, appears to affect the likelihood of tumors. In northern China, pickled vegetables contain high levels of nitrosamines, but groundwater nitrate concentrations are highest where esophageal cancer incidence is highest.

Clearly nitrosamines are important factors in some cancers. Nitrates and nitrites are important precursors, and so it seems likely that fertilizers have a role to play in the production of some human cancers.

RESOURCE-CONSERVING TECHNOLOGIES FOR SUSTAINABLE INTENSIFICATION

Sustainable agriculture involves the integrated use of a variety of pest, nutrient, soil and water management technologies and practices. These are combined on farms to give practices finely-tuned to local conditions. Most represent lower-external input options than in “modernized” agriculture. Natural processes are favored over external inputs, and by-products or wastes from one component of the farm become inputs to another. In this way, farms should remain productive as well as being environmentally sensitive.

There are a range of both proven and promising resource-conserving technologies that can be used for integrated crop nutrition. These technologies basically do two important things. They conserve existing on-farm resources, such as nutrients, water or soil. Or they introduce new elements into the farming system that add more of these resources, such as nitrogen-fixing crops or water harvesting structures, and so substitute for some or all external resources.

The best evidence for the effectiveness of resource-conserving technologies comes from farms and communities themselves. If a technology, such as a nitrogen-fixing legume is taken by farmers and adapted to fit their own cropping systems, and this leads to substantial increases in crop yields, then this is the strongest evidence of success. Wherever possible, the evidence for the following section is drawn from the field (see Boxes 2.1 to 2.7). Some of these are "traditional" practices that have been in existence for generations. Others are of recently developed technologies, transferred from other farmers and communities, or from research efforts.

Improving the efficiency of fertilizers

The application of fertilizer should closely match the needs of plants but often farmers, for reasons of cost, will apply fertilizer in fewer and larger doses. Recommendations are now available for farmers in Europe and North America, though these are largely based on the previously grown crops (Conway and Pretty 1991). Cereals are assumed fully to deplete reserves, for instance, whereas pasture leaves high reserves for the next crop. The outcome is a set of recommendations for fertilizer application rates dependent on both reserves and soil type.

However, more accurate systems have recently emerged that are based on soil testing within fields combined with global positioning systems (GPS). A GPS utilizes signals from satellites to fix the precise position of a tractor or combine harvester within a field. The system can produce yield or nutrient maps for fields by combining data from soil sampling and from existing yield monitors on combines. This means that seed, pesticide, herbicide and fertilizer rates can be matched to the variations within a field. In the UK, it has been common to see farmers cut nitrogen rates by 30 percent, which can reduce the amount of nitrogen leaching out in the field drains by 60 percent. One farmer put it this way: "*It must make sense to tailor input levels to as small an individual area as possible. Blanket rates over a large area are wasteful*" (Pretty and Howes 1993).

Nutrient uptake and absorption can also be improved by using foliar sprays, slow-release products or by incorporating, with the fertilizer, certain compounds that inhibit the bacterial conversion of nitrogen compounds. Low-input farmers are likely to be the greatest beneficiaries of deep placement fertilizers such as urea briquettes, urea marbles or urea supergranules (USG), as a small quantity of fertilizer is now capable of going further. In Taiwan, for example, USG increases rice yields by 20 percent on farms in marginal areas, but has no impact in the already high yielding zone (de Datta 1986). Sulphur-coated urea reduces the need for split applications and helps to fulfil sulphur requirements of the crop, with economic returns of the order of US$4-7 for every dollar spent (de Datta 1986). Polymer or resin-coated fertilizers can be tailored in such a way that the release period extends up to 12 months or more. Granules of fertilizer are coated with a diffusion barrier through which nutrients slowly pass (Alexander 1993; Mosier *et al.* 1994).

Nitrification inhibitors, such as dicyandiamide, nitrapyrin and sulfanilamide thaizole, prevent the conversion of ammonium to the more mobile nitrate form (Minami 1994; Mosier *et al.* 1994). These products can improve yields as well as cut losses of nitrate and N_2O to the environment. They are more costly than conventional fertilizers, however, and so are only available to richer farmers. Inhibitors that reduce gaseous ammonia losses from nitrogen in rice paddies delay the build up of ammonia in the water, but it is not clear whether there is a positive impact on yields too.

Livestock manures and composts

Farmers who can neither afford nor rely on a regular supply of inorganic fertilizers must find alternative organic sources of nutrients. This is particularly important in those countries where structural adjustment programs have sharply increased the price of fertilizers, leaving farmers in need of alternatives. Manures from cattle, pigs and chickens are important, as they positively affect soil structure and water retention, and benefit soil organisms. Livestock are therefore a critical component of sustainable agricultural systems. The nutrient value of manures largely depends on how they are handled, stored and applied. Losses of nitrogen tend to be highest when liquid systems of storage are used and when the manure is broadcast without incorporation.

It is becoming more common for farming households with only small farms to keep their animals permanently penned in zero-grazing or stall-feeding units rather than permit them to graze freely. In Kenya, zero-grazing units are a central part of efforts to improve agriculture through soil conservation (SWCB 1994). Fodder grown on the farm in the form of improved grasses, tree fodder and the residues of cultivated crops are cut and carried to the animals. Manures can be returned directly to the land, so improving nutrient supply and soil structure. In many parts of the world, including dryland Africa and central Asia, migrating pastoralists and their livestock are frequently welcomed by farmers. Livestock are kept overnight on the fields and in some areas farmers pay herdsmen for this service (Scoones and Toulmin 1993).

Where manures are in short supply, farmers are often willing to pay for them to be imported (Wilken 1987). In Mexico, farmers pay US$8-12 for a truckload of chicken manure, and vegetable growers in Guatemala buy chicken wastes that are transported 100 km from Guatemala City. In Oaxaca in Mexico, the highest value organic material is the nutrient-rich debris from the nests of ants. The material is collected in bags and applied to individual plants of high value crops, such as tomatoes, chilies and onions. The recent decline in use of ant refuse is said to be a result of substitution by commercial fertilizers (Wilken 1987).

Composting is a technique of long-standing that combines the use of animal manures, green material and household wastes. The materials are heaped or placed in a pit in such a fashion that anaerobic decomposition occurs. Harmful substances and toxic products of metabolism are broken down, whilst pathogens and the seeds and roots of weeds are destroyed by the heat generated within the compost heap. Composting is particularly valuable in the tropics since organic matter stores nutrients and protects them against leaching. It also makes the soil more friable and easier to plough, improves moisture retention and aeration, and remedies the problems caused by inorganic fertilizers. Farmers in Tanzania make compost from stall litter which includes crop residues, leafy tree branches and old roofing grass; in Rwanda farmers mix household wastes, crop residues, weeds, dried leaves and twigs of trees; and in Nepal farmers use a combination of up to 25 wild plants mixed with animal manures (Kotschi *et al.* 1989; Tamang 1993). In Kenya, compost has become an important source of income for many sustainable farmers (Box 4.1).

Box 4.1--The Manor House Agricultural Centre, Kitale, Kenya

Manor House Agricultural Center provides practical training to young people, farmers and staff of government agencies and NGOs, as well as conducts adaptive research on bio-intensive agriculture. The basic principle is that production can be increased by using soil, water, plant and animal resources that are available on most smallhold farms. The aim is to improve the use of renewable resources and reduce the use of external inputs. Farmers have been able to raise soil fertility, improve productivity and increase household income. The Center has trained some 6000 farmers in 185 community groups, of whom 3000 are known to be using new technologies. Many have doubled their vegetable yields by adopting double digging and composting, and using local methods of pest and disease control. There have been big savings on pesticides and fertilizers. Farmers have found phosphorus to be limiting over periods of 6 years of composting, and so bonemeal is being brought in to add to compost.

A successful group is the Pondeni Farmers Cooperative. This began when 15 farmers were trained at Manor House. They then exported a keen local student to go for more training who, on return acted as a village extensionist, persuading everyone in three villages to adopt bio-intensive farming. The cooperative was then formed, and now pays his salary. It is active and proud of its success, and makes money from two sources: it organizes the sale and marketing of the organic produce (there are no premiums received), and it sells compost, for which there is an increasing demand. It is sieved and mixed with bonemeal, packed into 90 kg bags, and sold for about $20 per bag.

Source: Pretty 1995a, from Eric Kisian'gani, personal communication 1994.

Legumes and green manures

Legumes grown together with or before a cereal crop can reduce, and sometimes eliminate, the need for nitrogen fertilizers. Symbiotic bacteria present in nodules that develop on the roots of legumes fix nitrogen directly from the atmosphere. The cultivation of cereal and legume crops together can improve both total yields and stability of production. In the Americas, the interplanting of maize, beans and squash, is a practice of great antiquity, probably dating back to when agriculture began in the valleys of Mexico (Gleissman 1990).

In temperate countries, legumes have long been used in milk production systems. But, the advent of cheap inorganic fertilizers however has led to a decline in the reliance on legumes to maintain soil fertility. Mixed grass-clover swards gave way to high-nitrogen input grass pastures as producers attempted to maximize yields in response to modern price incentives. Adding nitrogen reduces the content and production of clover, leading to monocultures of grass. In recent years, there has been renewed interest in the use of legumes. Grass-clover swards, for example, can fix 80-280 kg N/ha/yr. With no application of inorganic nitrogen, farmers can in this way successfully support diary cattle grazing and intensive silage making. The financial returns from high nitrogen input systems are no greater, and often substantially lower, than grass-clover systems (Younie 1992; Bax and Fisher 1993; Pretty and Howes 1993).

When vegetation is incorporated in the soil as a "green manure," nutrient levels and the physical properties of the soil are improved. Green manuring has long been practiced; the Romans grew lupins and ploughed them in before sowing cereals more than 2000 years ago. Quick-growing legumes are valuable green manures for many low-input systems, and have the potential to meet much, if not all, of the nitrogen requirements of succeeding non-legume crops. The equivalent amount of nitrogen fertilizer required to match the green manures can be 80-200 kg/ha. Many green manures can also add large amounts of organic matter, up to 30 tons/ha (Flores 1989).

One of the most remarkable crops is the velvetbean (*Mucuna pruriens*). This has been widely promoted by World Neighbors and COSECHA in central America, though its effectiveness is attested to by its spontaneous spread from village to village without outside intervention. It grows rapidly, is palatable to animals and humans, fixes large amounts of nitrogen, and can produce as much as 60 t/ha of organic matter. It can grow on most soils, and its spreading habit suppresses weed growth. Honduran and Guatemalan farmers are able to harvest more than 2.5 t/ha of maize when grown with velvetbean (Boxes 4.2 and 4.3).

Box 4.2--World neighbors in Guinope and Cantarranas, Honduras

The Guinope (1981-89) and Cantarranas (1987-1991) Integrated Development Programmes focused on soil recuperation where maize yields were very low (400-800 kg/ha), and where shifting cultivation, malnutrition, and outmigration prevailed. Both illustrate the importance of developing resource-conserving practices in partnership with local people. All the achievements were because farmers themselves were convinced that the changes were in their own best interests. They used a limited technology, mainly green manures with soil conservation measures. These technologies were appropriate to the local area, and were finely-tuned through experimentation by farmers. Extension was done largely by farmers who had already experienced success with the technologies on their own farms.

In Guinope, 1500 farmers in 41 villages tripled yields of maize (some had increases of 7-8 fold) after adopting the new technologies. Land fertility increased with greater use of chicken manures, green manures, contour grass barriers, rock walls and drainage ditches. Farmers also diversified crop production: once maize and beans production exceeded family needs, they began to reduce area planted to these crops and to plant others, such as coffee, oranges, and vegetable. The landless and near-landless benefitted with the increase in labor wages in the project area. Out-migration has been replaced by in-migration, with many people moving back from the urban slums of Tegucigalpa to occupy houses and farms they had previously abandoned.

In Cantarranas, the adoption of velvetbean (*Mucuna pruriens*), which can fix up to 150 kg N/ha as well as produce 35 tons of organic matter per year, has tripled maize yields to 2500 kg/ha. Labor requirements for weeding have been cut by 75 percent. Farmers say community spirit has improved, and that no one ever talks of leaving.

Sources: Pretty 1995a, from Bunch 1991; Bunch and Lopez 1994.

Box 4.3--Proyecto Centro Maya in the Petén region of northern Guatemala

The project works in what was the center of the Mayan empire, which supported more than 2 million people for some 600 years. Now there are just 300,000 people struggling with poverty and hunger. It is also the location for the largest piece of tropical rainforest in the Americas outside of Brazil. Existing agricultural systems are based upon shifting agriculture, and the project is developing alternative crop and livestock production systems that will encourage farmers to farm permanently the same piece of land. These alternatives involve the use of green manures; diversification into fruit and vegetable production; sylvopastoral development; and the development of community forestry management plans.

Experiments conducted by farmers on green manures and no-till farming are yielding benefits. One farmer said *"I will never again burn my land."* Interestingly, the planting of velvetbean is labor-saving for farmers: the amount of labor needed to farm is one third of that needed to clear primary forest and one half for secondary forest. *Mucuna* is also being used to rehabilitate acid, savanna soils, about which everyone says "the savanna is just for cows." One farmer said that through the impact of green manures, maize became stronger, weeds were controlled, and soil became softer, darker and easier to work. Maize yields have increased from about 0.95 t/ha harvested in the first year after forest clearing to some 3.8 t/ha every year on the same piece of land.

Source: Sergio Ruano, personal communication.

Substantial yield increases are common in many parts of the world (Table 4.2). *Sesbania rostrata* is probably the fastest nitrogen-fixing plant, accumulating 110 kg N/ha in only 45 days (Lathwell 1990). In Nepal, some green manures can produce rice yields that outperform those produced by as much as 100:30:30 kg of NPK/ ha (Joshy 1991). In Bhutan, *Sesbania* can substitute for external inputs, but the best performance occurs when farmers have access to some inorganic nitrogen. *Sesbania* with no fertilizers produces the same rice yields as 40:40:30 kg NPK/ha; but if fertilizers are added to rice after the *Sesbania* then yields increase to 5.4-5.5 t/ha, levels that can be achieved only if 120 kg N/ha are added. Use of *Sesbania* as a green manure can save the use of between 40-120 kg N/ha (Norbu 1991). The key lesson would appear to be that green manures increase crop yields significantly by providing nitrogen. But if farmers are able to get hold of small amounts of inorganic nitrogen, then they will benefit still further.

Recent research in semi-arid India has shown that some legumes, such as chickpea and pigeonpea, have a unique mechanism that allows them to access phosphate in phosphate-poor soils (Johansen 1993). They release acids from their roots, which react with calcium- and iron-bound phosphate to release phosphate for plant uptake. As their deep rooting also helps water infiltration, they have a positive residual affect on subsequent crops, as both phosphate and water availability are increased.

Azolla and Anabaena

Blue-green algae are another important source of nitrogen, the most widely exploited being the alga *Anabaena azollae*. These fix atmospheric nitrogen whilst living in cavities in the leaves of a fern, *Azolla*, that grows on the water of rice fields in both tropical and temperate regions. *Azolla* covers the water surface in the ricefield, but does not interfere with the normal cultivation of the rice crop.

Very high nitrogen production is possible following *Azolla* inoculation in rice fields. In the Philippines, 57 tons of freshweight *Azolla* can be harvested after 100 days yielding more than 120 kg/ha of nitrogen (Watanabe *et al.* 1977). Over the whole year, *Azolla* can fix more than 400 kg N/ha, a rate in excess of most tropical and subtropical legumes. The nitrogen is only available to the rice crop after *Azolla* has decomposed, so the ferns must be incorporated into the soil whilst wet as a green manure, or removed for drying and then re-applied to the ricefields.

The results of at least 1500 studies in China, Philippines, Vietnam, India, Thailand and USA have shown that when *Azolla* is grown in paddy fields, rice yields increase by on average 700 kg/ha, with a range of 400 to 1500 kg/ha (Liu and Weng 1991; San Valentin 1991). In India, wheat crops following rice with *Azolla* have also been shown to produce improved yields (Kolhe and Mitra 1987). For most farmers, *Azolla* offers the opportunity of substituting for inorganic fertilizers. The incorporation of *Azolla* as a green manure in parts of Brazil has permitted for a 30-50 percent reduction in the use of nitrogen fertilizers (Kopke 1984). In the Philippines, recent studies have shown that incorporation of *Azolla* would allow nitrogen applications to be reduced by at least half (San Valentin 1991). But *Azolla* with application of 30:30:20 kg NPK/ha can have yields of 5.9 t rice/ha.

Although the benefits of *Azolla* would appear obvious, many farmers are not using it. The National Azolla Action Programme was established in the Philippines to reduce the burden of high costs to farmers. A programme of working closely with farmers has indicated that *Azolla* combined with 30 kg N/ha will sustain current yields, saving the country some US$23 million each year in foreign exchange (Box 4.4).

Box 4.4--The National Azolla Action Programme, The Philippines

The National Azolla Action Programme was established to reduce the burden of high costs to farmers in the Philippines. The objective was to replace half of the fertilizer nitrogen requirement for rice production with internal resources. The programme aims to cover 300,000 ha of irrigated lowland rice areas. The process has been to:

- Establish a National Inoculum Center (NIC), with a network of regional sub-centers in agricultural universities and colleges, which screen and test local *Azolla* varieties;
- Establish a propagation centers to provide materials to municipalities and villages;
- Prepare information and materials on the culture and utilization of *Azolla* for extension workers and farmers;
- Conduct training, demonstrations and on-farm trials.

At the end of extensive on-farm trials, the results indicated that *Azolla* plus a small amount of nitrogen fertilizer (30 kg/ha) would give equivalent grain yields. The NAAP has estimated that if *Azolla* substitutes for half of the nitrogen requirement for rice in this way, this would generate annual savings of at least US $23 million.

Source: San Valentin 1991.

Contour farming

Another approach for conserving soil nutrients is to resort to physical or biological structures, such as terraces or bunds. These are common to many indigenous agricultural systems throughout the world (see Reij 1991; Kerr and Sanghi 1992). Most of these are designed to check the surface flow of water, and thus perform the roles of water and nutrient harvesting and retention. The simplest approach is to construct earth banks across the slope to act as a barrier to run-off. Sometimes earth bunds are reinforced by planting grass or trees. As such vegetative bunds are partly permeable, crops planted in front of the bund also benefit from water run off. These are not quickly damaged by runoff, and thus maintenance costs are low. The importance of contour earth and grass bunds in Rajasthan is shown in Box 4.5.

Simple walls may also be constructed on the contour and these are quickly strengthened by natural processes. After the first heavy rains, fine soil, branches and leaves begin to fill in the walls making them more impermeable. Rock walls, combined with other resource-conserving technologies, have helped to regenerate environments in Burkina Faso (Box 4.6).

Rather than construct physical structures that generally require large labor inputs, an alternative is to plant crops along contours. In this way as water flows across the surface, it meets with rows of plants growing perpendicular to the flow, which in turn slow it down and improve infiltration. In strip cropping the main row crop is grown along the contour in wide strips alternating with strips of protective crop, such as grass or a legume. If the protective strips are of grass they can be effective at filtering out particulate matter and nutrients from surface flow of water. Further, contour grass strips not only reduce soil loss but also help in the process of establishing terraces. There exists widespread evidence in many countries that following terracing, crop yields have improved and erosion has been reduced (Pretty and Shah 1994; Tato and Hurni 1992; Reij 1991).

Box 4.5--Watershed development by the Government of Rajasthan, India

The Watershed Development and Soil Conservation Department of the Government of Rajasthan was set up in 1991 to implement a participatory approach for integrated watershed development. In the previous 35 years, the government had implemented soil conservation works on 586,000 ha, but these measures were scattered, uncoordinated, and executed entirely by government with people only participating as wage laborers. The impacts were poor, and there has been near zero maintenance. With the high cost of these past approaches, the government has come to appreciate that people's initiatives are essential for success.

The new process involves working with local users' committees. The technologies are low-cost and based on indigenous and biological technologies. These include grass strips on the contour; contour bunds and contour cropping; field bunds; drainage line treatment; and regeneration of common lands with shrubs and trees. These technologies are developed through a process of participatory planning at the village level. Local people and government officials are jointly involved in analysis, technology selection and adaptation, and the development of the treatment plan. Field and contour bunds consequently have more than doubled sorghum and millet yields (with no addition of fertilizer); and grass strips have improved yields by 50-200 percent. Some 120,000 ha were treated under watershed development work in each of 1992-93 and 1993-94.

Source: Pretty 1995a, adapted from Krishna 1994.

Box 4.6--PATECORE in Bam and Passoré Provinces, Burkina Faso

The Projet d'Aménagement de Terroirs et Conservation de Ressources (PATECORE) is a government project working on the Mossi Plateau to improve village land use and conservation. It is a collaborative effort between a consortium of various ministries and NGOs operating in the field of resource management. The project involves local groups in the planning and implementation of soil and water conservation, so developing the self-help capacity at the local level. The project staff coordinate activities at the provincial and district level and train village extensionists (VEs) in technical skills and planning methodology.

The main technologies adopted have been permeable dams, stone bunds, contour ploughing, tree planting, the establishment of protected zones for regeneration, composting, and increased use of manures. The impact on yields is immediate, with sorghum yields increasing from 870 kg/ha to 1650-2000 kg/ha. Other major impacts include rapid replication in neighboring communities; decreased flood damage and soil erosion; stabilized yields; increased capacity of villagers to plan and implement improvements on their own; and increased understanding between government agencies and NGOs who are able to work together with fewer prejudices and better coordinated activities.

Sources: Pretty 1995a, adapted from GTZ 1992; Guijt 1992.

Mulches and cover crops

Soil, water and nutrient conservation is also improved with the use of mulches or cover crops. With a mulch, organic or inorganic material is spread on the soil surface to provide a protective physical cover for the topsoil. Mulches protect the soil from erosion, desiccation and excessive heating, thereby promoting good conditions for the decomposition and mineralization of organic matter. Mulches can also reduce the spread of soil born diseases, notably bacteria, as they reduce the splashing of lower leaves with soil during rainfall. In China, wheat or rice straw mulches can increase tea, fruit and legume yields by 6-16 percent, as well as reduce splash erosion (Jin 1991). In the savanna region of northern Ghana, straw mulches minimize erosion as well as increase yields. Combined with livestock manures, these mulches produce double the maize and sorghum yields than the equivalent amount of nitrogen added as inorganic fertilizer (Bonsu 1983). In Guatemala, farmers collect from the forests up to 20-30 tons of leaf litter for each hectare of cropland, which is incorporated into the soil to improve moisture retention and soil tilth (Wilken 1987).

Cover crops consist of vegetation that is deliberately established after or intercropped with a main crop, not necessarily with a view to harvest, but more to serve various regenerative functions. A good example of the effectiveness of cover crops comes from Santa Catarina in Brazil (Box 4.7). EPAGRI work with 60 species of cover crops, which act as both a green manure and mulch: some fix nitrogen, and all are cut and left on the soil surface. Some 38,000 farmers have now benefitted from these green manure/ mulch/ cover crops. Together they show that providing ground cover is more important than constructing physical structures to prevent erosion.

Box 4.7--EPAGRI in Santa Catarina, Brazil

The state government extension and research service, EPAGRI (Empresa de Pesquisa Agropecuária e Difusâo de Technologia de Santa Catarina), works with farmers to develop low-input and productive systems of agriculture. The focus is on soil and water conservation at the microwatershed level using contour grass barriers, contour ploughing and green manures. Farmers use some inorganic fertilizers and herbicides, but there has been particular success with green manures and cover crops. Some 60 species have been tested by farmers, including leguminous plants such as velvetbean, jackbean, lablab, cowpeas, many vetches and crotalarias, and non-legumes such as oats and turnips. These are intercropped with maize, onions, cassava, wheat, grapes, tomatoes, soybeans, tobacco and orchards or planted during fallow periods. Farmers use animal-drawn tools to knock over and cut up the green manure, leaving it on the surface. With another farmer-designed instrument, they then clear a narrow furrow in the resulting mulch into which the next crop is planted. Manures from pigs and chickens are now concentrated in pits and then applied to the fields. This has reduced pollution of waterways, as well as cut the dependency on inorganic fertilizers.

The major on-farm impacts have been on crop yields, soil quality and labor demand. Maize yields have risen since 1987 from 3 to 5 t/ha and soybeans from 2.8 to 4.7 t/ha. Soils are darker in color, spongy, moist and full of earthworms. The reduced need for most weeding and ploughing has meant great labor savings for small farmers. EPAGRI has reached some 38,000 farmers in 60 microwatersheds since 1991.

Source: Pretty 1995a, adapted from Bunch 1993; de Freitas 1994

SUSTAINABILITY AND NEW CHALLENGES FOR TECHNOLOGY DEVELOPMENT

Sustainability as a contested term

Although it is relatively easy to describe goals for a more sustainable agriculture, things become much more problematic when it comes to attempts to define sustainability: *"everyone assumes that agriculture must be sustainable. But we differ in the interpretations of conditions and assumptions under which this can be made to occur"* (Francis and Hildebrand 1989). A great deal of effort has gone into trying to define sustainability in absolute terms. Since the Brundtland Commission's definition of sustainable development in 1987, there have been at least 70 more definitions constructed, each different in subtle ways, each emphasizing different values, priorities and goals. The implicit assumption is that it is possible to come up with a single correct definition, and each author presumably regards his/her effort as the best.

But precise and absolute definitions of sustainability, and therefore of sustainable agriculture, are impossible. Sustainability itself is a complex and contested concept. To some it implies persistence and the capacity of something to continue for a long time. To others, it implies resilience, and the ability to bounce back after unexpected difficulties. In any discussions of sustainability, however, it is important to clarify what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria.

It is critical, therefore, that a more sustainable agriculture does not prescribe a concretely defined set of technologies, practices or policies. This would only serve to restrict the future options of farmers. Although many resource-conserving technologies and practices have been widely proven on research stations to be both productive and environmentally-sensitive, the total number of farmers using them is still small. Part of the problem is that scientists experience quite different conditions to those experienced by farmers, and few farmers are able to adopt the whole packages of technologies without considerable adjustments. Despite the benefits of resource-conserving technologies, if they are imposed on farmers, they will not be adopted widely.

One example is alley cropping, an agroforestry system comprising rows of nitrogen-fixing trees or bushes separated by rows of cereals, which has long been the focus of research (Kang *et al.* 1984; Attah-Krah and Francis 1987; Lal 1989). Many productive and sustainable systems, needing few or no external inputs, have been developed. They stop erosion, produce food and wood, and can be cropped over long periods. But the problem is that very few, if any, farmers have adopted these alley cropping systems as designed. Where there has been some success, it has occurred where farmers have been able to take one or two components of alley cropping, and adapted them to their own farms. In Kenya, for example, farmers planted rows of leguminous trees next to field boundaries, or single rows through their fields; and in Rwanda, alleys planted by extension workers soon became dispersed throughout fields (Kerkhof 1990).

But the prevailing view tends to be that it is farmers who should adapt to the technology. Of the Agroforestry Outreach Project in Haiti, it was said that *"Farmer management of hedgerows does not conform to the extension program... Some farmers prune the hedgerows too early, others too late. Some hedges are not yet pruned by two years of age, when they have already reached heights of 4-5 meters. Other hedges are pruned too early, mainly because animals are let in or the tops are cut and carried to animals... Finally, it is very common for farmers to allow some of the trees in the hedgerow to grow to pole size"* (Bannister and Nair 1990).

Another example comes from the Majjia Valley Windbreak Project in Niger, which was presented as a major success in the greening of degraded environments (Harrison 1987). By the end of 1988, 463 km of windbreaks had been planted, 4000 ha protected, and crop yields improved by some 15-20 percent. Later analyses and reflections (Kerkhof 1990; Leach and Mearns 1988) however indicated that the farmers were not consulted about where the windbreaks of neem should be planted, and they lost considerable crop area to the trees. Moreover, some 98 percent of the farmers thought the windbreaks belonged to the government forestry department. A project manager said *"if we were to leave Majjia Valley now, I wouldn't be surprised if there were no windbreaks left in 5 years time"* (Kerkhof 1990).

This contrasts starkly with a recent analysis of sustainable agriculture initiatives in Guatemala and Honduras. A learning group from the NGO, COSECHA, returned to areas where projects had ended three, four and fifteen years previously, and used participatory methods with local communities to investigate changes (Bunch and López 1994). They found that those communities in the project areas were even better off economically and socially. But, surprisingly, many of the technologies known to be “successful” during the project (those that had increased crop yields without damaging the environment) had been completely replaced by new practices and, in all, some 80-90 innovations were documented. This led Bunch and López (1994) to conclude that *"technologies are not sustainable: what needs to be made sustainable is the process of innovation itself."*

As conditions and knowledge changes, so must farmers and communities be encouraged and allowed to change and adapt as well. Again, this implies that any definitions of sustainability are time- and place-specific. As situations and conditions change, so must our constructions of sustainability change. Sustainable agriculture is, therefore, not simply an imposed model or package. It must become a process for learning and perpetual novelty.

Science and sustainability

Another reason why relatively few farmers have adopted new technologies and practices is that sustainable agriculture presents a deeper and more fundamental challenge than many researchers, extensionists and policy makers have yet supposed. Sustainable agriculture needs more than new technologies and practices. It needs agricultural professionals willing and able to learn from farmers.

Since the early 17th century, scientific investigation has come to be dominated by the Cartesian paradigm, commonly called positivism or rationalism. This paradigm posits that there exists an objective external reality driven by immutable laws. Science seeks to discover the true nature of this reality, the ultimate aim being to discover, predict and control natural phenomena. Investigators proceed in the belief that they are detached from the world. The process of reductionism involves breaking down components of a complex world into discrete parts, analyzing them, and then making predictions about the world based on interpretations of these parts. Knowledge about the world is then summarized in the form of universal, or time- and context-free, generalizations or laws.

This methodology of science has been hugely successful, producing technologies and medicines that have enabled many people to live safer and more comfortable lives than ever before (Funtowicz and Ravetz 1993). It is an approach that clearly works, and as a consequence, investigation with a high degree of control over the system being studied and where system uncertainties are low has become equated with good science. And such science is readily equated with "true" knowledge, and so the "only proper way" of thinking and doing.

It is this positivist approach that has led to the generation of technologies for farmers that have been applied widely and irrespective of context. Where it has been possible to influence and control farmers, either directly or through economic incentives or markets, agricultural systems have been transformed. But where neither the technologies have fitted local systems nor farmers been controlled, then agricultural modernization centered on positivist science has passed rural people by.

Michael Stocking (1993) described how the values of the investigators affect the end result when it comes to soil erosion data. Since the 1930s, there have been at least 22 erosion studies conducted in the Upper Mahaweli Catchment in Sri Lanka. These have used visual assessments of soil pedestals and root exposure, erosion pins, sediment traps, run-off plots, river and reservoir sediment sampling, and predictive models. Between the highest and lowest estimates of erosion under mid-country tea, there is an extraordinary variation of some 8000 fold, from 0.13 t/ha/yr to 1026 t/ha/yr (El-Swaify *et al.* 1983; NEDCO 1984; Krishnarajah 1985). The highest estimate was in the context of a development agency seeking to show just how serious erosion is in the Third World; the lowest was by a tea research institute seeking to show how safe was their land management. There was, however, nothing wrong with the scientific method; it was more a question of what the researchers defined as a problem, and how they chose to investigate it.

A similar case is described by Jerome delli Priscoli (1989) regarding water and energy in the northwestern USA. One projection for energy needs showed a steady growth to the year 2000; this was conducted by the utility company. Another showed a steady downward trend; this was conducted by environmental groups. Other projections by consultancy groups were found towards the center. What does this say about the data? *"Each projection was done in a statistically 'pedigreed' fashion. Each was logical and internally elegant, if not flawless. The point is, once you know the group, you will know the relative position of their projection. The group, organization or institution embodies a set of values. The values are visions of the way the world ought to be"* (delli Priscoli 1989).

Both cases illustrate that science is not the neat, objective collection of facts about nature and its processes. The data were clearly constructed by people with values and human foibles. As Stocking (1993) put it: *"What, then, is the right policy response? ... Not surprisingly policy makers pick the measurements to suit their needs."* The challenge is not just that these differences have to be recognized, but that the competing values need to be mediated so as to produce agreements between actors with very different agendas.

Alternatives and additions to the positivist paradigm

One problem with the positivist paradigm is that its absolutist position appears to exclude other methodologies. Yet the important point about positivism is that it is just one of many ways of describing the world, and what is needed is pluralistic ways of thinking about the world and acting to change it (Kuhn 1962; Checkland 1981; Vickers 1981; Reason and Heron 1986; Habermas 1987; Giddens 1987; Maturana and Varela 1987; Arthur 1989; Rorty 1989; Bawden 1991; Uphoff 1992; Waldrop 1992; Wynne 1992; Funtowicz and Ravetz 1993; Röling 1994). Recent years have seen the emergence of a remarkable number of advances in a wide range of disciplines and fields of investigation. The sources include the so-called "harder" sciences, such as physics, biology, chemistry, meteorology and mathematics, as well as the "softer" sciences of economics, philosophy, architecture, sociology and organizational management (see Pretty 1995b).

Despite this wide ranging list, those arguing for the importance of developing additions to positivism are still in the minority. Many scientists continue to argue strongly that information is first produced by science, and only then interpreted and applied by the public and policy makers. It is this process of interpretation that is said to introduce values and confuse certainties. Yet the results from any investigation are always going to be open to different interpretations. All actors and stakeholders, and particularly those with a direct social or economic involvement and interest, have different perspectives on what constitutes a problem and/or improvement in an agricultural system.

These advances in alternative paradigms have important implications for how we go about finding out about the world, generating information, and taking action. All hold that *"the 'truth' is ultimately a kind of mirage that in principle cannot be achieved because the worlds we know are those crafted by us"* (Eisner 1990). All suggest that we need to reform the way we think about methodologies for finding out about the world.

All of this indicates that it is clearly time to break the domination of the old paradigm of positivism for science, and so explore the alternatives. This is not to suggest that there is no place for reductionist and controlled science. This will continue to have an important role to play where system uncertainties are low and problems are well defined and agreed. But it will no longer be seen as the sole type of inquiry. The process will inevitably mean huge transformations. Thomas Kuhn's (1970) hugely influential analysis of paradigm changes in science describes the process of revolution for case after case. But the process can bring big shifts in understanding: *"During revolutions scientists see new and different things when looking with familiar instruments in places they have looked before"* (Kuhn 1970).

The fundamental challenge facing agricultural scientists and development professionals is to find effective ways of involving a wider peer community (Funtowicz and Ravetz 1993) and a greater breadth of social and cultural institutions (Woodhill 1993) in the business of developing a more sustainable agriculture. Fortunately, they do not need to start just with theoretical analyses to shift underlying values. From practice, there has emerged a rich experience on the use of participatory methods for just this purpose.

"PARTICIPATION" FOR TECHNOLOGY DEVELOPMENT

The many interpretations of participation

In recent years, there have been an increasing number of comparative studies of development projects showing that "participation" is one of the critical components of success. It has been associated with increased mobilization of stakeholder ownership of policies and projects; greater efficiency, understanding and social cohesion; more cost-effective services; greater transparency and accountability; increased empowerment of the poor and disadvantaged; and strengthened capacity of people to learn and act (Paul 1987; Baker *et al.* 1988; Reij 1988; Finsterbusch and van Wicklen 1989; Bagadion and Korten 1991; Cernea 1991; Guijt 1991; Pretty and Sandbrook 1991; Uphoff 1992; Narayan 1993; World Bank 1994; Pretty 1995a).

As a result, the terms "people's participation" and "popular participation" are now part of the normal language of many development agencies, including NGOs, government departments and banks (Adnan *et al.* 1992; Bhatnagar and Williams 1992; World Bank 1994). It is such a fashion that almost everyone says that participation is part of their work. This has created many paradoxes. The term "participation" has been used to justify the extension of control of the state as well as to build local capacity and self-reliance; it has been used to justify external decisions as well as to devolve power and decision-making away from external agencies; it has been used for data collection as well as for interactive analysis.

In conventional rural development, participation has commonly centered on encouraging local people to sell their labor in return for food, cash or materials. Yet these material incentives distort perceptions, create dependencies, and give the misleading impression that local people are supportive of externally-driven initiatives. This paternalism undermines sustainability goals and produces impacts which rarely persist once the project ceases (Bunch 1983; Reij 1988; Pretty and Shah 1994; Kerr 1994). As little effort is made to build local skills, interests and capacity, local people have no stake in maintaining structures or practices once the flow of incentives stops.

The many ways that development organizations interpret and use the term participation can be resolved into seven clear types. These range from manipulative and passive participation, where people are told what is to happen and act out predetermined roles, to self-mobilization, where people take initiatives largely independent of external institutions (Table 2.3). This typology suggests that the term "participation" should not be accepted without appropriate clarification. The World Bank's internal "Learning Group on Participatory Development" recently distinguished between different types of participation: *"many Bank activities which are termed 'participatory' do not conform to [our] definition, because they provide stakeholders with little or no influence, such as when [they] are involved simply as passive recipients, informants or laborers in a development effort"* (World Bank 1994). The problem with participation as used in types one to four is that any achievements are likely to have no positive lasting effect on people's lives (Rahnema 1992).

Great care must, therefore, be taken over both using and interpreting the term participation. It should always be qualified by reference to the type of participation, as most types will threaten rather than support the goals of sustainable agriculture. What will be important is for institutions and individuals to define better ways of shifting from the more common passive, consultative and incentive-driven participation towards the interactive end of the spectrum.

Alternative systems of learning and action

Recent years have seen a rapid expansion in new participatory methods and approaches to learning in the context of agricultural development (see *PLA Notes* 1988-1995; Pretty *et al.* 1995; IDS/IIED 1994; Chambers 1994a, Chambers 1994 b, Chambers 1994c). Many have been drawn from a wide range of non-agricultural contexts, and were adapted to new needs. Others are innovations arising out of situations where practitioners have applied the methods in a new setting, the context and people themselves giving rise to the novelty.

There are now more than 30 different terms for these learning and action systems, some of which are more widely used than others (Pretty 1995a). Participatory Rural Appraisal (PRA), for example is now practiced in at least 130 countries, but Samuhik Brahman is associated just with research institutions in Nepal, and REFLECT just with adult literacy programmes. But this diversity and complexity is a strength. It is a sign of both innovation and ownership. Despite the different contexts in which these approaches are used, there are important common principles uniting most of them. These systems emphasize the following six elements:

- *A Defined Methodology and Systemic Learning Process*--the focus is on cumulative learning by all the participants and, given the nature of these approaches as systems of inquiry and interaction, their use has to be participative. The emphasis on visualizations democratizes and deepens analysis.
- *Multiple Perspectives*--a central objective is to seek diversity, rather than characterize complexity in terms of average values. The assumption is that different individuals and groups make different evaluations of situations, which lead to different actions. All views of activity or purpose are heavy with interpretation, bias and prejudice, and this implies that there are multiple possible descriptions of any real-world activity.
- *Group Learning Process*--all involve the recognition that the complexity of the world will only be revealed through group inquiry and interaction. This implies three possible

mixes of investigators, namely those from different disciplines, from different sectors, and from outsiders (professionals) and insiders (local people).

- *Context Specific*--the approaches are flexible enough to be adapted to suit each new set of conditions and actors, and so there are multiple variants.
- *Facilitating Experts and Stakeholders*--the methodology is concerned with the transformation of existing activities to try to bring about changes which people in the situation regard as improvements. The role of the "expert" is best thought of as helping people in their situation carry out their own study and so achieve something.
- *Leading to Sustained Action*--the learning process leads to debate about change, and debate changes the perceptions of the actors and their readiness to contemplate action. Action is agreed, and implementable changes will therefore represent an accommodation between different conflicting views. The debate and/or analysis both define changes which would bring about improvement and seek to motivate people to take action to implement the defined changes. This action includes local institution building or strengthening, thereby increasing the capacity of people to initiate action on their own.

These alternative methodologies imply a process of learning leading to action. A more sustainable agriculture, with all its uncertainties and complexities, cannot be envisaged without a wide range of actors being involved in continuing processes of learning. When research is participatory, both farmers and researchers benefit. Researchers learn more about technologies, as farmers are able to test them in a wide variety of conditions. They have the satisfaction of knowing that technologies they produce really are what farmers want. They also develop better lines of communication. Once researchers appreciate that there are multiple sources of innovation, then they greatly increase the opportunity of helping to improve farmers' livelihoods. In this sense, change can come from joint learning that challenges perceptions, thoughts, and actions of both the researchers and farmer participants.

The contrast between systems of learning that involve a wider community than just scientists is illustrated by a recent example from the development of the Landcare movement in Australia (Woodhill 1993; Campbell 1994). Jim Woodhill (1993) put it this way: *"Scientists had been monitoring the problem [salinity] for a long time and producing a range of publications to inform farmers. What was now significant was the way the farmers talked about the dramatic impact 'doing their own science' had on their understanding, motivation to act, and willingness to engage in more fruitful ways with the 'experts'".*

Towards a new professionalism

These systems of learning are centered on the principle of ensuring the construction of timely, relevant, agreed information and knowledge that will support progress towards a more sustainable agriculture. This raises two challenges: finding ways of developing both new institutional arrangements and alliances to encourage greater learning and wider peer involvement; and a whole new professionalism with greater understanding of the range of scientific methodologies and an emphasis on the process of learning (and unlearning) itself.

The central concept of sustainable agriculture is that it must enshrine new ways of learning about the world. Such learning should not be confused with teaching. Teaching implies the transfer of knowledge from someone who knows to someone who does not know, and is the normal mode of educational curricula (Ison 1990; Bawden 1992; Pretty and Chambers 1993). Universities and other professional institutions reinforce the teaching paradigm by giving the impression that they are custodians of knowledge which can be dispensed (usually by lecture) to a recipient (a student). A move from a teaching to a learning style has profound implications for agricultural development institutions. The focus is less on *what* we learn, and more on *how* we learn and *with whom*. This implies new roles for development professionals, leading to a whole new professionalism with new concepts, values, methods and behavior.

But it would be wrong to characterize this as a simple polarization between old and new professionalism, implying in some way the bad and the good. True sensibility lies in the way opposites are synthesized. It is clearly time to add to the paradigm of positivism for science, and embrace the new alternatives. This will not be easy. Professionals will need to be able to select appropriate methodologies for particular tasks (Funtowicz and Ravetz 1993). Where the problem situation is well defined, system uncertainties are low, and decision stakes are low, then positivist and reductionist science will work well. Conversely where the problems are poorly defined and there are great uncertainties potentially involving many actors and interests, then the methodology will have to comprise these alternative methods of learning. Many existing agricultural professionals will resist such paradigmatic changes, as they will see this as a de-professionalization of research. Hart (1992) however, has put it differently: *"I see it as a 're-professionalization,' with new roles for the researcher as a democratic participant."*

A systematic challenge for agricultural and rural institutions, whether government or non-government, is to institutionalize these approaches and structures that encourage learning. Most organizations have mechanisms for identifying departures from normal operating procedures. But most institutions are very resistant to double-loop learning, as this involves the questioning of, and possible changes in, the wider values and procedures under which they operate (Argyris *et al.* 1985). For organizations to become learning organizations, they must ensure that people become aware of the way they learn, both from mistakes and from successes.

POLICY CHALLENGES FOR THE NEXT 25 YEARS

Policy discrimination against sustainable agriculture

Most, if not all, of the policy measures used to support agriculture currently act as powerful disincentives against sustainability. In the short-term, this means that farmers switching from high-input to resource-conserving technologies can rarely do so without incurring some transition costs. In the long-term, it means that sustainable agriculture will not spread widely beyond existing localized successes.

The principal problem is that policies simply do not reflect the long-term social and environmental costs of resource use. The external costs of modern farming, such as soil erosion, health damage or polluted ecosystems, are not incorporated into individual farmer decision-making. Resource-degrading farmers do not bear the costs of damage to the environment or economy. In principle, it is possible to imagine pricing the free input of a clean, unpolluted environment to farming. If charges were levied in some way, then polluters would have higher costs, and so would be forced to switch to more resource-conserving technologies. This notion is contained within the Polluter Pays Principle, a concept used for many years in the non-farm sector (OECD 1989). However, beyond the notion of encouraging some internalization of costs, it has not been of practical use for policy formulation in agriculture.

In general, farmers are entirely rational to continue using high-input degrading practices. High prices for particular commodities, such as key cereals, have discouraged mixed farming practices, replacing them with monocultures. In the USA, for example, commodity programmes inhibit the adoption of resource-conserving practices by artificially making them less profitable to farmers (Faeth 1993). In Pennsylvania, the financial returns to continuous maize and alternative rotations are about the same. But the continuous maize attracts about twice as much direct support in the form of deficiency payments. In addition, continuous maize farms use much more nitrogen fertilizer, erode more soil and cause 3-6 times as much damage to off-site resources. Putting this together shows that a transition to the resource-conserving rotations would clearly benefit both farmers and the national economy.

In this context of systemic support for high-input agriculture, many countries have sought to “bolt-on” conservation goals to policies. These have tended to rely on conditionality, such as “cross-compliance”, whereby farmers receive support only if they adopt certain types of resource-conserving technologies and practices.

Some have begun to introduce taxes and input levies on fertilizers and pesticides. Some of this revenue is used to subsidize exports (such as in Finland); to support further the input reduction program (such as in Sweden); to support research into alternative agriculture (such as in Iowa and Wisconsin), or to return to farmers resources in the form of income support (such as in Norway). There are also proposals to introduce similar taxes in Belgium, Denmark, the Netherlands and Switzerland (Pretty 1995a). It is generally felt, however, that these levels have been set too low significantly to affect consumption (OECD 1989; OECD 1992; Baldock 1990).

The alternative to penalizing farmers is to encourage them to adopt alternative low- or non-polluting or degrading technologies by acting on subsidies, grants, credit or low-interest loans. These could be in the form of direct subsidies for low-input systems or the removal of subsidies and other interventions that currently work against sustainability. Acting on either would have the effect of removing distortions and making the low-input options more attractive.

Policy reform has been underway in many countries, with some new initiatives supporting elements of a more sustainable agriculture. Only a few as yet represent coherent plans and processes that clearly demonstrate the value of integrating policy goals. There are seven areas where action can be taken immediately which would contribute to better adoption of integrated crop nutrition, and so encourage output growth throughout the agricultural sectors of all Third World countries (Pretty 1995a).

Policy 1: Declare a national policy for sustainable agriculture

The first action that governments can take is to coordinate policies and institutions more clearly. Policies have long focused on generating external solutions to farmers' needs. New policies must be enabling, creating the conditions for development based more on locally-available resources and local skills and knowledge. Policy makers will have to find ways of establishing dialogues and alliances with other actors, and farmers' own analyses could be facilitated and their organized needs articulated. Dialogue and interaction would give rapid feedback, allowing policies to be adapted iteratively. Agricultural policies could then focus on enabling people and professionals to make the most of available social and biological resources. Declaring a national policy for sustainable agriculture helps to raise the profile of these processes and needs, as well as giving explicit value to alternative societal goals. It would also establish the necessary framework within which the more specific actions listed below can fit and be supported.

Policy 2: Prioritize research into sustainable agriculture

There is a need for increased research by agricultural departments and colleges into resource-conserving technologies. Current research is heavily biased towards modern agricultural practices. At the present, too little is known about the economic and environmental benefits of resource-conserving agriculture because of a lack of professional and scientific incentives, including central and local funds, for research. Where possible farmers should be involved closely in research design and implementation, as it is they who know best their local conditions. Research should, therefore, constitute both more basic research into resource-conserving technologies in a wide variety of biophysical and socio-economic contexts, and more analysis and understanding of what farmers are already doing through case studies and participatory analysis. Indigenous knowledge and management systems form an important focus for such research.

Policy 3: Grant farmers appropriate property rights

Sustainable agriculture incorporates the notion of giving value to the future availability of resources. But if farmers are uncertain how long they will be permitted to farm a piece of land, then they will have few incentives to invest in practices that only pay off in the long term, such as soil and water conservation, agroforestry, planting hedgerows, and building up soil fertility. In some places, tenants risk eviction if they improve the land they farm--if the land becomes too productive, landlords may claim it and farm it for themselves. Where land reform has occurred, there have been substantial impacts on agricultural growth, poverty alleviation, and investments in resource-conserving technologies. The best option is to grant property and titling rights through national programmes for land reform. This can be supported by the innovative use of tenancy laws that encourage action by landlords to set lease conditions that specify the use of regenerative technologies, and that also ensure tenants receive the full economic value of any investments they have made during course of their tenancy.

Policy 4: Set appropriate prices (penalize polluters) with taxes and levies

Current policies tolerate external environmental and public health costs because of a lack of markets for public goods, such as landscapes, soil, biodiversity, and groundwater quality. These external costs are not accounted for by farmers. However, there are policies that seek to ensure that polluters pay some or all of these external costs. These policies include the imposition of taxes or levies on external inputs to reduce their use; and the adoption of transferable rights or permits systems, such as irrigation entitlements and transferable permits for nitrogen. These can be supplemented by establishing regulations to enforce compliance, such as groundwater protection zones, nitrate vulnerable zones, well-field protection, riverine protection zones, and wetland and erodible land protection.

The high returns available from external inputs, however, make it likely that taxes would have to be set at very high levels if they were to achieve a “desired” reduction in chemical use. Taxes below a certain threshold could simply result in a net flow of income from the agricultural sector, with consequent impacts on rural communities. At the moment, these schemes simply provide a convenient means of raising revenue for the government, though this is usually used to support research or other activities for sustainable agriculture.

Policy 5: Promote farmer-to-farmer exchanges

Farmers are the best educators of other farmers, and so farmer-to-farmer extension, visits and peer training can greatly help in information exchange and dissemination. External agencies can help in several ways. Most common are farmer exchange visits, in which farmers are brought to the site of a successful innovation or useful practice, where they can discuss and observe benefits and costs with adopting farmers. Professionals play the role of bringing interested groups together and facilitating the process of information exchange. During the visits, participants are stimulated by the discussions and observations, and many will be provoked into trying the technologies for themselves. But one of the greatest constraints for promoting wider use of farmer-to-farmer exchanges lies in the quality of available facilitators. They must have all the qualities of a new agricultural professionalism.

Policy 6: Encourage the formal adoption of participatory methods and processes

Many organizations have a poor record when it comes to participation with farmers. Yet there is good evidence that participation can lead to significant changes in economic and environmental status of communities. A wide range of participatory methods have been shown to be effective over recent years in almost every country of the world. However, professionals familiar with these methods are still in the minority. What is needed is wider support for the use of participatory methods and processes, and the establishment of appropriate incentives to encourage their institutionalization by researchers, extensionists and planners. Nonetheless, it will be important to ensure that too rapid institutionalization does not occur. If training manuals and guidelines convert participatory methods into simplistic steps, then methodologies will become too rigid and unable to change to suit diverse institutional and ecological conditions.

Policy 7: Foster stronger NGO-government partnerships

There are significant benefits in encouraging NGOs and governments to work together. The size of human capital and resources locked up in government institutions usually represents a huge underutilized potential. Opportunities for innovative work to catalyze change within governments do exist, particularly under conditions of increased decentralization. Collaboration between NGOs and governments to realize more of the potential and exploit more of the opportunities means working together in a mutually independent fashion. The primary objective can, therefore, be to foster change from within government. This can often be pursued best through supporting and working with innovative individuals and programmes. Personalities and relationships are a vital element in successful partnerships. NGOs working in this mode try to enlist support at all levels of the system, particularly amongst higher level administrators and politicians. All need to understand and appreciate the demands of the new approaches and to be aware of the potential benefits.

Table 4.1--Modernist perspectives on future strategies for agricultural development

Technical Assistance Committee of the CGIAR (1988):
"Indigenous farm populations have learned to manage their systems quite efficiently, making it difficult to increase their production without resort to external inputs".

FAO (1991):
"It seems likely that much of the growth in agricultural production will take place through increased use of external inputs".

Norman Borlaug (1992):
"Some agricultural professionals contend that small-scale subsistence producers can be lifted out of poverty without the use of purchased inputs, such as modern crop varieties, fertilizer and agricultural chemicals. They recommend instead the adoption of so-called 'sustainable' technologies that do not require fertilizers and improved varieties... The advent of cheap and plentiful fertilizers has been one of the great agricultural breakthroughs of humankind... The adoption of science-based agricultural technologies is crucial to slowing--and even reversing--Africa's environmental meltdown".

Norman Borlaug (1992):
"Development specialists ... must stop `romanticizing' the virtues of traditional agriculture in the Third World. Moreover, leaders in developing countries must not be duped into believing that future food requirements can be met through continuing reliance on ...the new complicated and sophisticated 'low-input, low-output' technologies that are impractical for the farmers to adopt".

International Fertilizer Development Center (1992):
"Higher yields per hectare produced by fertilizers will be the most persuasive argument to coax developing country farmers to abandon their environmentally destructive farming practices".

The World Bank (1993):
"experience such as obtained with the Green Revolution in parts of Asia has shown that broad-based agricultural growth, involving small and medium sized farms and driven by productivity-enhancing technological change, offers the only way to create productive employment and alleviate poverty on the scale required".

FAO (1993):
"When managed well, external inputs can lead to greater yields and improved nutrient content. This reduces the pressure to convert land to agriculture and improves food security. Few developing countries can therefore afford to forego the benefits of external inputs. Used incorrectly, however, they can result in environmental pollution, threats to human and animal health, greater volatility in production levels, and reduced production and incomes".

Source: Pretty, 1995a.

Table 4.2--The impacts of green manuring of legumes on cereal yields

Country	Green manure	Cereal	Impact on yields (as percent of conventional)	New yields (Kg/ha)
Rwanda[1]	*Tephrosia vogelii*	Maize	400%	2800
NE Thailand [2]	*Vigna spp.* (Cowpea)	Rice	105-120%	2875
Honduras[3]	*Mucuna pruriens* (velvetbean)	Maize	295%	2500
Brazil[4]	*Mucuna aterrima*	Maize	nd	6800
	Crotolaria striata	Maize	nd	5800
	Zornia latifolis	Maize	nd	
Bhutan[5]	*Lupine mutubilis*	Potato	133%	21500
	Sesbania aculeata	Rice	131%	4560
Vietnam[6]	*Tephrosia candida*	Rice	136%	2160
	Stylosanthes spp	Rice	145%	2000
	Vigna spp.	Rice	145%	2100
Nepal (mid-hill region)[7]	*Sesbania cannabeana*	Rice	116%	5845
	S. rostrata	Rice	118%	6030
	Vigna radiata	Rice	128%	6600
Nepal (terai region)[7]	*Sesbania cannabeana*	Rice	194%	3340
	S. rostrata	Rice	218%	3690
	Vigna radiata	Rice	200%	3380
Brazil (Santa Catarina)[8]	*Mucuna pruriens* (velvetbean)	Maize	nd	3000-5000
	Canavalia ensiformis (jackbean)	Maize	nd	3000-5000
	Dolichos lablab (lablab)	Maize	nd	3000-5000
	Vigna spp	Maize	nd	3000-5000
	Melilotus albus (sweet clover)	Maize	nd	3000-5000

Sources: (1) Kotschi et al, 1989; (2) Craig and Pisone, 1988; (3) Bunch, 1990; Flores, 1991; (4) Lathwell, 1990; (5) Norbu, 1991; (6) Thai and Loan,1991; (7) Joshy, 1991; (8) Bunch, 1993.

Note: nd = no data.

Table 4.3--A typology of participation: How people participate in development programs and projects

Typology		Characteristics of Each Type
1.	*Manipulative participation*	Participation is simply a pretense, with "people's" representatives on official boards but who are unelected and have no power.
2.	*Passive participation*	People participate by being told what has been decided or has already happened. It involves unilateral announcements by an administration or project management without any listening to people's responses. The information being shared belongs only to external professionals.
3.	*Participation by consultation*	People participate by being consulted or by answering questions. External agents define problems and information gathering processes, and so control analysis. Such a consultative process does not concede any share in decision-making, and professionals are under no obligation to take on board people's views.
4.	*Participation for material incentives*	People participate by contributing resources, for example labor, in return for food, cash or other material incentives. Farmers may provide the fields and labor, but are involved in neither experimentation nor the process of learning. It is very common to see this called participation, yet people have no stake in prolonging technologies or practices when the incentives end.
5.	*Functional participation*	Participation seen by external agencies as a means to achieve project goals, especially reduced costs. People may participate by forming groups to meet predetermined objectives related to the project. Such involvement may be interactive and involve shared decision making, but tends to arise only after major decisions have already been made by external agents. At worst, local people may still only be coopted to serve external goals.
6.	*Interactive participation*	People participate in joint analysis, development of action plans and formation or strengthening of local institutions. Participation is seen as a right, not just the means to achieve project goals. The process involves interdisciplinary methodologies that seek multiple perspectives and make use of systemic and structured learning processes. As groups take control over local decisions and determine how available resources are used, so they have a stake in maintaining structures or practices.
7.	*Self-mobilization*	People participate by taking initiatives independently of external institutions to change systems. They develop contacts with external institutions for resources and technical advice they need, but retain control over how resources are used. Self-mobilization can spread if governments and NGOs provide an enabling framework of support. Such self-initiated mobilization may or may not challenge existing distributions of wealth and power.

Source: Pretty 1995b, adapted from Pretty (1994), Satterthwaite et al (1995); Adnan et al (1992), Hart (1992).

Figure 4.1--The impact of sustainable agriculture on yields in three types of agricultural systems

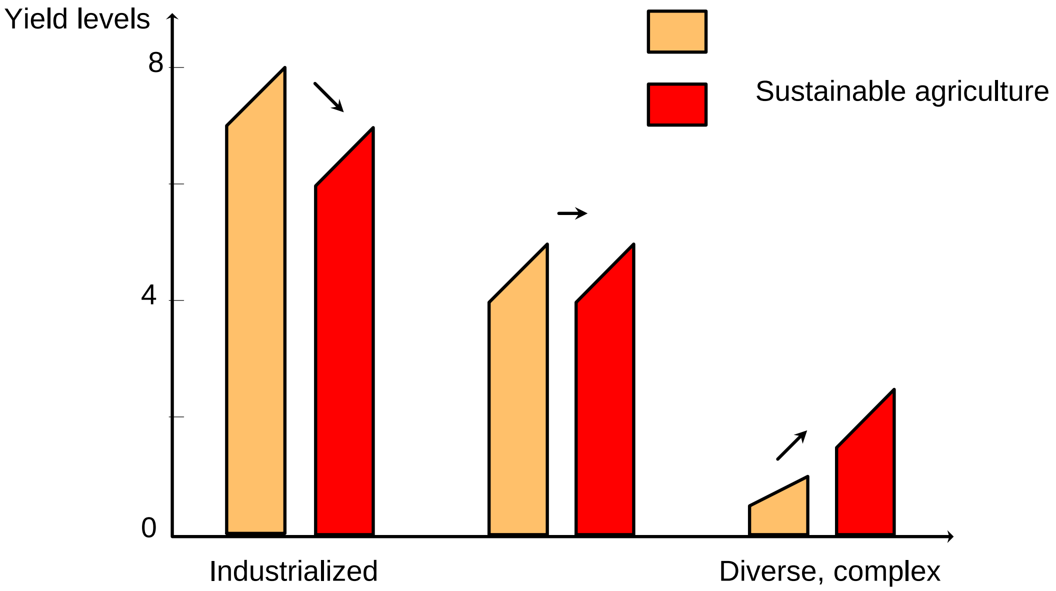
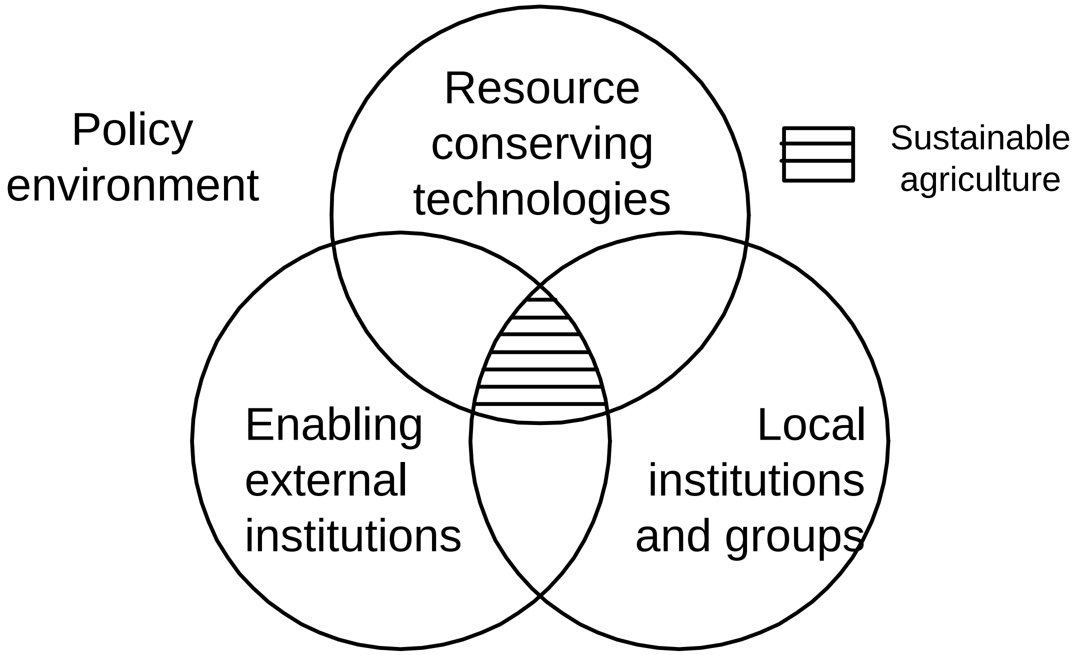


Figure 4.2--The conditions of sustainable agriculture



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SECTION 2: SUSTAINABLE INTENSIFICATION AND PLANT NUTRIENT

5. LOW USE OF FERTILIZERS AND LOW PRODUCTIVITY IN SUB-SAHARAN AFRICA

by Wilfred Mwangi[2]

INTRODUCTION

Population growth will continue to outstrip growth in food production in sub-Saharan Africa (SSA) for a long time to come unless serious action is taken to accelerate agricultural growth. Between now and the year 2000, population is expected to grow at more than 3 percent per year, while food production is likely to grow by 2 percent per year or less. By the year 2000, the production shortfall, in SSA is estimated to increase to about 50 million tons of grain equivalent - up from the current level of about 14 million tons (von Braun and Paulino 1990). By the year 2020, the World Bank (1989) estimates that the food shortage in Africa will reach 250 million tons, 20 times the current food gap. Furthermore, the region will not have the necessary foreign exchange to import such large amounts of food, nor will the African governments be able to count on enough food aid to make up the difference. Even if importing food were financially viable, most countries in SSA lack the infrastructure (ports, roads, trucks, distribution network, and so on) to handle it efficiently.

Although low-input extensive land using systems generally are highly efficient with respect to returns to labor and in terms of long term sustainability, they are also generally characterized by relatively low land productivity which cannot sustain rapidly growing rural populations. To grow enough food to feed an increasing population from these systems, farmers have to expand cultivated area, thereby moving onto easily degradable marginal lands (Matlon and Spencer 1984). Also, many parts of Africa are extremely land-scarce, despite their appearance of land-abundance (Binswanger 1986; Matlon 1987b). Intensification would reduce the need to cultivate marginal lands. Moreover, high-input systems would restore fertility via increased fertilizer use (Matlon 1987a), especially in areas where nutrient depletion is the major soil degradation problem. Thus, given its burgeoning population and scarcity of land, SSA's food needs cannot be met through low-input systems that are based largely on traditional practices; rather they require much more from farmers in terms of labor, knowledge and skill (Borlaug and Dowswell 1994).

The objective of this paper is to examine factors behind the low use of fertilizer and low productivity in SSA. The paper is organized in seven sections including the introduction. Section two outlines fertilizer use and the need for improving soil fertility. In section three, the factors that determine the probability of adoption of modern technology are reviewed. Demand and supply side factors constraining fertilizer use are examined in section four.

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Section five addresses the economic aspects of fertilizer use, the pricing environment, and infrastructure. The policy environment shaping fertilizer use is discussed in section six. Lastly, conclusions and future policy implications for facilitating and enhancing increased fertilizer use are presented in the final section.

INORGANIC FERTILIZER USE

Fertilizer is a critical input for improving the impact of agricultural production technology and increasing crop yields. Over the past 25 years, chemical fertilizers have been the primary means of enhancing soil fertility in small farm agriculture (Byerlee *et al.* 1994). Estimates suggest that in Asia and Latin America, chemical fertilizers are responsible for 50-75 percent of the increase in the food crop yield over the past two decades (Viyas 1983; Narayana and Parikh 1987). Also, given present knowledge, the rapid rate at which food production must increase in developing countries, and the severe degradation of soil, farmers probably have little choice but to depend heavily on external sources of nutrients in the foreseeable future (Desai 1990).

Researchers and policy makers widely recognize the importance of fertilizers in accelerating the growth of food production in SSA (Bumb 1988). Mellor et al. (1987) give fertilizer the first functional priority for accelerating food production in SSA. They suggest that, even with existing technology, a 15 percent annual growth rate in fertilizer consumption is both possible and of great potential significance for SSA.

However, SSA has very low levels of fertilizer use (Table 5.1). Average use in SSA in 1990 was 8.4 kg of fertilizer nutrients per ha of arable land and land under permanent crops. In that same year, the world average was 93 kg; for developing countries, the average was 81 kg (Gerner and Harris 1993). Slightly more than half of the fertilizer consumed in SSA is used on cereals, particularly maize. Although the area of the other two important cereals, millet and sorghum is also large, very little is fertilized and application rates are low (Gerner and Harris 1993).

In SSA, grain yields average about a third of those of east Asia. Differences in land quality are part of the reason, but so too is SSA's low fertilizer use--less than one-fifth east Asia's average (World Bank 1992). Given the low levels of fertilizer use in SSA and the demonstrated contribution of fertilizers in increasing crop yields and land productivity, the increased use of fertilizers has great potential for boosting food production and promoting agricultural development in SSA. But this potential can only be realized through sound government policies and investments that will promote the adoption and increased use of fertilizers by small-scale farmers (Baanante and Thompson 1988).

IMPROVING SOIL FERTILITY

Low use of fertilizer reduces soil fertility; it also increases soil degradation through nutrient mining (Byerlee *et al.* 1994; World Bank 1992). Nutrient inputs from organic and inorganic sources into sedentary agriculture has been insufficient to reverse the trend. Estimated rates of net nutrient depletion are high, exceeding 30 kg N and 20 kg K per hectare of arable land per year in Ethiopia, Kenya, Malawi, Nigeria, Rwanda and Zimbabwe (Stoorvogel *et al.* 1993). Hence, for sustainable agriculture low fertilizer use rates and the resultant mining of soil nutrients are far greater problems than excessive and poorly managed fertilizer applications (World Bank 1992).

Declining soil fertility has been identified as one of the most significant constraint to increased food production in SSA. This is true even in the highlands of eastern Africa (traditionally the region's most productive and fertile lands) due to human population pressure and intensification in land use (Waddington and Ransom 1995). Shifting cultivation and fallowing have been the traditional methods of maintaining soil fertility and replenishing nutrients in SSA (Blackie and Jones 1993; Blackie 1994a; Spencer 1994). However, due to increased population pressure in most areas, fallowing has disappeared from the system in some areas and is declining in others.

Byerlee *et al.* (1994) contrast the relatively high adoption of improved maize by farmers (improved varieties and hybrids now cover 33-50 percent of the maize area in Africa) with the lack of resource management technologies for maintaining soil fertility and increasing labor productivity. But when fertilizer is not applied, adoption of improved maize is often associated with only marginal gains in productivity under smallholder conditions. For example, in an extensive program of on-farm demonstrations in Malawi, hybrid maize grown without fertilizer gave grain yields of only around 1.6 t/ha in seasons of near normal rainfall (Jones and Wendt 1994; Conroy and Kumwenda 1994), and on some depleted communal lands in Zimbabwe, hybrid maize will yield nothing without fertilizer (Waddington and Ransom 1995).

In some ecologies, continuous cropping of maize has led to degraded soil structure and micro nutrient deficiencies, which, in turn, have led to a long-term decline in yields even where chemical fertilizer is used at relatively high levels (IITA 1991). Thus, it is important to seek a balanced approach to improving soil fertility, an approach that combines both organic and inorganic sources of nutrients (Byerlee *et al.* 1994). The efficiency of chemical fertilizers and long-term sustainability of yields can often be increased by adding organic matter from internal nutrient sources (e.g. green manures and farm yard manures), by employing reduced tillage technologies, and by alley cropping (Spencer and Polson 1991; Matlon 1990; Low and Waddington 1991; Borlaug and Dowswell 1994). Successful intensification will need to combine such soil management with greater use of inorganic fertilizers, which provide about 40 percent of nutrients for the world’s crops (World Bank 1992). This is particularly critical in arid areas, where, in most cases, organic material has virtually disappeared from the soil due to extraction and decomposition. The use of fertilizers in combination with organic materials and soil conservation measures can increase the low yields of food grain common in these areas. Some argue, however, that high labor demand, variable product quality, and constraints to producing the quantity of manure and compost necessary to affect soil fertility noticeably, have led to the rejection of organic fertilizer to enhance soil fertility in smallholder agriculture (Blackie 1994b).

MODERN TECHNOLOGY ADOPTION

Many cross-section studies conducted in SSA have shown that the following factors significantly determine the probability of adoption of modern technology: farm size, access to credit, membership in cooperatives, frequency of attendance at farmers' meetings, risk, education, farmer's age, experience, contact with extension, access to outside information, farm income, availability of inputs and distance to markets (Falusi 1974; Gerhart 1975; Akinola and Young 1985; Akinola 1987; Ongaro 1988; Kebede *et al.* 1990; Jha *et al.* 1991; Polson and Spencer 1991). Byerlee *et al.* (1994) also observed that the adoption of seed-fertilizer technologies is strongly influenced by the state of input supply markets (market development and infrastructure), the availability of credit and price policies (input subsidies and price stability). However, in general the adoption of intensive green revolution technologies has been very slow in SSA (Spencer 1994). Further, as observed earlier, there is a lack of resource management technology for maintaining soil fertility and increasing labor productivity. But even where research and extension systems have recommended improved soil and crop management technologies there has been virtually no small-farmer adoption (Spencer 1994).

FACTORS CONSTRAINING FERTILIZER USE

Demand and supply factors are hard to separate when evaluating farmers' decisions to adopt fertilizer and their subsequent decisions about application rates. Many of the key influences discussed in the adoption literature (farm size, access to credit, contact with extension, availability of inputs, distance to markets, etc.), may be related at least as much to supply side constraints as to farmer demand. Furthermore, in Kenya and some other countries, fertilizer consumption tends to be higher where input supply networks are well developed. In some cases, however, it is difficult to establish whether poorly developed input supply channels are demand-driven (arising from factors such as unattractive returns, lack of credit, and poor technical knowledge) or supply-driven. In most cases, these factors are interconnected.

Demand and supply factors

The demand for fertilizers is derived from the demand for agricultural products. The factors that affect and determine agricultural production and the demand for fertilizers may be classified as (1) climatic variables, (2) soil characteristics, and (3) economic and social variables. In conjunction with the knowledge and experience of farmers, these factors affect decisions about the use of resources for agricultural production (crops and cropping systems), and the use and management of fertilizers and other variable inputs (Baanante and Thompson 1988). As for supply factors, SSA imports about 85 percent of the fertilizer it consumes (Vlek 1990). Fertilizer supply constraints are thus associated with importation, distribution, and pricing. Policies that affect these areas, along with a lack of infrastructure, are the main source of potential constraints to fertilizer supply. The various demand and supply factors that influence fertilizer use in SSA are discussed in greater detail below.

PRICING ENVIRONMENT AND INFRASTRUCTURE

Farmers in SSA face very high fertilizer prices (Table 5.2). The price they pay for fertilizer, relative to the price they receive for their output, is thus much higher than in Asia. Some of the reasons for this high price result from SSA's dependence on fertilizer imports. Differences between world f.o.b. prices and landed cost tend to be twice as high in many sub-Saharan countries as compared to Asian countries (Shepherd and Coster 1987). Bumb (1988) indicates that this large difference is the result of the small volume of fertilizer that most African countries import; small volumes increase transport costs and weaken the nations' position in negotiating for lower prices. Almost half of the 40 countries Bumb analyzed imported less than 5,000 tons of nutrients annually in the mid-1980s; only Nigeria imported more than 100,000 tons.

Another reason for high fertilizer prices in SSA is the high cost of distribution. These costs are higher by several fold than costs in Asia. For instance, in Sri Lanka, the distribution costs for urea averaged about US$45/ton, as against US$92/ton in Zambia and

US$246/ton in Tanzania (Bumb 1988). Higher prices in SSA are the result of transportation costs, which in turn are a consequence of poor physical infrastructure and the small volumes to be distributed. The cost of transport and marketing can double the cost of imported fertilizer in a land locked country such as Malawi, compared with the cost in a country like Kenya, which has relatively good infrastructure and ready access to a port (Byerlee *et al.* 1994).

In 1990, almost one-third of all fertilizer imports in SSA were financed by aid; for 21 countries, all fertilizer was financed through donor programs. Undesirably, donors impose conditions (such as limitations on origin, transporters, and certain types of fertilizer products, etc.) that can lead to excessive marketing costs and margins (Gerner and Harris 1993), which ultimately translate into high fertilizer prices.

The involvement of the public sector in the fertilizer trade, its inability to operate fertilizer distribution systems efficiently and the absence of competition within the distribution network, is yet another reason for high fertilizer prices (Pinstrup-Andersen 1993).

Economics of fertilizer use

The economics of using chemical fertilizer on maize, for instance, is highly site-specific: depending on land pressure, agro-climatic variables, fertilizer costs (Byerlee *et al.* 1994) and farm gate maize prices. In Malawi, a recent program of 110 on-farm demonstrations over two years in one district found that it is financially profitable for food-deficit households to use fertilizer on local maize, while fertilizer use on hybrid maize at recommended doses provided even higher returns (Table 5.3). However, if the fertilizer subsidy were removed, fertilizing local maize varieties would not be economic. Even for hybrid maize, returns to fertilizer are less than the 100% rate of return usually assumed to be the minimum required for small-scale farmers to adopt this type of technology widely (Table 5.3). A similar situation has been observed for maize in Tanzania, where for farmers the profitability of fertilizer use is low, especially in interior locations where the high cost of transport reduces effective maize prices and increases the price of chemical fertilizers (Lele 1992).

An important consideration for small farmers who have little cash is the possible risk of using fertilizer. This is particularly true in marginal production areas with a high risk of drought. Results from marginal maize-growing areas of Kenya indicate that rainfall risk is probably a key factor in the low rate of fertilizer adoption in this area of highly degraded soils (McCown *et al.* 1992). But in favorable growing conditions like those of Malawi, risk is not an important factor in many farmers' decisions to accept or reject the seed-fertilizer technology (Smale *et al.* 1991). Price instability and input supply problems often pose a greater risk for fertilizer users than yield risk *per se* (Byerlee *et al.* 1994). In general, price instability leads to lower investment in new technologies such as fertilizer (Timmer 1993). It has also been observed that uncertainty in the profitability of fertilizer represents a serious disincentive to fertilizer adoption and use on staple crops (Vlek 1990).

Agricultural research

Future increases in food production must come primarily from higher yields per unit of land rather than from land expansion. Agricultural research must therefore continue to develop yield-enhancing production technology targeted to specific agro-ecologies, especially on food crops. Research must also build tolerance of, or resistance to, pests and adverse climatic conditions.

Because declining soil fertility is a major limiting factor to food production, soil fertility and fertilizer research should receive high priority and research on organic sources of nutrients must be encouraged and strengthened. Lynam and Blackie (1991) underlined the importance of crop and resource management research to overcome seasonal labor constraints, while conserving the soil base and enhancing soil fertility over the long run. They contend that this type of research will assume a major role in increasing the productivity and sustainability of maize-based cropping systems. However, this type of research is very site-specific and more detailed micro level research will be needed to define appropriate strategies for each location (Lele *et al.* 1989).

Despite recent studies showing high rates of return to research which has produced new technologies (Oehmke and Crawford 1993) and the extension systems that helped introduce the technologies to farmers (Bindlish and Evenson 1993), investment in research is declining. This trend must be reversed if SSA is to meet its food needs.

THE POLICY ENVIRONMENT SHAPING FERTILIZER USE

There is no consensus on policies to accelerate growth in fertilizer consumption in SSA. Experience with various policy instruments is mixed. In response to the need for improved access and structural adjustment, the fertilizer debate is currently centered on subsidy removal, distribution system privatization, and import liberalization. Pinstrup-Anderson (1993) notes that in most cases the farmers' limited access to the correct kind of fertilizer at the right time was just as important a constraint as the fertilizer price. As detailed below, the policy environment debate can be divided into policies that 1) influence the availability of fertilizer and other inputs and 2) affect the prices at which inputs are purchased and outputs sold (Byerlee *et al.* 1994).

Fertilizer (input) supply

Probably the most important element in a policy environment conducive to technology transfer is the reliable and efficient supply of inputs (Byerlee *et al.* 1994). A major constraint to technology adoption in much of Africa is the physical unavailability or untimeliness of inputs. One study of farmers' reasons for not following the extension recommendations developed through adaptive on-farm research in Zambia found that in 44 percent of the cases inputs simply were not available (Low and Waddington 1991). Blackie (1994b) observed that fertilizer would remain a scarce and expensive commodity for communal farmers in Zimbabwe until distribution problems were resolved.

The current response to these problems in SSA has been to urge rapid privatization of the distribution system and liberalization of fertilizer imports. The argument is based on experience in other parts of the world, which has shown that private enterprise is more effective in delivering improved technology to farmers and in developing marketing and credit institutions (Borlaug and Dowswell 1994). However, Vlek (1990), observes that although private enterprise appears better suited to handling fertilizer procurement, distribution, and marketing, dealers must be afforded a sufficient margin to cover investment and operating costs and to make profits if a nation is to have a dynamic private fertilizer distribution and marketing network.

So far, experience in SSA with privatization has been mixed. In Ghana, fertilizer marketing channels have functioned poorly even after the privatization of supply and distribution. The scant participation of the private sector in the retailing, wholesaling, and importation of fertilizer has been attributed to the relative profitability of the enterprise from the narrow margins allowed by the Ministry of Agriculture (Kwandwo Asenso-Okyere 1994). Experience from Cameroon shows that once a market is developed, the private sector can import and deliver inputs at a lower cost, provided that the public sector provides market information and other appropriate supports (Truong and Walker 1990).

Experience with privatizing the fertilizer trade underlines the importance of government in creating a favorable environment (i.e., eliminating constraints from government involvement). This calls for a clear definition of the role of government and private sector in development and operation of a fertilizer sector. Short and long-term roles and how these change as the sector develops will need to be clearly spelt out so that there can be mutual trust and confidence. This is important because governments consider fertilizer to be too strategic and politically sensitive to completely divest their interests in it to the private sector. For instance, lack of fertilizer will affect national food security, which in turn will lead to undesirable political and social instability.

Sodhi (1993) in his review of the fertilizer sectors in Ethiopia, Kenya and Uganda indicated that government's role includes setting standards and enforcing standards and quality control; estimating fertilizer demand in consultation with the private sector; monitoring and evaluating sector performance; setting up mechanisms for consultations between the private sector and government; providing incentives and creating a conducive environment; supporting research and extension, especially on soil fertility and fertilizer issues; and developing infrastructure, especially rural/feeder roads and transportation facilities. For the fertilizer sector to be effective, the government, in consultation with the private sector and donors will need to develop what most countries in SSA lack: a detailed national fertilizer-sector policy and plan that is carefully integrated with a comprehensive agricultural strategy.

Price policies and credit

Many countries in SSA have promoted fertilizer use through fertilizer price and/or credit subsidies. The high cost of fertilizer in SSA is the main justification for maintaining subsidies. Other reasons include compensating for low output prices, uncertainty about the profitability of fertilizer, promoting adoption, making fertilizer more readily available to small farmers (thus fulfilling an equity goal), and the high cost of capital in informal markets (Byerlee *et al.* 1994; Pinstrup-Andersen 1993; Vlek 1990). In recent years, governments in SSA have been pressured by the World Bank, the IMF, and other donors through structural adjustment programs (SAPs) to remove fertilizer subsidies. In countries where such actions have been taken, overall national demand for fertilizers has been substantially weakened, at least in the short run (Vlek 1990). Waddington and Ransom (1995) indicate that in most countries of the region, SAPs have eliminated price subsidies and reduced the availability of credit for inorganic fertilizer inputs and seed. The short- to medium-term consequence of SAPs are that smallholder farmers will apply even less nitrogen and phosphate fertilizers and will use less hybrid maize seed because of real price increases at the farm gate.

Experience in various African countries concurs. In Senegal the reduction in fertilizer subsidies led to declining demand for fertilizer (Shepherd 1989). In Malawi and Cameroon, some contended that subsidy removal will reduce fertilizer use by women farmers, whose use of fertilizers is already low (Gladwin 1992). In Ghana removing fertilizer subsidies in the absence of credit and remunerative output prices resulted in falling demand for the input (Kwandwo Asenso-Okyere 1994). A study from Nigeria, where fertilizer is subsidized heavily, showed that chaotic and untimely supply was one of the most salient reasons for non-adoption (Daramola 1989). In this case, continuing the fertilizer subsidy appears unjustified on either efficiency or equity grounds. However, others have argued that despite the supply problems, the fertilizer subsidy undoubtedly assisted the adoption and expansion of maize acreage (Smith *et al.*, l994). Furthermore, they indicated that the removal of fertilizer subsidy would reduce the profitability of maize, while reduced fertilizer use levels would necessitate major changes in soil maintenance practices in a production system that relies heavily on fertilizer for maintaining soil fertility. As demonstrated above, where subsidies have been removed, fertilizer use has been reduced significantly. Given the very low levels of fertilizer use and high prices, fertilizer subsidies should be continued in the short- and medium-terms to encourage adoption on both efficiency and equity grounds, especially where the majority users are small-scale food producers.

Fertilizer transportation accounts for the largest share of the difference in marketing margins between Asia and Africa. Reducing transportation and storage for a bulky input like fertilizer is essential if long-run consumption is ever to approach the social optimum. Investments in rural and agricultural institutions and rural infrastructure, especially rural/feeder roads, should therefore be accelerated. The need for investments in roads is underscored by the fact that SSA has only 5 km of roads per l00 km^2 compared to 45 km and 95 km of roads for the same area in Asia and in the industrialized economies, respectively (Vlek 1990). In Tanzania, poor feeder roads make primary marketing less efficient than secondary marketing because both private traders and cooperative societies refrain from trading in remote areas (Amani *et al.* 1992). In Iringa, Coulter and Golob (1991) observed that, for villages between 15-45 km off the main highway, the cost of primary marketing (wholesale assembly) ranges from 9 to 40 times the cost of secondary marketing. Private traders do not go to such areas to buy farm produce. Poor roads thus prevent fertilizer from coming in and produce from going out.

In Ghana, some have argued that reducing post-harvest losses, increasing the availability of effective storage structures, and improving transport infrastructure can increase the profitability of many crops, especially cereals, and serve as an incentive for increasing fertilizer use (Kwandwo Asenso-Okyere 1994). Such increases would reduce the price of fertilizer and eliminate the need for subsidies.

Besides subsidies, government-sponsored credit programs have commonly been used to promote input adoption, often by providing inputs in kind at low or negative real interest rates (Byerlee *et al.* 1994). While such programs have sometimes stimulated input adoption by a significant proportion of farmers (Kimuyu *et al.* 1991), adoption has usually been achieved at a high cost, and the programs have not been sustainable over the long term (Adams *et al.* 1984; Eicher and Rukuni 1992). Moreover, credit programs have tended to be monopolized by more powerful rural political groups and male farmers (Gladwin 1992) and are difficult to administer.

Other important elements in an environment conducive to technology transfer are producer price incentives and stability (Byerlee *et al.* 1994). In some cases, distortions in producer prices are the major factor limiting technology adoption. In Ethiopia, fertilizer use on maize was uneconomic at any level under prevailing prices for maize. If maize prices were to reflect import prices at a realistic exchange rate, however, fertilizer would become an attractive investment (Legesse Dadi *et al.* 1992).

In Ethiopia, consumption of chemical fertilizers averaged 50,000 tons during the 1980s. Major fertilizer use occurred after 1991: consumption doubled (to 113,000 tons) and rose to 160,000 tons in 1992 due to liberalization of the grain market (World Bank 1994a). But in Kenya, liberalization has been less encouraging: fertilizer use peaked at 271,000 tons in 1988-89 and declined steadily to 225,000 tons in 1991-92. This decline occurred mainly because the government liberalized the fertilizer market but did not liberalize the grain market, especially that of maize (Sodhi 1993).

In Zimbabwe, Conroy (1990) reported that fertilizer use in communal lands has not kept pace with population growth since 1985 although fertilizers, in terms of nutrient/crop price ratios, are cheaper in Zimbabwe than in other countries of the region (except Zambia). Moreover, the price of fertilizer relative to maize, cotton and wheat prices, has been falling over the last five years (Conroy 1990). The reasons for the limited use of inorganic fertilizer by communal farmers include problems of supply, the lack of an effective distribution network, and the absence of appropriate fertilizer recommendations (Blackie 1994b). Thus, it is clear that lack of price incentives is still an important factor that slows fertilizer use in many SSA countries.

CONCLUSIONS

In SSA, farmers use low levels of fertilizer. Given that fact and the current state of knowledge, low-input systems are unlikely to increase food production rapidly, reverse the decline in rural incomes, and slow environmental degradation. Increases in food production must come primarily from higher yields per unit of land rather than from land expansion. Historically, inorganic fertilizer has been a major component in achieving such increases. But a combined use of organic and inorganic fertilizers is a more sustainable agriculture practice for maintaining soil fertility.

The profitability of applying inorganic fertilizers often varies due to the variations in crop response, and high and variable costs of fertilizer in relation to product prices. In many areas of SSA, fertilizer adoption has been slowed by the absence of appropriate institutional structures to supply inputs, credit, and information within a conducive price environment.

Public research and extension investments will also play an important role in increasing the profitability of fertilizer use for farmers in SSA. Even though research investments have generated high rates of return, support for research is declining. This trend must be reversed, and investments must be accelerated, if research is to continue developing input-responsive and yield-stabilizing varieties, while improving crop and resource management strategies. Research and extension investments offer an assured way to satisfy increased demands for food at reasonable prices, while avoiding irreversible degradation of natural resource base.

Without subsidies, farmers in SSA pay a very high price for fertilizer. Such prices occur in part because most of the fertilizers used in SSA are imported and transportation costs are high. Given that the restoration of soil fertility is critical to increasing food production, in the short- and medium-terms, fertilizer subsidies can help to compensate for these cost-increasing factors.

In the long-term, however, SSA must find other ways to make the right type of fertilizer available at the right time, place and price. In addition, regional cooperation in international fertilizer procurement (Vlek 1990; Pinstrup-Andersen 1993) would help off set problems associated with the small volume of fertilizer purchased by countries in SSA, volumes that do not take advantage of scale-economies for purchasing and shipment. Governments in SSA consider fertilizer a strategic and politically sensitive commodity, however, and, given their experience with regional cooperation, this kind of cooperation may not be feasible.

The donor community (spearheaded by the World Bank and the IMF) is encouraging governments to promote private enterprise and competition with respect to fertilizer imports and distribution. Thus far, the experience has been mixed. Future strategies should include a greater mix of public- and private-sector initiatives involving organizations throughout SSA's fertilizer sector. The roles of each partner, especially that of government, will have to be clearly spelt out. Governments must make national fertilizer policies and plans a part of the overall agricultural development strategy. Such efforts should produce more predictable policies and more stable institutions so that the private sector can develop the confidence necessary to invest in the fertilizer trade. The policies should ensure that sufficient price incentives exist to make fertilizer use profitable for farmers and suppliers. Credit, for instance, must be extended not only to farmers but to private traders as well.

Lastly, poor rural infrastructure--especially rural/feeder roads--is a major cause of high fertilizer prices. Governments must increase their investments in infrastructure if they are to increase agricultural productivity. For fertilizer use to increase over the long-term, political commitment to agriculture must be translated into investments that develop institutions and infrastructure. Such support will enable agriculture to play its crucial role in SSA's overall economic development.

Table 5.1--Fertilizer consumption in Sub-Saharan Africa[1]

Country	1979-1980	1991-1992
Benin	7	60
Botswana	8	6
Burkina Faso	26	72
Burundi	7	4
Cameroon	47	26
Central African Republic	1	4
Chad	--	27
Congo	6	6
Cote d'Ivoire	165	104
Ethiopia	27	71
Gabon	3	13
Ghana	65	29
Guinea	31	27
Guinea Bissau	5	16
Kenya	169	391
Lesotho	144	174
Madagascar	25	31
Malawi	193	447
Mali	69	71
Mauritania	108	73
Mozambique	78	16
Namibia	--	--
Niger	5	1
Nigeria	36	133
Rwanda	3	14
Senegal	123	66
Sierra Leone	46	9
Somalia	1	--
Sudan	27	72
Tanzania	90	153
Togo	49	88
Uganda	--	2
Zambia	114	119
Zimbabwe	443	528
Sub-Saharan Africa	124	136

Source: World Bank, 1994b.

Note: [1] Fertilizer consumption in terms of hundreds of grams of plant nutrients per hectare of arable land.

Table 5.2--Ratio of farm-level prices of nitrogen fertilizer to maize grain prices in Sub-Saharan Africa and other regions

Country	Price ratio
Africa	
Cameroon	7.3
Ghana	8.0
Kenya	5.0
Malawi	11.1
Tanzania	6.0
Zambia	2.8
Zimbabwe	7.2
Asia	
India	2.1
Pakistan	2.6
Philippines	2.9
Thailand	7.9
Latin America	
Brazil	6.0
Chile	4.4
Mexico	1.6

Source: CIMMYT (1990); Byerlee *et. al.* (1994); Lele *et. al.* (1989).

Table 5.3--Effect of price policy on the profitability of alternative maize technologies in 110 on-farm demonstrations, Lilongwe, Malawi, 1990-1991

	Local maize with fertilizer	Hybrid maize with fertilizer
Fertilizer applied (kg nut./ ha)	55	145
Yield increase observed over unfertilized local maize (kg/ha)	750	2400
	Marginal rate of return (percent)[c]	
Subsidized input prices[a]		
Maize-deficit households[b]	133	237
Maize-surplus households[b]	64	136
Unsubsidized input prices		
Maize deficit households[b]	79	145
Maize surplus households[b]	27	72

Source: P. Heisey (Personal communication), based on data provided by the FAO/Ministry of Agriculture Fertilizer Program. Reported in Byerlee *et. al.*, 1994.

Notes:

[a] Subsidy of 25 percent on fertilizer and about 40 percent on hybrid seed.

[b] The price of maize in households that purchase maize is about 40 percent above the farm gate selling price.

[c] Marginal rate of return on input expenditures. A return above 100 percent is usually assumed to be necessary for widespread farmer adoption.

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6. PLANT NUTRITION MANAGEMENT, FERTILIZER USE IN CROP PRODUCTIVITY, PROPOSED INNOVATIONS AND INTEGRATION WITH FARMERS' PRACTICES IN ETHIOPIA

by Tesfaye Negussie

INTRODUCTION

Ethiopia has diverse physical features and climatic conditions from cool highland escarpments to a hot lowland rift valley which separates the country into two parts (Figure 6.1). The diverse altitudinal, climatic, soil, and other conditions result in a multitude of agro-ecological zones. Agriculture is the mainstay of the national economy. It is the main source of livelihood for over 85 percent of the population and accounts for 90 percent of export earnings and 45 percent of GDP.

Currently, about 88 percent of the human population and 70 percent of the livestock live in the highlands (that is, above 1,500 meters above sea level), which is about 44 percent of the country's land area. The remaining 56 percent is lowland and is mostly undeveloped, due to limited resources. The livestock population of Ethiopia is the largest in Africa and is ninth in the world (about 28 million cattle, 24 million sheep, 18 million goats, 1 million camels, and large numbers of equines). Despite its huge size and inherent potential, the livestock sector still remains undeveloped and economic benefits from the sector have not been commensurate with its size.

Ethiopia has a large area of inland lakes and rivers which provide extensive resources for the development of fisheries and irrigation. The potential area that could be developed for irrigated agriculture is estimated to be about 3.5 million hectares, mostly located in the lowlands. At present only about 5 percent of this potential has been developed.

Despite Ethiopia's significant agricultural potential, the country has been experiencing chronic food shortages for the past several decades. This is due to low soil fertility status, recurrent drought, lack of appropriate technologies both in crop and livestock production, and implementation of non-conducive socio-economic policies in the country (RRC 1982). As a result, the country has not managed to produce enough to feed the growing population. In the last two decades several attempts have been made to redress the situation. Unfortunately, agricultural productivity and food shortages remain critical and threaten to worsen in the face of a rapidly growing population. This is due to numerous reasons, among them, traditional farmers' practices and their production systems. These traditional practices would have to change over to plant nutrition management and efficient fertilizer use to increase crop production and productivity in a sustainable way. Thus, there is an urgent need to substantially raise agricultural production and productivity through improving dissemination of labor-intensive agricultural technology and improving management and use of fragile agricultural environments.

CROP PRODUCTION

Small-scale private farming is the dominant feature of Ethiopia's agriculture. It employs roughly 84 percent of the total labor force and accounts for about 94 percent of cereals, 98 percent of coffee products and nearly all livestock production in the country. Nevertheless, Ethiopia's agricultural production is far below national requirements. According to the Ethiopian Nutrition Institute in 1992/1993 (personal communication), food availability was estimated to be 1,515 kilocalories per person per day (about 76 percent of the UN and UNICEF daily subsistence requirement of 2000 kilocalories).

Ethiopia's highlands are important in agricultural production. The central highland areas cover Shewa, Gojam, southwestern Wollo, southern Gondar, and eastern Wollega. These areas account for about 60 percent of the total cultivated land, 50 percent of the rural population, 90 percent of the food production, and have an annual rainfall of 950 to 1,500 millimeters per year (Figure 6.1). The eastern highland areas, covering Sidamo, Bale, Arsi, and Harargie, account for about 16 percent of the cultivated land, 19 percent of the production, and receive 600-1,000 millimeters of rain per year. The southwestern highlands, comprising Kefa, Ilubabor, and western Wollega, account for about 90 percent of the coffee area and receive 1,500-1,600 millimeters of rain per year.

There are two major rainy seasons in the country. The belg season (small rainy season) runs from March to April while the meher (big rainy season) is from June 15 to mid-September. The main crops grown in the belg seasons are barley, field peas, lentils, chickpeas, maize and wheat produced mostly in the highlands. Belg crops account for up to 10 percent of production, while meher (main season) crops account for 90 percent of the production of the country.

As indicated in Table 6.1, the annual cultivated land for cereals, pulses and oilseeds is estimated to be 6.4 million hectares, for a production of 7.31 million metric tons. Overall average national crop production is estimated to be about 1.14 metric tons per hectare. Of total crop production, cereals account for about 70.6 percent, pulses 10 percent, and oil crops 6 percent. The major cash crops produced by small-scale producers include coffee, oilseeds (sesame, noug, etc.), pulses, and vegetables. About 92 percent of the cropped land is cultivated under annual crops and the remaining area is for growing perennial crops, like enset, coffee, chat, fruits, etc.

Teff (*Eragrostris tef*) is the main important cereal crop and is used for making the national staple food. It accounts for 27 percent of cereal crop production and 18.7 percent of the cultivated area. Teff yields are typically low (0.8 metric tons per hectare) compared to most cereals. However, since the crop is resistant to diseases and pests, drought, and waterlogging conditions; can be stored for long periods in few pest storage problems; it has a higher market value; and preferred over maize for the preparation of the staple food, the farmers' preference is to grow teff over any other cereal despite extension service recommendations. In addition, teff can be grown virtually anywhere, and despite its low yield, market prices are high and the limited surplus is highly profitable.

A total of 192,000 metric tons of coffee are produced every year, of which 98 percent originates from the peasant sector. About 50 percent of the total production of coffee is consumed domestically while the balance is exported in the form of green beans to African, Asian and European countries.

Over the last 15 years, the agricultural sector has grown, on average, by less than 2 percent annually while the population has been increasing at a rate of 3.1 percent per year. As a result, food deficits have become pervasive and forced the country to depend on imported food. The constant decline in food grain production, with an ever-increasing population, sharply raised the food deficit from 2.6 million metric tons in 1987 to 2.8 million metric tons in 1990 and to 3 million metric tons in 1993. Average annual food imports amounted to 250,000 metric tons, of which 25 percent was obtained in the form of aid. The widening of the food gap and the unavailability of foreign exchange have increased the proportion of the population who are vulnerable to undernourishment and famine.

With rapid population growth in the rural areas, crop farms have been expanded into forest lands, hillsides and grazing areas. Despite this, the average holdings have been constantly declining. The average holding nationally is estimated at 1.39 hectares per household. This figure, however, does not include pasture lands which are normally used communally. The size of holdings varies between and within regions, and ranges from 0.86 hectares per household in north Omo, to 2.16 hectares in Arsi. In a considerable number of awrajas, such as Wolayita, Kembeta, Hadiya, Chebo, Guragae, and Sidama average holdings per household are as low as 0.3 hectares (Negussie and Amare 1992). As this is hardly enough land to sustain a typical household, a substantial proportion of the labor force in these awrajas has to migrate to seek off-farm employment to supplement family incomes.

Because of Ethiopia's almost total dependence on agriculture, and the need to alleviate the threat of famine, it is essential that maximum effort and resources be allocated to the development and growth of this sector.

For example, there are substantial possibilities for the expansion of cropped areas in the west and southeast areas of the highlands. Expansion has however been slow because of limited immigration, insufficient accessibility, and low socioeconomic infrastructure. In other parts of the highlands, possibilities for area expansion are much more limited, being confined mainly to valleys and depressions, many of which are periodically waterlogged. In addition, increased cropping intensities should be sought by reducing fallows and making fuller use of growing periods. This can be achieved by earlier and quicker land preparation, multiple cropping systems, use of faster maturing crops and varieties, closer plant spacing, the use of residual soil moisture, and through integrated plant nutrient management.

PLANT NUTRIENT MANAGEMENT AND FERTILIZER USE

In Ethiopia, government policy has been to give priority to increasing domestic food production in order to meet the minimum food requirements of the population. Agricultural production growth will therefore depend increasingly on higher yields and cropping intensities. Part of the increase will be achieved through greater fertilizer use.

Fertilizers in Ethiopia are considered to be one of the most reliable and readily available inputs for increasing crop yields. The National Fertilizer and Input Unit (NFIU) of the Ministry of Agriculture (MOA) successfully demonstrated the positive response to the application of fertilizer nutrients on main cereal crops. As a result of extensive effort, fertilizer consumption in the country rose in the peasant sector from 13,979 metric tons in 1975, to 105,000 metric tons in 1993, and to 185,000 metric tons in the 1994 cropping season (see Table 6.2, Agricultural Input Supply Corporation 1994). The major fertilizer consuming regions are Shewa 30.8 percent, Gojam 16.4 percent, and Arsi 11.3 percent, with the other regions accounting for 41.5 percent (National Fertilizer and Input Unit 1994). The major products used were diammonium phosphate (DAP) and urea, representing 89 percent and 10.7 percent of the total respectively. Estimated fertilizer use on crop lands is very low in Ethiopia, about 14.1 kilograms/hectare of fertilizer applied in 1993, and about 24.9 kilograms/hectare in 1994.

As shown in Table 6.3, fertilizer consumption in the three regions of Arsi, Shewa and Gojam where the major cereals are grown was about 61 percent of total fertilizer use in 1993 and about 59 percent in 1994. In total these three regions account for 43 percent of the area and 60 percent of the agricultural production of the country.

Almost 90 percent of the imported fertilizers are used on cereals, with about 45 percent used solely on teff (National Fertilizer and Input Unit 1994a), 18 percent on wheat and maize, and the remainder used on all other crops. Fertilizer use for cereals is presented in Figure 6.2. Increased use of fertilizers offers the most promising option for increasing domestic food production and reducing the food deficit. As shown in Table 6.2, only a small amount of fertilizer is used in the country.

At present the population growth rate is about 3.1 percent per year while food production is estimated to be growing by about 2 percent per year. However, to keep pace with population growth and to supply raw materials for industry and export earnings, the growth rate in food production needs to exceed population growth. For food availability to be consistent with improving nutrition status and promoting overall economic growth, massive growth in the use of inorganic fertilizers will be required.

As shown in Table 6.4, crop yields, when fertilizers are applied, can be substantially high. Balanced application of N and P_20_5 fertilizers, increased yields by 438, 1,174, and 1,368 kilograms per hectare for teff, wheat, and maize grain could be produced, respectively. This implies that for each kilogram of nutrients, 3.5 kilograms, 6.9 kilograms and 9.6 kilograms of teff, wheat, and maize grain, respectively could be produced in the country. It would thus be far cheaper to import a kilogram of fertilizer than to import, on average, 6.7 kilograms of grain to meet the growing food deficit in Ethiopia.

In 1994, fertilizer consumption in the country reached a new high due to a decision made by the Transitional Government of Ethiopia (TGE) to give the farmers an opportunity to buy 100 percent on credit. While most farmers are aware of the high crop yield increase that they can achieve by using fertilizers, farmers' fertilizer usage is nevertheless much lower than the recommended rate. Hence, a strong extension service is required to demonstrate the advantages of using the recommended rate of fertilizer and to convince farmers to use the right amount of fertilizer on specific areas and soil types.

The National Fertilizer and Input Unit successfully completed its objectives during 1986-94 by providing a significant contribution to refining the old fertilizer recommendations in the country (Table 6.4). Starting from mid-1994 the National Fertilizer and Input Unit's efforts concentrated on a holistic approach to develop plant nutrition management techniques in food crops in major agricultural areas of the country. The efficient use of plant nutrients, proper utilization of possible and potential organic resources, adaption of measures to prevent soil and plant nutrient losses, moisture conservation techniques and draining excess water from vertisol areas, recognition of the role of livestock, proper cultural practices and socio-economic conditions (participatory approach, women in agriculture) are the main components envisaged in the program. The first objective of the program was to develop tests to convince farmers to use economically viable and locally available resources, to restore the soil fertility in the country. Even though the number of sites and the timeframe was limited, trial results indicate that some useful information can be drawn.

Some of the National Fertilizer and Input Unit test results are presented in Figures 6.3, 6.4, 6.5, and 6.6. The two major crops used for the test were teff and wheat. The recommended practice for wheat, which included improved tillage by using improved moldboard plow, row planting, and improved hand weeding, was somewhat different from the recommended practice for teff which was confined to the use of a ridge called Broad Bed Maker (BBM) to improve drainage.

The detailed effects of fertilizer use efficiency on yield are shown in Figures 6.3, 6.4, 6.5, and 6.6. Fertilizer application increased teff yields by up to 70 percent and wheat yields by up to 56 percent. Yield response was affected by many factors, particularly altitude (composite factor). Care must be taken in developing improved farming practices, which account for up to 20 percent of the teff yield increment and up to 40 percent of the wheat yield increment.

In 1994, the National Fertilizer and Input Unit established a network of reference farms within villages (eight farmers per village) for a minimum of three years. This program was undertake to assess the impact of technologies with crop rotation, mineral fertilizer, organic manure (dung, coffee hull, straw, compost, etc.), improved seeds, improved farm implements, and improved weeding, with a view to promoting a more sustainable way of increasing crop yield based on both local and external resources.

SOIL FERTILITY AND SOIL LOSS

Erosion is a large problem in Ethiopia; the total annual surface runoff from the major river basins of Ethiopia is about 110 billion cubic meters, over 75 percent of which drains to neighbouring countries (Egypt, Somalia, and Sudan) according to Negussie and Amare (1992). It is estimated that each year about a billion metric tons of sediment is carried away to neighboring countries as a result of Ethiopia's mountainous topography.

Allowing for such sediment deposition, it is estimated that cropped lands lose on average about 100 metric tons of soil per hectare every year (FAO 1988). The highest erosion rates are in the Wallo, Gondar, Tigre, Gojam and Shewa regions of the country where erosive cropping practices such as continuous cropping are used on steep slopes and where there has been enormous loss of vegetation cover. Losses in soil productivity are even more serious in the highlands of Ethiopia. Soil nutrient and organic matter losses, coupled in inadequate soil depth that reduced water holding capacity and root anchorage to the soil can lead to a low crop yield and encroachment into the marginal lands of pastures and forests.

Cropping by itself does not necessarily cause erosion. Perennial crops, for example, can protect the soil as much as natural forests. Rather, it is the system of annual cropping that has evolved in most of the highlands that is highly erosive. In Ethiopia, crops are more often grown on slopes, while the less erodible valley bottoms are grazed because of their susceptibility to waterlogging and because the soils are too heavy for the traditional ox-plow. Secondly, small seed crops like teff, sorghum, wheat, and barley require fine seedbeds which need criss-cross plowing to break up soil aggregates, which in turn make the land more erodible if the last plowing is with the slope instead of along the contour. Third, the soil is bare at the time of the most erosive rainfall. It is estimated that some 80 percent of annual soil losses from croplands occur in the period from the beginning of plowing to the end of the first month after planting. Lastly, crops are often planted in pure stand, rather than intercropped with root crops, trees, or perennial crops. They usually are separated from the areas of annual cereal cropping. This cropping pattern reflects the dominance to date of the labor-saving but land-extensive system of cereal monocropping using a simple ox-plow.

In addition to the choice of cropping pattern, farmers mismanagement of their land resources is a problem. In general, farmers only have limited awareness of the extent of damage that improper farming practices cause and, moreover, lack sufficient knowledge about alternative means of managing farmland effectively. Approximately 50 million head of livestock concentrated on the sedentary farming area of the highlands coupled with a reduction in pasture land due to the expansion of cultivated area has led to an overgrazing problem. Together, overgrazing and deforestation from the removal of trees, bushes, and shrubs in order to open up new agricultural land, has reduced vegetable cover and expand the land to soil erosion. There backward and important cultivation and land management practices have subjected the land to severe soil erosion.

The extent of soil loss from erosion in the country is frightening. According to the Ethiopian Highlands Reclamation Study, the country loses a billion metric tons of soil every year. So far, two million hectares of land are beyond rehabilitation, 14 million hectares have been significantly eroded, and two million hectares have been moderately affected by erosion. Fertility loss from soil erosion is crudely estimated at Birr 15 billion every year (Negussie and Amare 1992).

Appropriate and effective management of the soil can help minimize eroision in Ethiopia. In early times, because of the abundance of forest resources relative to the needs of society, it was not felt necessary to replace trees and thus, the rural population has not integrated tree planting with its agricultural practices. The solution lies in striking the right balance between the protection of the forest and the use of forest products to help Ethiopia to extract a meager living for survival. Farm forestry as an integrated farm management practice will need to be given priority as a source for increasing soil fertility, providing wood resources, and to establish shelter belts to protect against erosion.

Accelerated erosion is also influenced by the hammering effects of erosive rainfall and runoff. The erosive removal of clays and organic particles that provide plant nutrients are preferentially removed, thereby impoverishing the topsoil nutrient bank. Preventing the removal of organic matter by erosion is critical to maintaining soil fertility. Nitrogen-fixing plants will also help to increase organic matter and the nutrient content of the soil to improve the potential for plant growth.

Although a constructed terrace will afford some measure of physical erosion protection and fertilizer may increase crop growth in the short run, over the longer term, soil impoverishment will continue unless an integrated approach is used for soil fertility maintenance. This approach includes the adoption of low risk technologies which help to conserve natural resources, and the use of chemical fertilizer and organic matter sources of plant nutrients to increase nutrient availability and uptake efficiency. These measures will in turn result in higher production and productivity and help to conserve soil fertility.

In previous years, cereal growing highland farmers used to maintain soil organic matter content by leaving the land fallow, rotating legumes with cereals, and in some areas by burning the soil "guy". In some maize growing regions, animals are kraaled for two or three weeks and rotated over the arable land. In other areas, the weeds are heaped in rows in the cropped fields to decompose and are plowed under. With fewer legumes and oil crops being grown because of aphid and weed problems, the present farming system is showing a trend toward monocropping and chemical fertilizer application in some parts of the country.

Crop residues and animal manure are usually insufficient for farm needs. Most crop residues are removed from the fields for use as animal feed, thatch, and fuel. Moreover, farmers use 95 percent of the animal dung for plastering houses, grain storage containers, threshing grounds, making enjera covers, fuel, and for sale. The remaining five percent is usually used for homestead vegetable growing. Consequently, few nutrients are recycled back to the land, and farmers continue to mine soil nutrients every year.

Under Ethiopian agricultural systems, substantial nutrient losses through water runoff and soil erosion are expected, but little information is available to verify such losses for various agricultural systems. A 1994 FAO study estimated that annual crops remove over 429 thousand metric tons of nutrients. General estimates suggest that nutrient losses through runoff may be as high as that removed by cereals (FAO 1994).

FARMING SYSTEMS

Currently in Ethiopia, about 88 percent of the population and 70 percent of the livestock live in the highlands (1,500 meters above sea level), which account for about 44 percent of the country's land area (CISP and NFIU 1995). The remaining 56 percent is lowland providing mostly pastoralists with a scarce distribution of water and grass for their livestock.

There are four typical agricultural farming systems recognized in Ethiopia: a) high potential perennial livestock; b) high potential cereal livestock; c) low potential cereal livestock; and d) pastoral.

a) High potential perennial livestock system: This is used in southwestern and western parts of the country (Sidamo, Gamogofa, Kefa, Ilubabor, and southwest Shewa). Most farmers use a hand hoe and available family labor. Also oxen are used for tillage where cereal crops are grown. The main farming activities in this category are the forest/coffee/enset/livestock system, the coffee/cereals/livestock system, and the enset/barley/livestock system. Cattle are the dominant livestock and manure is an important input with part of it used for soil fertility maintenance.

b) High potential cereal/livestock system. This system is typical of the central highlands (part of Shewa, east Wollega, Arsi, Bale, Harargie highlands, the Lake Tana basin, and the northern highlands). Cereals are the main crops and livestock is an integral part of the system as draft power for tillage and threshing. Grazing and crop residues are the major feed resources in the system. There are two growing seasons per year: the belg (about 10 percent of crop production) and the meher (about 90 percent of crop production). About 90 percent of the farmers use maresha, the local plow for seedbed preparation. The frequency of plowing depends on the type of land owned by the farmers (5-6 times). In this system some legume/cereal rotation is practised when farmers notice that the land appears exhausted. The competition between family food needs, livestock feed requirements and organic source of nutrients for crops and for maintaining the soil fertility is very high. Usually crop residues are used as animal feed and manure as fuel sources.

c) Low potential cereal/livestock system. This system is typically employed in the degraded high altitude part of the country (Tigre, part of Gondar, western Wollo, northeastern Shewa). Here the land is cultivated so excessively that the vegetation cover has been lost and the top soil is being removed through soil erosion. Rainfall is generally erratic and insufficient to support steady production. Cereals are the main crops grown and residues are mainly used for animal feed.

d) Pastoral system. This system covers a large area of the Ethiopian lowlands. The area is arid and semi-arid. Nomadic and semi-nomadic livestock agricultural production are practiced. In some areas, shifting cultivation is also practised. Too often water becomes scarcer than forage and the temporal and spatial variations in the availability of water and forage are the major causes of pastoral migration.

FARMER CONSTRAINTS

The constraints to agricultural production can be summarized under the following categories.

Environmental

These constraints on farmers are related to erratic rainfall and environmental degradation which lead to soil erosion and soil fertility reduction (KUAWAB 1995). The most dramatic effect of erosion is severe drought which in a bad year, such as 1984/85, is estimated to effect over 10 million people.

Technological

These constraints originate from low level usage of agricultural technology, dependence on traditional tools and farming practices, low application of modern inputs like improved seeds and fertilizers, and poor animal breeds. Smallholders depend on traditional crop production techniques like fallowing which have increasingly failed to cope with growing population pressure. Moreover, pre- and post-harvest output losses are estimated at 15-20 percent, significantly higher than the African average of 12 percent. With limited access to modern agricultural technology and small, fragmented land holding, farming systems in Ethiopia have thus remained subsistence oriented.

In addition, average household farm size in Ethiopia is estimated to be between 0.5 - 1.44 hectares (Negussie and Amare 1992). Unless they change their traditional tools, methods of production, and choice of crops, farmers will find it increasingly difficult to sustain themselves on small acreage land holdings.

Policies and incentives

These issues are related mainly to land security or land tenure, access to agricultural marketing and credit, input availability, and cooperative and village formation. Strong policy guidelines are needed to replace the all too few, poorly designed, and counterproductive policies of the past into effective and efficient incentive schemes to encourage farmers to adopt improved systems of production.

Infrastructure

The country's infrastructural capacity in terms of irrigation, roads, and transport has been and continues to be poor. The problem is compounded by the low level of economic development which limits the availability of resources for investment in infrastructure. First, Ethiopia has a dissected terrain which makes the development of transportation and irrigation infrastructure difficult. Intensification of production in the densely populated highlands is constrained by the almost total dependence on rainfall and the virtual absence of irrigation. In order to overcome this, the irrigation practices of smallholder farmers need to be improved and water resources more fully developed. Second, there are only 31 kilometers of road per 1,000 square kilometers or less than 1 kilometer of road per 1,000 people. It is further estimated that approximately 75 percent of all farms are more than five kilometers from the nearest all-weather road (Hawe 1992). Moreover, owing to the absence of appropriate maintenance over the past few years, road conditions have deteriorated. Consequently, by retarding the movement of commodities, underdeveloped transport infrastructure has led to low output prices and high consumer prices for rural Ethiopian communities.

Institutional

Local people's institutions with strong organizational capacity are essential for effective mobilization of domestic resources. Attempts were made to create rural institutions to facilitate effective farmer's participation under the former government. Peasant associations were created with the power, among others, to redistribute and administer rural land, and service cooperatives were established to deliver inputs, sell merchandise goods, market outputs, and provide credit. Because of political interference and the top-down approach of the program, their effectiveness was limited and their objectives altered from an institution that protected farmers' interests to a tool of the government to enforce unpopular policies, such as villagization, collectivization, and delivery of grain quotas. Nevertheless, since these institutions provide a vital link between peasants and government, they money should be found to rehabilitate and revitalize these institutions in order to facilitate extension activities.

PROPOSED INNOVATIONS AND INTEGRATION WITH FARMERS' PRACTICES FOR INCREASING CROP YIELDS

Food grains dominate production in many regions because of their central position in the Ethiopia diet. However, productivity levels of all crops have remained low for many years due to the traditional food production systems in use.

Although innovations are available to increase crop production in the country, they tend to be commodity oriented and do not take into account the farmers' knowledge gap, the production systems employed in the region, and socio-economic realities. The opportunity to increase yields through sound crop-husbandry management practices is improving. Intensification seems to be the most feasible and acceptable option for raising sustainable agricultural production through the application of improved agricultural production technologies, integrated plant nutrition and pest management, appropriate livestock management, and soil and water conservation measures.

A number of innovations could be applied to help farmers increase crop production within a short period of time. First, communities should be involved during the planning, constraints and resources potential assessment, testing, and responsibility sharing process of new technology and infrastructure development. Second, chemical fertilizer, organic matter recycling, improved high yielding varieties, proper cultivation practices, and crop rotations suited to the different cropping systems should be integrated to increase crop yields and biomass production in a sustainable way.

Organic fertilizer

Soil amelioration is a necessary process to improve the physical and chemical characteristics of the soil and to increase fertilizer use efficiency and water availability for crop growth and higher yields. As studies in the Arsi zone show, most of the farmers know the advantages of using organic matter on the farmlands, but due to the unavailability of other alternatives, organic resources such as animal dung are used for fuel, construction materials, house plastering, and for making "enjera" (the staple food). Consequently, because of the high opportunity costs, farmers attach low priority to applying farmyard manure on their fields. If farmers are able to gradually develop alternatives such as increased biomass production through integrated use of organic and inorganic fertilizer, soil conservation measures, multipurpose tree planting, and fuel wood, farmers will have a chance to better use and integrate organic matter into the management of their farmlands. Extension staff have an important role to play to encourage adoption by farmers.

The role of livestock

Livestock is an integral part of the mixed farming system of the country, hence enough feed has to be generated by increasing the biomass production of crops, forage crop production, or by planting multipurpose trees in order to alleviate the shortage of feed and fuel wood. However, at present the productivity of the indigenous breeds of livestock is very low. Local cattle milk yields cannot be expected to exceed 500 liters per year during a lactation period of less than 200 days, even under best management practices. Similarly, milk yields from local dairy goats are only about 300 milliliters per day. Improved milk animal varieties could yield three to five times as much milk under reasonable management conditions. Clearly, the emphasis in the livestock sector must shift from mere numbers to productivity per animal. Moreover, it is very important to strengthen veterinary service and the supply of veterinary drugs to increase livestock production and productivity.

Rice and waterlogging

It will also be important to introduce a rice crop into the country so that waterlogged areas can be efficiently used. In the Gondar area, encouraging results have been obtained in identifying high yielding upland rice varieties. Some of these varieties have been distributed to farmers in the area to encourage adoption and food production results.

Land management

Improved management practices on vertisol soils is necessary. Vertisol management practices in the highlands of Ethiopia seek to reduce waterlogging problems by using the broad bed maker developed by the International Livestock Center for Africa. Many areas of black clay soils and similar soils are currently not used to their full potential because of waterlogging and allied problems associated with poor drainage. The problem has been recognized by both the Institute of Agricultural Research and the International Livestock Center for Africa who have developed camber bed and broad bed techniques to assist in-field drainage. To date these techniques have not been extended to the peasant farmer.

According to the International Livestock Center for Africa Report (1988), an estimated 7.6 million hectares out of a total of 11.2 million hectares of vertisol area, which is the largest vertisol area in Sub-Saharan Africa is available to smallholder farmers in the Ethiopian highlands of which 1.96 million hectares is farmed. Table 6.5 indicates that, wheat yields increased from 0.8 mt/ha using traditional ridge and furrow systems to 1.1 mt/ha when modern management practices were used, and increased to 2.2 mt/ha when improved soil management practices were augmented by fertilizer (NP) application. This shows that a slight improvement in the drainage mechanisms on vertisol areas or a good vertisol management system can increase yields by 42 percent in both fertilized or unfertilized fields compared with traditional practices.

Broad bed and tied ridgge systems improve yields by using different technologies for different circumstances. Broad beds are used on heavy soils in wetter areas to improve drainage and to control runoff. Crops are planted on the bed where drainage is better, and runoff is directed along gently sloping (usually 0.1-5 percent) furrows to grassed waterways and thence to storage or safe disposal areas. Tied ridges are used to maximize rainfall percolation on medium textured soils in areas with short growing seasons. Ridges are formed on the contour and these are joined to form elongated basins which trap rainfall and allow it to soak in. Intense rainfall can cause serious erosion with tied ridges if the basins overflow and concentrate runoff into gullies. Crops are generally planted into ridges early in the wet season. One or two hand weedings are usually needed to control weeds, as tillage is limited to a single operation to create the tied ridge.

Cropping techniques

Erosion can also be reduced by a number of other techniques. Crops grown at optimum plant densities in fertile soils achieve canopy cover rapidly and produce large quantities of dry matter. The use of mulch and other soil amendments, together with high levels of crop residues, promotes soil fauna activity which improves soil structure and soil fertility. Improved soil structure increases rainfall acceptance and thereby reduces runoff and soil loss. Pasture lays on well structured and fertilized soils are also highly productive, particularly if they are not overgrazed. With appropriate management the pasture phase of a rotation helps to control weeds, and restores soil structure and fertility. In locations where the pressure for arable land is low, land can often be returned to pasture fallow for brief or extended periods to promote soil recovery. Strip cropping where alternate strips of different crops are planted across the slope or, wherever possible, along the contour can also be employed. With strip cropping, the crops grow over different periods and are not harvested at the same time, such that there are always strips of growing crops to help restrict soil movement down the slope. Both these approaches offer great potential for inclusion in integrated erosion control programs.

Alley cropping

Alley cropping is somewhat similar in concept to strip cropping except that it involves strips or lines of shrubs or small trees. The alleys are aligned on the contour and help to ensure that cultivation and strip rotations are kept on the contour. For alley cropping, rows of trees/shrubs are established on the contour on 4-6 meter spacing. When annual crops are planted between the rows of established shrubs, the shrubs are cut back to stumps, and then kept pruned through the cropping season. The foliage is used for mulch and the woody stems for fuel or stakes. After harvest the shrubs are allowed to grow freely to provide mulch for the following year. Limited grazing by animal stock of alley regrowth in combination with crop stover provides a useful feed supplement in the early dry season, particularly where the alley shrub is a legume. The high protein browse from the shrubs allows animals to more efficiently use the high carbohydrate stover. Alley shrubs may also be grazed in the early wet season, prior to pruning for the cropping season. Grazing of alley shrubs needs to be carefully controlled so that sufficient mulch is available for erosion control at planting.

Alley cropping is a long-term management option that combines cropping and fallow phases on a concurrent and permanent basis. Work at the International Institute of Tropical Agriculture in Nigeria has shown that alley cropping, combined with relatively low rates of fertilizer, has maintained crop yields over periods of up to ten years. Yields on similar areas, but without alleys, could not be maintained, despite heavy applications of fertilizer. In combination with suitable rotations and fertilizer use, alley cropping may also lead to stable production in the long term. Suitable rotations may need to include pasture lays or cover crops, particularly where weeds are a problem. If rotations are not sufficient to control weeds and maintain production levels, alley trees may be left to grow for a year or more as a short bush fallow. The presence of established trees with deep root systems markedly accelerates the bush fallow process. Income from wood or charcoal from the short fallow helps to offset the loss of crop production. The long-term effects of alley cropping in the tropical highlands are not yet established but work is proceeding at International Livestock Center for Africa in the Ethiopian highlands.

Crop rotation

Regular crop rotation is an integral part of farming practices aimed at preserving soil fertility and soil structure and at providing a measure of pest, disease, and weed control. Most rotations aim at exposing a given field to crops with different degrees of nutrient requirements, different rotting patterns, and, wherever possible, to leguminous, green manure or forage crops. Proper crop rotation may assist the stabilization of soil structure by increasing the amount of leaf litter, and by reducing the amount of tillage. This is particularly true when a pasture phase is included in the rotation, and where the pasture is adequately fertilized and not overgrazed.

In the past, a few years cropping followed by a bush fallow of several years met nutrient replenishment requirements in most developing countries. As the pressure on land increased, bush fallow has been replaced by a pasture fallow to allow adequate feeding of livestock, as well as to meet soil recovery requirements. As the pasture phase becomes shorter and grazing pressure higher, the value of the lay fallow is reduced. Nevertheless, lay farming in a crop rotation can lead to substantial short term increases in yields of some arable crops. Recent studies by the International Livestock Center for Africa have demonstrated the benefits of growing *Trifolium spp.* on subsequent crop production. Crop rotations that include lay farming are not widely practised by peasant farmers and are rarely related to soil fertility and structure conservation. The potential value of crop rotation as a low cost means of sustaining overall productivity needs to be fully assessed and needs to be demonstrated by extension staffs to convince farmers to use it in their farm plots.

Intercropping

Combining annual with perennial crops is a feature of intercropping. Crops like bananas, enset, or fruit trees can be intercropped with cereals and pulses. Hedgerows of trees or shrubs are used as windbreaks and as shelters for livestock in highly developed agricultural systems. Intercropping of fruit and other trees with annuals is also practised in the early years of establishment and can help to offset the costs of establishment. Trees established as windbreaks or for shelter do not interfere with cropping and may be harvested for fuel and timber in a controlled program consistent with their primary function.

The increasing pressure on land in Ethiopia means that any procedure which increases land use should be exploited. Intercropping and relay cropping offer well-proven measures for achieving higher production. Intercropping also offers additional advantages in terms of enhanced pest, disease, weed control, and reduced soil erosion. Relay cropping also provides the opportunity to harvest a food crop fairly early in the season when food may not be readily available from the more traditional method of single cropping.

Weeds and pests

Excessive weed growth can be a major limitation on crop production. According to the UNDP 5th country program report, weed infestation has been shown to reduce crop yields in Ethiopia by 30 - 50 percent. In some areas even a single weeding at the right time of crop growth will be adequate. Low weed pressure in the farm plots is absolutely necessary to optimize crop productivity. The advantage of a single weeding over the other practices is enormous (Australian Agricultural Consulting and Management 1986).

The concept that pest, disease, and weed prevention is better than a cure should be fully promoted. The benefits of the various methods for breaking life cycles, removing food substrates, maintaining low or zero carryover populations, removing alternate hosts, and minimizing the presence of different aged plants to harbor pests need to be fully evaluated. For the long-term control of pests, diseases, and weeds, and increased crop production, appropriate technology, rather than the extensive use of chemicals, is necessary. In order for the system to be adopted, it has to be demonstrated for farmer awareness to be created by extension staffs. However, for present situations, the pesticide use is minimal and needs to be increased from the low levels in order to increase agricultural production and establish an improved land management system, while taking care to protect the environment.

Soil and water conservation

With an estimated 52 percent of the highlands of Ethiopia affected by severe soil fertility depleting erosion arising from poor traditional cropping methods, effective soil and water conservation measures are required. Modified farming systems that incorporate good farming and vegetative practices are an important first step. Since physical conservation structures can take 10 to 15 percent of land out of production and require maintenance, such structures should be seen as a last resort, to be used when vegetative measures alone are insufficient. They are not a substitute for improved land use. Grass strips are far cheaper and almost as effective as bunds in conserving soil on slopes of up to 10 percent. The relatively high cost of these structures (in terms of land and labor) justifies the subsidy for their construction implicit in the Food For Work program, which should be considered for expansion into some areas for soil and water conservation activities.

Conservation can also be achieved by improving productivity (primarily through increased sorghum and root crop production, agroforestry, and water and soil conservation measures) on the most productive crop lands, which can also improve food security. On the most productive crop lands, biological and physical soil conservation methods will have to be intensified in order to achieve these results.

Credit and inputs

The need for the extension of credits for the acquisition of new technologies is vital. Credits and input supply are important given the low level of cash income of the farmer. At present, less than 20 percent of the farming population receive production inputs of any sort. With the exception of fertilizers, small private farmers have received hardly any institutional production credit. Financial institutions should devise the means for providing adequate services to farmers, while also ensuring that peasants are not brought into a vicious circle of accumulating debts. Since the branch networks of the two banks (the Commercial Bank of Ethiopia and the Agricultural and the Industrial Development Bank) have not done enough in extending credit to the peasant sector, power should be delegated to bank branches who in turn should be given higher limits for sanctioning loans.

In addition, since it is too expensive and time consuming for the Agricultural Input Supply Corporation (AISCO), a parastatal organization, to make the necessary investment nationwide for the distribution of inputs, the participation of private traders at the wholesale and retail level should be encouraged (CISP and NFIU 1995).

Women in agriculture

The role of women in agriculture in crop production and household welfare is vital. The potential contribution of women to increasing food production and to improving household welfare has been constrained by a) cultural influences which limit women from actively and fully participating in the decision-making process at all levels; b) the disregard by agricultural extension systems of the contribution of women to food production and household food processing; and c) inadequate attention of research to generating appropriate technologies designed to relieve women from arduous tasks in their reproduction functions. To obtain the full benefit of women’s participation in all walks of life, cultural, social, and legal barriers have to be removed. There is also a need to generate effective technology which reduces typical women's activities like fuel wood gathering, fetching water, and grain milling to create ample time for women to participate in the activities of crop production.

Agriculture research and extension services

Poor formulation and dissemination of technical packages and a lack of technologies relevant to the exiting production system have been factors hampering improved output. Rather than concentrating on setting up elaborate and costly research centers, the merits of simple, practical and adaptive types of agricultural research should be examined in the formulation of technical packages for the smallholder sector. Apart from the complementarity of various technologies, technical packages should center on the crop production needs of farmers.

While delivery of technical advice from development centers has proved to be satisfactory, concentration of technical manpower in the higher levels of the extension network hierarchy and a lack of work discipline among extension workers, have negatively affected their contribution. Moreover, field workers' involvement in non-agricultural activities and the low material and non-material incentives they receive have limited the effectiveness of extension efforts. To improve the effectiveness of extension and research activities, the top-heavy extension structure should be trimmed down with an aim of allocating more resources to the development level. Research and extension workers should be rewarded on the basis of their contribution to production/productivity increases. Apart from a formal agricultural training, extension agents working at farmer level should develop knowledge of traditional farming practices, and learn to speak the farmers' language.

Training farmers is a vital activity that should be carried out by extension agents. First, there is a need to organize and formalize relations and responsibilities among the various extension agencies to create and institutionalize an effective research extension linkage system. Second, the government extension services need to be strengthened by improving the effective development agent to farmer ratio. The observed inadequacy of operating budgets, transport and office facilities should also be redressed. Third, the existing farmer training centers need to be revitalized, strengthened and expanded to bring the farmer into direct contact with research and extension. This will provide the vital "lab-to-land" link for increasing agricultural productivity and production. Fourth, the mass media should be used to disseminate extension messages. Fifth, although existing organizations cover quite a significant proportion of the diverse agro-ecological zones in Ethiopia, there is a need to provide research support to agricultural activities in some other agro-ecological zones that have not received such support so far or where the level of support has not been adequate. Sixth, there is also a strong need to strengthen research output in food grain, root/tuber crops, livestock, fishery, soil and water conservation, dryland agriculture, biotechnology, microbiology, food processing, storage mechanization, water storage and use, and farm research. Lastly, the current process of technology generation requires a long period of time until the technologies are available to farmers. There is a need to reduce this gestation time without seriously jeopardizing the quality of the result.

The country has to continue to promote the generation of new agricultural technology. It is also crucial that existing technology be used effectively. Available evidence indicates that existing agricultural technologies are underused. Underuse can be linked to technology design, technology supply and associated costs, the mode of delivery, and the demand for and access to new low-cost technology on the part of the farm population. The focus should be to understand the factors constraining adoption and dissemination of new technologies, and to devise policies to enhance their adoption.

CONCLUSIONS

As indicated earlier, intensification on vertisol soils in the highlands of Ethiopia might be one of the priorities of the country. This requires improvements in vertisol management by using BBM (Broad Bed Maker) and early planting. If BBM is integrated with plant nutrition management (higher use of fertilizer and organic matter application, proper cultural practices, better weed management, pest control, deep plowing, soil conservation activities, etc.), the vertisol areas of the highlands of Ethiopia could easily achieve an additional yield of 1,000 kilograms per hectare. Assuming that farmers adopt these systems on only 20 percent of the 1.96 million hectares of cultivated land, an additional 392,000 metric tons of grain could be produced each year. Within five years' time, these vertisol areas could easily produce more than two million metric tons of grain, which would be enough grain to equal the expected food deficit in the country.

By and large, Ethiopia's agriculture is at the subsistence level. If a slight change were made in the adoption process of the suggested integrated plant nutrition management technologies, a boost in crop production could be obtained very easily. Moreover, since Ethiopia is endowed with abundant water resources that can be used for irrigation (UNDP 1993), the country's potential for small- and medium-scale irrigation could be on the order of about 3.5 million hectares, of which only five percent are as yet developed. The potential for irrigation can be increased if farmers use water harvesting techniques. Although some areas of the highlands and drought prone areas suffer from erratic rainfall, irrigation developments that allowed farmers to irrigate one or two times during the flowering and/or grain filling stages could lead to a considerable increase in crop production. Lastly, for traditional irrigation schemes to be efficient in water use, structures and canals need to be improved.

One way of increasing agricultural production in Ethiopia is through expansion, which involves bringing additional land suitable for agricultural production under crop production. There is sufficient land available to achieve the desired expansion, especially in the central, western, southwestern, southern, and southeastern highlands of the country. A strategy needs to be developed to encourage farmers to cultivate more land, all while taking care not to expand into fragile environments without the introduction of appropriate soil conservation measures.

Intensification seems perhaps the most feasible and acceptable option for raising sustainable agricultural production through the application of improved production technologies and appropriate crop and animal management practices. Increasing yield levels through improved agricultural inputs and sound crop husbandry practices offers a potent opportunity for significantly raising agricultural productivity. Greater use of improved agricultural inputs is necessary, most notably by the smallholders who account for more than 90 percent of the agricultural output. Since use is very low, there is ample room for raising the application of these inputs without undue concern for the environment. Similarly, the use of improved tools, implements, and equipment is insignificant. There is sufficient evidence, however, to suggest that effective demand for these inputs among small farmers is high, that the yield response of most crops is favourable, and that cost-benefit analysis justifies an expanded use of inputs.

Ethiopia's potential for increasing crop yields through intensification methods seems enormous indeed. Short- to medium-term agricultural development strategies need to focus on environmentally aware intensification programs in traditional surplus producing, drought prone, and seriously degraded areas. The highland reclamation study of the mid-1980s warns that considerably more effective and widespread conservation measures need to be undertaken with the fullest participation and involvement of smallholder farmers. Underpinning sustainable and improved labor and land productivity, especially in the highly degraded and food deficit highlands, is the integration of soil and water conservation in the farming systems of smallholders. This intensification should involve increasing soil vegetative cover through the cropping pattern, agro-forestry, and silvo-pastoral systems.

The intensification strategy must also call for strengthened extension services to smallholder farmers in drought prone, food deficit, and severely degraded highlands. Extension in these areas should focus on promoting the production of grain legumes, oilseeds, root crops and horticultural crops to provide intensified vegetative cover, to improve household nutrition, and to increase feed supply for livestock. Extension must also focus on intercropping systems, including relay cropping for cash crops; increased use of perennial, semi-perennial, crop rotation, and agro-forestry. Manure application, composting, and rotational practices of leguminous crops, grasses and trees should be popularized. Extension should also place emphasis on mobilizing community resources to develop micro-irrigation.

Through strengthened extension services, farmers should be encouraged to cultivate early and plant the crops immediately after the onset of rain in order to efficiently use the moisture, escape the dry spells during the flowering stages, and optimize yields. Dryland farming techniques in the lowlands also help to produce better yields. A large area of the lowland is not used due to infrastructure problems. However, if these areas are given to investors, it may be one of the possible solutions for increasing the production of the country. Strengthening the training program for subject matter specialists, extension agents, farmers, women, and farmers' groups on plant nutrition management systems, and highlighting the advantages of practising them, could be vital for sustainable crop production in the country.

The integration of all factors of production can also mean more production of cash crops for farmers and better income, which in some cases means better re-investment in the farmlands for intensification. In addition, as shown by the International Livestock Center for Africa in Table 6.5, if vertisol areas are intensified, more biomass is produced. In turn, this means more feed for livestock which means better income for the farmer in terms of animal production and livestock by-products as a source of cash. Also, if more biomass is produced, some of it can be used as organic matter on farm plots as an integral part of the sustainable crop management practices. Once this is achieved, the recycling process of organic and inorganic fertilzers, cultural practices, crop rotation, and other agricultural activities will continue as part of an integrated plant nutrition management system that enhances the well-being of the farmers and of the rural population and communities as a whole.

With the cultivation of underdeveloped lands, intensification (integrated plant nutrition management), the introduction of high yielding root crops, irrigation (both modern and traditional), vertisol management, the strengthening of extension services, improved credit availability, and continuous training of farmers, the country can hope to produce sufficient amounts of grain to meet the food demands of the population. Also the government's commitment to provide enough inputs (fertilizer, improved seeds, vegetable seeds, etc.)

and to collect surplus production from the rural areas is vital for sustainable production. Moreover, by developing the infrastructure in rural areas, by developing strong agricultural policies and strategies, and through international assistance, the hope is that Ethiopia will be able to feed its ever-growing population and solve the food deficit it has experienced for many years.

Table 6.1--Estimated cultivated area production and productivity in Ethiopia

Crop	Estimated area	Estimated production	Yield
	(thousand hectares)	(thousand tons)	(tons per hectare)
Cereals			
Teff	1388	1207.56	0.87
Wheat	708	977.04	1.38
Barley	991	1169.38	1.18
Maize	1123	1841.72	1.64
Sorghum	817	1062.10	1.30
Other	217	217.00	1.00
Pulses			
Faba beans	278	305.80	1.10
Field peas	113	84.75	0.75
Chick peas	133	91.77	0.69
Lentiles	51	30.09	0.59
Haricot beans	84	85.68	1.02
Others	69	48.99	0.71
Oil crops			
Linseed	137	64.39	0.47
Noug	264	97.68	0.37
Others	46	27.60	0.60
Vegetables	110	880.00	8.00
Fruits	24	360.00	15.00
Root crops	60	660.00	11.00
Tuber crops (enset and yam)	280	896.00	3.20
Coffee[a]	384	192.00	0.50
Cotton[a]	30	63.00	2.10
Chat[a]	92	1,472.00	16.00
Others	27	27.00	1.00
Total	7,426	10,134.51	

Source : Central Statistic Agency, Ministry of Agriculture 1993.

Note:

[a] Not included in total food production.

Table 6.2--Fertilizer consumption by peasant sector Ethiopia

Product	Fertilizer		Nutrient			
	1993	1994	1993		1994	
			N	P_205	N	P_20_5
DAP (tons)	90,000	165,000	23,100	41,400	38,900	75,900
Urea (tons)	15,000	20,000				
Average consumption (kg/ha)	14.14	24.91	3.10	5.58	5.24	10.22
NP Consumption (kg/ha)				8.68		15.46

Source: AISCO 1994.

Table 6.3--Fertilizer consumption by major regions

Region	Cultivated land	1993		1994	
	(thousand hectares)	(tons)	(percent)	(tons)	(percent)
Arsi	510.4	12,600	12	20,905	11.3
Shewa	1,776.7	33,600	32	56,980	30.8
Gojam	977.1	17,850	17	30,340	16.4
Others	4,161.8	40,950	39	76,775	41.5
Total	7,426.0	105,000	100	185,000	100.0

Source: AISCO 1994.

Table 6.4--Average crop response to recommended rate of fertilizer, 1992

Crop and Category	Recommended rate (N, P_2O_5)	Control yield (kg/ha)	Yield at economic optimum rate (kg/ha)	VCR
Teff				
National	77-49	731	1169	2.1
Gojam	58-49	698	1048	2.0
Shewa	61-54	809	1250	2.3
Arsi/Bale	78-20	1140	1486	2.1
Vertisols	65-37	897	1332	2.6
Nitosols	61-0	707	1051	3.3
Andosols	78-48	1024	1319	1.4
Cambisols	64-75	738	1,206	2.0
Wheat				
National	98-73	1416	2590	2.8
Shewa	86-64	1258	2368	3.0
Gojam	74-62	1288	2774	4.4
Arsi/Bale	79-44	1615	2644	3.4
Tigre	52-64	1813	2459	2.3
Vertisols	93-70	974	2307	3.3
Nitosols	89-57	1422	2445	2.8
Andosols	72-74	1911	2974	3.0
Cambisols	95-99	1,979	3,346	2.9
Barley				
National	70-55	1525	2453	2.5
Shewa	64-55	1073	1859	2.2
Gojam	64-21	1421	2268	3.3
Arsi/Bale	42-74	1434	2536	3.3
Tigre	63-31	2342	3152	2.9
Vertisols	52-58	1052	2011	3.0
Nitosols	69-67	1283	2457	3.0
Luvisols	78-36	1,705	2,642	2.8
Maize				
National	81-62	2677	4045	2.7
Shewa	68-57	2694	3951	2.9
Goja,	86-68	2660	4192	2.8
Nitosols	84-62	2,627	3,887	2.4
Sorghum				
National	32-53	441	977	2.5
Tigre	32-53	441	977	2.5
Cambisols	32-53	441	977	2.5

Source: Ho 1992.

Table 6.5--Wheat and faba bean yields at Were Ilu, 1987, as influenced by surface drainage and fertilizer inputs

Crop and land preparation	Number plots	Fertilizer inputs DAP	Urea	Grain yield	CV	Straw yield	CV
		(kg/ha)	(kg/ha)	(kg/ha)	(%)	(kg/ha)	(%)
Wheat ET 13							
BBM	20	0	0	1335[a]	41	1442[a]	38
	15	50	0	1291	36	1544	41
	19	100	0	1,658[b]	27	2013	31
	5	50	50	1776	11	2154	9
	5	100	100	2,247	11	2,683	8
Ridges and furrows	19	0	0	802	50	1,039	45
	17	50	0.00	999	40	1187	47
	20	100	0.00	1205	43	1440	42
	5	50	50.00	1030	18	1799	11
	5	100	100.00	1582	9	2032	9
Wheat (Enkoy)							
BBM	26	100	0.00	801[b]	37	1,028[b]	34
Ridges and furrows	25	100	0.00	575	47	757	46
Faba beans							
BBM	16	0	0.00	538	82	584	97
	16	50		660	75	678	91
	18	100		737	78	714	89
Ridges and furrows	15	0	0.00	489	88	500	106
	15	50		530	84	533	100
	17	100		548	88	535	101

Source: International Livestock Center for Africa, 1988.

Notes:

[a] Effect of drainage on yield for any one fertility level significant at $P < 0.05$.

[b] Effect of drainage on yield for any one fertility level significant at $P < 0.01$.

Figure 6.1--Map of Ethiopia

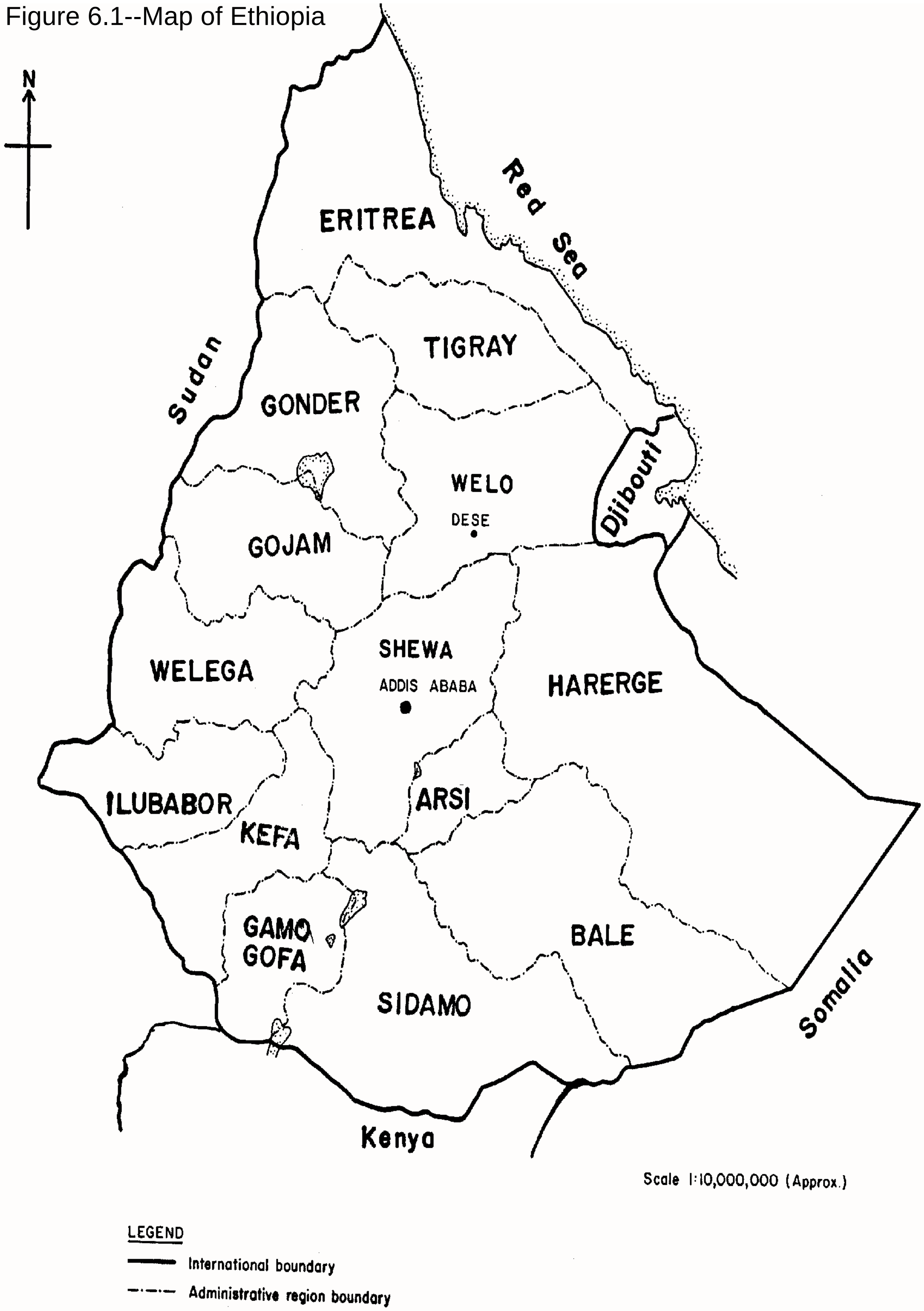
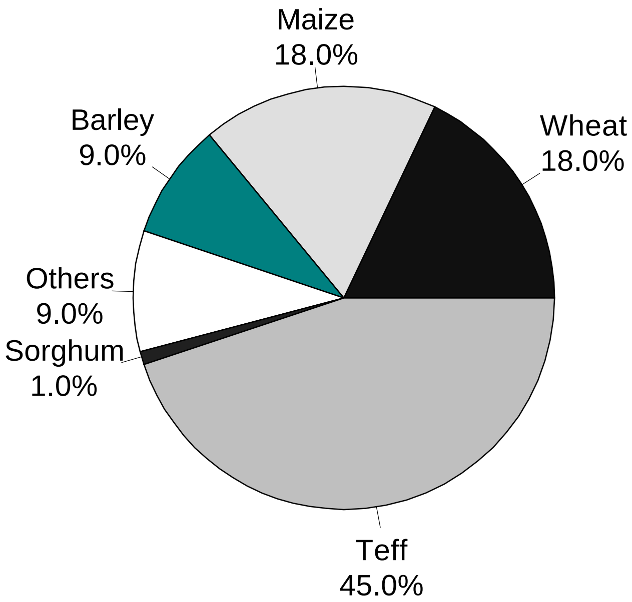
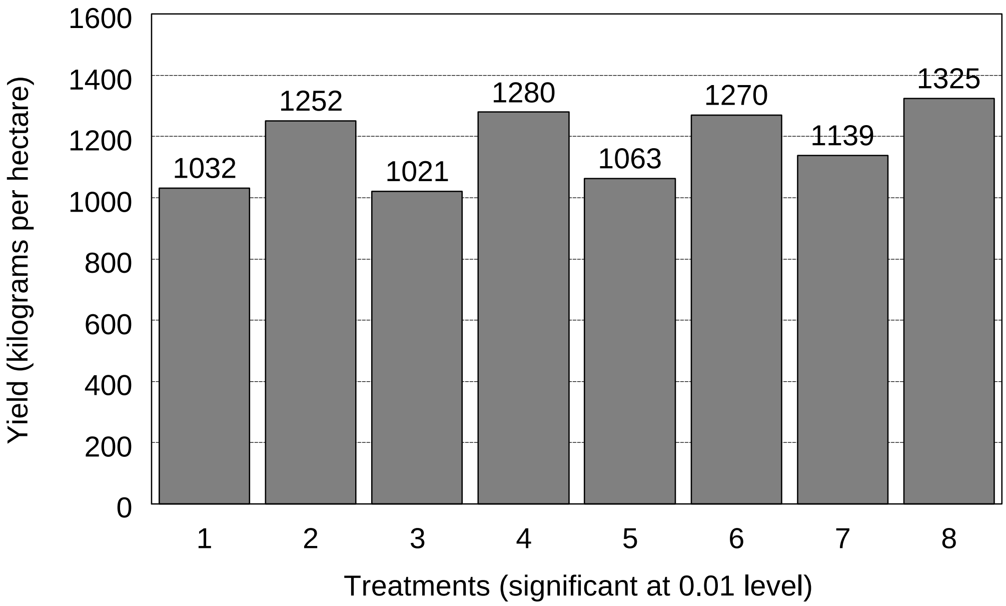


Figure 6.2--Fertilizers used for cereals in Ethiopia



Source: Central Statistics Agency, Ethiopia, 1991-92.

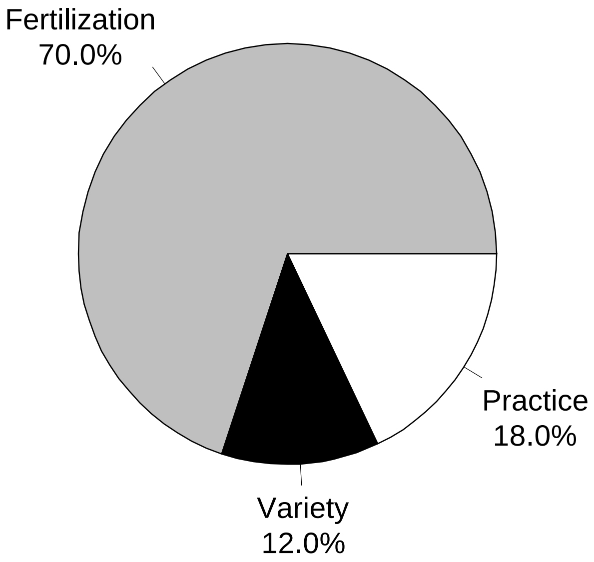
Figure 6.3--Dispersed simple fertilizer management trial for teff crop for 16 sites in 1993



Treatment details:
1. Farmer's practice +local variety +farmers' fertilization
2. Farmers' practice +local variety + recommended fertilization
3. Farmers' practice + improved variety + farmers' fertilization
4. Farmers' practice + improved variety + recommended fertilization
5. Improved practice + local variety + farmers' fertilization
6. Improved practice + local variety + recommended fertilization
7. Improved practice + improved variety + farmers' fertilization
8. Improved practice + improved variety + improved fertilization

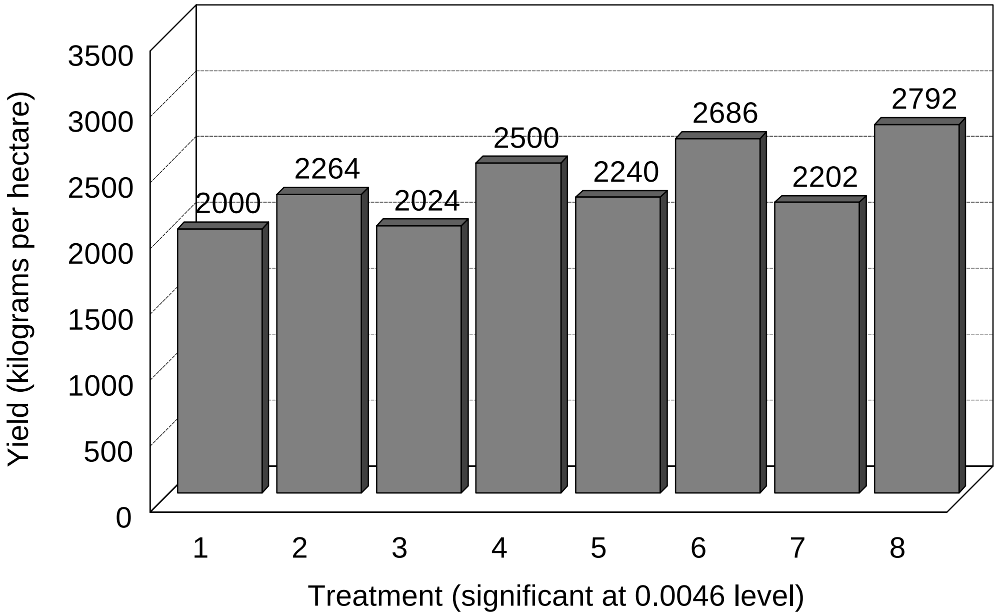
Source: NFIU 1994a.

Figure 6.4--Factor contribution to yield increases in teff in 1994



Source: NFIU 1994a.

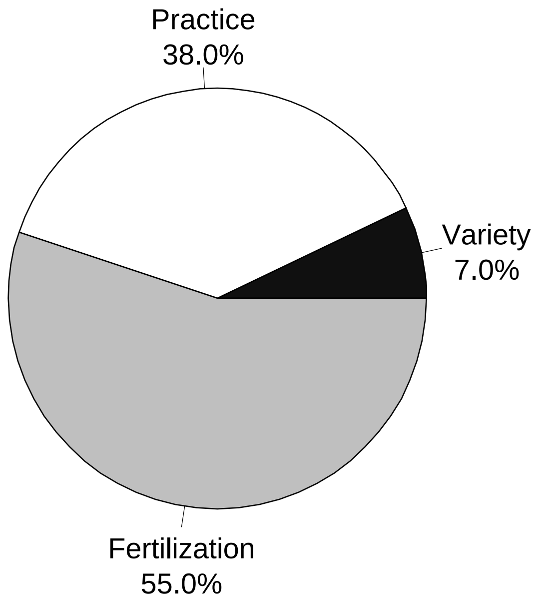
Figure 6.5--Dispersed simple fertilizer management trial for wheat crop for 10 sites in 1993



Treatment details:
1. Farmer's practice +local variety +farmers' fertilization
2. Farmers' practice +local variety + recommended fertilization
3. Farmers' practice + improved variety + farmers' fertilization
4. Farmers' practice + improved variety + recommended fertilization
5. Improved practice + local variety + farmers' fertilization
6. Improved practice + local variety + recommended fertilization
7. Improved practice + improved variety + farmers' fertilization
8. Improved practice + improved variety + improved fertilization

Source: NFIU 1994a.

Figure 6.6--Factor contribution to yield increase in wheat in 1993



Source: NFIU 1994a.

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SECTION 3: SUSTAINABLE INTENSIFICATION AND PLANT NUTRIENT MANAGEMENT: ASIA

7. FERTILIZER USE IN ASIAN AGRICULTURE: IMPLICATIONS FOR SUSTAINING FOOD SECURITY AND ENVIRONMENT

by M. Hossain and V. P. Singh

INTRODUCTION

During the last three decades, the threat of crop failure and famine in Asia has been kept away by the expansion of fully or partially irrigated agriculture environments. In these environments, the use of improved varieties, an eightfold increase in chemical fertilizer use, more effective control of weeds, insects and diseases, and optimum utilization of soil moisture from rainfall and irrigation have played a key role in pushing the yields of cereal crops, mainly wheat, rice and maize, to win the race between population growth and food grain production. In order to encourage adoption by farmers, nitrogen responsive modern varieties were developed and governments made additional investments in irrigation and drainage, and in supply and distribution arrangements for chemical fertilizer. With the transfer of lands from traditional to modern varieties, the consumption of chemical fertilizers and total cereal grain production continued to increase with very little addition to cropped land. For example, since 1966, when IR8, the first green revolution rice variety was released, rice harvested area in Asia increased by only 13 percent, while rice production doubled from 240 to 483 million tons, and fertilizer consumption increased from 8.6 to about 60 million tons of nutrients (N, P_20_5 and K_20). Further during the 1966-93 period, fertilizer consumption per hectare of arable land has increased from 20 to 140 kg of nutrients.

Over the last decade, however, there has been a significant change in policies regarding the government's involvement in the fertilizer sector due to the fiscal burden of fertilizer subsidies and concerns about efficient use of this input. There has also been a fundamental change in the importance attached to chemical fertilizers due to growing environmental concerns. At the same time, expansion of irrigation, which provides a relatively risk-free environment to farmers for fertilizer use, has slowed down due to a decline in donor support and the dampening of private sector investment for water control (Rosegrant and Svendsen 1992). As a result, fertilizer consumption growth has started to slow down. In view of the continued pressure of population on limited land resources, however, food grain production growth based on continuous yield increases on good quality land must be sustained to address food insecurity concerns (Pinstrup-Andersen 1993).

This paper attempts to review the role of chemical fertilizers in sustaining food grain production growth in the major rice growing countries of Asia. Section II reports past trends in fertilizer consumption and the intensity of fertilizer use in cereal crops. Section III assesses yield response policy change in the fertilizer sector, and their impact on fertilizer prices. Section IV analyzes the implications of sustaining food security and the environment on fertilizer use, and suggests some areas of research needed to achieve the targets. The main conclusions are stated in Section V.

TRENDS IN FERTILIZER CONSUMPTION

The growth of fertilizer consumption in a country depends on its state of economic development. At low levels of per capita income, the rate of population growth is very high. With economic growth, per capita consumption of cereals increases. Consequently, the demand for staple food grains increases rapidly due to pressure from these two factors. Faced with limited land resources, staple grain demand has been met in most Asian nations through greater use of chemical fertilizers that have raised crop yields. When income reaches a threshold level and the energy needs of the people have been met, population growth slows down. As consumers are increasingly able to afford a diversified diet containing more proteins and vitamins, the demand for staple grains slackens and farmers become more interested in increasing labor productivity than in raising crop yields. Consequently, the growth in demand for fertilizer slows down.

The trend in fertilizer consumption in different regions of the world can be seen from Table 7.1. After reaching a peak in 1988/89 at 146 million metric tons, world fertilizer consumption has started declining. In developing countries, however, consumption continues to grow, although the rate of growth has slowed.

At the beginning of the green revolution in the mid-1960s, fertilizer consumption in the world was only about 47 million metric tons, of which some 80 percent was used in the developed industrial countries (Table 7.1). The next decade witnessed a rapid growth in consumption both in the developed and developing countries. Fertilizer use reached 109 million metric tons by 1978/79. Over the next decade, consumption levels remained almost stagnant in the developed countries as per capita cereal consumption started declining and population reached near stationary levels. In Asia, however, fertilizer consumption continued to grow, though at a lesser rate. By 1992-93, Asia's share of total fertilizer intake increased to 47 percent from only 14 percent in 1965-66.

The recent decline in fertilizer consumption is due mostly to a dramatic drop in fertilizer use in Europe. This is mainly due to environmental concerns, an increasing demand for agricultural products grown under organic farming, and economic disruptions in the countries of the former Soviet block.

Table 7.2 shows the growth in fertilizer consumption in the major rice growing countries in Asia. In the mid-1960s, fertilizer consumption was limited largely to China, Japan and Korea, which accounted for more than 70 percent of the total consumption. Albeit from a low base, fertilizer consumption in the other Asian countries (excluding the Philippines) increased by more than 15 percent per year during the early green revolution period. In Japan technology-induced high food grain yields were achieved by the mid-1960s. From 1965-78, fertilizer use grew at an annual rate of only 1.4 percent. By 1992, fertilizer consumption was about 20 percent lower than that in 1978. In South Korea fertilizer use grew at 7.6 percent per year during the 1965-78 period. Consumption growth, however, has been stagnant since then. In other Asian countries, fertilizer consumption continued to increase rapidly till 1988. By 1992, the share of Japan, Korea, and China in Asia's consumption of fertilizer dropped to 54 per cent. Since then, the rate of growth slackened considerably in the other Asian countries except for Vietnam, Thailand, and Bangladesh.

Another interesting point is the decreasing trend in the growth rate of nitrogen consumption over the increased extent of irrigation in rice in Asian countries during the last decade (1992 over 1985). It is 50 percent or lower in countries (China, Indonesia, Japan, South Korea, North Korea, Malaysia and Pakistan) having more than 60 percent irrigated rice lands. And all such countries having irrigation extent of less than 60 percent (Bangladesh, India, Nepal, Philippines, Thailand and Vietnam) had higher growth rates (50 to 135 percent). This indicates that under the present level of technological knowledge and availability and management of other resources the demand for fertilizers in "irrigated rice countries" has reached, or is reaching its maxima, whereas in "rain-fed rice countries" there still exists a large potential for increased in fertilizer consumption.

How much fertilizer is used to produce staple food grains? What is the intensity of fertilizer use in these crops? These are some of the difficult questions to answer since time series data on fertilizer consumption in different crops is not available for most countries. Estimates of the share of cereal crops in total fertilizer consumption made by the International Fertilizer Development Center (IFDC) from farm survey data are shown in Table 7.3. Rice accounts for 70 to 80 percent of the total fertilizer consumption in Bangladesh, Myanmar and Indonesia, and more than 40 percent in the Philippines, Thailand, Korea and Sri Lanka. In China, India and Pakistan, wheat and maize are the important staples beside rice, and consume large quantities of fertilizers. In Pakistan and India, almost half of the total fertilizer consumed is on account of wheat, maize and other coarse grains, whereas in China, the share is about 40 per cent. As a whole, cereal crops account for over two-thirds of the total fertilizer intake in most Asian countries (Table 7.3).

Our estimate of the change in the intensity of fertilizer use in cereal crops and its change over the last two decades for the major rice growing countries of Asia is given in Table 7.4. In arriving at these estimates, we have assumed that the share of cereals in total fertilizer consumption has remained unchanged over time. This may not be valid in countries with rapid economic growth. Hence these estimates should be carefully viewed. It may be noted that except for Japan and Korea, fertilizer use in cereal crops, even by the mid-1970s, was very low in most Asian countries ranging from 12 kg/ha (Thailand) to 45 kg/ha (China, Vietnam and Sri Lanka). In Japan and Korea, however, the consumption level was more than 200 kg per ha, because they had already achieved higher crop yields by that time, i.e., 4.5 t/ha in Korea, and 5-6 t/ha in Japan, which was about two to four times higher than that in other Asian countries. Along with yields, fertilizer consumption per ha stagnated in Japan and increased only marginally in Korea. Other Asian countries experienced a rapid increase in the rates of fertilizer use in cereal crops; the present level, however, is still substantially below the level attained in Japan and Korea. Only in China and Indonesia has the rate of fertilizer (nutrient) use exceeded 150 kg per ha. Low application rates and high fertilizer consumption growth, particularly in the rainfed areas in South and Southeast Asia compared to the high yield area of East Asian countries, suggest that there is still a large potential for increased fertilizer consumption in Asia.

FACTORS AFFECTING FERTILIZER DEMAND

Since fertilizer is an input, the demand for fertilizer is a derived one. It depends on (1) the use of land and other complementary inputs such as irrigation, modern varieties, and soil quality which affect the yield response of crops to the use of fertilizer inputs; (2) the dependability of rainfall and other agro-climatic factors that determine the variability of crop yields from one season to another and the degree of risks involved in investments in fertilizers and (3) the price of fertilizer in relation to the prices of crop output and other complementary inputs that determine profitability of cultivation at given physical levels of outputs and inputs.

Yield response of fertilizers

The most important factor that would affect the demand for fertilizer is the crops' response to different levels of application of this input. As long as the marginal product from fertilizer use is higher than the marginal cost of fertilizers, farm profits will continue to increase with input use and farmers would have the incentive to increase fertilizer application rates.

Agronomists estimate crop response to fertilizer use from the results of fertilizer trials conducted on experimental farms in research stations and/or both in farmers' fields. Fertilizers are applied in different dose combinations of various nutrients that are required by the crop while other inputs are held constant at the optimum levels. A comparison of different outcomes identifies the maximum yield that can be obtained under non-limiting conditions for other inputs. Yield responses, may however, be lower under actual farming conditions owing to low and unbalanced application, sub-optimal management practices, adverse weather conditions and uneconomic mixes of complementary inputs such as labor, draft power, irrigation and pesticides.

Fertilizer use efficiency is determined primarily by the crop's growth rate, its nutrient demand and by the ability of the plant to compete effectively with other processes that draw off nutrients (De Datta *et al*. 1990; Zaman 1987; Buresh *et al.* 1988). The timing and method of fertilizer application, source of fertilizer, nutrient dose combination, and field moisture conditions and water control are crucial elements for getting the optimum response of fertilizer (De Datta *et al*. 1990; Singh *et al*. 1995; Tandon 1990; Prasad *et al*. 1990; and Singh *et al*. 1979). Agronomic estimates show that it is possible to obtain an average response of 50 kg of unmilled rice per kg of applied nitrogen. Marginal response drops sharply with nitrogen application rates above about 80 kilograms per hectare.

Crop nitrogen uptake is typically 20 to 50 percent of the amount applied due to losses from volatilization, leaching, runoff and nitrification-denitrification; hence, the actual response rate is much lower. Nitrogen losses are recorded to be much lower with incorporation of fertilizer into the soil, deep placement of fertilizers, use of enzyme inhibitors, coating of fertilizer granules and use of supplemental nitrogen sources, such as organic manures (green manure, azolla, etc.). Likewise, phosphorus removal by a crop normally does not exceed 15-20 percent of added phosphorus, with the remainder retained in the soil. The magnitude of the residual effect depends on the rate and kind of fertilizer, cropping and management practices, and soil type. In neutral, low iron and aluminum oxides containing soils, the P-fertilizer applied to a single crop often can meet the P-requirement of the subsequent crop(s) because P-fixation in such soils is low. The recovery of residual-P is not possible in P-deficient high P-fixing soils, such as Oxisols and Ultisols.

Intensive cultivation of high yielding crop varieties without application of the required nutrient elements and the use of inappropriate sources of fertilizers results in nutrient depletion of the soil and deficiency in crop plants. Potassium, sulfur and zinc deficiencies have become widespread in recent years (De Datta *et al.* 1990). However, the efficiency of use of these nutrients is relatively higher than nitrogen and phosphorus and they can also be managed easily. The efficiency of use of N, P, and K is also affected by their interaction and other management factors.

Fertilizer response is usually obtained by estimating the following functional form:

$$Y \quad a \quad bF \quad CF^{2} \quad e$$

where Y is the crop yield (kg/ha), F is the amount of fertilizer applied per ha of land, and e is the error term. The F^2 term is added to estimate the decline in marginal return with additional fertilizer application.

Fertilizer response functions estimated from time series data (1964-92) for the major rice countries of Asia are reported in Table 7.5. The regression coefficient of the square term of the NPK rate was found statistically insignificant and hence was dropped from the equation. Countries with relatively high levels of fertilizer use (Japan, Korea and China) have relatively low rates of response. Countries such as Thailand, India and Pakistan, which experience low rates of fertilizer application, also have low fertilizer responses. Crop growing environments, agro-climatic factors, and price regimes may be responsible for the relatively low yield responses for these countries.

The constant term of the regression equation shows what the crop yield would have been without fertilizer use. It varies from 1.0 ton/ha for Pakistan and Philippines to 2.0 to 2.3 tons for China and South Korea and 3.5 tons for Japan. It suggests that as crop husbandry improves over time, and scientists develop new cultivars that are able to take up more nutrients and use them more efficiently, yield rates will increase even under “without fertilizer” conditions.

The International Rice Research Institute has generated farm level input-output data for rice cultivation for a number of Asian countries to study the impact of modern rice technologies under different production environments (David and Otsuka 1994). Estimates of fertilizer response obtained from these data sets are given in Table 7.6. The marginal productivity and output elasticity of fertilizer derived from the parameters are presented in Table 7.7. Since fertilizer application rates varied largely across households, we incorporated the square term for fertilizer to see whether the rate of response declines with additional fertilizer use. Since farmers did not control the use of other inputs, we also incorporated in the model labor use per ha, and dummy variables to represent different rice growing environments.

The average rate of fertilizer application in rice cultivation is found to vary from 38 kg/ha of nutrients for Thailand to 121 kg/ha for Indonesia. The regression coefficient for F^2 was found negative and statistically significant, except for Thailand, suggesting that fertilizer response declines with additional rates of application. At the average rate of application, marginal productivity of fertilizer was estimated at 9 kg of unmilled rice per kg of nutrients for the Philippines and 7 to 8 kg for Indonesia, Bangladesh and Thailand. The fertilizer application rates at which the marginal productivity would be zero (technical optimum) was estimated at 213 kg for Bangladesh, 195 kg for Thailand, 165 kg for the Philippines and 221 kg for Indonesia. The output elasticity of fertilizer varied from 0.12 to 0.23. Thus, if rice output were to be increased by 2.0 percent a year, fertilizer application rates must increase at l0 to 16 percent every year.

The fertilizer application rate is economically optimum when the marginal productivity of fertilizer is equal to the price of fertilizer relative to the price of rice. In the world market, the nitrogen/rice (unmilled) price ratio for 1992 was assessed to be 1.7. The fertilizer response rate is higher than the price ratio for all-rice growing countries in Asia. In Thailand, which exports rice (hence domestic prices are closer to the import parity price), the price ratio for 1993 was 3.8. The marginal productivity of fertilizer is higher than this price ratio for most Asian countries. Thus, in many countries farmers use fertilizer at sub-optimal rates.

Biophysical and agro-climatic factors

An important factor why the average use of fertilizer at the national level appears sub-optimal is that the biophysical and agro-climatic conditions under which farmers raise their crops, vary across farms and regions and hence the crop's response to fertilizer use is highly variable (De Datta 1986; Zaman 1987). Fertilizer response is usually high under assured soil moisture conditions. Droughts during the effective nutrient utilization period adversely affect crop yield by limiting nutrient uptake. Even mild drought can affect the level of oxidation in the soil and thus increases losses of nitrogen by leaching and nitrification-denitrification during subsequent soil wetting. Thus, fertilizer response would be lower under rainfed farming which is subject to frequent moisture stress in comparison to more stable moisture supply under irrigated farming.

In flood prone areas and coastal wetlands, problem soils such as acid sulfate soils, peat soils and saline soils pose problems for water and soil management and affect the yield response of fertilizers (Singh and Senadhira 1986). Wetland rice cultivation on acid sulfate soils is hampered by toxic levels of soluble iron and aluminum, as well as by low phosphorus availability (Singh *et al*. 1991). Salinization is usually associated with increased soil pH, sodium toxicity and micronutrients deficiencies (Singh *et al*. 1994). Salinity problems are worsened by drought stress. Long rainy periods and poor drainage produce prolonged waterlogging and contribute to the problem of optimal nutrient management and poor nutrient status of the soil. Flooding and drainage reduce the effectiveness of fertilizers by increasing losses through leaching and run-off.

Table 7.6 shows the effect of rice ecosystems on crop yield when the effects of fertilizer and labor inputs are controlled. The regression coefficients of the dummy variables representing ecosystems suggest that rice yields would be substantially lower for the rainfed and the upland ecosystems compared to irrigated ecosystems. Since yield levels are lower, average fertilizer response would also be less in rainfed ecosystems.

Agroecological factors also affect the fertilizer demand by influencing the adoption of more fertilizer responsive modern cultivars and by contributing to rice cultivation risk. David and Otsuka (1994) estimated fertilizer demand functions in rice cultivation using farm household level survey data for a number of Asian countries. Estimates of demand elasticities for fertilizer with respect to irrigation and the adoption of modern varieties are shown in Table 7.8. Based on these estimates, a 10 percent increase in the area under modern varieties would increase fertilizer use by 24 percent for the Philippines, 14 percent for Indonesia, 13 percent for Thailand, 10 percent for India and 3 percent for Bangladesh. Further, irrigation usually contributes to increasing fertilizer use by facilitating the adoption of modern varieties, although it also has independent positive effects. A 10 percent increase in irrigated area would increase fertilizer use by 4.9 percent for Thailand and 2.3

percent for Bangladesh. For China, the response is insignificant, as almost the entire rice area is irrigated and is under modern varieties.

The yield response to nitrogen, obtained from agronomic experiments in farmers fields for different rice ecosystems in Eastern India, is reported in Table 7.9. Response was the highest for irrigated areas, i.e., about 42 kg of unmilled rice per kg of applied nitrogen. For rainfed land, the yield response was inversely related with the depth of flooding. As shown by the low R^2 and the large value of the standard error of the estimated yield response, with shallow flooding depths of up to 30 cm, yield response was 23 to 24 kg (almost as stable as for irrigated ecosystems). With higher flooding depths, yield response was low and highly variable. In some cases the yield response would be negative even for land that is flooded at more than 50 cm in depth. Thus, risk averse farmers would not apply any fertilizer on such land.

It is not surprising that farmers apply very little fertilizer when they grow traditional rice varieties under rainfed conditions (Table 7.10). Modern varieties in rainfed conditions are mostly grown in the more favorable environments, where land is well drained and rainfall is evenly distributed during the growing season. Even then, fertilizer application rates are substantially lower when compared to irrigated conditions (Table 7.10). Variation in fertilizer use across countries is relatively small in irrigated ecosystems. This probably reflects the difference in input-output prices and farmers' economic capacity. Conversely, where the proportion of area under irrigation and the adoption of modern varieties is higher, the greater is inter-country variation in fertilizer use intensity.

Fertilizer distribution and pricing policies

Government policies affect the production, procurement and distribution of fertilizer use through the extent by which they distort the prices that farmers pay and the response of farmers to these price changes. Government policies may also affect fertilizer use by controlling availability and rationing scarce supplies. Fertilizer demand studies using farm level cross-sectional data (David and Otsuka 1994; Sidhu and Baanante 1982, Sidhu and Baanante 1984) show a very high price elasticity of demand for fertilizer. These estimates, however, are not particularly dependable because of small price variations across farm households. Studies on the price response of fertilizer demand using time series data are lacking. Estimates based on such data would however also be subject to errors because of heavy public sector investment in fertilizer trade and changes in government control of fertilizer markets over the study period. Estimates based on time series data are available for the Philippines (David 1976), and Bangladesh (Hossain 1987). For the Philippines the own price elasticity of fertilizer demand was estimated at -0.5 for the short run and -0.8 for the long run. For Bangladesh the elasticity was estimated at -0.6. This suggests that if fertilizer prices increase by 10 per cent, the demand for fertilizer would decline by 6 to 8 per cent, all other things remaining unchanged.

In the early 1970s, the governments of most Asian countries were heavily involved in the fertilizer sector. To ostensibly increase agricultural production, governments maintained a monopoly over procurement, distributed fertilizer through parastatal institutions, established fertilizer subsidy programs, regulated private trade, and controlled input and output prices. Since then, governments have reduced the role of the public sector and liberalized the fertilizer sector. An overview of the deregulation and privatization policies introduced in selected Asian countries is presented in Table 7.11. Although substantial progress has been made, barriers still exist that distort market forces. These include price setting of fertilizers produced in factories under government controls, the supply of raw materials to factories at subsidized prices, licensing of companies permitted to participate in foreign trade, allocation of foreign exchange to import fertilizers, lengthy import procedures, inadequate port, warehouse and transportation facilities, etc. Because of these bottlenecks, localized shortages and price fluctuations that occur at critical times of high fertilizer demand are still a common feature in many Asian countries.

The impact of government policy on fertilizer markets can be reflected in the difference in prices paid by farmers compared to world market prices. Under competitive markets, domestic prices would be closer to C.I.F. prices for importing countries and to F.O.B. prices for countries that are self-sufficient or have surplus production capacity. World market prices for various fertilizers and their retail prices in selected Asian countries are shown in Table 7.12. Domestic retail prices for largely imported phosphate and potash fertilizers are relatively close to world market prices. For both urea self-sufficient countries (e.g. Bangladesh, Indonesia) and large importing countries (e.g. China and India) domestic urea prices are less than world market prices. Competitive market inducing policy reforms are expected to increase urea prices. Since nitrogen accounts for 60 to 70 percent of total fertilizer intake, and these four countries account for over 77 percent of the total cereal production in Asia, policy reforms are expected to put significant downward pressure on fertilizer consumption.

The absolute price of fertilizer however may be less important in the decision making process of farmers than the price of fertilizer relative to crop output prices. In Asia, output prices vary considerably across countries. The domestic price of rice is relatively low in rice exporting countries such as Vietnam, Myanmar, and Thailand, while it is relatively higher in the Philippines and Bangladesh, where food shortages often occur during years of natural disasters. Price variation is also a consequence of non-economic reasons. Since staple food production self-sufficiency is often a major political objective, most Asian governments intervene in output markets. Faced with increased land and labor costs, and in order to sustain the incentive of farmers to produce rice, Japan and Korea protect their internal rice markets from foreign competition.

Table 7.13 reports the relative nitrogen-rice price ratio for selected Asian countries. During the 1980s, relative nitrogen prices became more favorable in Thailand, the Philippines and India and less favorable in Indonesia, Myanmar, and Sri Lanka. The price ratio is high in policy liberalizing and/or rice exporting countries (e.g., Sri Lanka), and in fertilizer importing countries (e.g. Thailand, Myanmar, Vietnam, Philippines). India, Indonesia and Bangladesh, which are struggling to sustain self-sufficiency in the production of staple grains, maintain a relatively low fertilizer-rice price ratio. The price ratio is lowest in Japan and Korea, where rice prices are very high in comparison to international markets. The high levels of fertilizer use in cereal production in Japan and Korea (Table 7.4) may also partly be due to the extremely favorable fertilizer-rice price ratio.

SUSTAINING FOOD SECURITY AND ENVIRONMENT AND FERTILIZER DEMAND

Although tremendous progress has been made in increasing cereal production in Asia over the last three decades, Asia is still home to the largest absolute number of poor and chronically undernourished people. Over 60 percent of children suffer from malnutrition in India and Bangladesh, and two-thirds of the estimated 1.1 billion poor people of the developing world live in South and Southeast Asia. With the alleviation of poverty, per capita food grain consumption is going to increase, as people meet their unmet demand for food. The major force, however, behind the increasing demand for food grains is continued high population growth. Population in Asia is expected to increase by about 18 percent during the 1990s, and by 53 percent over the next 30 years. Largely due to the larger population's feeding requirement, the demand for cereal grains may increase by about 65 percent by the year 2020.

For most countries in Asia, it will be difficult to bring additional land under cereal grains, as most good quality crop land is already under cultivation. With population and economic growth, crop land is being diverted to meet the demand for housing and infrastructure, the needs of industrialization and commercialization, and income induced substitution of crop land away from cereal grain to vegetables, fruits and fodder. In order to meet demand on limited land resources, crop yields in the production of cereal grains must increase at a faster rate than population induced food needs. Consequently, to meet plant nutrient needs and to achieve these higher yields, demand for fertilizer will increase.

The challenge of sustaining food security will be particularly difficult for the low--income countries in Asia. In the high and middle income countries, population growth has slowed, and per capita cereal grain consumption has started declining as people can afford a more diversified diet containing less calories and more proteins and vitamins. It is in the low-income countries, where population growth is still high, that per capita consumption is expected to increase with the alleviation of poverty.

To illustrate the magnitude of the challenge for sustaining food security and its implication for chemical fertilizers demand, we have made crude projections of the required increase in yields and fertilizer intake of cereal crops by the year 2020 for the low-income countries of Asia. In making those projections, we have assumed that (1) for making adequate cereal grains available to all households at affordable prices, the per capita production must increase to 300 kg per person per year, (2) there will be no further increase in area under cereal grain, (3) the population will increase at the rate shown by the World Bank (Bos *et al.* 1992), and (4) the average yield response to fertilizer during the 1990-2020 period will be the same as the historical rate for the 1975-90 period. The last assumption is somewhat restrictive. Average responses should decline with increased in fertilizer application rates, unless innovative strategies and methods of nutrient management are quickly developed and extensively applied. Since the efficiency loss in nutrient uptake of cereal crops is still very large, one would expect that further scientific advances would help farmers reduce the loss and maintain the productivity of fertilizer at historical levels.

Projection results are presented in Table 7.14. Thailand and Myanmar would require small yield increases to meet their internal demand and a modest increase in fertilizer intake to achieve the required yield. These two countries can easily produce surplus grains to meet deficits in other countries. Other countries in Asia, however, would need a substantial increase in fertilizer intake to achieve the required increase in crop yield. The required increase in fertilizer intake is more than 250 kg per ha. This is above the technical optimum estimated from farm level fertilizer response functions. Unless the crop production environment is improved through (1) further investment in water control (irrigation, drainage and flood protection), (2) the development of more nutrient-efficient and pest-resistant cultivars, and (3) the development of innovative nutrient management techniques which can curtail nutrient and soil losses and improve efficiency under varied agro-climatic conditions, it will be uneconomic to apply fertilizer at such high rates. In the absence of an environment conducive to crop growth, increased rates of fertilizer application, particularly in rainfed areas, would lead to further environmental and resource degradation and pollution of land and water resources.

The historical experience of East Asia shows that Japan and South Korea achieved high levels of fertilizer consumption. The incentive to use fertilizer in such high doses was maintained through control over domestic markets and assuring farmers output prices many times higher than for the world market. With the liberalization of agricultural trade under the Uruguay round of trade negotiations, South and Southeast Asian countries may not be able to follow the examples of their East Asian neighbors to establish the price incentives needed to encourage such high levels of fertilizer use. Irrigation development probably coincided or even preceded heavy fertilizer application in East Asia, and led to high yields as early as the 1970s. In comparison to levels in the early 1970s, application rates in the developing Asian countries over the next two decades are estimated to be lower, and despite an improvement in irrigation, the trend in fertilizer use is downward.

In order to effectively address the dilemma of "feeding a fertile population from infertile soil in a fragile world" (Borlaug and Dowswell 1993), it is therefore, essential to develop improved technologies that enhance crop productivity through improved resource use efficiency and a reduction in losses as soon as possible. It should be emphasized that this can not be fully realized by making adjustments in only one or a few components in the existing technology package(s). In the context of the present dilemma, the technology package has to be treated as a package in which components complement each other rather than just fit together. Therefore, improvement in any component, say fertilizer use efficiency, has to be addressed through various approaches and multidisciplinary participation (e.g. efficient genotypes, reduced fixation and other losses from the soil-plant system, etc.). In addition, the emphasis has to be placed on the management of other complementary inputs (land and water resources, labor, seed, etc.) to improve the efficiency of their use, and on the development of farm contingency plans to provide farmers with the flexibility to use technology to achieve productivity targets, improve resource use efficiency and reduce losses under changing agro-climatic conditions.

Low external input agricultural practices also need to be examined. With such practices, supplemented nitrogen is added to the field from on-farm sources through the application of organic manures such as green manures, azolla, mulches, etc., or livestock-generated farmyard manure. This will be more feasible if the crop and livestock systems are physically integrated at the farm level, rather than incur the additional costs associated with the transportation of inputs, outputs, and by-products. It is always cheaper to transport the finished product rather than the raw material for the simple reason of volume. Addressing these issues are highly pertinent in the context of system sustainability because a system which can generate and/or utilize its available resources most efficiently will be more sustainable than the other which can not.

CONCLUSIONS

The increase in fertilizer consumption largely depends on the growth in demand for staple food grains. In the developed countries of the world, fertilizer consumption has started declining as population has become stationary and consumers are substituting high-price, better quality foods for staple grains. In developing countries, however, population growth is still high and the food needs of a large proportion of the people are yet to be fully met. As the demand for food grains increases with population growth and greater per capita consumption of cereals, fertilizer consumption is expected to increase further in the low-income countries of Asia.

To sustain food security, land scarce Asian countries would need to increase fertilizer intake to more than 250 kg of NPK fertilizer per hectare by the year 2020 from the present level of less than 100 kg per hectare. The increase in demand for fertilizer is however, constrained by crop nutrient uptake efficiency, an unstable supply of soil moisture, risks associated with yield fluctuations from climatic variations and nitrogen-pest interactions, and the fertilizer-grain price ratio. The intensity of fertilizer use is higher for modern varieties of cereals than for traditional varieties, on irrigated farming compared to the rainfed, and on well-drained land with medium elevation than on lands that are subjected to droughts and floods. Liberalization of agricultural markets will further increase the fertilizer-grain price ratio. To achieve the targeted increase in fertilizer intake to sustain food security in Asia, scientists must develop modern varieties that take up nutrients more efficiently and are more resistant to pest, water, and soil related constraints. Innovative methods for curtailing nutrient losses also need to be developed. Lastly, governments must adopt appropriate policies and support further investment for the development and more efficient utilization of irrigation and drainage facilities.

Table 7.1--Trend in fertilizer consumption, Asia compared to other regions

Region	Nutrient consumption				Rate of growth		
	1965/66	1978/79	1988/89	1992/93	1965-78	1978-88	1988-92
	(million metric tons)				(percent/year)		
Asia	6.7	25.7	51.9	59.2	10.9	7.3	7.3
Africa	1.1	2.7	3.7	3.8	7.1	3.5	0.4
South America	0.7	4.2	5.8	5.4	14.6	3.1	-1.7
Europe	17.9	31.8	32.5	19.9	4.5	0.2	-11.5
North and Central America	12.7	24.3	22.9	23.7	5.1	0.6	0.8
Oceania	1.5	1.7	1.7	1.9	0.7	0.3	2.1
Former USSR	6.3	18.4	27.2	12.0	8.6	4.0	-18.5
World	47.0	108.8	145.6	125.9	6.7	3.0	-3.6

Source: FAO AGROSTAT database.

Table 7.2--Trend in fertilizer consumption in major rice growing countries in Asia

Country	Nutrient consumption				Rate of growth		
	1965	1978	1988	1992	1965-78	1978-88	1988-92
	(thousand metric tons)				(percent/year)		
Bangladesh	54	356	772	998	15.6	8.0	6.7
China	2,604	10,871	25,322	29,155	11.6	8.8	3.6
India	785	5,131	11,077	12,218	15.6	8.0	2.5
Indonesia	95	763	2,392	2,580	17.4	12.1	1.9
Korea, South	336	871	921	964	7.6	0.6	1.1
Japan	1,852	2,221	1,943	1,784	1.4	-1.3	-2.1
Myanmar	9	86	83	69	18.9	-0.3	-4.6
Philippines	113	312	503	496	8.1	4.9	-0.3
Thailand	34	288	802	1,095	17.9	10.8	8.1
Vietnam	78	341	542	902	12.0	4.7	13.6
Asia	6,695	25,665	51,892	59,158	10.7	7.3	3.3

Source: FAO AGROSTAT database.

Table 7.3--Share of cereal grains in total fertilizer consumption in major rice growing countries

Country	Reference year	Rice	Wheat	Maize/ coarse grain	Total cereals
Bangladesh	1980	85.4	8.7	--	94.1
China	1978	28.5	21.0	18.8	68.3
India	1979	32.3	31.2	15.2	78.7
Indonesia	1980	71.8	--	5.3	77.1
Japan	1979	32.5	2.1	1.4	36.0
Korea, South	1975	45.7	--	6.7	52.4
Malaysia	1980	19.0	--	--	19.0
Myanmar	1985	78.3	2.1	2.6	83.0
Pakistan	1978	14.6	48.7	4.1	67.4
Philippines	1980	52.0	--	3.2	55.2
Sri Lanka	1980	42.7	--	--	42.7
Thailand	1978	53.4	--	--	53.4

Sources: Martinez and Diamond 1992; Myanmar 1984; Stone 1987.

Table 7.4--Fertilizer use and productivity growth in cereals in major rice growing countries, 1974-76 and 1990-92

Country	Nutrient consumption		Yield rates		Yield response to fertilizer use
	1974-76	1990-92	1974-76	1990-92	
	(kilogram/hectare)				(kilogram/kilogram of nutrients)
Bangladesh	18.0	83.8	1,770	2,574	12.2
China	43.7	211.9	2,477	4,347	11.1
India	24.7	99.1	1,179	1,948	10.3
Indonesia	35.1	149.2	2,353	3,826	12.9
Japan	240.6	265.0	5,619	5,714	3.9
Korea, South	201.9	361.6	4,448	5,884	9.0
Philippines	21.1	82.4	1,289	2,041	12.3
Pakistan	37.7	76.1	1,389	1,818	5.7
Thailand	11.9	49.0	1,890	2,159	7.3
Vietnam	43.3	108.5	2,141	3,100	14.7

Source: Compiled from FAO AGROSTAT database.

Table 7.5--Fertilizer response from national level time series data (1964-1992)

Country	Constant	Regression coefficient	Estimated standard error	R^2
	(tons/hectare)	(kilograms/hectare)		
Bangladesh	1.64	9.63	1.25	0.68
China	2.15	6.99	0.97	0.65
India	1.30	5.95	0.86	0.63
Indonesia	1.84	10.57	1.22	0.73
Japan	3.52	2.86	0.50	0.55
Korea, South	2.34	5.32	0.78	0.65
Myanmar	1.66	40.08	6.20	0.60
Pakistan	1.08	4.94	0.37	0.87
Philippines	1.03	11.63	2.67	0.40
Thailand	1.86	3.38	0.86	0.36
Vietnam	1.82	9.33	2.51	0.33

Source: Estimated from time series data on area and production of cereal grains and fertilizer consumption from FAO AGROSTAT.

Model: $Y = a + bF$ where Y = yield rates of cereal grains and F is kg of nutrient consumption per hectare of area under cereal crops.

Table 7.6--Estimates of fertilizer response from farm survey data

Country	Equation	Term (kg/ha)	Regression coefficients of			Coefficients of dummy variables representing rice ecosystems		
			Labor/ha	NPK/ha	NPK/ha^2	Rainfed	Upland	Coastal wetland
Bangladesh	(1)	2398	0.57	11.07	-0.0260			
			(1.71)	(5.81)	(-3.52)			
	(2)	2436	0.48	13.45	-0.0298	-306	-535	36
			(1.47)	(6.47)	(-4.07)	(-2.28)	(-4.40)	(0.21)
Philippines	(1)	1230	9.5	21.92	-0.0665			
			(4.24)	(5.89)	(-4.14)			
	(2)	1821	13.4	11.44	-0.0347	-136	-1538	n.a.
			(5.74)	(3.19)	(-2.31)	(-1.10)	(8.13)	
Indonesia	(1)	3002	-0.19	14.16	-0.0261			
			(0.12)	(5.04)	(-2.93)			
	(2)	3321	0.47	11.49	-0.0214	-117	--	621
			(0.30)	(3.63)	(2.31)	(-0.57)		(-1.89)
Thailand	(1)	1340	3.84	21.57	-0.0554			
			(3.76)	(7.58)	(-3.18)			
	(2)	2603	2.20	7.92	-0.0115	-1200	-1270	
			(2.74)	(2.43)	(-0.83)	(12.31)	(10.90)	

Source: Estimated from unpublished farm survey data, collected under the Differential Impact Study Project, IRRI, 1985-88. Figures within parentheses are estimated “t” values of the regression coefficients.

Table 7.7--Estimates of average and marginal productivity of fertilizer and technical and economic optimum rates of application

Country	Rice yield	NPK	Average productivity of fertilizer	Marginal productivity	Output elasticity of fertilizer	Fertilizer application rate	
						Technical optimum	Economic optimum
	(kilograms/hectare)		(kilograms)			(NPK/hectare)	
Bangladesh	2948	66.7	44.2	7.6	0.17	213	140
Indonesia	4194	120.6	34.8	7.9	0.23	221	198
Philippines	3345	81.2	41.2	8.6	0.21	165	136
Thailand	2257	38.1	59.2	7.0	.12	195	160

Source: Estimated from parameters of equation (1) in Table 7.6.

Table 7.8--Elasticity of fertilizer demand with respect to prices, irrigation and adoption of modern varieties

Country	Irrigation	Modern varieties	Fertilizer prices
Bangladesh	0.23*	0.31*	-2.07*
China	--	0.06*	-0.37*
India, Southern	-0.05	0.97*	n.a.
Indonesia	0.17	1.40*	0.07
Philippines	0.13	2.42*	-2.43*
Thailand	0.49*	1.26*	n.a.

Source: David and Otsuka, 1994.

Table 7.9--Response of rice yield to nitrogen application in different rice ecosystems, estimates from experiments in farmers' fields

Rice ecosystems/ flood depth (cm)	Constant	Yield response		
		Mean	Standard error	R^2
	(kg/ha)	(kg of unmilled rice per kg of nitrogen)		
Rainfed				
Up to 15 cm	1665	23	9	0.55
15-30 cm	1368	24	10	0.39
30-50 cm	1752	14	16	0.20
50-100 cm	1837	9	14	0.15
100 and above	1210	1	17	0.02
Irrigated	1395	42	10	0.57

Source: Singh, V. P. Unpublished results.

Table 7.10--Estimates of fertilizer use (NPK/ha) in irrigated and rainfed rice cultivation in selected Asian countries

Country	Irrigated modern	Rainfed modern	Rainfed traditional
Bangladesh	173	109	41
Cambodia	83	--	18
China	368	--	--
India	172[a]	--	32[b]
Philippines	114	62	24
Vietnam	173	--	15

Source: IRRI, 1995 (Draft).

Notes:

[a] Average of Punjab and Tamil Nadu.

[b] Average of Bihar and Madhya Pradesh.

Table 7.11--Overview of policy changes in fertilizer sector, selected Asian countries

Country	Year of initiating policy change	Restrictions in fertilizer trade	Production capacity owned by the govt (%)	Fertilizer trade operated by the govt (%)	Pricing policy	Subsidies
Bangladesh	1978	None	100	nil	Ex-factory price fixed by govt	None since 1973
China	1979	Import controlled by state designated trading companies	199	50	Govt fix prices for certain portion of fertilizer	Yes
Indonesia	1986	None	100	100	Prices fixed by govt	Yes
India	1991	Import controlled by Mineral and Metal	53 for urea and 29 for phosphate		Ex-factory prices fixed	Yes
Myanmar	1990	Allocation of foreign exchange to importers	100	80	Fertilizer retail price fixed	No subsidy
Pakistan	1986	Import controlled by state designated trading companies	30	50	Prices of potash and compound fertilizer fixed	Yes
Philippines	1986	5% excise duty on fertilizer manufactured in the country	77	50	No intervention since 1992	No subsidy
Thailand	1990	No restriction	0	0	Export tax on rice before 1984 and export subsidy since 1993	No
Vietnam	1989	Import controlled by state designated trading companies	100	12	Import duty abolished	Transport subsidy on phosphate and potash

Source: FADINAP, 1994, *Agrochemical News in Brief*, ESCAP/FAO/UNDP.

Table 7.12--Domestic retail prices of fertilizer compared to world prices, 1993

Market	Price of fertilizer (US$ per ton)				Domestic product of fertilizer as a % consumption for 1990-1991		
	Urea	TSP	DAP	Muriate of potash	Nitrogen	Phosphate	Potash
International Market							
FOB	129	150	145	108	--	--	--
CIF	163	178	190	132	--	--	--
Domestic Market							
Bangladesh	103	195	--	163	107	24	0
China	113	123	--	66	77	193	4
India	88	--	257	187	90	74	7
Indonesia	115	149	--	170	159	103	0
Korea, South	208	--	--	133	124	164	0
Myanmar	354	--	--	--	38	0	0
Philippines	187	--	267	196	48	190	0
Thailand	202	--	--	--	0	0	0
Vietnam	188	230	--	--	4	53	0

Source: FADINAP, Agrochemical News in Brief, Special issues, November 1993 and Fertilizer Trade Information. Monthly Bulletin.

Table 7.13--Nitrogen-rice price ratio in selected Asian countries

Country	1983/84	1990/91
Bangladesh	1.78	1.70
India	2.64	1.89
Indonesia	1.17	1.70
Japan	0.64	0.74
Korea	0.98	0.85
Myanmar	1.28	2.51
Pakistan	2.50	2.09
Philippines	4.17	3.07
Sri Lanka	1.83	3.20
Thailand	5.52	3.78

Source: IRRI, 1995 (Draft).

Table 7.14--Project increase in yield and fertilizer intake in cereal production to achieve food security by 2020

Country	Cereal production in 1990	Cereal grain requirements for 2020		Projection of fertilizer requirement
		Production	Yield rate	
	(million tons)		(ton/ha)	(NPK/ha)
Bangladesh	28.3	50.1	4.52	244
China	389.0	528.0	5.73	336
India	195.0	385.2	3.78	276
Indonesia	53.0	77.0	5.73	297
Myanmar	14.7	19.8	3.69	105
Philippines	14.2	28.7	4.04	245
Thailand	23.4	24.1	2.17	51
Vietnam	20.0	32.7	5.60	239

Source: Own estimates.

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8. PLANT NUTRIENT MANAGEMENT AND SUSTAINABIILITY OF WHEAT BASED CROPPING SYSTEMS IN CHINA

by Jin Jiyun and Zhang Guilan

INTRODUCTION

China is a large agricultural country with limited land resources and a large expanding population. It has to support over 22 percent of the world's population (1.198 billion in 1994) on less than 7 percent of the world's arable land (95.33 million hectares in 1994). Arable land per head is only 0.0796 hectares. Annual population increases by 15 million and cultivated land decreases by 350,000 hectares annually. To support the large and ever-increasing population with limited and ever-decreasing cultivated land, China has to develop sustainable agriculture production systems which can (1) ensure an adequate supply of food, oil, fiber, and other products to improve people's living standards and provide enough raw materials for related industry developments; (2) make the most efficient use of limited land resources and purchased external inputs; (3) improve soil fertility and productivity; (4) increase the profitability of farming; and (5) improve environmental quality.

To develop such sustainable agriculture production systems, under heavy pressure from the large population and limited land resources, is a great challenge for the government, scientists, and farmers in China. However, it can be achieved by using good agricultural policies, modern science and technology, and good soil management to ensure the most efficient use of the limited land resources and costly input materials. Among the various agricultural input materials, fertilizer is the most expensive. It has been reported that, in general, chemical fertilizer inputs (cost) account for 30-40 percent of the total external inputs (energy plus materials) in China (China International Consulting Corporation 1988). In some high yielding regions, fertilizer costs account for 50 percent or more of total input costs. However, fertilizer is the most effective of the various external input materials used. It has been reported that 30-50 percent of the increases in total crop production in the recent past has been due to the use of chemical fertilizers (Bao and Jin 1991). To make the most efficient use of this costly input material, one must rely on advances in fertilizer-related science and technology. In addition, research has indicated that balanced use of fertilizers can improve the soil resource and environment, while imbalanced use of fertilizer will damage the soil and environment. Therefore, plant nutrient management is one of the key factors in the development of sustainable agriculture in China.

HISTORICAL REVIEW

China has a long tradition of using organic manures to maintain and improve soil fertility. According to historical records, the use of organic manure in China can be traced back to 3000 B.C. in the Shang dynasty. The widespread use of manures started in the Warring States period and Qin dynasty (221-206 B.C.), about 2,000 years ago. Historically, manure use in China has contributed greatly to agricultural production and the development of civilization. In some periods of China's long history when the population was low and there was sufficient arable land available for low yielding cultivation systems, organic manure alone sustained agricultural production. However, three facts must be mentioned in order to fully understand how China was able to sustain a reasonable yield using only organic sources of nutrients. One fact is that in the early days, sufficient arable land was available, and people continuously opened up new reasonably fertile land for agriculture as needed. The second fact was that nutrients in lowland soils were supplemented by the transport of organic materials from upland soils. This resulted in heavy degradation and erosion of upland soils, causing considerable environmental problems which people still suffer from today (Bao, Jin, and Dowdle 1989). The other fact is the relatively low requirement that a slowly growing population with low living standards placed on agriculture.

The situation has completely changed in recent times. With the rapid increase of population and improvement in living standards, demands on agriculture have increased quickly. At the same time, most arable land had already been opened for agricultural use, and the heavily degraded and eroded upland soils could not afford further transport of any remaining nutrients to the lowlands, especially given the increased concern about soil erosion and environmental quality. Therefore, new solutions were needed to sustain the soil fertility of the lowlands and improve those of upland soils, while maintaining a sustained increase in agricultural production.

Average yields of wheat and rice in China from 221 B.C. to the present are presented in Table 8.1 (China Agriculture Year Books 1980-1993; Gengling 1988). Before the 1950s, only organic manures were used to maintain internal nutrient cycling in China's agricultural systems. It may be concluded that agricultural production and soil fertility were sustained for more than 2,000 years by using organic fertilizers alone. However, both crop yields and soil fertility were improved slowly. It took more than 2,000 years for wheat yields to double. For rice, it took 1,731 years for yields to increase from 603 kilograms per hectare to 2,930 kilograms per hectare. This traditional low-input and low-output agricultural production system could not meet the demands of the rapid increase in population and improvement in people's living standards. Therefore, input of materials and energy from outside the agricultural system became necessary. During the 1950s, inorganic fertilizer use became an important measure to sustain rapid increases in agricultural production.

It is interesting to look at the historical trends of wheat and rice yields to determine the contribution of fertilizer, both organic and inorganic, to crop production (Table 8.1). The increase in wheat yields from 793 to 1,465 kilograms per hectare covered a period of more than 2,000 years in the low-input and low-output organic farming system, an average increase of 17 kilograms every 50 years. However, from 1952 to 1990, with modern agricultural production systems, wheat yields increased from 735 to 3,225 kilograms per hectare, an average increase of 66 kilograms every year. For rice, the increase from 603 to 1,560 kilograms per hectare spanned about 1,200 years in traditional agriculture, an average increase of 40 kilograms every 50 years. However, from 1952 to 1990, with modern agricultural production systems, rice yields increased from 2,408 to 5,805 kilograms per hectare, respectively, an average increase of 89 kilograms every year.

This historical perspective demonstrates that increases in grain yields since 1952 have exceeded those of any other period in China's long history. There are many factors responsible for this accelerated growth in agricultural production, including the development and use of high yielding varieties, improvement in water management and pest control, etc.

However, one of the most important factors has been the increased use of inorganic fertilizers.

Organic manure has been an important nutrient resource in China's long history, and still is today. Before 1949, almost no inorganic fertilizer was used in China. Plant nutrients applied to agricultural production systems came almost exclusively from the application of organic manures. Since then, with the continuous increase in crop production, plant nutrient supply in the form of organic manures has increased considerably. From 1949 to 1990, the annual application of nitrogen, phosphate, and potash nutrients ($N+P_2O_5+K_2O$) in organic manures increased from 4.28 million metric tons to 15.57 million metric tons (Table 8.2) (Soil and Fertilizer Institute 1994). However, at the same time, agricultural production increased rapidly. The nutrient requirement was far in excess of the amount of nutrients supplied in organic manures. Therefore, inorganic fertilizers were introduced to agriculture systems in the 1950s, and their use increased rapidly thereafter. As a result, the contribution of organic manures in total nutrient supply decreased with time, from almost 100 percent in 1949 to only 37.5 percent in 1990.

Organic manures supplied only 24.5 percent of total N input and 31.1 percent of total P_2O_5 input in 1990, but a large percentage (77.6 percent) of the total K_2O consumption was still from organic manures (Table 8.2). With time, nutrient input as inorganic fertilizers has become more and more important in agricultural production in China. Statistics indicate that in the 40 years from 1951 to 1990, total consumption of chemical fertilizers was significantly correlated with total grain production, and with total cotton production. A close correlation was also found between the fertilizer application rate and grain and cotton yields (Jin and Portch 1991). Assuming that 80 percent of all fertilizer was used for grain production and that one kilogram of applied nutrient increased grain production by eight kilograms, it has been estimated that about 35 percent of the total grain production in the five years from 1986 to 1990 was due to the use of chemical fertilizers (Jin and Portch 1991).

From the above, it is clear that both organic and inorganic fertilizers are vital nutrient sources for the sustained development of agriculture in China. The following examples from Henan state, the main wheat producing state in China, will provide a detailed picture about the contribution of plant nutrients in both organic and inorganic forms to the sustained production of wheat based cropping systems.

OVERVIEW OF WHEAT BASED CROP PRODUCTION IN HENAN STATE

Henan state, located in central China, is China's most important wheat producing area. In 1993, the planted area of wheat covered 70.44 percent of the total cultivated land of the state. The total planted area for the two major wheat based cropping systems (wheat-corn and wheat-soybean double cropping) covered 61.47 percent of the total planted area of all agricultural crops. Wheat in Henan in 1993 accounted for 18.1 percent of the nation's total wheat production (Table 8.3) (China Agriculture Year Books 1980-1993; Henan Agriculture Year Books 1980-1993).

Like everywhere else in China, the cultivated land in Henan has decreased, at the rate of about 20,000 hectares annually. Cultivated land per head in 1993 decreased to about 0.080 hectares, about the average of the country. However, the total planted area increased slightly from 1980 to 1990, due to the increase in the multi-cropping index (about 1.72), and stabilized at about 12 million hectares after 1990. The planted area of wheat has covered about 70 percent of the total cultivated land, and the planted area of wheat-corn and wheat-soybean has covered more than 60 percent of the total planted area for all agricultural crops in recent years (Table 8.3) (Henan Agriculture Year Books 1980-1993).

Yields of all three crops, wheat, corn, and soybean, have increased with time. In 1993, average yields for wheat, corn, and soybean were 3.98, 4.85, and 1.70 metric tons per hectare, 75.3 percent, 52.5 percent and 68.3 percent more than in 1980, respectively. Many factors have contributed to the steady increase in crop yields, such as the introduction of high yielding varieties and other management practices. However, increased plant nutrient inputs in the form of inorganic fertilizers is one of the most important factors. From 1980 to 1993, total nutrient consumption of inorganic fertilizers increased from 0.73 million metric tons to 2.88 million metric tons, and the nutrient application rate per hectare of sown area increased from 67.7 kilograms per hectare in 1980 to 238.6 kilograms per hectare in 1993 (Table 8.3). Statistics indicate that from 1980 to 1993, the nutrient application rate was significantly correlated with the yield of wheat ($r=0.7404$, $p<0.01$) and of corn ($r=0.7898$, $p<0.01$).

NUTRIENT BALANCE IN AGRICULTURAL SYSTEMS IN HENAN STATE

Nutrient removal by crops, and nutrients applied in organic and inorganic forms in Henan state in 1980 and 1992 have been estimated and their balance calculated (Tables 7.4 and 7.5). In 1980, the amounts of N, P_2O_5, and K_2O added to the agriculture system were 911,300, 240,600 and 403,900 metric tons, respectively, of which organic manures contributed 36.9 percent N, 60.9 percent P_2O_5, and 94.0 percent K_2O, resulting in a 230,100 ton surplus of N, and negative balances for both P_2O_5, (-45,700 metric tons) and K_2O (-278,400 metric tons). With time, crop yields increased quickly, and at the same time, more and more inorganic fertilizers were applied. By 1992, a total of 1,873,300 metric tons of N was applied, of which 79.3 percent was from inorganic fertilizer, resulting in a great surplus of N in the system (793,600 metric tons). Part of this excessive N may have leached out of the soil into groundwater, creating an environmental problem. The amount of P_20_5, applied also increased quickly, with a total of 814,800 metric tons (79.2 percent from inorganic fertilizer), 420,700 metric tons more than required by the crops.

A large percentage of the total K_2O added to the system (513,300 metric tons) was still from organic manure (80.3 percent) in 1992, resulting in a large negative balance of K_2O in the agriculture production system (-278,400 metric tons). The ratio of N: P_2O_5: K_20 from all nutrient inputs was 1: 0.26: 0.44 in 1982, and 1: 0.43: 0.27 in 1992. With increasing crop yields and N and P fertilizer application, and continuous depletion of soil K, K fertilizer use has gradually become a significant factor for the sustained development of agriculture in recent years (Guilan et al. 1994).

CONTRIBUTION OF ORGANIC AND INORGANIC FERTILIZERS IN WHEAT-CORN CROPPING SYSTEMS

To evaluate the relative contribution of organic and inorganic fertilizers in wheat-corn cropping systems, long-term fertilizer trials were set up in the major wheat-corn producing regions of the state in 1980. At the research farm of the Henan Academy of Agricultural Sciences in Zhengzhou, a split-plot design was used with organic manure (M-30 metric tons compost per hectare per year) treatment in main plots, and four chemical fertilizer treatments in sub-plots: 1) CK--no chemical fertilizer used; 2) N--at a rate of 300 kgs N per hectare per year; 3) NP--300 kgs N+150 kgs P_2O_5 per hectare per year; and 4) NPK--300 kgs N + 150 kgs P + 120 kgs K_20 per hectare per year.

Yield results (Table 8.6) indicated that without any nutrient input to the system (the CK treatment), both wheat and corn yields fell considerably during the 13 years, especially wheat yields. Organic manure application alone (M treatment) supplied some nutrients, which maintained the yields of wheat and corn at a relatively low level, but was not sufficient to support a high yield. The complete treatments (NPK and MNPK treatments) showed the highest yield for both wheat and corn crops. The results also indicated that a non-balanced use of fertilizers (N, NP, MN, and MNP treatments) could not sustain high yield production over the long term. Yields dropped with time, especially in N and MN treatments where only N fertilizer was applied. The combined use of organic manure and N, P, and K fertilizers sustained high yields throughout the 13 years (Hongxun, Chunhe, and Zhangxiang 1994).

The relative contribution of native soil fertility, and organic and inorganic fertilizers to the yield of wheat and corn in the 13 years of production at fixed sites were calculated (Table 8.7). Results indicated that without organic manure application, the contribution of native soil fertility in the 13 years was 35.0 percent to wheat production, 47.3 percent to corn production, and 41.7 percent to the total production of wheat and corn; while inorganic fertilizers contributed 65 percent to wheat production, 52.7 percent to corn, and 58.3 percent to the total production of the two crops. When organic manure was applied at the rate of 30 metric tons per hectare per year, with a total of 928.2 kilograms N, 765.3 kilograms P_2O_5, and 916.1 kilograms K_20 applied in 13 years, the organic manure contributed to 22.0 percent of wheat production, 13 percent of corn, and 17.1 percent of the total production of the two crops; and the chemical fertilizer contributed to 46.6 percent of wheat production, 43.4 percent of corn, and 44.9 percent for the two crops. The contribution of native soil fertility decreased slightly when organic manure was applied (31.4 percent to wheat, 43.6 percent to corn, and 38.0 percent for the two crops).

For the 13 years, the balance of nitrogen, phosphate, and potash in the wheat-corn cropping system were calculated, and the soil available N, P, and K was determined (Table 8.8). Results indicated that in the CK treatment, where no nutrients were added to the system, large amounts of N (1,171 kilograms per hectare), P_2O_5 (754 kilograms per hectare), and K_2O (1,432 kilograms per hectare) were removed, resulting in a significant drop in the available nutrients in the soil. When N was applied alone (treatment N) or with organic manure only (treatment MN), excess N was left in the system, part of which could be leached out of the soil profile to groundwater, causing environmental problems. When P and K fertilizers were added, most of the N added was used by the high yielding crops, which resulted in higher nitrogen use efficiency and minimized the leaching problem. When P_2O_5 was added in the organic form alone, it could not provide enough P to the crops, even at a relatively low yield level (Hongxun, Chunhe, and Zhangxiang 1994).

When P fertilizer was used, especially together with organic manure, this fertilization provided an adequate amount of P_2O_5 for the high yield production system.

Large amounts of K were removed by the crops resulting in a large negative balance in all of the treatments. Even when K was added in an organic or inorganic form, or in both forms, a negative balance was still obtained, resulting in a considerable drop in soil available K (Hongxun, Chunhe, and Zhangxiang 1994).

Another fixed site trial was set up in a different wheat-corn producing area of the state. Nine treatments, CK, M, MN_{120}, MN_{240}, MP_{60}, MN_{120}, P_{60}, MN_{240}, P_{60}, MN_{240}, P_{120}, and MN_{240}, P_{120}, K_{120}, were used, where M represents pig manure at the rate of 30 metric tons per hectare per year with a total nutrient input of 660 kilograms N, 375 kilograms P_20_5, and 2,310 kilograms K_20 per hectare in the ten years from 1981 to 1990. N, P, and K represent N, P_2O_5 and K_2O with the rate in kilograms per hectare indicated in the subscripts.

The results (Bao, Jin, and Dowdle 1989) of ten years of wheat and corn production, and the relative contribution of native soil fertility and of organic and inorganic sources of nutrients provided similar conclusions to those of the 13-year trial, except that inorganic fertilizer showed an even greater contribution to wheat (58.5 percent) and corn (63.0 percent) production, because of the relatively lower initial soil fertility, which contributed only 27.8 percent for wheat and 19.3 percent for corn production (Guilan *et al.* 1992).

Nutrient balance analysis also showed that when nitrogen was applied alone, especially at the high rate (240 kilograms N per hectare), excessive N was left in the soil-crop system. Balanced use of N, P, and K fertilizer improved N fertilizer use efficiency. Depletion of soil P and K occurred when less than adequate P and K were added. A positive balance was obtained when these nutrients were applied. However, soil available P and K did not change much, because the soil had a heavy texture, with relatively high reserves and a high adsorption capacity of P and K (Guilan et al. 1992).

The above calculations and discussions were based on specific fixed site experiments. However, it is clear that organic manure alone, although at a relatively high dose, cannot provide nearly enough nutrients to the system, and, therefore, cannot sustain the cropping system. Additional inputs of nutrients in the form of inorganic fertilizers are necessary to sustain high yield crop production. However, inorganic fertilizer must be used in a balanced manner to make the most efficient use of this resource, and to maximize output and profit for farmers.

BALANCED SUPPLY OF NUTRIENTS FOR HIGH YIELD WHEAT AND CORN PRODUCTION

In order to develop a balanced fertilization program for high yield and high benefit wheat-corn production in Henan state, from 1990 to 1994, 50 field trials were conducted in four major wheat-corn double cropping areas of the state. The design of the field trials was based on soil testing, with all essential plant nutrients considered. The amounts of nutrients applied in the selected high yield and high benefit treatments for wheat and corn are shown in Tables 7.9 and 7.10. These may not necessarily be the most economic recommendations, but they provide general ideas about nutrient requirements and their ratios for high yield production of wheat and corn in the areas (Guilan, Guibao, and Kegang 1994).

CONCLUSIONS

Both organic and inorganic fertilizers are important resources for China. A good nutrient management and system must combine these two nutrient sources for the most efficient use.

Organic manure has played an important role in the long history of Chinese agriculture, and it is still an important resource for the sustained development of modern agriculture. However, with increasing demands on agriculture for ever higher production yields, organic manure alone cannot supply sufficient nutrients for the sustained development of intensified cropping systems.

All essential plant nutrients must be applied in a balanced manner in order to make the most efficient use of these costly resources. Imbalanced use of one nutrient, often N in China, can result in low fertilizer use efficiency, low production, depletion of other nutrients, and some environmental problems.

Table 8.1--Average yields of wheat and rice in China from 221 B.C. to the present (kilograms/hectare)

Dynasty	Year	Yield	
		Wheat	Rice
Qin	221-206 B.C.	793	--
W. Han	206 B.C. - 23 A.D.	904	603
Song	960-1279	780	1560
Ming-Qing	1368-1911	1465	2930
People's Republic of China	1952	735	2408
	1965	1020	2940
	1980	1890	4133
	1986	3040	5338
	1990	3225	5805

Source: Gengling (1988) and China Agricultural Yearbooks.

Table 8.2--Nutrient consumption and contribution of organic manures in China

Year	Total nutrients	Total organic nutrients		Contribution of organic manure					
				N		P_2O_5		K_2O	
	(m.t.)	(m.t.)	(percent)	(m.t.)	(percent)	(m.t.)	(percent)	(m.t.)	(percent)
1949	4.29	4.28	99.9	1.62	99.6	0.79	100.0	1.87	100.0
1957	6.95	6.58	91.0	2.49	88.7	1.23	96.0	2.86	100.0
1965	9.13	7.37	80.7	2.93	70.8	1.38	71.5	3.06	99.9
1975	16.03	10.65	66.4	4.10	53.0	1.94	54.6	4.62	97.3
1980	24.00	11.31	47.1	4..16	30.6	2.06	41.8	5.09	92.8
1983	28.62	12.02	42.0	4.23	26.2	2.17	35.5	5.62	88.5
1990	41.47	15.57	37.5	5.62	24.5	2.93	31.1	7.03	77.6

Source: Soil and Fertilizer Institute, Chinese Academy of Agricultural Sciences, 1994.
Note: m.t. means million tons.
Percent is percentage from organic manures.

Table 8.3--General statistics of Henan state related to wheat production

Variable	1980	1985	1986	1987	1988	1989	1990	1991	1992	1993
Cultivated land (million hectares)	7.13	7.03	7.00	6.97	6.96	6.94	6.93	6.92	6.89	6.87
Cultivated land per person (hectare)	0.098	0.089	0.087	0.085	0.083	0.082	0.080	0.080	0.080	0.080
Planted area of all crops (million hectares)	10.78	11.68	11.82	11.95	11.93	12.00	11.89	12.00	11.94	12.07
Planted area of grains crops (million hectares)	8.86	9.03	9.37	9.36	9.05	9.26	9.32	9.04	8.80	8.97
Planted area of wheat (million hectares)	3.93	4.25	4.64	4.69	4.67	4.72	4.78	4.80	4.71	4.84
Wheat yield (tons per hectare)	2.27	3.35	3.38	3.47	3.26	3.59	3.44	3.24	3.48	3.98
Planted area of corn (million hectares)	1.68	1.66	1.89	1.94	1.83	2.04	2.18	2.09	1.96	1.96
Corn yield (tons per hectare)	3.18	3.23	2.33	3.50	3.27	3.98	4.41	4.07	4.11	4.85
Planted area of soybean (million hectares)	0.98	0.88	0.97	0.91	0.68	0.67	0.64	0.51	0.50	0.62
Soybean yield (tons per hectare)	1.01	1.17	0.77	1.22	1.04	1.19	1.35	1.29	1.25	1.70
Nutrient consumption (million tons)	0.73	1.44	1.49	1.36	1.51	1.84	2.13	2.40	2.51	2.88
Nutrients/ha planted area (kg/ha)	67.7	123.3	126.1	113.8	126.6	153.3	179.1	200.0	210.2	238.6

Source: Henan Agriculture Year Books, 1980-1993.

Table 8.4--Nutrient balance in the agriculture system in Henan state, 1980

Variable	N	P_20_5	K_20
Nutrient removal			
Total (thousand tons)	681.2	286.3	682.3
Ratio	1	.042	1
Nutrient added			
Organic form (thousand tons)	335.9	146.5	379.6
Inorganic form (thousand tons)	575.4	94.1	24.3
Total (thousand tons)	911.3	240.6	403.9
Ratio	1	0.26	0.44
Balance (thousand tons)	230.1	-45.7	-278.4

Source: Zhang Guilan *et. al.*, 1994.

Table 8.5--Nutrient balance in the agricultural system in Henan state, 1992

Variable	N	P_20_5	K_20
Nutrient removal			
Total (thousand tons)	1079.7	394.1	1074.4
Ratio	1	0.4	1
Nutrient added			
Organic form (thousand tons)	388.7	169.5	412.4
Inorganic form (thousand tons)	1484.6	645.3	100.9
Total (thousand tons)	1873.3	814.8	513.3
Ratio	1	0.43	0.27
Balance (thousand tons)	793.6	420.7	-561.1

Source: Zhang Guilan, *et. al.*, 1994.

Table 8.6--Effects of organic and inorganic fertilizers on crop yields in a fixed site trial in Zhengzhou, Henan

	Treatment							
	CK	N	NP	NPK	M	MN	MNP	MNPK
Wheat	(yield in tons per hectare)							
1981	4.40	5.21	5.19	5.58	4.61	5.81	5.94	5.76
1991	1.78	2.64	5.16	5.44	2.70	5.01	5.29	5.59
Average of 1981-93	1.85	4.09	5.31	5.29	3.15	5.70	5.79	5.90
Corn								
1981	4.98	5.89	6.34	6.47	5.25	6.05	6.41	6.54
1993	3.86	4.52	6.30	7.65	4.52	5.61	6.90	7.89
Average of 13 years	3.02	5.60	5.97	6.39	3.92	6.34	6.52	6.93
Total of two crops								
1981	9.38	11.10	11.53	12.05	9.86	11.86	12.35	12.30
1993	5.64	7.16	11.46	13.09	7.22	10.62	12.19	13.48
Average of 13 years	4.87	9.69	11.28	11.68	7.07	12.04	12.31	12.83

Source: Zhu Hongxun, Cun Chunhe, and Zhang Xiang 1994.

Table 8.7--Contribution of fertilizers to yields during 13 years at a fixed site trial in Zhengzhou, Henan

Treatment	Wheat	Corn	Two crops
Without organic manure			
Yield in CK treatment (tons/hectare)	1.85	3.02	4.87
Yield in NPK treatment (tons/hectare)	5.29	6.39	11.68
Contribution of native soil fertility (percent)	35.0	47.3	41.7
Contribution of NPK fertilizers (percent)	65.0	52.7	58.3
With organic manure			
Yield in CK treatment (tons/hectare)	1.85	3.02	4.87
Yield in M treatment (tons/hectare)	3.15	3.92	7.07
Yield in MNPK treatment (tons/hectare)	5.90	6.93	12.83
Contribution of native soil fertility (percent)	31.4	43.6	38.0
Contribution of organic manure (percent)	22.0	13.0	17.1
Contribution of NPK fertilizers (percent)	46.6	43.4	44.9

Source: Zhu Hongxun, Cun Chunhe, and Zhang Xiang 1994.

Table 8.8--Nutrient balance sheet in a 13 years fixed site field trial in Zhengzhou, Henan, 1981-1993

Treatment	CK	N	NP	NPK	M	MN	MNP	MNPK
N added (kg/ha)	0	3180	3180	3180	928	4108	4108	4108
N removed (kg/ha)	1171	2871	3069	3311	1433	2929	3232	3216
N balance	-1172	309	111	-131	-505	1179	876	892
Soil alkali hydrolysable N change in 13 years mg/kg	-45	-41	-38	-40	-27	-36	-33	-33
Soil organic matter change in 13 years (%)	-0.16	0.06	0.06	0.14	0.13	0.10	0.10	0.22
P_2O_5 added (kg/ha)	0	0	1590	1590	765	765	2355	2355
P_2O_5 removed (kg/ha)	754	1128	1464	1533	864	1309	1619	1609
P_2O_5 balance	-754	-1128	126	57	-99	-544	736	746
Soil Olsen-P change in 13 years (mg/kg)	-30	-39	-10	-13	-26	-34	1	4
K_2O added (mg/ha)	0	0	0	1560	916	916	916	2476
K_2O removed (mg/ha)	1432	2582	2984	3538	1831	2826	3173	3869
K_2O balance	-1432	-2582	-2984	-1978	-915	-1910	-2257	-1393
Soil NH_4O/ac- K change in 13 years (mg/kg)	-40	-43	-44	-25	-24	-29	-40	-21

Source: Zhu Hongxun, Cun Chunhe, and Zhang Xiang 1994.

Table 8.9--Fertilization rate for high yield wheat production in Henan state (kilograms per hectare)

Region	Soil type	Ratio							Yield	Ratio
		N	P_20_5	K_2O	S	Zn	Mn	Cu		$N:P_20_5:K_2O$
South	SS	180	120	112.5	30	15	--	--	6648	1:0.8:0.6
East	FS	270	120	112.5	30	15	30	--	5720	1:0.4:0.4
North	CS	180	75	112.5	--	15	30	15	8072	1:0.4:0.6
West	CS	150	150	112.5	30	--	--	15	5310	1:1:0.8

Source: Zhang Guilan, Li Guibao, and Sun Kegang 1994.
Note: SS is Shaijiang black soil; FS is Fluvo-aquic soil; and CS is Cinnamon soil.

Table 8.10--Fertilization rate for high yield corn production in Henan state (kilograms per hectare)

Region	Soil type	Ratio							Yield	Ratio
		N	P_20_5	K_2O	S	Zn	Mn	Cu		$N:P_20_5:K_2O$
South	SS	270	120	112.5	30	15	--	--	8505	1:0.4:0.4
East	FS	180	150	112.5	15	15	--	--	10100	1:0.8:0.6
North	FS	300	75	112.5	30	15	15	--	10564	1:0.3:0.4
West	CS	150	150	112.5	30	--	--	15	7528	1:1:0.8

Source: Zhang Guilan, Li Guibao, and Sun Kegang 1994.
Note: SS is Shaijiang black soil; FS is Fluvo-aquic soil; and CS is Cinnamon soil.

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9. INTEGRATION OF VARIOUS INPUTS FOR SUSTAINABLE INTENSIFICATION: ROLE OF FARMERS' UNIONS, EXTENSION SERVICES, AND THE PRIVATE SECTOR IN THE PROMOTION OF SOUND INTENSIFIED PRACTICES

by Abdul Majid

AGA KHAN RURAL SUPPORT PROGRAMME (AKRSP), GILGAT, PAKISTAN

AKRSP is a non-governmental, non-profit organization established by the Aga Khan Foundation in 1982. It is designed to function as a catalyst to promote equitable and sustainable improvement in the quality of life of one million people in northern Pakistan.

The objectives and strategy of AKRSP

The Aga Khan Rural Support Programme was established to promote four basic objectives, that are then linked to the conceptual framework of the organizational model and its strategies:

1. Raise the income and quality of life of about one million mostly poor people in the high mountains and isolated regions of northern Pakistan;
2. Develop institutional and technical models for equitable development;
3. Evolve sustainable, long-term strategies for the productive management of natural resources in a fragile environment; and
4. Demonstrate approaches and packages that can be replicated elsewhere.

The approach of AKRSP has been evolutionary, and hence flexible. From its very beginning, AKRSP has emphasized organization, capital, and skills. They have been the basic elements of its strategy, even as it has evolved, to

1. Establish a social organization around a sustainable productive activity in which members would participate on a long-term basis;
2. Generate savings to build equity capital to be used as collateral for obtaining credit for individual and collective investments; and
3. Produce new skills or upgrade existing ones to increase the productive capacity at the village organization level.

Basic models of AKRSP

AKRSP has adopted three basic models.

The economic model. This model underlies the others. The rural poor are risk averse because their resources are stretched and their incomes are low and unstable. They require high returns from any innovation to offset the risk associated with its adoption and the extra demands on their family's labor. The infrastructure projects funded by AKRSP have high returns because their externalities can be internalized by the participants and they increase the productivity of other resources for additional returns on an ongoing basis.

The institutional model. Building the village organization and its new links is at the core of AKRSP and needs careful attention, since the village organizations soon begin to develop their own initiatives and demands, which may threaten some groups. Managing these emerging relationships between the village organizations and others requires constant vigilance and good judgment. Their links with government agencies and the private sector must be fostered with great care and attention. The roles of village activist and AKRSP catalysts are critical in nurturing the village organization and in strengthening the outside links.

The technical or production model. This model contains a variety of packages and services to build the capacity of the village organizations and its members to increase production and sell surpluses. Numerous specializations and complex methods are required to find appropriate new technologies, adapt them to the working environment, and convey them to a large number of smallholders. Considerable resources are required to develop these packages for village organization members and to impart technical skills to "village specialists."

FORMATION OF THE VILLAGE ORGANIZATION

The village organization is a coalition of those residents of a village whose common economic interest is best served by organizing as an interest group. Without organization the smallholders and the poor cannot rise above the level of subsistence. Their biggest handicap is their small holding. To overcome this handicap, they must pool their resources to achieve economies of scale, to reduce overheads, and to obtain the best prices for their produce. In the program area, AKRSP has been able to establish over 2,400 village organizations (including women's organizations).

The membership of the village organization depends on the size of the interest group. The majority of the village organizations in the program area comprise more than 50 households. To be viable, a village organization must meet as a general body regularly and not leave the affairs of the organization to be managed by a few members. It is through regular meetings of the general body that the supremacy of the members is assured. The role of the members in keeping the village organization on the right track has to be continuously emphasized. The members are urged to insist on the office bearers keeping the members informed of village organization savings, accounts and other matters. The role of the general body in achieving equitable, productive, sustainable development and growth with social justice at the village level has been established.

Village activists and specialists

The presence of an activist is of paramount importance for the sustainability of the village organization. It is the activist who helps the village organization understand the vision of development; who devotes time to communicating program messages to the general body of the village organization; and who makes the services provided by AKRSP accessible to the village organization members. The success or failure of a village organization is directly attributable to the village organization activist.

In addition, there is a cadre of village level specialists, trained by program staff and paid by the village organization members, who help in the implementation of program packages. Thus, the actual responsibility for implementing the packages is borne by the village organization through its cadre of trained specialists. So far more than 10,000 specialists have been trained in various disciplines, namely, president and manager, plant production and protection, livestock, poultry, nursery, marketing, forestry, etc. Now a cadre of master trainers is being formed at the cluster level.

AREA AND FARMING SYSTEMS

The physiography of the area is rugged and hilly, with steep and heavily dissected slopes. Most elevations in the area are at least 1,500 meters above sea level and more than half are above 4,500 meters. The region displays great ecological variation over relatively short distances, both vertically and horizontally. In this fragile and harsh environment, people have established their livelihood in a variety of ecological conditions. These include old river terraces and fans on valley floors, unstable slopes on valley sides, and high elevation forests and meadows. Being dry and far from the sea, the thermal climate is continental and dictates the length of the growing period and types of crops to be grown. The growing seasons and cropping pattern change with the altitude and microclimate of the valleys. Except for the alpine pastures, almost all crop production depends on irrigation water from snow melt, glaciers, springs, and, occasionally, rivers.

Agriculture is constrained by a scarcity of land and irrigation water. The farming systems can be described as arable crops mixed with fruit, forests, and livestock. While there is a range of farming systems in the region, they all contain the common cereals, grain, legumes, fodder, vegetables, small livestock, fruit and nut trees, and trees for fuel and timber. Low and high altitude pastures are an integral part of this intricate crop-animal nexus.

PROMOTION AND ADOPTION OF AGRICULTURAL TECHNOLOGIES

The basic aim of the production model is to increase productivity and to improve the management of resources on a sustainable basis. Given the complexity and interdependence of the existing systems of farming, AKRSP has paid increased attention to the issues of sustainability and environmental protection. The idea of intervention in the existing system of resource management and production is based on the premise that innovations are grafted onto traditional systems, thereby making use of considerable indigenous knowledge and methods. AKRSP is aware that imported biological and other technologies have to be adapted to local conditions. Moreover, they have to be sufficiently profitable for the average farm household to adopt them quickly. Improved biological technology forms only one part of the production package; it also includes training in technology and resource management, setting up supply lines, supply of credit on demand, and introduction of marketing options.

At the farm level, expansion of irrigated land and improved accessibility to and from markets are factors affecting the current pattern of resource use and farmers' assessment of local comparative advantage. New options in resource management are also created by the growing availability of technologies and inputs that increase the productivity of existing resources and production of outputs.

Agricultural credit can be a great facilitator of change in resource management. While the formal banking sector in the region has greatly expanded its network in recent years, its lending is focused mainly on a small number of individuals. A large majority of small farmers are left out. AKRSP's interventions in the past have made credit accessible to small farmers for agricultural development to meet their relatively small credit needs. Access to credit means new options for improving the allocation of resources and the productivity of inputs.

AKRSP has focused on four specific objectives in its activities with the village organizations in agriculture.

1) Introduction of improved packages for production of crops, including cereals, fruits, vegetables, and fodder;
2) Organization of technical inputs to improve resource management at the household, village, and valley levels;
3) Dissemination of results of trials on improved packages through courses, field demonstrations, establishing supply lines for inputs, and collaborating with government agencies; and
4) Promotion of awareness about agricultural sustainability and devising new methods to reduce the visible threats to it.

AGRICULTURAL PACKAGES

Given the complex and highly interdependent nature of the farming systems of northern areas and given the lack of relevant adaptive research suited to these conditions, the development of new agricultural packages is necessarily a slow process. AKRSP has made some progress in the spread of wheat technology, prevention of crop losses, production of vegetable and seed potatoes, and the planting of fruit orchards.

Wheat production technology

Wheat is the most important crop in the region occupying about 39 percent of the cropped area in Gilgit, 54 percent in Chitral, and 40 percent in Baltistan. AKRSP has been involved in the development of seed-cum-fertilizer packages for wheat in the region in collaboration with the Pakistan Agricultural Research Council (PARC) and Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). Initially, informal surveys were undertaken for diagnostic purposes. These showed that wheat was a dual purpose crop: grain for humans, and straw for livestock. It was also discovered that existing varieties produce low yields due to rust susceptibility. The challenge was to identify and test varieties, that were high biomass yielders of grain and straw, resistant to pests and diseases, responsive to fertilizer, and suited to the varied agro-ecological zones in northern Pakistan.

Since AKRSP began its credit program and set up the supply line for fertilizers, farmers have been able to receive the fertilizer on their doorsteps through the village organization. AKRSP began its farm trials involving village organizations with three main semi-dwarf varieties: Pak-81, Suneen, and Pirsabak, which performed well only under good water and fertilizer regimes. The wheat trials showed that Pak-81 out-yielded local and improved varieties by a wide margin both in grain and straw. Moreover, the net benefits per hectare were nearly doubled. With the visible success of the seed and fertilizer package, village organizations' demand for new seed increased greatly and was met by supplies from local seed producing village organizations and from the Seed Supply Corporation. By the early 1990s AKRSP had distributed over forty thousand metric tons of improved seed in one region alone. A survey showed that 45 percent of the farmers were using the improved seed with fertilizer on about 41 percent of the wheat area. The impact study also showed that fertilizer use has had a significant impact on wheat yields and produced high net returns per hectare.

The development of improved wheat technology and its diffusion have not been limited to the Gilgit region. Efforts are underway to spread the new varieties in the Baltistan and Chitral regions by increasing the production and distribution of improved seed. The results are very encouraging. In Baltistan, Chunda valley had always been a net importer of wheat. Since village organizations started using the new variety of wheat and made arrangements for fertilizer by linking them with seed and fertilizer agencies, the area has become a net exporter of wheat grains. However, sustainable improvement have to be based on a continuing process of testing and demonstration. This is important as any given variety will degenerate by increased susceptibility to diseases and pests and by mixing of seed through mismanagement at the farm level.

Seed potato production

The higher altitudes in the region are well suited to the production of seed potato. In 1984/85 the Department of Agriculture and the FAO/UNDP (project) introduced a new variety of potato which performed well and was highly profitable. As the market for seed potato is in the plains, links were developed with a private company to produce and purchase the certified seed. The company used village organizations for contracts with individual farmers. AKRSP helped in the establishment of a Seed Certification Laboratory in the region by providing them with equipment and transport. The Seed Certification Department provided the staff. As the market for seed is expanding, so to is the area under potato production.

There is an integrated effort by AKRSP, village organizations, the Department of Agriculture Extension, and the private sector to promote the seed production industry in the northern area. The Department of Agriculture provides pre-basic and basic seed to the village organization commercial cooperative association (Gilgit Agricultural Marketing Association established in 1992), and AKRSP and the extension department provide the necessary training. The Federal Seed Certification Department helps in the certification of seeds, and down country potato growers purchase the seed for further multiplication. Fertilizer is arranged by the Gilgit Agricultural Marketing Association. Other inputs, like spraying, are undertaken by village specialists, who are paid for their services. The seed potato crop is extremely profitable and, therefore, replacing cereal crops in the Hunza valley.

Vegetable production

Traditionally, rural households in the northern area used to grow and consume few vegetables. The agro-ecological conditions are well suited to producing a variety of vegetables. Now almost all households grow vegetables. A recent survey has shown that some households grow as many as 13 vegetables. New marketing possibilities are opening up with greater accessibility to, and integration with, local markets. There seems to be definite potential for supplying off-season vegetables to the markets down country. Since vegetable production in all villages is the domain of women, AKRSP has developed an improved technology package on a commercial basis, along with, training and marketing components. The packages include improved seeds, tools, production, and storage techniques. These were introduced through on-site demonstrations and training on collectively managed plots in the village. After the introduction of the package, the women were encouraged to expand production on individual land.

In the development of the vegetable package the women's (village) organization specialists act as catalysts in their respective areas: they impart training, and transfer information on varieties and seeds, seed bed preparation, and also on gathering the produce for marketing. The demonstration plots play a key role in the extension of new technologies. The AKRSP field staff assist the women's (village) organization at critical stages in the crop season to give on-site training: over 700 women have been trained as specialists. These specialists are the main cadre for imparting further training to women's organizations.

Fruit development

The present pattern of fruit production has evolved in response to the subsistence needs of rural households in the region. All households have some fruit trees scattered around the homestead and on the farm, but orchards are rare. With greater market integration and availability of new planting material, opportunities have emerged to exploit the region's comparative advantage in producing a variety of fruits. AKRSP has introduced three packages: improved species of fruit types, fruit nurseries with improved rootstock, and organized orchards (fruit women's (village) organization). Over 350,000 improved plants, mostly apple and cherry trees have been distributed in the program area and nearly 410,000 have been planted by village organization members from their own resources.

More than 100 fruit nurseries have been established, largely by women's (village) organization specialists. AKRSP helped them with planting material either from the Department of Agriculture or from the private nursery owners. The specialists were also given training in collaboration with the extension department. AKRSP initially assisted village organizations in establishing demonstration orchards. Based on these demonstrations, about 150 village organizations established orchards on their individual lands, replacing wheat and maize crops. In each village organization, at least 50 percent of the members participated in this package. These orchards are protected from free grazing either by fencing or through collective efforts.

10. USE OF EXTERNAL INPUTS AND THE STATE OF EFFICIENCY OF PLANT NUTRIENT SUPPLIES IN IRRIGATED CROPPING SYSTEMS IN UTTAR PRADESH, INDIA

by H. L. S. Tandon[3]

INTRODUCTION

The need to intensify foodgrain production in India arises from a population that is expanding more rapidly than is the area available for foodgrain production. Between 1950 and 2000, the population is expected to grow by 281 percent but the foodgrain area is expected to increase by only 30 percent or one-ninth as much. The number of people to be supported by each hectare with foodgrains increased from 4.6 in 1950 to 6.6 in 1981 and is expected to reach 9.6 by the year 2000 (Figure 10.1). Swaminathan (1994) cautions about the serious crisis on the food front in the early 21st century if population growth is not checked and if sustainable land and water use policies are not adopted. A recent assessment of food production for meeting population demand underscored an increase in yields as one of the two most important factors (Islam 1995). Yield increases imply further land use intensification because of constraints on the expansion of land and water resources.

For India as a whole, cropping intensity is 130 percent. It increases with the expansion in irrigation availability and results in growing more than one crop a year on 43 million hectares, which is comparable to adding the entire area under rice. Assuming that 70 percent of this 43 million hectares is devoted to foodgrain production, then at current productivity levels, the food needs of almost 260 million people are being met through a more intensive use of the net cropland. If this were not the case, there would either have been even greater pressure on increasing crop yields such that foodgrain availability per person would have been reduced, or close to 43 million metric tons of foodgrains would have had to be imported annually.

This paper provides a brief account of the use of external inputs, particularly various nutrient sources, the state of their efficiency, and soil nutrient balances in irrigated cropping systems in the state of Uttar Pradesh, India. For a sharper insight into various facets of intensive cropping, the western region of the state has been selected, of which nine districts are taken as a representative sample (Table 10.1). These are more intensively cropped than other regions in the state of Uttar Pradesh.

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AGRICULTURE IN UTTAR PRADESH

The state of Uttar Pradesh (net cultivated area 17.3 million hectares, population 139 million) can at best be described as being at an intermediate stage of intensification. As compared to the most intensively cultivated state of Punjab, fertilizer use intensity (kilogram per hectare) in Uttar Pradesh is 47 percent of that in Punjab and the average foodgrain productivity is 57 percent of that in Punjab. Thus, at a moderate level of intensification, the impact of various constraints on crop productivity, nutrient use efficiency, and on response rates to applied nutrients will also not be vary marked, unless of course there is severe mismanagement of various inputs.

Wheat and rice account for 84 percent of the total foodgrain production in the state. About 50 percent of the wheat area is rotated with rice and this system is followed on about 4.7 million hectares (Ambekar 1995). Current productivity of rice and wheat in Uttar Pradesh is 1.9 metric tons per hectare and 2.3 metric tons per hectare, respectively. The state department of agriculture believes that it is possible to raise average foodgrain productivity by one ton per hectare between 1995 and 2000. Past performance, however, shows that such a magnitude of yield increase took place over 11 - 12 years. It may take even longer in the future.

Agriculture in the intensively cropped Western Uttar Pradesh

The study area comprising nine districts is located in the northwestern Indo Gangetic alluvial plains. The main crops are rice, sugarcane, and maize. While rice and maize are *Kharif* (monsoon season) crops, wheat is a *Rabi* (post-monsoon season) crop. Sugarcane, the most important cash crop of the area, occupies the field from May of year one to November of year two during which period one plant crop and one ratoon are taken. The most important cropping systems of the region are a two-year rotation of sugarcane--sugarcane-wheat and annual rotations of rice-wheat, maize-wheat, and maize-potato.

Eighty percent of farm holdings are smaller than two hectares and account for 44 percent of the cropped area. Only three percent of farms are bigger than five hectares. These cover 16 percent of the cultivated area. The sample area of nine districts has a cropping pattern in which sugarcane, rice, and wheat account for about two-thirds of the cultivated area (Table 10.1). The farming in this area is more intensive when compared with the state of Uttar Pradesh as a whole as shown below.

Cropping intensity	122% of U. P.	Rice yield	132% of U. P.
Irrigation intensity	126% of U. P.	Wheat yield	127% of U. P.
Fertilizer use Intensity	149% of U. P.	Sugarcane yield	108% of U. P.

Growth in crop yields in the past have resulted largely from increases in yield per hectare in the case of wheat, while both expansion in area and productivity have contributed to production increases in sugarcane in the Meerut area (Table 10.2). In this region, neither the response rates nor crop productivity trends show a declining trend, which can be attributed to an intermediate level of intensification and moderate yields (Figures 10.2 and 10.3).

The resource base

Climate. The climate is semi-arid tropical. The mean annual rainfall of 760 millimeters is received over a 100-day period mostly during July and August when the main crops grown are rice, sugarcane and maize. The highest mean monthly temperature is 39°C (May) and the lowest is 6°C (January). The climate permits year-round cultivation during the two main seasons called *Kharif* (monsoon) and *Rabi* (post-monsoon).

Land. Most soils are alluvial, medium-deep, of varying textural classes, and are generally deficient in nitrogen (N), low to medium in phosphate (P), and medium to high in potassium (K). Zinc (Zn) deficiency is widespread and sulphur (S) deficiencies are becoming important in several areas.

Water. The mean annual rainfall is 750-1,250 millimeters. In addition, 42 percent of the cropped area is covered by irrigation, out of which 30 percent is serviced by canals and the rest by various types of wells.

Human resources. The rural population constitutes 87 percent of the total. These families have been engaged in farming for generations, often tilling the same piece of land. Recent trends indicate that occupations other than farming are also taking a fair amount of their time, energy and attention.

Fertilizers. The state of Uttar Pradesh is at present the largest user of fertilizers. During 1993-94, total consumption of fertilizers in all forms was 1.89 million metric tons N, 0.36 million metric tons P_2O_5, and 0.04 million metric tons K_20, or a total of 2.29 million metric tons at an average application rate of 90 kilograms of nutrients per hectare. A major share of the fertilizer used goes to wheat, sugarcane, rice, and potato production. The state has a surplus in the production of N fertilizers, but most of its supplies of P and K come from elsewhere, either from other states or from imports.

Other. According to official statistics, Uttar Pradesh is better placed than other states in terms of organic resources. It accounts for 12 percent of the country's arable land but is reported to produce 25 percent of the total urban compost and 34 percent of the total rural compost. Thus, potentially, about six metric tons of compost is available for each hectare. The nutrient sources and their practical aspects are discussed in greater detail in a later section.

Nutrient needs of intensive cropping systems

Under normal conditions, nutrient uptake by crops constitutes the major route of nutrient withdrawal from soils. Non-leguminous foodgrains absorb 60 to 70 kilograms of nutrients for every ton of grain produced. Intensive crop rotations (two or three crops per year) under optimum management are associated with an uptake of 500 to 900 kilograms per hectare per year of nitrogen, phosphate, and potash ($N + P_20_5 + K_2O$) (Tandon and Sekhon 1988; Tandon 1991).

Successful intensive farming relies heavily on external nutrient application. This is primarily due to large amounts of nutrients absorbed and removed by harvested crops coupled with low soil fertility, particularly with respect to nitrogen and phosphorus. Since most crops are harvested manually (even where sown by machine), much of the straw is also exported from the field, thus further depleting soil fertility. Apart from nutrient removal through harvested crops, substantial amounts of nitrogen can be lost from the system through various routes, and potassium can be lost through leaching in coarse-textured soils from heavy rainfall or over-irrigation.

Impact of external nutrient supplies on crop yields, responses and the state of nutrient use efficiency

There is a large difference in this respect between the findings of research experiments and the situation at farm level. The difference is primarily due to the wide gap in terms of inputs used, yields obtained, and level of management. It is important to recognize that economics gives low importance when raising a crop at the research station, but, it is of paramount importance for the farmer. Thus, while a researcher is primarily concerned with agronomy, the farmer cannot lose sight of the agro-economic aspects.

In long-term experiments at research stations, crop yields, particularly of rice, have shown a declining trend thus giving lower efficiency of the fertilizer nutrients applied. This feature is more evident when nutrients are applied through fertilizers alone, and restricted to N, P and K. Table 10.3 illustrates yield trends in a well-monitored long-term experiment at Pantnagar, Uttar Pradesh.

The fall in yields was much greater in rice and smaller in the case of wheat in the system. After 20 years, yields seem to have stabilized around five metric tons of rice per hectare and four metric tons of wheat per hectare, giving an annual grain yield of nine metric tons per hectare (over 200 percent more than the present state average) worth Rs 31,500 or US$1,000 per hectare without considering the economic value of about 12-13 metric tons straw. The annual application of 15 metric tons of farm yard manure (FYM) per hectare maintained the soils' initial organic carbon level at 1.4 percent and also P and K levels. Use of NPK alone regularly for 20 years maintained available P and K, but not the organic matter content. The causes of the large decline in rice yields in experiments have not been investigated in depth but have been attributed to decreases in organic matter, late planting, fall in management levels, declining potential of high yielding varieties (HYV), and the onset of other deficiencies. It is unfortunate that in such vital experiments, the soil microbiological, pathological, and entomological changes are not monitored, thereby limiting their utility to gaining insights into this nutrient system.

In another long-term experiment at Pantnagar, Uttar Pradesh, where a rice-wheat system is used, grain yields could be sustained at very high levels (seven metric tons of rice per hectare and four metric tons of wheat per hectare) if optimum NPK was supplemented with farm yield manure (FYM) and zinc, as shown in Table 10.4.

Declining yield trends in N or even NPK-treated plots seen in several long-term experiments are understandable. It is more pronounced in plots that did not receive FYM with fertilizers than in those which received FYM and fertilizer. A decline in yields in NPK-treated plots over a period of time is to be expected because these are not the only nutrients needed by crops to sustain high yields. With continuous cropping, other nutrients are absorbed and exported from the soil, in the process making even once well-supplied soils deficient in certain nutrients. Unless these deficiencies are corrected, response rates to NPK application are expected to drop. This calls for redefining balanced fertilizer use which, by and large, is equated with NPK application. It should include the deliberate application of all those nutrients which the soil cannot provide to sustain expected yields. At present, deficiencies of zinc and sulphur are the most important after those of nitrogen and phosphorus.

In the most important sugarcane-wheat system, current productivity is much below the realizable potential. For sugarcane, the average yield is 55 metric tons per hectare while the potential is 80-90 metric tons per hectare. For wheat, the corresponding figures are 3 metric tons per hectare and 5 metric tons per hectare, respectively. The root causes of low productivity in both cases are (i) delayed planting, and (ii) sub-optimal, imbalanced use of fertilizers. The decline in response rates to fertilizers is more a feature of research station experiments than at the agricultural level (Figures 10.2 and 10.3). This is primarily because crop yield levels in the region are well below their potential. One important finding from several such experiments is that high yield levels cannot be sustained with N alone, only in a few cases by NPK, but in most cases by applying optimum levels of NPK and 10-15 metric tons FYM per hectare per year on neutral and alkaline soils, and NPK and lime on acid soils (Nambiar and Abrol 1989). Where the deficiencies of zinc and sulphur are important, their inclusion or omission can safeguard or jeopardize yield sustainability in spite of having adequate NPK.

Furthermore, nutrients are not the only inputs which affect crop productivity and efficiency. The total package required consists of various inputs, their positional availability, resources, management skills, decision-making, and infrastructural support. If the irrigation department does not release canal water at crucial stages of crop growth, the impact of all other investments is sub-optimal. In an analysis of the contribution of only three factors on wheat productivity, irrigation by itself increased yields by 24 percent (at the expense of soil nutrient capital), while irrigation plus weed control plus fertilizer increased crop yields by 124 percent, as shown in Table 10.5.

One implication of this type of information is that inputs work as a team and should not be examined on a piecemeal basis. Another is that fertilizer use coupled with good management practices improves the efficiency and returns from investments in irrigation. This is significant because a fertilized crop does not necessarily require more irrigation than an unfertilized one. Water use efficiency could thus be raised three times by controlling weeds, four times by adding fertilizer, and five times by using the total input package. This is exactly where detailed constraint analyses in intensively cultivated areas are needed if returns from investments are to be maximized and high productivity sustained at lower unit production cost. Expansion in water resources has already been identified as a major constraint (Islam 1995). Hence, its most efficient use needs no repetition.

ADOPTION OF RECOMMENDATIONS BY FARMERS IN WESTERN UTTAR PRADESH AND CONSTRAINTS

Surveys in the Meerut division show that in 1989-90, the expenditure on inputs for the sugarcane-sugarcane-wheat system was Rs 12,955 per hectare over a two-year period (Table 10.6). Out of the money spent on these inputs, 52 percent went for raising plant cane, 32 percent for wheat, and 16 percent for the sugarcane ratoon. For the system as a whole, 36 percent of expenditure was on plant nutrient supplies, 22 percent on labor wages, 22 percent on seed, 19 percent on irrigation, and 1 percent on plant protection (Figure 10.4).

Even adoption of the most basic input, seed, is flawed at the farm level. Most farmers used 11-25 percent less seed than recommended for sugarcane, presumably because of its high cost, but used 49-76 percent more seed than recommended for wheat, apparently to compensate for anticipated yield loss due to delayed planting. Even though irrigation facilities cover most of the cropland, adequate water is not available for all crops. For wheat, most farmers could provide four irrigations against the five recommended but about one out of four small-medium farmers could give only three irrigations. In the case of sugarcane, most small-medium farmers were able to give up to 5 irrigations instead of the 7-8 recommended. Small landholders used irrigation water more judiciously than those having comparatively larger land holdings.

A number of production constraints on obtaining higher crop yields in intensive cropping systems have been identified (Singh and Sharma 1994). General production constraints include incomplete mechanization (tractors without tools and implements); inadequate and imbalanced fertilizer use (N accounts for 75-80 percent of total nutrients used); inadequate plant protection (potential yield loss 30-80 percent); high farm labor wages and shortage of labor; and inadequate produce storage and marketing facilities. Additional crop specific constraints are detailed in Table 10.7.

Nutritional constraints in intensively cropped areas are no longer confined to N, P and K. That era is over. Now, several others nutrients, particularly zinc and sulphur also need to be applied in order to sustain high yields. In the area of western Uttar Pradesh under consideration, the application of zinc (above NPK) increased sugarcane yield significantly. In addition, 26 percent of soils samples were found to be deficient in plant-available sulphur (Yadav 1995).

Nutrient application ratios in Uttar Pradesh are less balanced than in similar regions having higher cropping intensity and crop productivity. For example, the N:P_2O_5 consumption ratio, fertilizer use level, and rice and wheat productivity at three levels of intensity are shown in Table 10.8.

From the table, it can be concluded that it is not the quantity of nutrient use alone which determines the response rate, but also the ratio in which the required nutrients are distributed. Nutrient application rates of, say, 180 kilograms per hectare will produce entirely different responses and nutrient-use efficiencies depending on whether it is 180 kgs N, 120 kgs N + 60 kgs P_2O_5, 100 kgs N + 50 kgs P_2O_5 + 30 kgs K_2O, or, say, 90 kgs N + 45 kgs P_20_5 + 25 kgs K_2O + 20 kgs zinc sulphate. Some reasons for imbalanced fertilizer use have been analyzed (Figure 10.5).

Farmers in many intensively cropped areas are often termed as "progressive" but are not necessarily top-class decision-makers or managers. A diagnostic survey of farmers in the Terai region of western Uttar Pradesh revealed that a) most farmers used more N than recommended; b) about 75 percent used phosphate and 15 percent used potash on rice; c) use of organic manure or green manuring was very limited; and d) no FYM was used for wheat. When farmer practices are improved, substantial yield improvements can be made. This does not always occur from using more resources, but rather by better deployment. In farm trials in western Uttar Pradesh, improving farmer practices through recommended fertilizer rates and supplementing recommended fertilizer with organic and green manures could raise sugarcane yields by 14.3 metric tons per hectare or 30 percent (Singh and Sharma 1994).

In the present scenario of fertilizer pricing policies, it is not easy to expect farmers to do large-scale balancing of nitrogen with phosphate or potassium. The N:P_2O_5:K_2O ratio which was 6.0:2.4:10 in 1991-92 has now widened to 10:3:1. This is a direct consequence of the retention of the subsidy on nitrogen fertilizer, but its withdrawal from phosphate and potash fertilizers. Such imbalanced economic treatment of plant nutrients, which interact and work as a team in crop nutrition, favors imbalanced as well as inefficient fertilizer use, encourages over-application of nitrogen, leads to accelerated removal of soil nutrients, and threatens the sustainability of high yields. Subsidized nitrogen fertilizer acts as a disincentive for practicing integrated plant nutrient supplies (IPNS) in general, and raising green manures in particular.

If response rates to fertilizer application decline, the reasons for this are partly agronomic and partly economic. These declines are not so much due to the nutrients applied (most farmers are using sub-optimal rates) but rather to the nutrients which should have been, but were not, applied.

INTEGRATED PLANT NUTRIENT SUPPLIES (IPNS) AND THEIR FARM-LEVEL STATUS

The annual nutrient need of intensive cropping systems is so large that it is beyond the availability of any single type of nutrient source to supplement the soil nutrient capital on its own (Tandon 1993a, Tandon 1993b, Tandon 1995b). Through IPNS, diverse nutrient sources can be deployed to sustain crop yields and maintain or even enhance soil productivity, provided such resources are actually available at the farm level and the farmer finds it attractive to use them (Roy 1992; Tandon 1992). It seems that the most abundant renewable resources available for recycling of nutrients on the land are crop residues and not necessarily farm yard manure (FYM).

Crop residues

Among crop residues, sugarcane leaf trash and straw from wheat and rice are the most important. For every ton of grain, 1.0-1.5 metric tons of straw are generated. For every ton of sugarcane produced, 100 kilograms of dry leaf residue and 50 kilograms of dry root mass is produced. A 60 ton per hectare cane crop, thus, generates six metric tons of leaf residue and three metric tons of roots. A major proportion of cane residue is often recycled on the land when the ratoon is taken. However, since it is burnt in the field after the harvest of the ratoon crop in order to prepare the field for wheat, less than 50 percent of the residue is recycled for reincorporation into the soil.

Wheat straw is a valuable cattle feed and very little of it is returned directly to the land. However, it is recycled in the form of cattle manure. Wheat straw, being a common animal fodder, is a valuable traded commodity and can fetch a price of Rs 500 to 1,000 per ton depending upon demand and supply. A farmer harvesting four metric tons of wheat will consequently have six metric tons of straw for sale, if he has no animals. There is thus limited scope for recycling wheat straw in intensive farming. Alternatively, rice straw has multiple uses, such as (i) industrial raw material, (ii) animal fodder, (iii) roof thatch, (iv) packing material, and (v) application to the field, where it is often simply burnt.

Green manures

Once a standard feature of sugarcane cultivation, these have almost disappeared from sugarcane culture to give way to cereals (Singh 1993). Its role, utility, and soundness in agro-technology at the research level is unquestioned, but major initiatives will be necessary to encourage its use as part of IPNS. For example, a good green manure crop of *Sesbania* grown for six weeks and plowed under before planting rice can increase yields on a par with 60 to 80 kilograms of urea fertilizer. Green manure also adds much needed organic matter to the soil, results in improved soil physical properties, and recycles nutrients from the subsoil to the top. However, this is where green manure seems to meet a dead end.

Hardly any serious exercises in the non-agronomic aspects of green manuring have been carried out. Estimates by different researchers for raising a *Sesbania* green manure in the same area vary from Rs 500 to 2,000 per hectare. The figure of Rs 600 to 700 is closer to reality. At this level of investment, a farmer can either raise a green manure or grow a short duration pulse, sell the grain, recycle its straw, purchase 60 kilograms N expected from a green manure, and still save money. Operationally, green manuring before planting rice has a better scope in Uttar Pradesh than in other intensively cultivated states like Haryana and Punjab. This is because after the wheat harvest, rice is planted early in Haryana and Punjab but not in Uttar Pradesh where sufficient time is available for raising a good green manure (Modgal 1994). At the field level, it is difficult to obtain good quality green manure seeds. This calls for a serious initiative by the seed industry, breeders, and agricultural planners.

Farm yard manure

Use of cattle manure (FYM) is common before sugarcane. Many farmers apply 10 to 15 metric tons of FYM per hectare to plant cane, i.e. once every two years. The net availability of cattle manure is declining due to gradual mechanization and other important competing uses, the most important of which is its use as a domestic fuel. Pressure on the use of the cattle dung as fuel occurs because of the increased scarcity and high price of fuel wood. It is thus unlikely that the amount of cattle manure will increase to any great extent in the coming years. Due to the decreasing availability of cattle dung, FYM is also becoming a traded commodity. Some farmers pay Rs 50 per ton of FYM, for a two ton trolley.

According to one estimate, 25 percent of Indian agriculture's NPK needs can be mobilized through FYM, crop residues, urban wastes, green manures, and biofertilizers (Pandey no date). To realize this, certain resources will be required for use on the land (see Table 10.9). While all these resources, particularly legume residues and green manures can augment nitrogen supplies very well, and crop residues are an ideal supplement as a source of potash, the position of phosphate is weak. Most of these resources are phosphorus-depleted, and hence it is not automatic that the effect of residue recycling will be at the same level for all three major nutrients.

Industrial waste

Press mud, a waste from sugar factories, is also available in the region. It is a valuable source of nutrients. For every ton of cane crushed, 4-5 metric tons of press mud is generated. Press mud is used in the brick industry and for application as manure. Estimates of the percentage used on land vary widely from 10 percent to 75 percent. At times, it is purchased at Rs 200 per ton from the factory site.

Biofertilizers

Among biofertilizers, the use of rhizobiuin inoculants for legumes is accepted but its availability is a constraint. A *zotobacter* could find use in sugarcane cultivation but the agricultural university is not convinced about its efficacy and hence its use is not recommended.

Some researchers are still undecided about the role of IPNS in sustainable crop production. Out of a dozen suggestions offered on the subject by the Cropping Systems Research Project of the ICAR, sustainable resource use is restricted to land and water while nutrient management finds no mention. Assessments on the contribution of organic resources to the nutrient needs of Indian agriculture also vary too widely. One assessment puts the possible role of these resources at 25 percent of total nutrient needs (Pandey no date), while another states that most nutrient needs can be met (Pyare and Srivastava 1994).

Venugopal and Bhatia (1994) conclude that as intensive agriculture is becoming a necessity, soil nutrient balances are becoming increasingly negative, warranting appropriate supplements. Even when all kinds of organic manures and all forms of crop residues available are recycled on the land, nutrient balances will still remain negative. This may not necessarily be so. A recent assessment of long-term experiments shows that the application of neither organics (FYM, groundnut cake), nor fertilizers alone could sustain sugarcane productivity (Singh and Yadav 1994), rather their integrated use was required. Furthermore, although regular application of FYM did not raise the soil organic matter level, groundnut cake increased it by 25 percent. Groundnut cake is, however, too valuable a material to be used as manure. The use of non-edible oil cakes needs to be explored.

It is foreseen that IPNS will be increasingly mentioned as the strategy for soil fertility management, in which fertilizer will be a key component. It is the author's assessment that in most high productivity, intensive cropping systems, IPNS packages in India will be fertilizer-driven by necessity, due to inadequate contributions from other sources, all of which can otherwise be fully integrated.

SOIL NUTRIENT BALANCES UNDER INTENSIVE CROPPING SYSTEMS

There are hardly any farm-level exercises which have been or are being conducted to monitor nutrient balances in intensively cropped areas. It is generally accepted that soils are being mined and that their nutrient capital is being continuously depleted throughout intensively cropped areas. No quantitative or semi-quantitative estimates, however, are available on nutrient recycling or balances based on various input-output components at the farm level. This is an area where some insights from a few well-defined benchmark farms (not research stations) will be extremely valuable in developing sustainable systems, not only for site-specific adoption, but also for transfer to similar environments.

In the upper Gangetic plains, where the study area is located, average nutrient removal in 1988-1989 was 204 kilograms $N+P_20_5+K_20$ per hectare. This is expected to rise by 31 percent by 2000, as compared to a 27 percent rise for the country as a whole. This is in spite of the fact that fertilizer use intensity in the area is 50 percent higher than the national average. Due to higher cropping intensity and productivity, the region accounted for 12 percent of nutrient removal from 8.5 percent of all-India cropped area. This resulted in a nutrient deficit of 77 kilograms $N+P_2O_5+K_2O$ per hectare, which was 40 percent higher than for the country as a whole in 1988-89, but it is expected to be 50 percent more than the country average by 2000 (Kumar 1991).

The fate of soil nutrient capital and balance in the two most important cropping systems in the region is illustrated below (Tables 10.10 and 10.11). These computations are primarily illustrative and based on several assumptions, mainly due to the present inadequate database. The initial soil nutrient capital is taken to reflect the soil's low status in nitrogen, medium in phosphorus, and high in potassium for the plow layer. Fertilizer inputs for the sugarcane-wheat system are typical of the practice in the region, while those for rice-wheat are based on actual data applied by 15 medium size (2 to 5 hectares) farm holders. On average, 25 percent of nitrogen fertilizer is assumed to be lost from the soil under upland crops and 50 percent under rice.

The analysis shows that after one cycle of the sugarcane-wheat system, the initial soil nutrient capital decreased by 23 percent in the case of nitrogen, increased by 102 percent in the case of phosphorus, but decreased by 104 percent in the case of potassium. The improvement in phosphorus status was attributed to its application to both the main crops and input from FYM and press mud, less being removed to the crop than was added, and the ability of phosphorus (unlike nitrogen) to accumulate in the soil. The large depletion in potash was due to its very weak position in the fertilizer use pattern and crop removal exceeding the potassium input.

Under the rice-wheat system, the soil's nitrogen capital was more or less maintained because crop uptake plus losses matched fertilizer input. There was, however, a net depletion in phosphorus because the farmers applied it only to wheat. Potash balances were negative, primarily for the same reason as under the sugarcane-wheat system. The net effect of intensive irrigated cropping at the current level and pattern of input use and the removal pattern on the soil nutrient status is summarized in Table 10.12. These examples illustrate that intensive cropping depletes the soil of its nutrient capital. Further, if it continues, then low nutrient reserves will adversely effect the sustainability of crop yields, which at the present can only be described as moderate and not high.

PLACE OF FERTILIZERS IN SUSTAINING INTENSIVE IRRIGATED CROPPING

In order to cover basic population demand, Asia (and this holds true for India as well) cannot avoid heavy use of fertilizers for many years to come (Angé 1993). However, the required amount of food can be obtained with comparatively lower fertilizer input through more efficient use. To meet the food needs, grain yields must reach 3.5 metric tons per hectare by 2010 and 5.5 metric tons per hectare by 2030 (see Table 10.13).

India will need 235 million metric tons of foodgrains by 2000 and 325 million metric tons by 2010. To attain this, the production increase, which was 52 million metric tons between 1980-81 and 1990-91, will have to be 65 million metric tons during the 1990s and another 90 million metric tons from 2000 to 2015. This will not be easy. According to estimates by the Fertilizer Association of India (FAI) (various years, b) and the Government of India, without increasing cropped area, Indian farmers will need to use 235 kilograms per hectare of $N+P_2O_5+K_2O$ by 2010 to harvest the required yield levels. The amount of nutrients needed can, however, vary depending upon the balance between them and how efficiently these are deployed. For example, the requirement can be:

33.3 million metric tons $N+P_20_5+K$ at balanced ratios, or
37.9 million metric tons $N+P_20_5+K$ at present imbalanced ratios.

The difference between these two demand figures is equivalent to US$ 2.4 billion (each year).

In order to meet foodgrain needs by 2010, the average productivity of most crops must be raised substantially. For example, rice productivity will have to rise by 57 percent, wheat by 46 percent, pulses by 65 percent, roots and tubers by 30 percent, sugarcane by 25 percent, groundnuts by 73 percent, rapeseed by 50 percent, and cotton by 80 percent.

The input use pattern, the emerging trends in competing uses of resources, and the need to raise yields all point toward a much greater role for fertilizer within the IPNS approach. Due to the limited availability and use of FYM, the low level of residue recycling, and field-level limitations on the extension of green manuring, the main burden of providing external nutrients for sustaining crop yields in intensive irrigated areas will fall on having adequate fertilizer supplies. The alternatives and options at the grassroot level are far weaker in quantitative terms than are reflected in research findings.

At present, the only major possibilities towards making the nutrient supply pattern more broad based are (i) to supplement fertilizer with as much area as can be green manured either before the main crop or through a short intercrop; (ii) to discourage burning of crop residues; (iii) to recycle cattle dung through biogas plants in order to generate both fuel and manure; and, last but not least, (iv) given a certain amount of fertilizer supplies or financial resources, to use them in the most balanced ratios backed by best management practices.

ECONOMIC ASPECTS

Throughout the 1980s, fertilizer prices in India remained more or less unchanged while the support/procurement prices of grains were periodically increased. After the withdrawal of subsidies on phosphate and potash, their farmgate prices shot up overnight from Rs 7.57 per kilogram to Rs 12.10 for phosphate and from Rs 2.83 to Rs 7.50 per kilogram for potash (Table 10.14). This was the first time that potash had been costlier than nitrogen, and phosphate almost twice as expensive as nitrogen.

These price escalations reduced the net returns from fertilizer use because input prices rose faster than produce prices. It also upset and reduced the farmer's budget to buy the same application rate he was using. A fertilizer dose of 120-60-40 kilograms NPK fertilizer, which is typically recommended for irrigated high-yielding cereal varieties, cost Rs 1,365 per hectare at subsidized prices, but Rs 2,150 per hectare or 58 percent more after the withdrawal of the subsidy. The net effect was a decline in the consumption of phosphorus and potash fertilizer because the farmer's budget could only go so far and the need for additional credit was not planned for.

Since late 1992, the returns from fertilizer application have improved significantly and fertilizer use is, on the whole, profitable. This is primarily due to (i) a Rs 1,000 per ton rebate on di-ammonium phosphate (DAP) and mono-ammonium phosphate (MAP), and a proportionate rebate on complex fertilizer to partly soften the blow of subsidy elimination, and (ii) large increases in the official support prices for almost all crops in the last few years. This has restored the returns from fertilizer use to the level of the early 1990s. However, the reality is that the farmer purchases fertilizer 5 to 10 months before he can sell his produce. Thus, he needs resources first and that is where the role of adequate, timely, and speedy credit disbursement becomes crucial. If adequate credit is not available, the farmer is likely to invest more in the subsidized nitrogen than in the costlier phosphorus and potassium, without realizing that in crop production nitrogen cannot do what phosphorus and potassium can. The importance of credit is thus not restricted to the disbursement of funds. It holds a key place in enabling farmers to practice balanced fertilizer application, which is a prerequisite for efficient fertilizer use, which in turn is necessary for optimizing returns from high input and high output intensive cropping systems for sustaining high yields.

When the economics of the sugarcane-wheat system are calculated including most items along with purchased inputs (family labor, interest, rental value of the land), it is primarily the ratoon crop of sugarcane which makes the system profitable. This is because it yields almost as much as or sometimes more than the planted crop but all the costs associated with planted material and land preparation are saved. In addition, it receives residues from the preceding cane crop. An additional contributor to net returns is wheat straw which is mostly used as cattle fodder either on the farm itself or sold for the same purpose. A three-ton per hectare wheat crop generates about four metric tons of straw which can be worth Rs 2,000 to 4,000 depending upon demand and supply.

The share of different nutrients in the fertilizer budget (Rs 1,365 per hectare) for HYVs of cereals earlier was 58 percent (N), 34 percent (P_2O_5), and 18 percent K_2O. After the removal of subsides on phosphate and potash, the share in the escalated fertilizer budget (Rs 2,150 per hectare) rose to 49 percent for phosphate and 12 percent for potash, while that of subsidized nitrogen decreased to 40 percent. To offset these levels of investment in fertilizer, the farmer required 500 kilograms of wheat grain when fertilizers were subsidized but 614 kilograms grain at present, taking into account the periodic increases in wheat prices which have risen by 30 percent since August 1992.

CONCLUSIONS

Intensive cropping is a high input and high output system. If crop productivity is not sufficiently high in such areas, then the efficiency of various inputs and resources is under-utilized, returns from investment are sub-optimal, and the cost of production per unit of produce escalates. This is neither in the interest of the individual farmer, nor of the country. However, there are hardly any viable alternatives for over-populated countries other than to raise crop productivity on a sustained basis.

Concerns regarding intensive agriculture based on "modern inputs" basically arise from the fact that the adoption of physical inputs is not always backed by technical knowledge with which these inputs should be employed by the farmer. While such practices at the farm level need considerable improvement, reverting from intensive (green revolution) to extensive farming (pre-green revolution period) in India has been equated with food scarcity for almost 400 million people (Hazell 1995). This certainly is not acceptable when there is such a large yield gap to be harvested within safe limits of the use of available inputs.

The nutrient needs of intensive agriculture are so large that no resource by itself can fully meet them, be it soil, fertilizer or any other input. Present levels of nutrient input are sub-optimal in large areas and so are the harvested yields. While the gap between nutrient additions and removals can be decreased by serious adoption of available nutrient sources, the rate at which population pressure on the soil is increasing means many soils will continue to be depleted of their nutrient reserves (erosion of the capacity factor).

In order to achieve required growth rates in agricultural production, it will be necessary (i) to have durable, properly worked out policies, (ii) to develop efficient resource management strategies, (iii) to bridge the yield gap, (iv) to improve yield potential and stress tolerant crop varieties, (v) to make great efforts in reducing wasteful use of resources when available at low tariffs (for example, over-irrigation when the tariff is based on horsepower of the pump and not on the amount of power used), and (vi) to undertake large-scale fine tuning and validation of existing technologies.

The emphasis on development of new crop varieties, though important, often ignores the fact that special features of existing varieties have not been sufficiently used. A large number of crop varieties have been developed which are tolerant to several types of stresses (Tandon 1995a). At a given level of NPK application, tolerant rice cultivars often outyield the susceptible ones by as much as two metric tons per hectare. This much paddy rice is worth Rs 7,000 per hectare (US$225) at current support prices in India.

If crop productivity is to be sustained to meet future population needs, then sectors such as these which have been overlooked will need attention. At present, this is virtually an untouched area, partly because the approach to seeds has become an oversimplified one in which they are either HYVs/hybrids or traditional/tall varieties. The opportunities offered by the genetic diversity within the camp of HYVs itself have somehow been missed. It seems that while being fascinated by the forest, we are ignoring the trees.

Table 10.1--The importance of wheat, sugarcane and rice in selected districts of western Uttar Pradesh

District	Gross cropped area (000 ha)	Percent of gross cropped area under Wheat	Sugarcane	Rice	W+S+R
Haridwar	178	28	31	11	70
Saharanpur	433	29	25	14	68
Muzaffarnagar	499	28	38	7	73
Meerut	493	30	34	3	67
Bulandshahr	596	35	8	2	45
Ghaziabad	297	32	18	3	53
Bijnor	499	26	38	12	76
Moradabad	739	36	18	13	67
Rampur	316	33	10	30	73
All 9 districts	4003	31	10	24	64
Uttar Pradesh State	25480	34	7	13	54
India	185,480	13	2	23	38

Source: Fertilizer Association of India, various years.

Table 10.2--Contribution of area, yield, and productivity to sugarcane and wheat production

Variable	1978/79 to 1988/89	
	Sugarcane	Wheat
	(percent)	
Change in area	17.6	- 4.0
Change in production	31.1	46.9
Change in productivity	12.2	51.4

Source: Based on Fertilizer Statistics, Fertilizer Association of India, various years.

Table 10.3--Effect of different fertilizer applications on rice and wheat yields

Treatment	1972-74		1990-92	
	Rice	Wheat	Rice	Wheat
	(tons per hectare)			
No fertilizer applied	5.78	2.00	1.66	1.20
Optimum NPK rate applied	7.72	4.20	4.09	3.90
Optimum NPK rate + 15 tons FYM/ha/year	8.47	4.70	4.79	4.40
Optimum NPK rate + Zn to rice	8.15	4.50	4.73	4.30
1.5 times optimum NPK rate	7.82	4.40	3.45*	3.50*

Source: Nand 1995.
* Severe deficiency of zinc.

Table 10.4--Effect of continuous fertilizer on rice and wheat yields

Treatment	Rice yield		Wheat yield	
	Year 1	Year 10	Year 1	Year 10
	(tons per hectare)			
Only N (120 kg/ha to each crop)	7.2	3.0	3.0	1.2
$N+P_2O_5+K_2O$ (120-40-40 to each crop)	7.5	6.1	3.6	3.5
$N+P_2O_5+K_2O$+5 tons FYM/ha and Zinc spray to rice	7.3	7.0	3.6	4.1

Source: Pandey 1995.

Table 10.5--Effect of irrigation, weed control, and fertilizer on wheat yields

Irrigation	Weed control	Fertilizer	Yield increase (percent)
Yes	No	No	24
Yes	Yes	No	70
Yes	No	Yes	92
Yes	Yes	Yes	124

Source: Biswas and Tewatia 1990.

Table 10.6--Expenditure on cash inputs for the sugarcane-sugarcane-wheat system based on farm surveys, 1989-1990

	Rs/hecatre (Rs 31=1 US$)			
Input	Sugarcane (P)	Sugarcane (R)	Wheat	Total system
Seed	2204 (33)[a]	0	646 (15)[a]	2.850 (22)[a]
Fertilizer and manure	1784 (26)	902 (45)[a]	1930 (46)	4616 (36)
Plant protection	153 (2)	41 (2)	16 (1)	210 (1)
Irrigation	737 (110)	783 (39)	885 (21)	2405 (19)
Hired labor	1882 (28)	285 (14)	707 (17)	2874 (22)
Total	6760 (100)	2011 (100)	4184 (100)	12955 (100)
Share of crop in system	52%	16%	32%	100%
Share of fertilizer in system	39%	20%	41%	100%
Share of fertilizer in inputs/crops	26%	45%	46%	36%

Source: Singh *et al.* 1993.
Note: [a] Percent share of total.

Table 10.7--Major crop-specific constraints

Wheat	Sugarcane	Potato
• Late planting	• Late planting material	• Non-availability of good seed
• Weed infestation	• Over ripe planting material	• Poor plant stand
• Seeding by broadcast	• Imbalanced fertilization	• Blight
• Imbalanced fertilization	• Excessive irrigation	• Lack of storage facilities
• Delayed harvesting	• Limited use of FYM	
	• Poor crop husbandry	

Source: Singh and Sharma 1994.

Table 10.8--Effect of fertilizer intensity on paddy and wheat yields

Intensity rank	State	Fertilizer use		Paddy and wheat yield
		$N+P_2O_5+K_2O_5$	$N:P_2O_5$	(1990-91)
			(kilogram/hectare)	
I	Punjab	169	100:34	6,740
II	Haryana	123	100:31	6,260
III	Uttar Pradesh	90	100:27	3,990
	Uttar Pradesh/Punjab	0.47		0.57

Source: Based on Fertilizer Statistics, The Fertilizer Association of India, various years.

Table 10.9--Resource requirement to generate NPK nutrient by 2000 and 2050

Resource	Year 2000	Year 2050
FYM (million tons)	200	400
Crop residues (million tons)	30	50
Urban/rural (million tons)	10	50
Green manure (million hectares)	25	50

Source: Based on Pandey (no date).

Table 10.10--Nutrient balance after a sugarcane-sugarcane-wheat system in western Uttar Pradesh (productivity 120 ton cane/ha/2 crops + 3 tons wheat grain/ha)

Item	N	P_2O_5	K_2O
Initial available soil nutrient capital (kilograms per hectare)[a]	280	40	336
For sugarcane plant crop			
Fertilizer input (kg/ha)	125	58	10
10 t/ha FYM (0.75-0.175-0.55) of N-P_2O_5-K_2O	75	18	55
1 t/ha press mud (0.026-1.70-0.24 % available N-P_2O_5-K_2O)	1	17	2
Green manure (not practiced)	0	0	0
Crop residues (not recycled)	0	0	0
Total nutrient capital	481	133	403
Nutrient uptake by 60 t/ha sugarcane crop (kg/ha)	135	30	188
Losses from soil (25% of fertilizer N)	31	0	0
Nutrient balance after cane harvest (kg/ha)	315	103	215
For sugarcane ratoon crop			
Starting soil nutrient capital	315	103	215
Fertilizer input (kg/ha)	62	29	5
3 t/ha cane residues recycled (0.4-0.18-1.28)	12	5	38
FYM not used	0	0	0
Total nutrient capital	389	137	258
Nutrient uptake by 60 t/ha ratoon crop (kg/ha)	135	30	188
Losses from soil (25% of fertilizer N)	16	0	0
Nutrient balance after ratoon	238	107	70
For wheat crop			
Starting soil nutrient capita (kg/ha)	238	107	70
Fertilizer input	100	50	10
FYM not used	0	0	0
Crop residues burnt	0	0	38
Total nutrient capital	338	157	118
Nutrient uptake by 4 t/ha wheat crop (kg/ha)	96	36	132
Losses from soil (25% of fertilizer N)	25	0	0
Nutrient balance after wheat (kg/ha)	217	121	-14
Change in initial soil capital	-63	81	-350
Percentage change	-23	102	-104
Summary			
Initial soil nutrient capital	280	40	336
Capital after sugarcane plant crop	315	103	215
Capital after sugarcane ratoon			
Capital after wheat	217	121	-14
Capital after the system	217	121	-14
Change after 2 years (one crop cycle) in percent	-63 (-23%)	81 (102%)	-350 (-104%)

Source: Tandon 1995, based on PDCSR data, personal communication.

[a] Corresponds to low, medium, and high fertility status for N, P, and K respectively.

Table 10.11--Soil nutrient balance after a one-year wheat-rice system in western Uttar Pradesh

Item	N	P_2O_5	K_2O
Initial soil nutrient capital	280	40	336
Rice crop			
Fertilizer input (kg/ha)	147	0	0
Residues (not recycled)	0	0	0
FYM (not used)	0	0	0
Green manure (not done)	0	0	0
Total input for rice	427	40	336
Nutrient removal by 4.6 tons paddy/ha (kg/ha)	92	46	138
Losses from soil (50% of added N)	74	0	0
Nutrient balance after rice	261	6	198
Wheat crop			
Fertilizer input to wheat (kg/ha)	124	65	4
50% rice residue burnt	0	0	32
FYM not used	0	0	0
Total inputs for wheat	385	59	234
Nutrient uptake by 3.3 tons wheat	79	30	109
Losses from soil (25% of added N)	31	0	0
Nutrient balance after wheat	275	29	125
Nutrient balance after rotation	275	29	125
Net change over initial soil capital	-5	-11	-211
Percent changes over initial soil capital	-2	-25	-62

Source: Tandon 1995, unpublished based on data of PDCSR, personal communication.

Table 10.12--Effect of intensive irrigated cropping on soil nutrient balances

System		Change (percent)		
	Duration	N	P_2O_5	K
Sugarcane-sugarcane-wheat	2 years	-23	+102	-104
Rice-wheat	1 year	-2	+25	-62

Source: FAO-sponsored survey on the use of nutrient sources and related agricultural inputs in intensive irrigated cropping systems, India, 1995, unpublished, and PDCSR, personal communication.

Table 10.13--Low and high efficiency nutrient requirements to support grain yields

Year	Productivity needed grain	Fertilizer nutrients needed	
		Low efficiency	High efficiency
	(tons/hectare)		
2010	3.5	230	160
2030	5.5	380	300

Source: Angé 1993.

Table 10.14--Recent trends in some economic indicators of fertilizer use

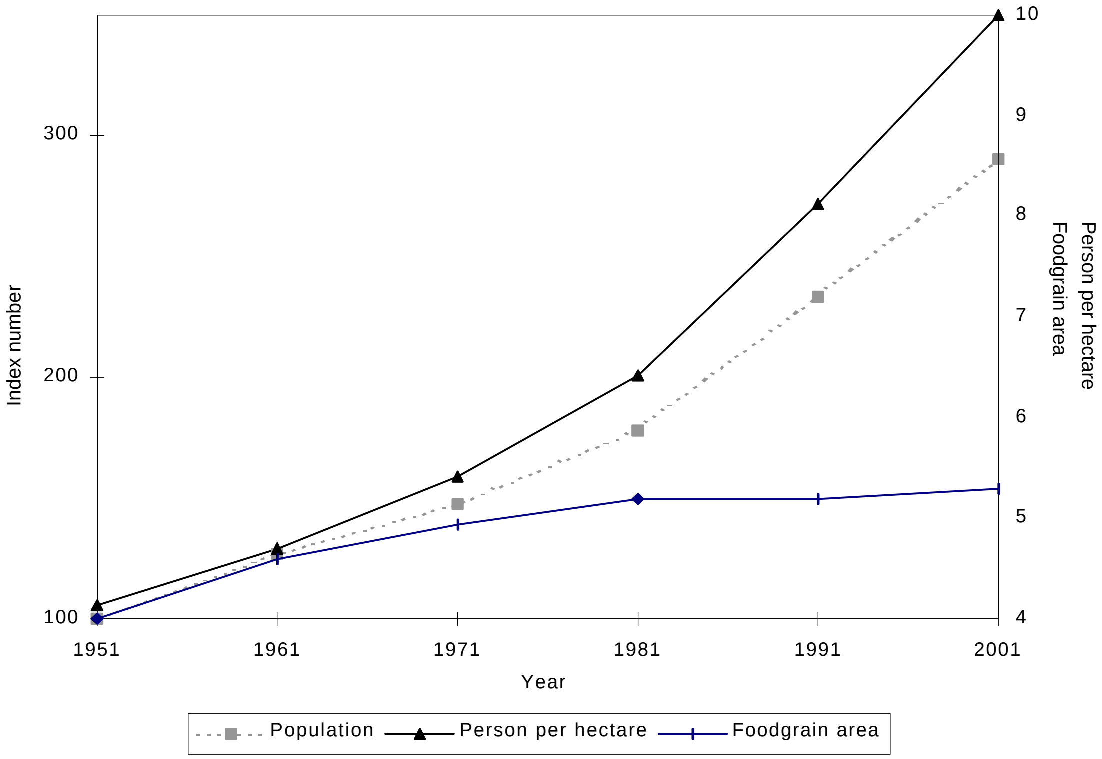
Item	Before August 25, 1992*	After August 25, 1992*	1993-94	1994-95
Nutrient prices (Rs/kg)				
Nitrogen through urea	6.65	6.00	6.00	7.22
Phosphate through DAP	7.57	12.10	12.10	13.12
Potash through MOP	2.83	7.50	6.34	6.28
Produce prices (Rs/kg)				
Paddy	2.70	2.70	3.10	3.40
Wheat	2.75	2.75	3.30	3.50
Kg produce needed to pay for 1 kg nutrient				
Rice				
Nitrogen	2.46	2.22	1.94	2.12
Phosphorus	2.80	4.48	4.05	3.86
Potash	1.05	2.78	2.15	1.88
Wheat				
Nitrogen	2.42	2.18	1.82	2.60
Phosphorus	2.75	4.40	3.64	3.75
Potash	1.03	2.72	1.92	1.79

Source: Fertilizer Association of India, various years (a).

Note:

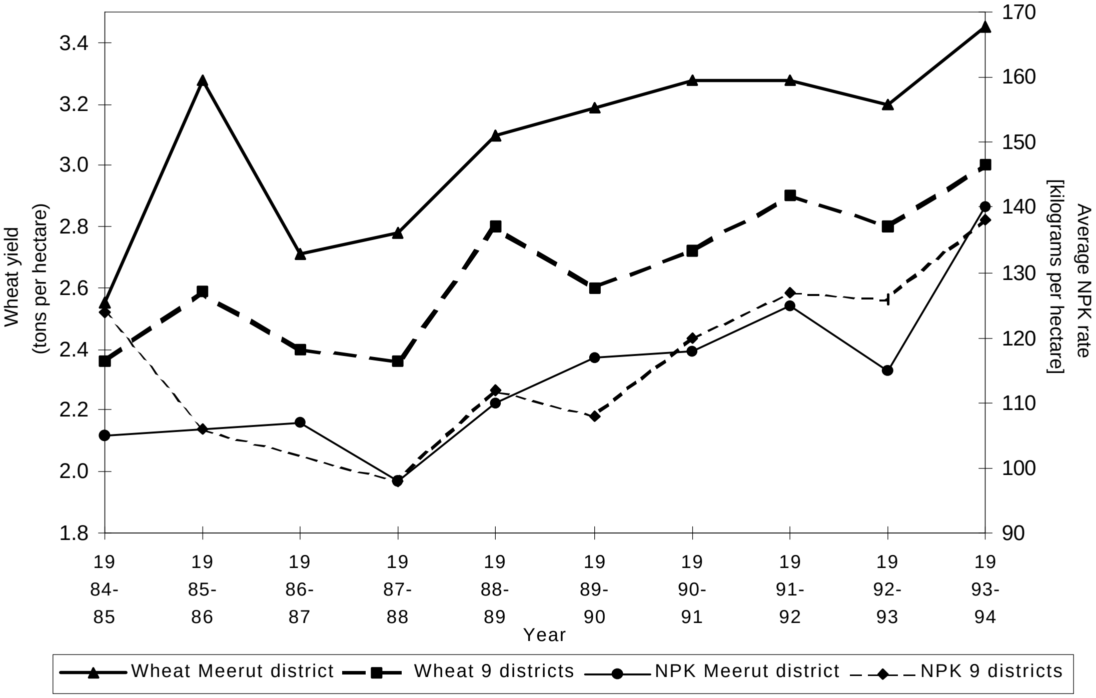
*Subsidies on phosphorus and potassium were withdrawn on this date.

Figure 10.1--The reason behind the need for intensification of foodgrain production in India



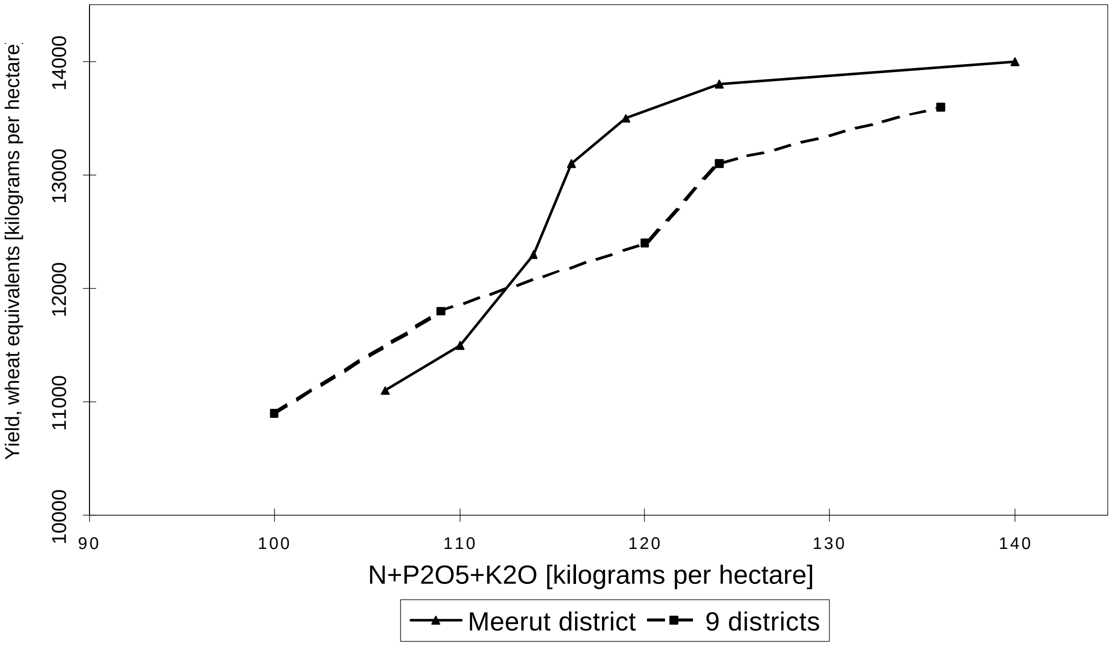
Source: Based on Ange 1993.

Figure 10.2--Trends in fertilizer use and wheat yields in Meerut district and nine districts in western Uttar Pradesh



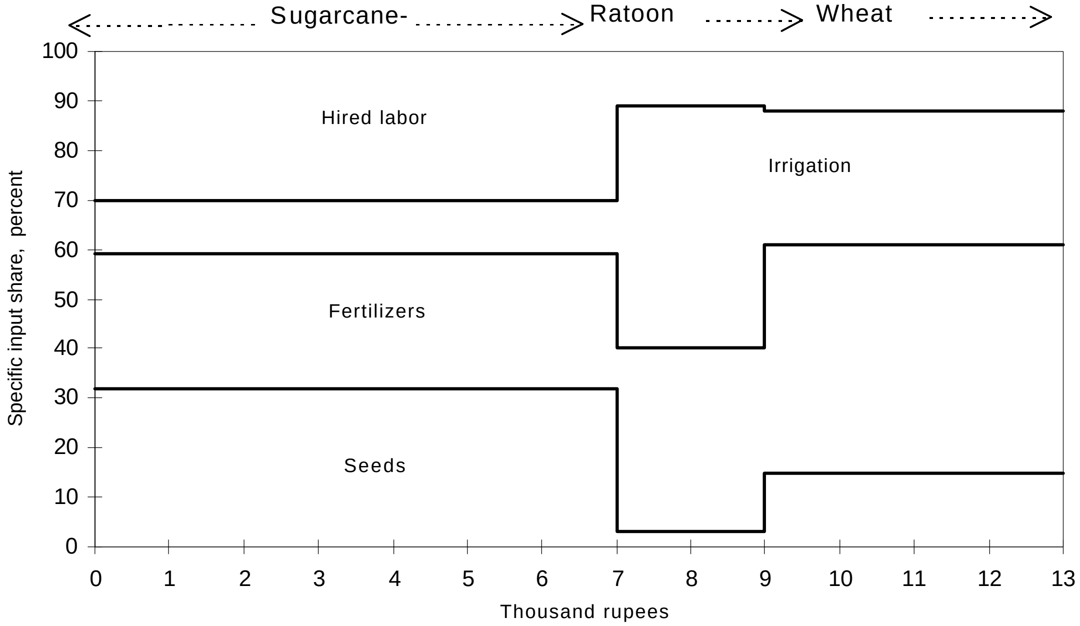
Source: Fertilizer Association of India, various years.

Figure 10.3--Relationship between fertilizer use and sugarcane plus wheat productivity in western Uttar Pradesh



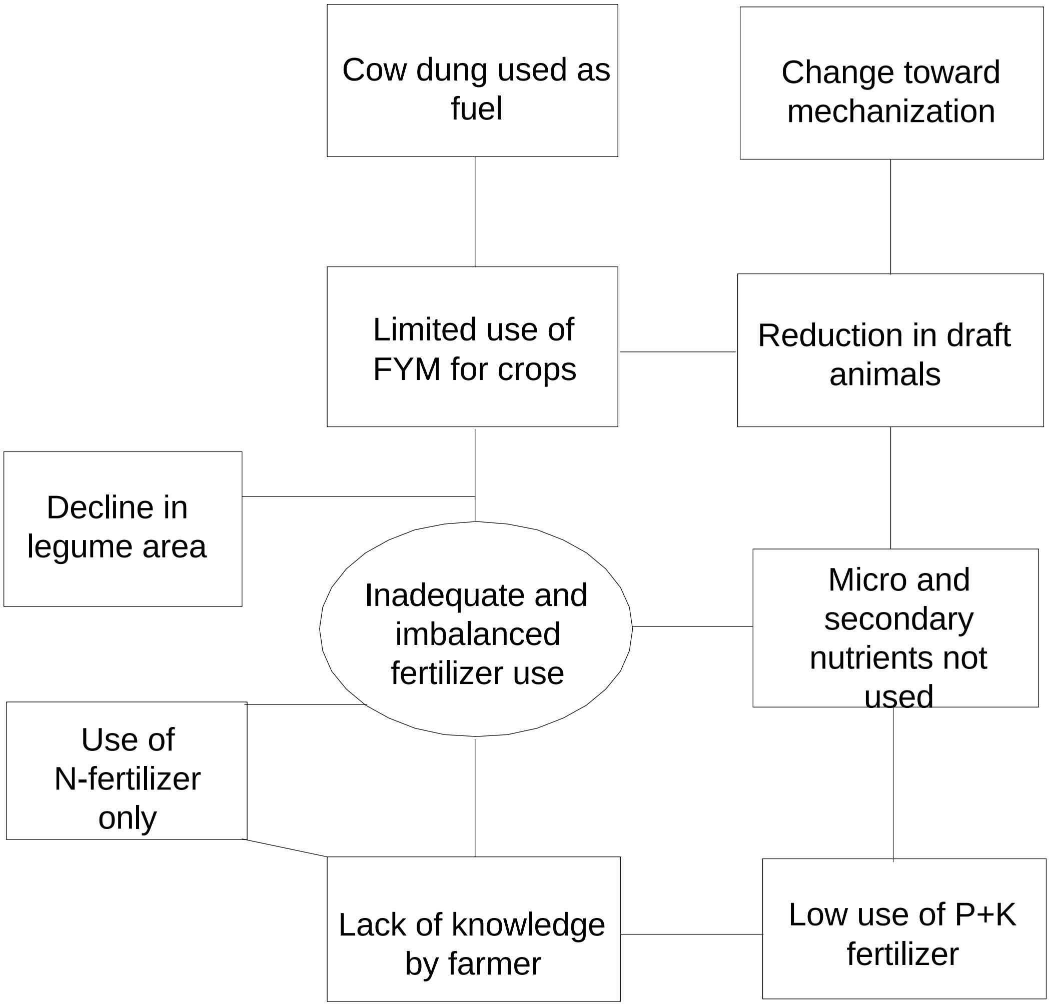
Source: Fertilizer Association of India, various years.

Figure 10.4--Crop and input investment incurred in a two-year sugarcane-sugarcane-wheat system in western Uttar Pradesh



Source: Based on Singh *et. al.* 1993.

Figure 10.5--Possible causes of inadequate and imbalanced fertilizer use



Source: Sharma and Gangwar, no date.

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APPENDIX

CONCLUSIONS AND RECOMMENDATIONS: IFPRI-FAO WORKSHOP ON PLANT NUTRIENT MANAGEMENT, FOOD SECURITY, AND SUSTAINABLE AGRICULTURE: THE FUTURE TO 2020

May 16-17, 1995
Viterbo, Italy

CONCLUSIONS

1. There will have to be a very substantial increase in the use of mineral fertilizers to meet the food needs of human populations by the year 2020, especially in the developing countries, even though organic sources can and should make a larger contribution to supply plant nutrients.
2. There is a lack of prioritized and strategic problem-solving agricultural research with respect to plant nutrition management, incorporating mineral and organic sources of plant nutrients.
3. There is a need for participatory and farmer-adapted approaches to technology development.
4. There is a need to emphasize to donors and national governments that in most developing country situations, attention to the future of their agricultural sectors is of paramount importance, including macro-economic considerations and other related sectoral policies affecting transport and energy.
5. In view of current forecasts of production capacity, fertilizer prices are likely to increase after the year 2000, especially those of phosphates.
6. Fertilizer use in sub-Saharan Africa is too low. While in some local situations increased recycling of organic materials is possible and desirable; increased fertilizer use is essential to break out of the constraint of low biomass production in the region. Although farmers often appreciate the need for fertilizer inputs, this is not yet translated into an effective demand because of high prices, insecure supplies, and in some cases because farmers have a high aversion to the risks associated with food production in marginal agro-climatic and socio-economic conditions. Fertilizer prices at the farm gate are also excessively high because of thin markets, lack of domestic production capacity, poorly developed infrastructure and inefficient production systems.
7. The notion of declining efficiency of fertilizer use in Asia is over-simplistic. Possible reasons for apparent diminished returns from increased fertilizer applications in this region include: (i) more fertilizers are being used on lands with poorer soils or uncertain water supply; (ii) the increased intensity of cropping, especially changes in crop sequences, makes current management practices, including fertilizer use, less effective; (iii) there is an imbalance in the supply of N, P, and K, applications of the latter two nutrients often being too low; (iv) deficiencies of secondary and micro-nutrients are beginning to appear; (v) there is an over-all decrease of soil organic matter and an increase in soil degradation in general; and (vi) adverse effects from pests and diseases are increasing in the region.
8. There is a future strategic problem of procurement of raw materials for P and K fertilizers, especially in Asia, and of the pricing of natural gas for local N-fertilizer production compared to its use for energy.
9. Environmental considerations, such as pollution and degradation of natural resources are important, but need not necessarily involve costly trade-offs between environmental and agricultural production concerns. Environmental priorities will

differ between countries and regions. Agricultural intensification can be sustainable, provided that there is effective management of all plant nutrients.

10. Non-government and private sector involvement is essential for the effective stimulation of the use of plant nutrient inputs, with appropriate monitoring by governments of effective, equitable and pollution-free distribution of these inputs.

RECOMMENDATIONS

A. Promote effective and environmentally sound management of plant nutrients.

A1. The balanced and efficient use of plant nutrients from both organic and inorganic sources, at the farm- and community level, should be emphasized; the use of local sources of organic matter and other soil amendments should be promoted; and successful cases of integrated plant nutrient management should be analyzed, documented and disseminated.

A2. Innovative approaches to support and promote integrated plant nutrient management should be pursued.

A3. The joint UN Inter-Agency and Fertilizer Industry Working Group on Fertilizers should be revitalized, and should henceforward give attention to the wider topic of Plant Nutrient Management.

A4. Encouragement should be given to FAO to develop further, in cooperation with all relevant organization, a Code-of-Conduct on the effective and environmentally sound management of plant nutrients, for dissemination at both international and national levels.

B. Improve database, research, monitoring, and extension of effective plant nutrient management.

B1. Participatory forms of design, testing, and extension of improved plant nutrient management strategies that build upon local institutions and social organizations, including trained farmer groups, should be promoted.

B2. A network of benchmark sites on representative farmers' fields in major farming systems should be developed to monitor the stocks and especially the flows of plant nutrients.

B3. A comprehensive data base needs to be developed for all mineral and organic sources of nutrients, including their amount, composition, processing techniques, their economic value, and their availability.

B4. The impact of micro- and macro-economic policies on plant nutrient management should be evaluated.

C. Support complementary measure to lower costs, recycle urban waste, secure land tenure, and increase production capacity.

C1. Ways and means should be sought to lower the price of fertilizers at farmgate and to reduce the farmers' perception of the risk in the use of fertilizers by: (i) investing in distribution infrastructure; (ii) research innovative ways to share risks and to provide finance; (iii) encouraging sub-regional cooperation for country-level fertilizer production facilities and/or procurement; and (iv) improving dialogue between different sectors and agencies to arrive at a common approach to improved plant nutrition.

C2. Improvement of security of access to land is essential for the intensification of fertilizer use and the successful promotion of integrated plant nutrient management systems.

C3. The recycling of pollutant-free organic urban waste into the wider peri-urban agricultural sector should be promoted, considering that such waste constitutes an increasingly significant and so far largely untapped source of plant nutrients.

C4. Investment in production capacity for mineral and organic fertilizers should be increased and facilitating the procurement of raw materials and energy for their processing enhanced.

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