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Irrigated Cropping Systems of South Asia: Technological Change and Sustainability to the Year 2000 and Beyond

Derek Byerlee, Larry Harrington and Mohammed Sharif

ABSTRACT: This paper interprets the recent trends in South Asia’s irrigated cropping systems, giving particular attention to irrigated systems in which wheat is the major food crop. We emphasize the particular situation in Pakistan, but also draw on evidence from similar irrigated systems elsewhere in the region. The paper focuses on emerging sustainability issues, both technical and institutional, that will impinge on the ability to maintain gains in food grain productivity and sustain the quality of the resource base over the next 10-20 years. It is concluded that a new strategy must be adopted to ensure sustainable productivity increases in Pakistan’s cropping systems in the future. This strategy not only implies profound changes in agricultural research priorities, but also in the institutions that foster technical change in agriculture.

Over the past three decades, with the advent of the Green Revolution, food grain production has grown at an unprecedented rate in Asia compared both to historical growth rates in the region and to growth rates in other regions. However, there are now indications that this stage of rapid growth is ending. By the 1980s the growth rate of cereal production in South Asia was the lowest of the four decades, 1950-89. This reversal largely reflects a radical slowing of the growth of area sown to cereals. From the 1950s when increased area accounted for about half of the growth in cereal production, the contribution of area...
expansion has declined in every decade since then. In the 1980s, area sown to cereals stagnated (Figure 1).

This slowing of the contribution of growth in cereal area is also evident in Pakistan. However, in the case of Pakistan, there has also been a sharp decline in the growth rate of yields which dropped from 3.3 percent per year in the 1960s to just 0.8 percent per year in the 1980s. This slowdown in yield growth which applies to all three major cereal crops—wheat, rice and maize—was less evident elsewhere in South Asia, and raise special challenges in maintaining the growth in food production in Pakistan.

The slowdown in the growth of cereal area and in some cases cereal yields, has three important implications in projecting future food production in South Asia. First, increases in the area sown to cereal crops will make virtually no contribution to future increases in food production. In fact total area sown to cereals is likely to fall. Second, because cereal crops in South Asia have experienced an unusually high rate of yield gain in the past 25 years, due to the widespread diffusion of Green Revolution technologies, the easy gains have been made and more modest progress must be expected in the future due to diminishing returns to using higher levels of inputs. Third, the recent trends in yields raise concern about sustainability problems in the increasingly intensive cropping systems of South Asia. The slowing in growth in food production may reflect a deterioration of the resource base in irrigated agriculture which will have important implications for future generations, when population pressure on the land will be even greater.

In looking to the future, researchers and policy makers in Pakistan and elsewhere in Asia are faced with a major challenge in increasing food production to the year 2000 and beyond. In Pakistan, in particular, where population growth is projected at 2.7 percent per year, the highest in the region, demand for wheat will increase at 3.3 percent per year, substantially higher than growth in production in the recent post-Green Revolution period (Byerlee and Siddiq, 1990). In addition, increased productivity in basic food grains is a key factor in alleviation of poverty, both because cereal production is often seen as an engine for labor intensive growth and because of the importance of food prices in determining the welfare of the poor (Mellor, 1990). Poverty alleviation must remain central to development efforts in a region such as South Asia, where over 500 million people or half the world’s poor live (World Bank, 1990).

**Overview of Technical Change and Input Intensification in Irrigation Cropping Systems**

**A Conceptual Framework**

We view the recent history of agricultural development in Asia’s land-intensive systems as a continuum of technical and institutional change which can be divided into four stages (Byerlee, 1990).²

²In practice these stages often overlap.
1. The pre-Green Revolution phase, when gains in productivity per unit of land area were modest. Instead, expansion in area planted to food grains played an important role in increasing food production (Phase I).

2. The Green Revolution phase, when a technological breakthrough in the form of new, high-yielding varieties (HYVs) responsive to inputs provided the potential to dramatically increase the productivity of land (Phase II).

3. A first post-Green Revolution phase, beginning after the widespread adoption of HYVs, when intensification of input use, especially chemicals, substituted for increasingly scarce land for agriculture (Phase III).

4. A second post-Green Revolution phase, beginning after input use has reached high levels and improved managerial and information skills substitute for input use and increase input efficiency (Phase IV).

Figure 2 depicts these phases in the conventional framework of a production function. The introduction of modern varieties (MVs) shifted the production function sharply upwards to MV₁, and increased the response to inputs, especially fertilizer and water. Adoption of modest levels of these complementary inputs accompanied the adoption of MVs. However, for various reasons, farmers were not able to exploit the full benefits of the new technology immediately and operated at B below the technological frontier, MV₂. In the next phase, when input use intensifies, farmers moved along the new production function by using higher levels of complementary inputs. This phase may be viewed as a time of improving allocative efficiency as the marginal value of productivity of each input approaches its acquisition price. Finally, as farmers approach allocative efficiency, they move toward the production frontier (i.e., increase technical efficiency) by employing better information and skills to increase the efficiency with which they use inputs.

To be successful, each stage in the process of technical change identified above should be accompanied by appropriate changes in institutions and policies. For example, during the initial stage of technical change the contribution of the local research system was limited since the new technology (for example, a new MV) was imported. However, once this technology was adopted, strong local crop breeding developed, a) to maintain the gains that had been made, especially where resistance to pests and diseases of the new varieties breaks down (Pray and Ruttan, 1990 and Heisey, 1990) and b) to tailor varieties to more specific niches determined by agroclimatic variables and cropping patterns. At the same time, the adoption of MVs, the learning process of farmers as they use the new technology, and institutional improvements in the input distribution system contributed to increasing levels of input use. However, moving toward the input efficiency stage requires strong crop management research programs capable of developing site-specific recommendations (e.g., the use of integrated pest management). In this phase of technical change the institutions responsible for disseminating information, such as extension services, must evolve rapidly to serve farmers' needs for more technical information and skills.

Figure 2. Simplified view of stages of changes in productivity in land intensive agriculture.

Finally, the price policy environment has adjusted to each phase of technical change. The early stages of technical change were characterized by stabilization of producer prices for food grains and by subsidization of input prices. These policies aimed to provide incentives for using inputs more
intensively and overcoming market imperfections arising from perceived risk, scarce capital, and the costs of learning to use the new technology. Removing these subsidies in the later stages of technological evolution provides one incentive for using inputs more efficiently and possibly moving from C toward E in Figure 2.

Current Status of Technical Change and Input Use in Cereal Production

Changes in productivity in irrigated cropping systems of Pakistan and elsewhere in South Asia over the past three decades have followed the stages enumerated above. Most of the productivity gains have come about through the release of new MVs accompanied by increased intensification in the use of inputs, especially fertilizer and water. The use of each of these inputs is now high in many places, as data from the Pakistan Punjab indicates (Table 1). The following summary of changes in input use suggests that more intensive use of inputs will make a smaller contribution to productivity increases in the future.

Table 1. Input Use and Yields of Wheat in Various Cropping Systems of Pakistan

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Percent fields with at least 1 year's continuous wheat in rabi season 77 51 n.a. 27</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Percent planted late (after December 1st) 48 91 8 29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed rate (kg/ha) 99 117 135 123</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Weighted mean age of varieties (years)b 9.7 13.2 15.1 11.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent area planted to dominant variety 59 26 34 49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average fertilizer applied (kg/ha) N 82 122 102 112 P2O5 54 45 45 Total 131 176 147 177 Recent apply herbicide 17 23 9 16 Average yield (t/ha) 2.4 2.4 3.1 2.8</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

* Data are for previous surveys.  

Modern Varieties

The rapid diffusion of modern semidwarf wheat and rice varieties in irrigated areas is well documented (e.g., Dalrymple, 1986a and 1986b). For the purposes of this paper, two aspects of the diffusion process should be noted. First, the adoption process in irrigated area was essentially completed by the late 1970s (Figure 3). During the 1980s, only minor gains have been made by the substitution of MVs for local varieties. Second, breeders have substantially increased efforts to develop locally adapted varieties and maintain disease resistance to evolving pathogens (especially rust pathogens). At the same time researchers have made steady improvements in the genetic yield potential of newer wheat varieties at the rate of 0.5-1 percent per year (Byerlee, 1990 and Waddington et al., 1986). Although adoption of newer varieties has often been slow (Heisey, 1990), most farmers in the main wheat belt of India and Pakistan have replaced their varieties at least twice since adopting the original Green Revolution varieties in the late 1960s. The superior disease resistance and higher yields of the newer varieties have helped stabilize yields and have provided modest to high returns to investments in wheat breeding (although lower than the return to the original development of MVs) (Byerlee, 1990). In contrast, in the case of rice, little progress has been made in increasing yield potential (Khush, 1990) although Pakistan has experienced a second rice revolution in the late 1980s with the rapid adoption of a short-statured high yielding Basmati rice variety in the Punjab (Sharif et al., 1990).

Figure 3. Percentage area sown to semidwarf wheat varieties in irrigated areas of India and Pakistan.
Irrigation

Increasing supplies of irrigation water made a major contribution to increasing cereal area and yields in the 1960s and 1970s in much of South Asia. For example, in India the percentage of wheat area under irrigation grew from 33 percent in 1961 to 75 percent in 1988 as irrigation facilities became available on formerly rainfed land (Figure 4) and as wheat substituted for other crops on irrigated land. However, after irrigation facilities were developed on the less expensive and less difficult sites, the expansion of irrigated area in the region has slowed sharply in the 1980s. Rapid installation of tubewells has also meant that groundwater accounts for an increasing share of the total irrigation water supply.

![Figure 4. Trends in rainfed and irrigated wheat area in India, 1963-86.](image)

Fertilizer

While increases in the area sown to MVs and the proportion of irrigated area tended to level off in the 1970s, fertilizer use continued to expand rapidly in the 1980s, a period of input intensification in much of South Asia. Only in the most advanced areas, such as in the Indian Punjab, is fertilizer use on wheat levelling off at around the recommended level of 200 kg of nutrients per hectare (Figure 5). Increasing fertilizer use, of course, leads to diminishing returns: the marginal grain-to-nutrient ratio, which was around 15:1 when MVs were first adopted, is now as low as 5:1 in the Punjabs of India and Pakistan (Grewal and Rangi, 1983 and Aslam et al., 1989).

![Figure 5. Estimated fertilizer use on wheat in South Asia.](image)

Pesticide Use

Contrary to popular opinion, the application of pesticides on MVs is minimal in most areas because of their high levels of disease resistance, especially in the case of wheat. However, herbicide use has been adopted rapidly in some areas in the 1980s. Although farmers use various cultural practices (rotation, delayed planting, and hand weeding) to control weeds in irrigated areas, these practices have not prevented the rapid spread and build-up of some weeds in intensive cropping systems. The weed Phalaris minor is an especially persistent problem in the rice-wheat systems of South Asia. However, beginning in the early 1980s, herbicide use became common in the Indian Punjab and quite recently this practice spread rapidly to other areas of northern India and Pakistan. In these areas, chemical control has proven to be a critical part of an integrated weed management strategy, giving a significant boost to wheat yields in rice-wheat systems (Aslam et al., 1989).

Mechanization

Parallel with the changes in Biochemical technology, agricultural mechanization has proceeded rapidly throughout Pakistan and much of
northwestern India. The greatest change has occurred in land preparation and planting. For example, in Pakistan and the Punjab of India, tractors are used on as much as 75 percent of the cropped area. Various policies (e.g., subsidized credit) and rising costs of labor and draft power have promoted these changes. However, the evidence generally indicates that increased mechanization has usually saved labor rather than served as means to intensify land use (Binswanger, 1978 and Tetley et al., 1990).

The evidence presented above suggests that although yields are still low (2-2.5 t/ha) in much of the irrigated wheat-based systems, especially in Pakistan, further efforts to intensify the use of inputs will give much lower returns than in the recent past. On-farm experiments suggest an economically recoverable yield gap of 1-1.3 t/ha (Aslam et al., 1989). Factors that can close the yield gap in the short term are timely planting (e.g., through zero tillage), better plant stand, improved weed control, and more balanced fertilizer applications in terms of the mix of nutrients applied. However, gains from adopting these practices will provide smaller yield increments and often be less profitable than gains from adopting the original seed-fertilizer technology, and hence are more difficult to achieve. Nonetheless, in many of these areas, there appears to be considerable potential to close the *technical efficiency gap*, which is estimated at about 30 percent in many settings in South Asia (see Ali and Byerlee, 1991 for a review).

**Increasing Intensity and Specialization of Cropping Systems**

As input use has intensified in irrigated areas, a broad-based increase in cropping intensity at a steady 0.5-1 percent per year has also occurred. Crop intensification has resulted from the adoption of MVs, which mature earlier than the traditional varieties they replaced, accompanied by improved supplies of irrigation water. The increase in cropping intensity has also been achieved by specialization in certain cropping systems that have come to dominate much of South Asia. These rotations generally involve growing wheat after a cash crop planted in the summer season, such as cotton, rice, or soybeans. Such rotations also reflect the growing commercialization of agriculture, as they have partly replaced the traditional, more diversified cropping patterns emphasizing coarse grains, pulses, and oilseeds. For example, the rice-wheat cropping pattern, now estimated to occupy over 10 million hectares in South Asia, has spread rapidly in the past two decades (Hobbs et al., 1988).

It is in these newer rotations that problems arising from conflicts in planting and harvesting dates have become most acute. Wheat planting is commonly delayed across most of the irrigated wheat belt of South Asia. In Pakistan, survey data indicate a steady progression over time toward later planting in both major cropping systems—rice-wheat and cotton-wheat (Figure 6). Delayed wheat planting is generally estimated to lead to a loss of 1 percent in yield per day beyond the optimum planting date and may be a major cause of the low and declining productivity of wheat in many systems.

**Figure 6.** Percentage of wheat planted late (after 1 December), the Punjab, Pakistan.
In recent years, some progress has been made toward resolving these conflicts. Plant breeders now give priority to developing earlier maturing varieties of rice and cotton. Released in the late 1980s, these varieties have probably arrested and perhaps even reversed the tendency toward late planting (Byerlee et al., 1987 and Sharif et al., 1990). Breeders also screen for wheat varieties that perform well when planted late and are beginning to obtain positive results.

Nonetheless, increased crop intensification and specialization may have additional costs. Weeds and other pests can build up because farmers practice the same rotation continuously, without a break crop. Also, crops grown in a system, such as rice and wheat, may have different needs with respect to soil physical structure and drainage. For example, in the rice-wheat area of Pakistan’s Punjab, yields in fields planted continuously to rice and wheat for three or more years (the dominant rotation) show a significant negative tendency because of these problems (Byerlee et al., 1984).

Emerging Sustainability Issues

While sustainability is considered by some to be another in a continuing series of fads in the international development community, it does provide the opportunity to refocus research efforts onto some of the longer term issues in resources degradation which have been ignored in previous work. While resource degradation is often considered a problem of marginal areas and much of the concern about sustainability has been directed to those areas, we consider that sustaining the quality of the resource base in favoured areas, such as Pakistan’s irrigated tract, to be even more important in ensuring future food supplies.

Definitions of Sustainability

Sustainability and sustainable agricultural development have been conceptualized and defined in numerous ways which can be broadly classified into three groups (Harrington, 1991).

1. Agroecology. Some definitions focus on sustainability in terms of system resilience, or the ability of an agricultural system to maintain its productivity when subjected to stress or perturbation (Conway, 1986). Sustainability in the agroecological sense is enhanced through system diversity to foster the recycling of nutrients, increased efficiency in the use of moisture, nutrients and sunlight; and a reduction in the incidence of weeds, pests and diseases (Altieri, 1987). Modern monoculture, characterized by low levels of diversity, is viewed as having a fragile ecological equilibrium, with control coming from external inputs (Ingram and Swift, 1990).

2. Equity. Other definitions focus on sustainability in terms of equity, especially intergenerational equity. This conceptualization is founded on the belief that future generations have the right to an environment, and a stock of renewable and nonrenewable resources, no worse than the enjoyed by the current generation. In this conceptualization, the sustainability of agriculture can best be enhanced by slowing down economic development, stabilizing human population growth, and reducing the exploitation of natural resources (especially common property resources).

3. Sustainable Growth. A third major view of sustainability focuses on the need for continued growth in agricultural productivity, while maintaining or even enhancing the quality of resources devoted to agriculture production (Lynam and Herdt, 1989). Sustainability in this view can be measured through trends in total factor productivity (TFP) and in resource quality. This view of sustainability takes into account foreseen increases in the demand for food arising from continuing population and income growth, yet is sensitive to the prospect of resource degradation. Given the challenges to increasing food production and alleviating poverty in South Asia, this is the definition of sustainability applied in this paper.

Sustainability issues can be grouped into classes or categories. One suggestion is to distinguish between internal and external issues. External issues of sustainability are those associated with changes in farmers’ external circumstances. Global warming and future climate change, future availability and prices of fertilizers and other purchased inputs, and changes in global biodiversity are examples. On the other hand, internal issues of sustainability are associated with farming system operations and farmers’ decision making e.g., soil erosion, nutrient mining, building of pests and disease, salinisation, environmental pollution from agricultural chemicals, etc. This distinction helps to highlight the relative importance of farm-level decisions in causing sustainability problems.

Another way of delineating sustainability problems is to distinguish between problems that are reversible and those that are (for all practical purposes) irreversible. The permanent effects of irreversible problems cause special concern. Many of the problems commonly associated with the sustainability of agriculture are reversible. For example, there is no obvious reason why problems such as soil nutrient depletion, loss of soil structure, or buildup of pests and diseases cannot be turned around. On the other hand, severe salinisation or massive deforestation can often be considered as irreversible, except under optimistic and unlikely assumptions.
Is there Evidence of a Sustainability Problem?

Good measures of sustainability should consider changes in productivity, changes in the quality of the resource base, and system resilience, or the capacity of the system being analyzed to withstand external shocks. If productivity is defined narrowly in terms of yield per unit area, then lack of sustainability would be identified with a decline in yields over time. In irrigated areas of South Asia, such a decline can be documented in only a few cases. A more meaningful measure of productivity is changes in total factor productivity (TFP), which is especially appropriate for assessing sustainability problems in Asia, where biological and chemical inputs have rapidly substituted for land. Unfortunately, TFP is difficult to measure because of the extensive data requirements. A restricted case is to examine trends in yields over time for fixed levels of all inputs (declining yields for the same input levels are an indicator of a sustainability problem). Data from long-term experiments are most appropriate for measuring such changes.

Substantial information is available from long-term experiments in India over about 15 years. The results of these trials indicate a tendency for yields to decline at some sites, depending on soil type, cropping pattern, and level of input use (Figure 7) (IARI, 1989). In most experiments, declining yields seem to be arrested by applying higher levels of macronutrients (especially nitrogen), using organic manures, or adding sulphur or micronutrients (IARI, 1989). Few long-term experimental data are available from Pakistan although there is some evidence of a declining trend in yields observed in on-farm soil fertility trials conducted over time (Byerlee and Siddiq, 1990).

Another approach to inferring changes in TFP is to examine changes in farmers’ yields in relation to changes in specific, readily measurable inputs. Byerlee and Siddiq (1990) use this approach to decompose yield changes in the Punjab of Pakistan into effects on yield from: 1) substituting MVs for local varieties; 2) adopting newer MVs, and 3) increasing the fertilizer dose (Table 2). Using conservative agronomic assumptions about each of these effects, they found a significant negative residual, which pointed to some factors that tend to reduce yields over time. Indeed, yields of MVs of wheat in the Punjab of Pakistan have not changed in nearly two decades, despite the adoption of newer MVs and a tripling of the fertilizer dose (Figure 8).²

Table 2. Projected and Actual Gains in Wheat Yields in the Irrigated Punjab, 1972-86

<table>
<thead>
<tr>
<th>Source of Gain</th>
<th>Effect (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching from old to new varieties on remaining 33 percent of area still sown to old varieties.</td>
<td>141</td>
</tr>
<tr>
<td>Genetic gain in yields of newer varieties (0.75 percent/year).</td>
<td>138</td>
</tr>
<tr>
<td>Increased fertilizer use of 73 kg/ha at grain : nutrient ratio of 8:1</td>
<td>446</td>
</tr>
<tr>
<td>Total projected gain</td>
<td>725</td>
</tr>
<tr>
<td>Actual gain</td>
<td>375</td>
</tr>
<tr>
<td>Unexplained</td>
<td>-350</td>
</tr>
</tbody>
</table>


Where sufficient data are available, the most comprehensive approach is to measure the TFP over time. Recent estimates of TFP for Pakistan’s agricultural sector indicate that after rapid increases in the 1960s, there has been little change in TFP since about 1970 (Figure 9). This is despite the rapid mechanization of agricultural operations in the period which has undoubtedly increased labour productivity, as has occurred in the Indian Punjab (Sidhu and Byerlee, 1990). Together stagnant TFP and increasing labour productivity suggest the presence of long term negative influences on productivity.

²However, overall average yields have increased due to continuing increase in the percentage of the total area planted to MVs.
The most comprehensive approach would explain TFP trends in terms of underlying changes in technical efficiency and resource quality. However, there is a general lack of research of this kind.

Finally, an important issue in assessing sustainability of an agricultural system is its resilience in the face of external shocks. In Pakistan, the major biotic shock in terms of food security is likely to arrive in the form of a new race of one of the rust disease of wheat, leading to a disease epidemic and substantial yield losses, as occurred in 1978. Sustainability in this sense is promoted by varietal diversity, both in terms of the number of varieties planted at one point in time, as well as by rapid replacement of varieties over time. However, Pakistan’s agricultural sector and food security, with a very slow rate of wheat varietal replacement and a tendency for large areas (often over half of the Punjab irrigated area) to be planted to a singly variety, is vulnerable to disease shocks (Heisey, 1990). Data in Table 3 show that by this measure, Pakistan is behind other post-Green Revolution countries in developing a sustainable system. This lack of diversification appears to be less of a plant breeding problem and more of an institutional problem created by ineffective seed systems and extension.

Table 3. Rates of Varietal Replacement in Selected Post-Green Revolution Wheat Areas

<table>
<thead>
<tr>
<th>Selected Area</th>
<th>Weighted Average Age of Varieties Planted 1980-89 (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab, Pakistan</td>
<td>11.1</td>
</tr>
<tr>
<td>Punjab, India</td>
<td>5.3</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>10.7*</td>
</tr>
<tr>
<td>Sonora, Mexico</td>
<td>3.1</td>
</tr>
</tbody>
</table>

* Data refer to 1989-90 only.

Source: CIMMYT files.
Overall the evidence on changes in productivity in the irrigated wheat-based systems of South Asia is not conclusive. Worrying indications of declining productivity are apparent from results of some long term trials and from trends in various estimates of partial or total factor productivity. These trends seem to be most pronounced in Pakistan, where yields are low considering the relatively high levels of inputs employed. Moreover, lack of varietal diversity suggests that little progress has been made in achieving more stable production systems.

Emerging Sustainability Problem at the Regional Level

An important element in assessing sustainability is to monitor changes in the quality of the resource base over time. A reasonable amount of information exists to evaluate two major sustainability problems in irrigated systems: excessive groundwater exploitation and increased problems of salinity/waterlogging. Both are internal problems associated with farmer management of a common property resource - irrigation water. Falling groundwater levels have become a major issue in irrigated areas, and it seems that much of the Indian and Pakistan Punjab have reached the maximum sustainable level of groundwater use. Over-exploitation of groundwater is encouraged by the spread of electrification, high subsidies on electricity, flat rate payments for electricity per crop season (in India), and lack of control on the installation of new tubewells.

Less is known about pollution of groundwater by agricultural chemicals, but given that high rates of nitrogen are used in many intensively cropped systems of Asia, nitrate contamination of groundwater is expected to be an increasing problem. Farmers in Ludhiana District in the Indian Punjab now apply over 300 kg/ha of nitrogen to the dominant rice-wheat cropping pattern - over double the annual rate of nitrogen application to maize in the USA. Not surprisingly at least one study shows a substantial increase in nitrate contamination of groundwater in the Indian Punjab since the mid-1970s (Singh et al., 1987).

A review of major salinity and waterlogging problems is beyond the scope of this paper. Some areas, such as the Punjab and Haryana states in India, have made significant progress in reducing this problem (Chopra, 1990). In other areas, such as the Sindh, the problem has worsened. But while the threat of salinisation in major irrigation systems remains a serious issue, the significant investments made in draining and reclaiming saline land in recent years seem to be paying off in India (Joshi and Parshad, 1989) and possibly in Pakistan too.

Emerging Sustainability Issues at the Farm Level

Several potential sustainability problems have been identified at the farm level. Because these problems often involve much more gradual changes over time and are soil-or pest-related, they are often much less visible than large-scale problems, such as groundwater depletion, and are difficult to observe and measure over time. (Harrington et al., 1989). Most of these problems arise from the intensification of input use and greater intensification and specialization of cropping systems:

Nutrient depletion or mining. Perhaps the most common sustainability problem occurs because nutrients are extracted from the soil (because of increased cropping intensity and higher yields) at a faster rate than they are added, especially given the fact that crop and animal residues are increasingly used for non-farm purposes. In some cases nutrient depletion involves macronutrients (nitrogen, phosphorus, and potassium) and sometimes secondary and micronutrients such as sulfur, zinc, and boron. In long term trails, a yield decline may be observed even at the recommended level of fertilizer. In farmers' fields, lower doses of fertilizer and unbalanced mixes of nutrients may lead to even more of a problem of nutrient mining (Table 4).

Declining soil organic matter. Accumulating evidence indicates that the use of organic matter is declining in the intensive irrigated production systems of South Asia. This decline is observed in comparative survey data across time (Byerlee and Siddiq, 1990; Sidhu and Byerlee, 1990) and can be deduced from balance sheets for recycling organic manure and crop residues (Chopra, 1990). Farmers appear to be applying less organic manure because tractors are increasingly substituted for bullock power, more organic manure is being used as cooking fuel, and costs of the labor-intensive activities of collecting and applying manure are high (Figure 10). The decline in use of organic manures and the general pattern of removing all crop residues is probably reducing soil organic matter content, as observed in several long term trials (IARI, 1989). This change in practices has implications for nutrient availability, nitrogen efficiency, and soil physical properties. For example, low soil organic matter may explain low efficiency in utilization of nitrogen fertilizer observed in many areas of South Asia (Desai and Ghandi, 1989; Byerlee and Siddiq, 1990; Abrol and Katyal, 1990).
Other soil-related problems. Various other factors may gradually increase certain soil problems which are difficult to detect in the short term without careful measurement. For example, the use of poor quality groundwater in Pakistan and India has exacerbated sodicity problems (Byerlee and Siddiq, 1990; Bajwa and Jasan, 1989; IIMI Personal Communication). Excessive tillage and inappropriate tillage instruments have increased soil compaction (Razzaq et al., 1990). Other soil properties may have deteriorated as well, especially in the rice-wheat system (Hobbs et al., 1988).

Pest-related problems. Increasingly specialized cropping patterns such as continuous rice-wheat rotations may increase the incidence of pests. The most obvious example is the spread of Phalaris minor in wheat in much of the rice-wheat system. Soil disease problems in these systems may also be more serious than currently believed, as indicated by yield increases of 10-20 percent in experiments on rice-wheat rotations in Nepal when soils are pasteurized to kill micro-organisms (Dubin and Bimb Personal Communication).

### Table 4. Nutrient Input for Rice-Wheat System in Punjab

<table>
<thead>
<tr>
<th>Nutrient Input</th>
<th>Rice</th>
<th>Wheat</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer (kg/ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>47</td>
<td>72</td>
<td>119</td>
</tr>
<tr>
<td>P</td>
<td>3</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>114</td>
<td>164</td>
</tr>
<tr>
<td>Percent Use FYM</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Percent Use Zinc</td>
<td>4</td>
<td>0.4</td>
<td></td>
</tr>
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Source: Sharif (Personal Communications)

This brief review of micro-level sustainability problems suggests that many problems, such as nutrient mining, can be resolved in the short term by technical solutions. More intractable problems, such as declining soil organic matter, might also be arrested in the long medium to long term; it is estimated that 0.2 million ha in the Indian Punjab is now sown annually to green manure crops, although the use of green manure crops in Pakistan is still negligible.
But by far the most important limitation to understanding and solving these sustainability problems is the lack of information to make accurate assessments of the long term changes in the quality of the resource base. To identify emerging sustainability issues more precisely and take appropriate remedial action, there is an urgent need to allocate resources to monitor trends in the use of inputs and other management practices, soil physical and chemical properties, groundwater quality, and pest populations in major cropping systems of South Asia. In Pakistan, in particular, there is a dearth of information to assess changes in resource quality in its irrigated systems, although the low productivity of these systems in relation to the inputs applied suggests that the sustainability problems may be even more serious in Pakistan. The investment required for monitoring of sustainability is modest in relation to the potential implications of these problems to the hundreds of millions of people depending on continued productivity increases in irrigated agriculture in South Asia.

Pakistan: the Outlook to the Year 2000

Given the situation on input use, productivity and sustainability reviewed above let us now consider the prospects for cereal production in Pakistan to the year 2000. In Pakistan, food security and poverty are intimately linked to wheat production and prices. Based on reasonable assumptions, wheat consumption in Pakistan is projected to grow at 3.3 percent annually to the year 2000. This is above the growth rate in production in the 1980s of 2.4 percent per year.

Growth in wheat area is determined by a) bringing new land under cultivation, especially through increased irrigation water supplies; b) increased cropping intensity; and c) increasing wheat area as a percent of total cropped area. There is little reason to expect any significant increase in total cultivated area over the next decade or more. Increase in canal water supplies will be marginal (since no new dams are under construction), and, increases in tubewell water supplies have slowed significantly in the 1980s. However, there is substantial scope to increase water use efficiency and to use savings in water to expand cropped area and cropping intensity which is low relative to its potential. Through more efficient use of water and more appropriate varieties for double cropping intensity can be expected to increase at about the same rate as in the past or about 0.8-1 percent annually. However, it is unlikely that wheat will expand as a proportion of total cropped area, so total wheat area will also expand by about 1 percent annually, given a small margin for new land being brought under cultivation—say 0.2 percent annually.

With this somewhat optimistic projection on expanded wheat area, an increase in yields of about 2.3 percent per year will be needed to match the growth in wheat demand to the year 2000. To attain the required rate of yield gain in the future will require new sources of growth compared to the recent past, which has rested heavily on increased use of MVs and fertilizer. The process of switching from tall to semidwarf varieties is now complete in irrigated areas. Newer varieties with steadily increasing yield potential are continually released and adoption of these newer varieties, has the potential to contribute about 0.75 percent per year to increased yields (Byerlee, 1990).

Given fertilizer responses estimated by the National Fertilizer Development Centre (1989) and Aslam et al., (1989), and a price ratio of nitrogen to wheat of about 3:1, the optimum nitrogen dosage that Punjab farmers should apply would appear to be no more than 130 kg/ha. The documented response to P2O5 is more variable (Aslam et al., 1989 and NFDC, 1989), but an average optimum of 40 kg/ha P2O5 may be appropriate. To reach these optimum, fertilizer use on wheat would need to increase by only 2.9 percent per annum to the year 2000 (from 120 kg/ha to 170 kg/ha) compared to the overall average increase in fertilizer use of 5 percent annually projected by the National Commission on Agriculture. The marginal gain to nutrient ratio observed from on-farm experiments (Malik, 1986; Aslam et al., 1989 and NFDC, 1989) for increasing fertilizer use from the current 120 kg/ha to 170 kg/ha (mostly through increasing nitrogen) is about 6:1. Hence fertilizer use may add only about a 1 percent annual growth rate (that is, a total of 300 kg/ha) to average yields over the next decade.

There are a number of other technological components that can increase productivity and help improve the efficiency of water and fertilizer use. Weed losses are a major problem in many irrigated areas; herbicides are now beginning to be adopted in some areas, even by small farmers, and should spread rapidly over the next decade (Ahmad et al., 1989). Reduced and zero tillage promises to not only to lower costs, but by allowing more timely planting will increase yields; adoption could be rapid in the next few years.

The combination of genetic gains, increased fertilizer use, and improvements in management practices should allow an increase in yields of 2.3 percent annually, without considering for the moment the negative influences on yields due to sustainability problems discussed above. However, there are a number of obstacles to achieving even these modest yield gains:

1. Realizing genetic gains from release of newer varieties requires that new varieties spread much more rapidly to farmers’ fields than the current average lag of 10 years (Heisey, 1990). Major changes in seed distribution and extension are needed to ensure that new varieties are adopted more rapidly in the future.

\*Assumes annual population growth and income of 2.7 percent and 5.6 percent, respectively, and an income elasticity of demand for wheat of 0.2. Our projections are somewhat higher than those of Hamid et al. (1987), who assumed a slower rate of population growth.

\*In fact there will be pressure to reduce wheat as a percent of cropped area in order to satisfy the increasing demand for other crops, especially oilseeds.

\*This is a much more modest target than the 3 percent yield growth specified by the Government of Pakistan’s National Commission on Agriculture (1988).
2. The projected rate of fertilizer growth, although modest, seems unlikely given current price incentives and the removal of all subsidies on fertilizers. At current prices, farmers' average fertilizer doses are approaching the economic optimum indicated by responses in on-farm experiments.

3. Improvements in other cultural practices such as weed control, balanced fertilizer doses, and irrigation scheduling will require a well-developed adaptive research and extension system to formulate location-specific recommendations and provide farmers improved technical information to address the management needs of an increasingly complex agriculture (Byerlee, 1987).

In addition, a critical element in achieving an adequate growth rate in wheat yields will be to find ways to reduce the apparent tendency for yields to decline. The evidence presented in this paper suggests that these negative influences could cancel most of the expected yield gain from improved genetic potential, increasing fertilizer dosages and improvements in other cultural practices. The pressure of increased cropping intensity has been one cause of this trend. The greater research emphasis in the 1980s on varieties to fit intensive cropping systems should partly alleviate this problem. Recent progress in breeding early rice and cotton varieties may have positive effects on future yield increases in wheat. Likewise, success with improving input supplies of seeds of new varieties and herbicides will reduce the problem of increasing disease and weed losses. Further gains are also possible through application of gypsum to ameliorate the effects of sodic tubewell water, and through use of micro-elements where specific micro-nutrient deficiencies have been identified.

However, the most urgent need at present is a concentrated research program to quantify the magnitude of the yield decline (for given input levels) and to identify more precisely its causes. This poses a major challenge to researchers to organize a truly interdisciplinary long-term research approach to understand critical soil-water-pest-rotation interaction as discussed in the next section.

Institutional and Policy Issues

Progress along the continuum of technical change in Asia, from the technological breakthrough to input intensification and on to input efficiency, requires that institutions and policies evolve to serve the changing needs of the food grain sector at each stage of technical change. In particular, there is a need for research and technology transfer institutions to develop new strategies to respond to the challenges of improving productivity and maintaining sustainability through increasing input efficiency.

The Research System

The rice and wheat revolutions originated with the use of improved varieties, which were largely an imported technology. The spectacular success of this technology simulated the development of strong national plant breeding programs for major food grain crops. These programs have matured over time to release newer, even higher yielding varieties resistant to diseases, and to develop more locally adapted varieties that fit specific agroecological niches and cropping patterns.

The strength of plant breeding research contrasts with the relative weakness of crop and resource management research (CMR) — that is, research on tillage, fertilization, pest control, irrigation scheduling, planting date and establishment, etc. In the input intensification stage, which depends on increasing levels of inputs, research has played a minor role relative to improved input distribution. For example, the rapid growth in fertilizer use in Pakistan owes more to input subsidies and improved fertilizer distribution networks than to the thousands of fertilizer trials that have been conducted.

The successful transition from the stage of input intensification to input efficiency and maintenance of the resource base will require much improved information on crop and resource management for specific sites. Most of this information will need to be provided by CMR programs, which must become more decentralized and focus on the agroecological and socioeconomic circumstances of farmers at specific locations. Technological recommendations must evolve beyond the current recipe approach, which emphasizes the package of inputs to be used and which takes little account of agroclimatic and socioeconomic differences among farmers. If farmers are to enter the input efficiency stage, they will need a wider range of technical information enabling them to grasp the scientific basis of the new technology and better adapt the technology to their own needs.

In addition, to address the emerging sustainability issues reviewed in this paper, CMR must adopt a longer term research approach combining 1) strategic research focusing on critical issues for major crop rotations (e.g., declining organic matter or late planting and poor stand establishment in the rice-wheat rotation); 2) monitoring the resource base at the farm level; and 3) adaptive research to tailor sustainable practices (e.g., reduced tillage, green manure crops, etc.) to local conditions.

A major challenge to research on sustainability problems is to evolve institutional mechanisms that promote an integrative approach to research that brings together a broad range of disciplines in the physical, biological, and social sciences, and effective participation of farmers to address priority long-term problems. Increased intensity and specialization in cropping systems will also
require commodity research programs to coordinate their work and communicate more effectively with each other. This is particularly true for the rice, cotton, and wheat research programs, because of the importance of these crops in major cropping systems. Most research systems in South Asia are presently too compartmentalized by commodity and discipline, and to meet the needs of research on complex problems emerging in Asia’s intensive irrigated systems.

**Technology Transfer**

The activities of the public sector were crucial to initiating the Green Revolution, for the public sector played the chief role in releasing seed of the new varieties and in providing complementary inputs—especially fertilizer and water. The public sector also made a substantial investment in rural infrastructure, roads, and irrigation systems, which were important to the continued success of the Green Revolution. With the input intensification stage came a major shift from public to private sector distribution of inputs. This shift was facilitated by the increasing volume of inputs (especially fertilizer) being used and by continuing improvements in infrastructure.

In the input efficiency stage, improvements in information and skills play a much larger role than increased use of inputs in improving productivity. Most studies indicate that the variables that consistently explain the technical efficiency gap are farmers’ knowledge and skills (e.g., extension contact, technical knowledge scores, and education) (Ali and Finn, 1989 and Hussain, 1989). The increasing emphasis on sustainable practices, most of which are quite complex and managerially-intensive, will further increase the need for improved information and skills.

Efforts in the 1980s to upgrade extension systems in part reflected institutional efforts to meet this new stage of technical change. For example, the T & V extension system promoted by the World Bank is now widely used in South Asia. Although it has met with some successes (Feder et al., 1987), this system remains directed toward promotion of input use rather than promotion of input efficiency. In addition, in Pakistan this system appears to have had little impact on farmers’ knowledge of or use of improved technologies (Khan et al., 1984 and Hussain and Byerlee, 1991). Effectiveness of extension is limited by continued poor contact with research, the failure of CMR to provide appropriate information, and reliance on the recipe approach to delivering extension messages.

Complicating the difficulties of transferring information to farmers is the fact that levels of formal education are low in much of South Asia, and especially in Pakistan, which may increasingly limit farmers’ capacity to efficiently use more complex technologies. Thus institutional change in extension, private sector information transfer, and rural schooling have failed to keep pace with farmers’ needs for better technical information that can substitute for input use and accelerate the transition to the input efficiency phase of post-Green Revolution agriculture. This evolution of the information and skill systems is a major challenge for maintaining productivity increases and sustainability in the future.

**Technology vs Policy in Addressing Sustainability Issues.**

Changes in institutions and policies will also be important in addressing many of the sustainability issues discussed above. This is particularly so because new technology may be a blunt instrument for solving sustainability problems. For example, the depletion of groundwater or other renewable resources, may be traced to inherent problems of managing common property resources. In solving such problems changes in institutional arrangements (e.g., property rights), may be more important than changes in technology.

At a more general level, it has been argued that policies that encourage broad-based improvement in rural incomes and employment are more likely to lead to a greater willingness and ability on the part of farmers to conserve resources (IFPRI, 1989). These might include macroeconomic policies (e.g., setting exchange rates that favor agriculture), agricultural sector policies (e.g., that favor the production of labor-intensive commodities), land reform policies (that improve land values and incentives to conserve land resources), policies that improve capital markets (and thereby reduce interest rates, making it more profitable to invest in land improvements), and policies that support agricultural research and extension. Increased food crop production and income opportunities in high potential agricultural areas can also result in less pressure to abuse fragile, marginal areas.

**Conclusions**

Over the past 25 years, food grains in South Asia have experienced extraordinarily rapid and broad-based gains in productivity, especially in wheat. Over the same period, new agricultural land has essentially been exhausted. The area increases that were important in the growth in cereal production up to the 1960s can no longer be expected to contribute to increased food production. Indeed in many densely populated areas, yield increases will need to compensate for a decline in area sown to cereals. In the 1980s, the growth rate of yields has also slowed, moving to a level only slightly exceeding the population growth rate for the region as a whole, and below the population growth rate in the case of Pakistan.

The rapid gains in productivity in the 1960s and 1970s were stimulated by the widespread adoption of MVs (especially for rice and wheat) and fertilizer, and improvement in irrigation water supplies. In the 1980s growth was largely
due to more intensive and balanced use of fertilizer and in some cases adoption of chemical weed control, seed treatment, and other improved practices. In many areas the returns to further intensification of input use are diminishing rapidly, and further gains in productivity will come largely through using inputs more efficiently. Nonetheless, for large areas, a significant and economically recoverable yield gap still exists. The increase in production that would result from closing the yield gap should be sufficient to meet the demand for food grains in the next decade or so. This can be done by using higher levels of inputs, but productivity gains will increasingly depend on the adoption of better cultural practices which enhance input efficiency, such as improved plant establishment, balanced fertilizer doses, and better weed control. Closing the yield gap thus requires a somewhat different research strategy, will be the sum of many small incremental changes in productivity, and will be more difficult to organize and manage.

A major uncertainty is whether the quality of the resource base can be sustained, especially in light of the increasing intensification and specialization in cropping systems in many areas of South Asia. At this stage the evidence for sustainability problems is mixed. There appear to be problems in many areas of South Asia, and especially the extensive irrigated systems of Pakistan. Although discussions of sustainability often emphasize large-scale problems such as groundwater depletion, salinisation, etc., the evidence presented here suggests that more attention should be given to the micro-level problems of long term changes in soil fertility, soil, physical and chemical properties, soil diseases, and weed populations as well lack of diversification to protect against external shocks, such as disease epidemics. These changes, which are often difficult to measure and track over time, deserve far more attention. Research to assess the current status of these variables and to monitor changes over time is urgently needed since the cost of solution is likely to increase as these problems worsen.

Realizing future gains in productivity in South Asia will also require important changes in the institutions serving agriculture. Research systems need to adjust to a new stage of technical progress in which information will substitute for inputs to enhance efficiency and sustainability. In particular, research must adopt a more integrative and longer term approach to crop and resource management that promotes multidisciplinary and multicommodity collaboration in diagnosing and solving problems in major cropping systems. Likewise, the technology transfer system will need to give more attention to providing information and skills to farmers confronted with managing an increasingly complex agriculture. The growing interest in managerially complex sustainable practices, such as integrated pest management, only increases the urgency for developing appropriate institutions that can support the transition to the next stage of post-Green Revolution development in South Asia.

Our review suggest that these challenges are most acute in the case of Pakistan. On the demand side, rapid population growth means that demand for food grains will slow only slightly, if at all, in the coming decade. On the supply side, the slow down in yield growth of cereals has been more pronounced in Pakistan than in other countries in the region. At the same time, the evidence suggests that Pakistan may face more serious problems in sustaining the quality of its land and water resources. While the evidence is still inconclusive, the potential threat to Pakistan’s food security posed by these apparent trends lends urgency to the need for a concerted effort to understand better the causes of these trends and to design an appropriate mix of technological, institutional and policy solutions.

References


