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Farm-Level Effects of Soil Degradation in Sharda Sahayak Irrigation Project

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FOREWORD

Expansion of irrigation has been the mainstay of India's agricultural strategy, and for good reasons. Consequently, irrigated area has grown by more than 40 million hectares during the last four decades. Although critically important in the growth of agricultural production, this vast expansion of irrigation has also been beset with a variety of technical, institutional, and socioeconomic problems.

This study focuses on one of the problem areas--adverse effects of surface irrigation on land productivity due to growing incidence of salinity, alkalinity, and waterlogging. Most of the major irrigation systems in India have reported this problem. Yet so far the concern has remained inadequately addressed. This might be due to the overriding influence of the food self-sufficiency objective and the crucial role of irrigation expansion in achieving the objective. But now, with shrinking opportunities for new surface water schemes, their rising costs, and growing concerns for the environment, quality of irrigation deserves more attention. Nevertheless, informed discussion on policies that incorporate quality considerations is constrained by an extraordinary diversity of issues and insufficient analysis of specific situations--more so because research in this direction is difficult, since the problems are often localized and unidentifiable in aggregate statistics. This study is an attempt to demonstrate how such information can be generated and used to address an important problem area.

The study was initiated by the authors when Pramod Joshi from the Central Soil Salinity Research Institute in India spent about three months at IFPRI under a UNDP fellowship. It is the first working paper in a series on future growth in Indian agriculture, reporting the results of a five-year collaborative research program developed under a memorandum of understanding with the Indian Council of Agricultural Research, with funding from the U.S. Agency for International Development (Grant No. 386-0282-G-IN-8334-00). The overall aim of the program is to increase understanding of the options and complexities of future policies for agricultural growth. The research agenda was developed after extensive discussions with a wide range of Indian policymakers and researchers. Through studies in collaboration with more than a dozen Indian institutions, the program aims at analyzing key policy issues in five broad spheres: economic efficiency of technology-based growth in the production of major crops, fertilizer use,

irrigation, technology transfer, and rural infrastructure. We expect the results of the present study to be useful in informed discussion and policy formulation processes, not only in India but also in other countries, especially since India's richness in data and experience allows analysis that may be difficult to duplicate elsewhere.

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1. SUMMARY

Since independence, India's most critical investment in agriculture has been in irrigation. Irrigated area grew from 22.6 million hectares in 1950/51 to 60 million hectares by 1985. The contributions of these investments, and those in modern technology, are well documented. However, the efficiency of these and future investments in irrigation as well as the issue of negative externalities has been seriously questioned in recent debates. It has been argued that, apart from generating low returns, inefficient use of irrigation water threatens the long-term sustainability of irrigated production systems. An informed debate on these issues requires quantitative information on the extent of these problems and the losses that result. This study attempts to demonstrate how such information can be generated and used.

The study focuses on the salinity/alkalinity and waterlogging caused by expansion of surface irrigation. Most of the major surface irrigation systems in the country have reported these problems. This study measures the farm-level effects of these land degradation processes, based on a survey of 110 farming households in Gauriganj Block of Sultanpur District in Uttar Pradesh. The impact is evaluated in terms of resource use, production, and income from crop production. Canals under the Sharda Sahayak Irrigation Project are the main source of irrigation in the area. This project, initiated in the early 1970s, has a projected command area of about 2 million hectares spread over 12 districts of eastern Uttar Pradesh.

Small farms predominate in the study area. The average farm size was only 0.63 hectare in Sultanpur district in 1981, and 94 percent of the farming households had less than 2 hectares of land. Paddy and wheat accounted for 73 percent of the cropped area. Production of paddy grew 6 percent a year and wheat 12 percent a year during 1973-85. For crops like paddy, wheat, sorghum, and maize, 4-5 percent growth in yield has been recorded . These numbers effectively camouflage the growing menace of land degradation and its consequences.

Studies show that there has been a rapid rise in the groundwater table since the inception of the canal system. Although the number of tubewells has grown phenomenally in the district, in areas covered by the canal system, tubewells have actually decreased.

Examination of data at the subdistrict (block) level reveals that fallow area has increased from 0.4 percent to 16.0 percent over the last seven or eight years. This is unusual in a densely populated area.

Farm data show that the problems of salinity/alkalinity and waterlogging were not experienced before the inception of the canal network. In 1985-86, nearly 87 percent of the farmers surveyed reported incidence of these problems, affecting 53 percent of the farm area: 34.4 percent of the area was salt-affected and 18.3 percent was waterlogged. According to soil tests, alkalinity is the main salt-related problem. These numbers indicate that degradation problems are growing rapidly; it would be unwise to treat them as long-term problems.

On the basis of the extent of alkaline and waterlogged area, 30 percent of the farms were identified as "problem-affected". On these farms, 29 percent of the area was uncultivated, whereas on "normal" farms only 11 percent was uncultivated. Most of these were alkaline. The cropping intensity was 110 percent in the problem-affected and 166 percent in the normal category of farms. When the use pattern for each category of land was examined separately, the intensity was found to be 178 percent on normal, 81 percent on alkaline, and only 54 percent on waterlogged lands. In the *kharif* season, only 4 percent of the area under normal soils was fallowed; on salt-affected and waterlogged lands 47 percent and 52 percent of the area was uncultivated. Degradation due to alkalinity and waterlogging thus affects land resources in two ways. In extreme cases, cultivation is abandoned; where land is cultivated, even with irrigation, the land use intensity is low. Moreover, crop choice becomes restricted under degraded soil conditions. High-value crops like sugarcane and potato and pulses are excluded from the cropping pattern. Thus, land scarcity is aggravated both quantitatively and qualitatively due to alkalinity and waterlogging.

When cultivation is abandoned on highly alkaline soils, use of nonland resources is cut back. This has not been addressed in the study. The results indicate that use of modern inputs like fertilizers and machinery is lower on degraded cultivated soils. Aggregate input use falls by 21-22 percent. The decline is higher for high-yielding varieties (HYV) of paddy, compared with traditional varieties in the *kharif* season, and for wheat, compared with barley in the *rabi* season. Use of soil amendments is recommended for reclamation of alkali soils, but this was not adopted by any farmer in the sample. In general, as soil conditions deteriorated, farmers favored low-input traditional varieties and practices.

Results on productivity and profitability of crop production were more dramatic. According to farmers' perceptions, yields of paddy and wheat were reduced by half in about eight years due to increasing soil degradation. Cross-section data indicated that paddy yields went down by more than 51 percent, and wheat by 56 percent on alkaline lands.

Barely, with only an 18 percent decline, emerged as the most tolerant crop. Net incomes from HYVs of paddy fell by 54 percent on waterlogged and 87 percent on salt-affected lands. Cultivation of traditional paddy varieties resulted in a net loss on alkaline lands; for wheat, net income in this situation fell by 92 percent. Barley registered the lowest decline in net income per hectare. These results indicated that, with the exception of barley, it was not economically viable to cultivate alkaline lands. Improved technology for reclamation and use of such lands has been developed, but these were not adopted on the sample farms. These efficiency losses due to soil degradation are also illustrated by the findings that unit cost of production rises by 59-61 percent for paddy and by 85 percent for wheat when cultivation is extended on alkaline lands. In comparison, waterlogging results in an 18-19 percent rise in unit costs for paddy.

Finally, the decomposition analysis showed that 66-88 percent of the difference in output between normal and degraded soil situations was due to the soil degradation effect. Input use was lower on these problem soils, but the contribution of decline in input use did not exceed one-third of the observed difference. As mentioned earlier, output was more sensitive to the degradation phenomenon than input use.

Four policy conclusions are suggested. First, in areas where these problems occur, the adverse effects are substantial. It is important, therefore, that such areas be identified in different canal command areas in the country. This will require strengthening the statistical reporting and soil testing capabilities of the different command area authorities. It will be necessary to combine the sophisticated monitoring techniques now available for evaluation of soil health with on-field verification.

Second, research on development of salt-tolerant varieties has a narrow crop focus. It will be necessary to expand this effort to cover more crops. Similarly, there is a need to develop some adaptive research capacity at the command area level so as to enable evaluation of reclamation technologies under field conditions. This calls for close working relationships between research and command area administrations.

Third, there was no evidence that improved technology for cultivation of alkaline soils (such as salt-tolerant varieties, amendments, and better water management) had been adopted in the study area. This could be due to neglect by the extension service or nonavailability of recommended materials, such as seeds and chemicals to be used as soil amendments. These systems are still preoccupied with the mainstream recommendations for 'normal' situations.

Finally, steps to prevent canal seepage, to rationalize canal operation, and to improve drainage are crucial. The results of this

study suggest that it would be worthwhile to invest in these improvements. However, a proper evaluation requires data on the extent of problem soils and on how they affect output at the command area level. Investment decisions in the irrigation sector have become more complex, and these kinds of data have become essential for evaluating different options.

2. INTRODUCTION

Development of its sizable water resources for irrigation has been the most important component of India's agricultural strategy since Independence. Consequently, irrigated area grew from 22.6 million hectares in 1950/51 to 60 million hectares by the end of the Sixth Five-Year Plan (India, Planning Commission 1985). Irrigated area grew at an annual rate of 0.7 million hectares during the First Five-Year Plan, accelerating to 1.6 million hectares during the Fifth Plan and 2.2 million hectares in the Sixth Five-Year Plan (India, Planning Commission 1985). Total investment in irrigation by the end of this period was about Rs 194 billion. The contribution of this investment to Indian agricultural growth has been well established and adequately documented in the literature.

In recent times, serious questions have been raised about the efficiency of investment in irrigation, particularly investment in large surface irrigation systems. The Sixth Five-Year Plan emphasizes that returns from this investment, both in yield and in finances, has been disappointing. On average, states have been losing more than Rs 4.3 billion per year on their irrigation investments (India, Planning Commission 1980).[1] Average productivity with canal irrigation is reported to be in the neighborhood of 1.1 ton per hectare, not significantly higher than the rainfed yield rate in a normal year (Venkateswarlu 1985).

Seckler, cited in *The Times of India* in 1984, summarizes the main concerns about large canal irrigation systems as follows: (1) average yields of crops on irrigated lands are still three to four times lower than what could be achieved; (2) those farmers who are located favorably at the head of the canal system receive an adequate (sometimes more than adequate) amount of water at the expense of those located further down (the tail-enders); (3) the reliability of water delivery, both quantity and timing, is deteriorating; and (4) long-term productivity is threatened by increased salinity, alkalinity, silting, waterlogging, and flooding. Figure 1 summarizes the main diseconomies and consequences of canal irrigation systems.

The magnitude of these effects are not precisely known. They are often localized and unidentifiable in aggregate statistics. Lack of

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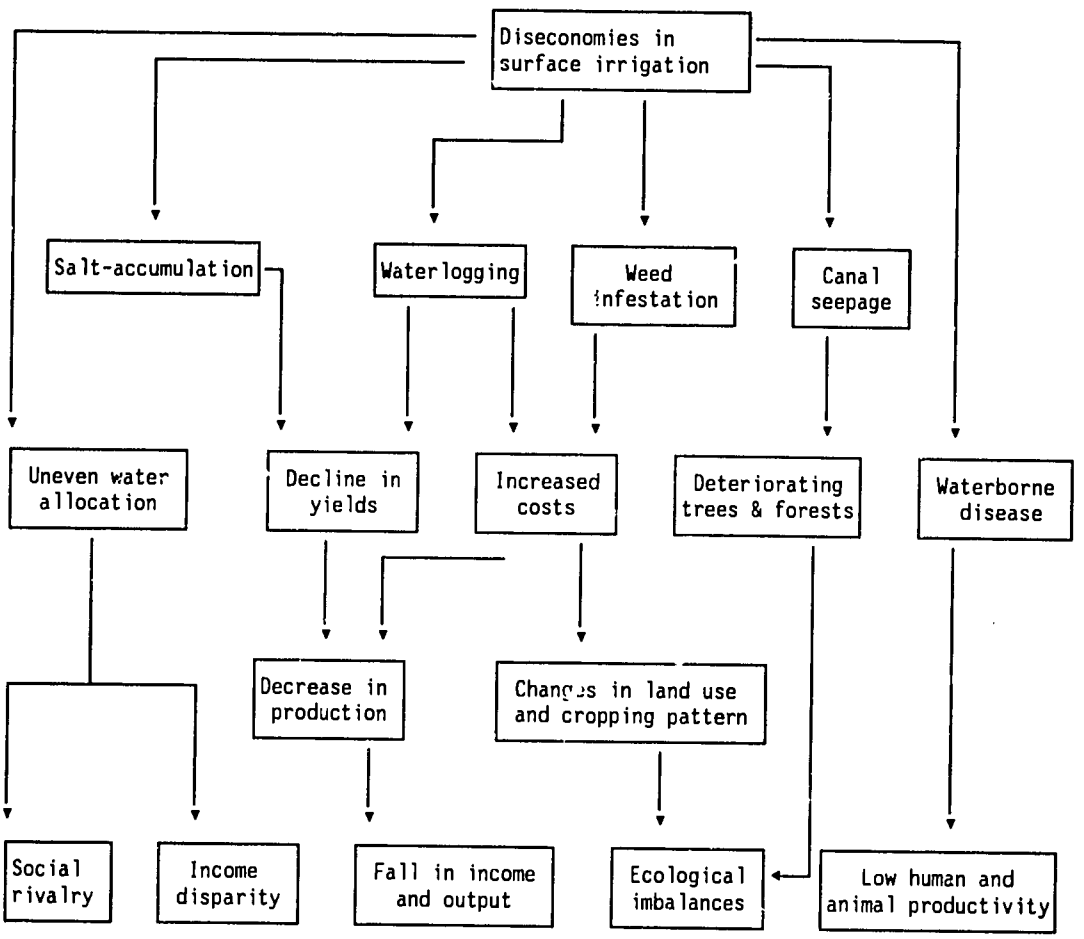
[1] Also see Bhumbla 1980 and Joshi and Agrihotri 1984.

Figure 1--Adverse effects of surface irrigation



Source: P. K. Joshi. "Effect of Surface Irrigation on Land Degradation: Problems and Strategies," *Indian Journal of Agricultural Economics* 42(3, 1987):416-423.

such data is one reason why these concerns are inadequately addressed in irrigation investment decisions.

The present study focuses primarily on the problem of soil degradation caused by salt accumulation and waterlogging in major surface irrigation systems. It attempts to measure the effects on resource use, productivity, and profitability of crop production at the farm level.

THE PROBLEM OF SALINITY AND WATERLOGGING

Soil degradation and waterlogging have plagued irrigated agriculture down through the ages. Historical evidence shows that in the long-run these problems lead to land abandonment (Rhoades 1988). In the short and medium terms, there are adverse effects on productivity. As a result of research in soil science, agronomy, and other disciplines, the scientific relationships involved are now understood (Abrol and Fireman 1977). Under certain conditions, water seepage from canals and field percolation from excessive irrigation cause the groundwater table to rise and salts to move upward through capillary action. Soil salinity or alkalinity and waterlogging are the result. High accumulations of salt in the soil restrict plant growth and eventually lead to barrenness (ICID 1987, Abrol and Bhumbla 1977). In addition to faulty water management, several technical factors such as poor soil permeability, inefficient drainage, and low precipitation contribute to this problem.

Salt-affected soils and waterlogging were first observed in irrigated plots of Western Yamuna Canal Command in 1855. Since then several estimates have been made by expert committees and individual researchers. As the following paragraphs indicate, these are tentative estimates and location-specific. A comprehensive technoeconomic survey indicating which of India's land resources are vulnerable to these hazards is lacking. This is well-recognized: in 1985 the Seventh Five-Year Plan specifically recommended that states compile such information (India, Planning Commission 1985). Nevertheless, some estimates are available that highlight the significance of the problem.

The National Commission on Agriculture (1976) estimated that at that time about 6 million hectares in the country were waterlogged. Kanwar (1977) indicates that about 20 million hectares of land in the canal irrigated areas were under risk of being degraded by salts. Others contend that 7 million hectares of agricultural land have been lost due to salinization (Abrol and Bhumbla 1977). In addition, large areas are gradually being affected by rising water tables and salinity, even in comparatively new irrigation projects (Afroz and Singh 1986). The Administrative Staff College of India recently estimated that roughly 10 million hectares are threatened by waterlogging and another

25 million hectares by soil salinity (Bowander and Ravi 1984). Another estimate categorizes nearly 35 percent of all irrigated land in India as salt-affected (Rhoades 1982).

Many of the major irrigation projects suffer from serious waterlogging and consequent soil salinity/alkalinity. The problem is particularly alarming in the Chambal Project Command in Madhya Pradesh and Rajasthan, Tawa Irrigation Project in Madhya Pradesh, Indira Gandhi Canal Project in Rajasthan, Kosi and Gandak Project Command Areas in Bihar, the Tungabhadra and Malprabha areas of Karnataka, Sri Ramsagar and Nagarjunasagar areas in Andhra Pradesh, Ukai Kakarpar and Mahikadana Command Areas in Gujarat, and Sharda Sahayak and Ramganga Command Areas in Uttar Pradesh. Appendix Table 17 presents a compilation of problem-related land in selected irrigation projects obtained from diverse sources.

These problems are likely to be aggravated further as canals are built in new areas are and existing irrigated lands are unattended. The following statement sums up the perception and prescription at the highest policy level:

> In existing irrigated areas where salinity and waterlogging have resulted in good agricultural land becoming unusable, adequate drainage facilities would be provided on a priority basis and proper usage of surface and groundwater encouraged, as also reclamation and revised cropping pattern for preventing recurrence of waterlogging and salinity. As precise statistical data are not yet available, states have been requested to carry out surveys for a correct assessment of irrigated lands that have fallen into disuse because of waterlogging and salinity (India, Planning Commission 1985, p. 74).

As a consequence, unlike more visible soil-related problems such as floods, deforestation, and soil erosion, control of salt-affected and waterlogged areas has not yet evoked an adequate policy response (Shah 1988). The overriding influence of the food self-sufficiency objective and recognition of the crucial role of irrigation in meeting this objective have also contributed in a historical context. Also, these problems are often localized and not reflected in aggregative data on performance of the agricultural sector. Lack of quantitative information on economic losses at the farm level makes analysis of trade-offs in irrigation-sector investments (for example, between additional irrigation and system improvement or between drainage and salinity control) even more difficult.

OBJECTIVES

Awareness of these issues is evident from statements in policy documents such as the five-year plans (India, Planning Commission 1985). Some funds have been allocated to drainage, canal lining, and other measures that help in alleviating these problems. However, what the policymakers need for better investment decisions are quantitative estimates of the consequences of salt-accumulation and waterlogging at the field level. The present study is an attempt in this direction. Because the study focuses on the impact of salinity/alkalinity and waterlogging, the selection of farmers and the study area was based on the incidence of these problems. Measuring the extent of the problem is itself an important and pressing issue, but this aspect is beyond the scope of this inquiry.

Based on farm-level data collected from villages in the Sharda Sahayak Command Area in eastern Uttar Pradesh, India, this study quantifies the effects of soil alkalinity/salinity and waterlogging on the farm economy. First, the effects on resource use patterns of farmers are measured. The main focus is on land resources where the impact ranges from crop substitution to adjust for deteriorating soil conditions to abandonment of cultivated land. Changes in nonland resources in cultivation of major crops are examined next. Finally, the resulting effects on productivity and profitability of major crops are analyzed, and an attempt is made to quantify the output-depressing effects of deteriorating land quality.

DATA

It was envisaged that the Sharda Sahayak Canal System would potentially irrigate about 1.6 million hectares in the lower reaches of the main Sharda Canal Command area, covering 12 districts. However, problems of soil salinity/alkalinity and waterlogging in the command area have been reported (Afroz and Singh 1986).

Gauriganj Block in Sultanpur District was randomly selected from others where canal irrigation was important. Four villages of this block were then selected, and from these, 110 farmer households were randomly selected. The survey covered the 1985/86 cropping season. Information was collected from the selected households on land use and cropping patterns, history and extent of problem-infested soils, inputs and outputs, and marketing and prices. Secondary data on irrigated area, land use and cropping patterns, rising water tables, and other relevant aspects for the district and the Sharda Sahayak Canal system were also collected from published or unpublished sources.

3. THE STUDY AREA

Sultanpur district is located in the central-eastern plains of Uttar Pradesh.[2] The population of the district was 2.04 million in 1981, nearly 96 percent of which live in rural areas. Farming is the main occupation of about 80 percent. The density of population per square kilometers was 460 persons as against 376 for the state of Uttar Pradesh. More than 64 percent of the workforce are cultivators and 23 percent are landless laborers.

The district's climate is semi-arid with hot summers and cold winters. During the months of May and June the temperature goes as high as 41°C. The minimum temperature during December and January is about 3°-4°C. The average annual rainfall of the district is about 984.5 millimeters and is concentrated between June and October: about 94 percent of the annual rainfall is received during this period in about 41 days.

FARM SIZE AND CROPPING PATTERN

Small farms characterize the agriculture of the district; the average farm size in 1981 was only 0.63 hectares. Table 1 shows that more than 82 percent of the holdings were less than 1 hectare in size. These accounted for only about 41 percent of the cultivated area of the district. At the other extreme, less than 1 percent of the holdings in the largest category (more than 5 hectares) claimed 11 percent of the cultivated area. Changes in the size distribution pattern over time show a systematic increase in the smaller categories and persisting inequalities.

Important crops grown in the district along with their acreages are shown in Table 2. Paddy and wheat are the major crops of the district, accounting for 73 percent of the cropped area. Pulses form the third major group. Cash crops like potato and sugarcane account for only 3.5 percent of the cropped area.

The table shows that production of all crops except barley, pearl millet, and pulses increased during 1973-85 period. The performance of wheat and paddy was particularly impressive, the former growing 12

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[2]This chapter draws heavily from Indian Agricultural Research Institute 1986.

Table 1--Distribution of land holdings in Sultanpur District, 1981

Farm Size	Number of Holdings	Percent of Total	Cultivated Area	Percent of Total
(hectares)	(1,000)		(1,000 hectares)	
Less than 1	420.4	82.3	130.8	40.7
1-2	58.2	11.4	78.0	24.3
2-3	17.2	3.3	40.3	12.6
3-5	10.2	2.0	37.8	11.8
More than 5	4.6	0.9	33.9	10.6

Source: Indian Agricultural Research Institute, *Resource Analysis for Integrated Development, Sultanpur District*, Water Technology Centre, (New Delhi: IARI, 1986).

Table 2--Cropping pattern and growth in crop production in Sultanpur District, 1984/85

Crop	Cultivated Area	Share	Annual Rate of Growth[a]		
			Production	Area	Yield
	(1,000 hectare)		(percent)		
Paddy	146.1	38.5	6.3	1.1	5.2
Wheat	129.2	34.1	12.0	7.5	4.4
Barley	10.6	2.8	-9.9	-10.7	0.8
Sorghum	11.8	3.1	2.9	-2.0	4.9
Pearl millet	1.4	0.4	-4.2	-5.2	1.2
Maize	6.3	1.7	4.0	-1.4	5.4
Pulses	60.3	15.9	-4.0	-3.7	-0.3
Sugarcane	7.8	2.0	0.8	-2.3	3.2
Potato	5.6	1.5	2.9	1.9	1.1

Source: India, Directorate of Economic and Statistics, Ministry of Agriculture, unpublished data.

[a] Annual compound growth rate between 1973/74 and 1984/85.

percent a year and the latter more than 6 percent a year. Acreage expansion was the main source of production increase for wheat, while productivity growth was the dominant contributor for rice. In fact, wheat, paddy, and potato were the only crops that gained acreage: all others recorded declines. These shifts have been influenced by expansion in irrigation and different rates of technological change among crops. Area under rainfed crops (such as sorghum, millets, pulses, oilseeds, and barley) moved to paddy and wheat.

It is significant to note that with the exception of barley and pulses, yield levels of all other crops recorded positive growth. Paddy, wheat, sorghum, and maize yields grew at 4-5 percent per year.

The numbers illustrate a point made in Chapter 2. The lowest level of aggregation for official statistics is the district. Table 2, based on district data, shows an impressive agricultural performance. Some concerns, such as decline in pulses, are captured and eventually attract policy attention, but effects of localized problems like soil degradation are completely swamped in aggregation.

IRRIGATION

Nearly 42 percent of the gross cropped area of the district was irrigated in 1982/83. Tubewells and canals were the main sources of irrigation, and these accounted for more than 89 percent of the total irrigated area (Table 3).

Table 3--Irrigated area in Sultanpur District, 1982/83

Source	Area	Percent
	(1,000 hectares)	
Canal	59.3	38.0
Tubewells	80.3	51.4
Well	10.6	6.8
Tanks, lakes, ponds	5.5	3.5
Others	0.3	0.3

Source: Indian Agricultural Research Institute, *Resource Analysis for Integrated Development, Sultanpur District*. Water Technology Centre (New Delhi: IARI, 1986).

The canal irrigation network in the district, sponsored by the Sharda Sahayak irrigation project, is quite extensive. The project was initiated in 1974 to provide irrigation in the lower reaches of the Sharda Canal Command area by diverting flows from two important rivers--the Ghaghra and the Sharda. The irrigation potential of the project is about 1.6 million hectares, spread over 12 districts of eastern Uttar Pradesh. Appendix Table 18 shows the progressive development of irrigation potential and utilization in the project.

Two branch canals, namely Sultanpur and Jaunpur branch canals, supply irrigation water to Sultanpur district. The regulation of the canal system is based on the availability of water and water requirements as assessed from cultivators. During the monsoons, irrigation depends upon the occurrence and distribution of rainfall. Appendix Table 18 reflects this variability during the rainy season. Management of the canal system is divided into two components. The operation and management up to the canal outlet is under the jurisdiction of the irrigation department of the state government. Distribution of water below the canal outlet to the fields of farmers and other activities like land development, transfer of technology, conjunctive use of surface and groundwater, provision of drainage, and so forth are the responsibility of the Command Area Development Authority.

As in most other canal systems in the country, irrigation charges are based on crops grown rather than amount of water used. These are shown in Appendix Table 19. These vary from less than Rs 50 per hectare for sparsely irrigated crops like fodders and green manures to Rs 237 per hectare for sugarcane. For paddy, wheat, and barley, the charge is Rs 143 per hectare.

Several studies have been carried out to estimate the extent of salt-affected and waterlogged area in the Sharda Sahayak Irrigation Project. Studies conducted by the Remote Sensing Agency revealed that, in an area of about 1.43 million hectares, about 74,000 hectares were waterlogged on the surface. Similarly, a study carried out in 120 villages of Sultanpur, Barabanki, Rae-Bareilly, and Lucknow showed that the area sown in winter crops has declined by about 54 percent between 1976/77 and 1981/82 due to waterlogging. A similar study covering 208 villages of Lakhimpur Kheri, Sitapur, Barabarki, Lucknow, and Rae-Bareilly districts found that more than 16,000 hectares of winter crops had been lost. In addition to rising groundwater tables and surface waterlogging, about 2,6,000 hectares were affected by alkalinity.

Seepage problems in the Sharda Sahayak Canal existed from the beginning. A study conducted during 1985 showed that about 7,500 hectares of land had gone out of cultivation due to seepage. Damage to settlements, houses, and property were also reported (Afroz and Singh 1986).

WATER TABLE

The main sources of groundwater recharge are rainfall and irrigation. The average depth of the water table in the area has been rising since the inception of the canal system (Figure 2). The water table rose from 8.5 and 6.7 meters in the pre- and postmonsoon seasons, in 1974 to 5.3 and 3.9 meters in 1984.

Another study covering four districts in the Sharda Sahayak Canal Command area showed even more alarming rises (Table 4).

Table 4--Magnitude of the rise in the groundwater table in four districts of the Sharda Sahayak Canal Command area

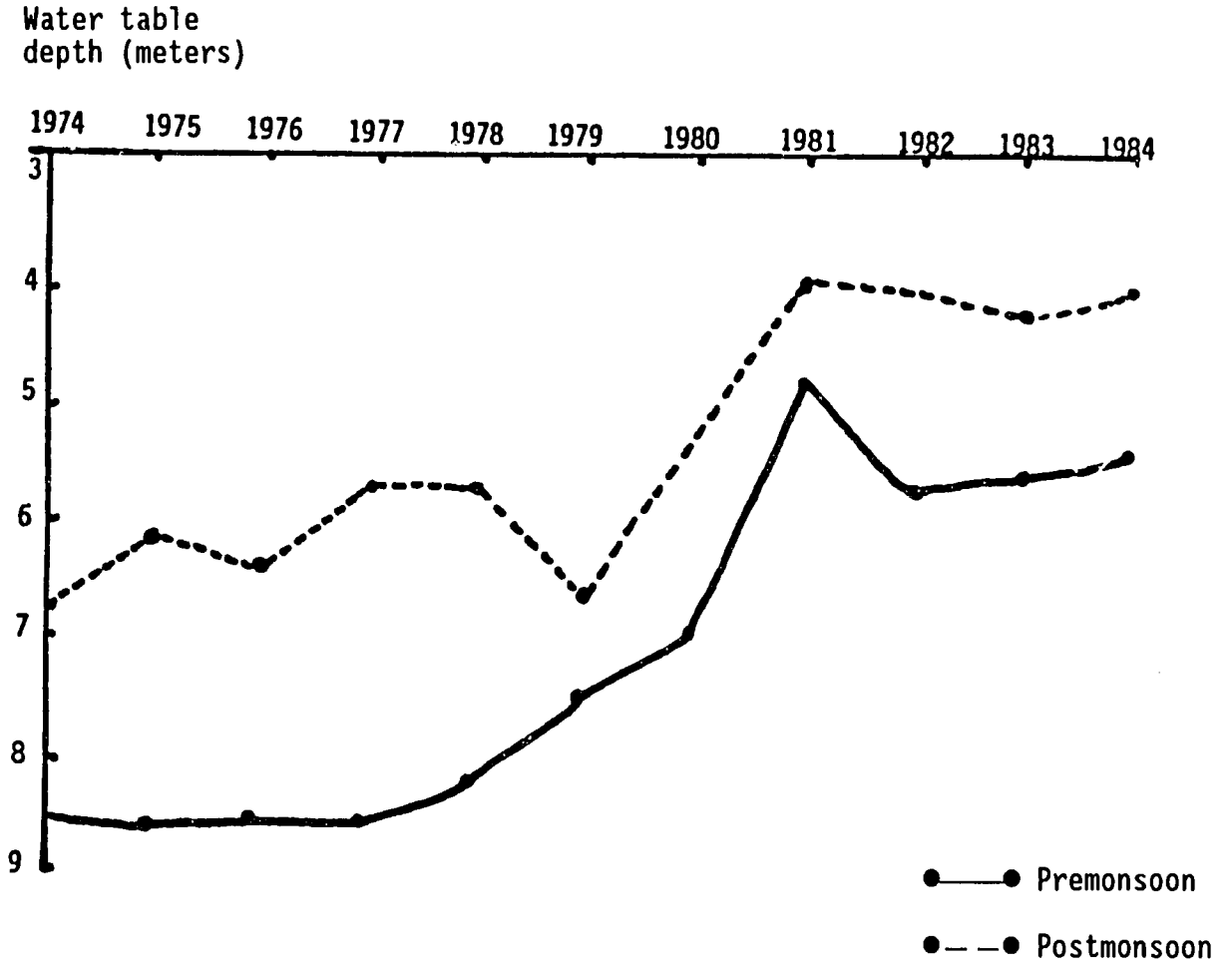
District	Groundwater Level	
	1974	1983
	(meters below surface)	
Lakhimpur and Sitapur	5.33	1.71
Barabanki	2.79	1.03
Rae-Bareli	3.60	0.23

Source: Ahmad Afroz and Pashupati P. Singh, "Assessment of Environmental Impacts of Sarda Sahayak Canal Irrigation Project of Uttar Pradesh," *International Journal of Environmental Studies* 28 (1986):123-130.

These levels are too high for normal crop growth. The rise in the water table encourages the rapid upward movement of salts, which accumulate in the root zone. At moderate levels, this affects yields; at very high levels, it renders the land uncultivable. Although the effects of these changes on land use and cropping patterns will be discussed in the next chapter, an important point needs to be made at this stage. The number of pump sets for tubewells has grown phenomenally in the district.[3] One would expect that an increase in tubewells would help solve the problem of the rising water table. However, in areas where there are canals, there has been a decline in the use of tubewells, as farmers have substituted cheaper canal water for underground water (Afroz and Singh 1986). This is another example of how aggregative data could lead to misleading conclusions.

[3]The number of pump sets has grown from 2,400 in 1970-73 to 9,100 in 1980-83, (Bhalla and Tyagi 1989).

Figure 2--Rise in the water table in Sultanpur District, 1974-84



Source: Indian Agricultural Research Institute, *Resource Analysis for Integrated Development, Sultanpur District*, Water Technology Centre (New Delhi: IARI, 1986), p.254.

4. SOIL DEGRADATION AND THE RESOURCE USE PATTERN

Deterioration in the physical production environment leads to changes in resource use. This chapter examines the nature and extent of problem soils, and its effects on use of land and other resources on sample farms.

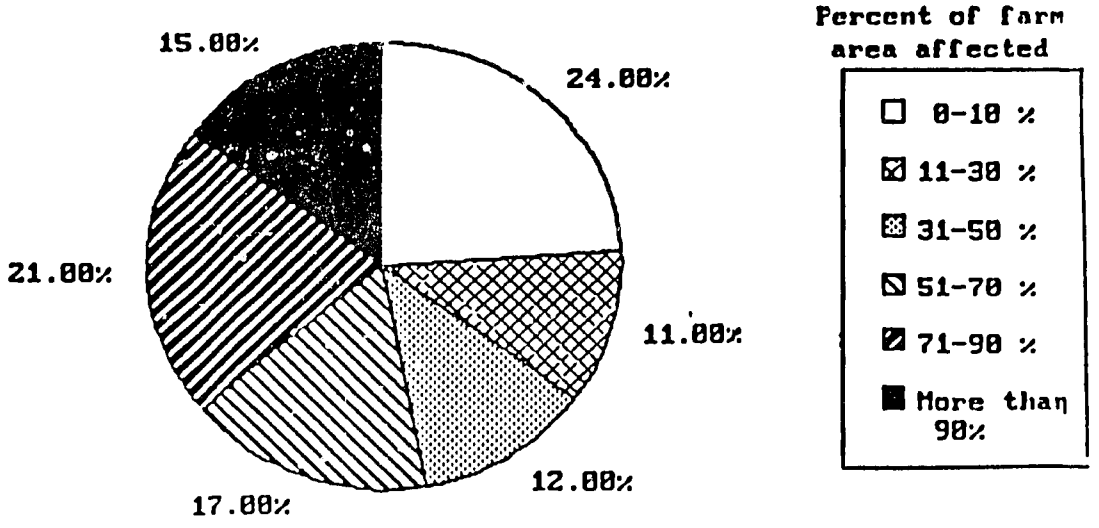
NATURE AND EXTENT OF PROBLEM-AFFECTED SOILS

Nearly 87 percent of farms reported the presence of alkalinity/salinity and waterlogging on their farms, and 53 percent of the total farm area was affected (Figures 3 and 4). Salt accumulation was the main problem in 34.4 percent of the area and waterlogging in 18.3 percent. Figure 3 shows that on 24 percent of the farms the problem was nonexistent or negligible. At the other extreme, on 15 percent of the farms, more than 90 percent of the farm area was affected. On 53 percent of the farms, saline/alkaline or waterlogged soils accounted for more than 50 percent of the farm area. Clearly, land degradation problems are serious in the study area.

Figure 4 shows how these problems have grown over time. This is based on the perception of problems by farmers and recall. It reveals that extensive problems are of relatively recent origin. Only 15 percent of the farmers recall having a problem before 1975. Apparently, the water table was low enough and the natural precipitation was adequate to keep most salts below the root zone. Natural drainage was effective and there was little waterlogging. Since then the problem has grown steadily so that by 1985, more than 87 percent of the farmers have experienced waterlogging to varying extents. As noted earlier, the expansion of the canal network in the area started in the mid-1970s. The figures not only make the point that the problem is pervasive but also that it does not take too long to manifest itself. This suggests that soil-related diseconomies in canal irrigation systems cannot be viewed as long-term problems that do not require attention in the short run.

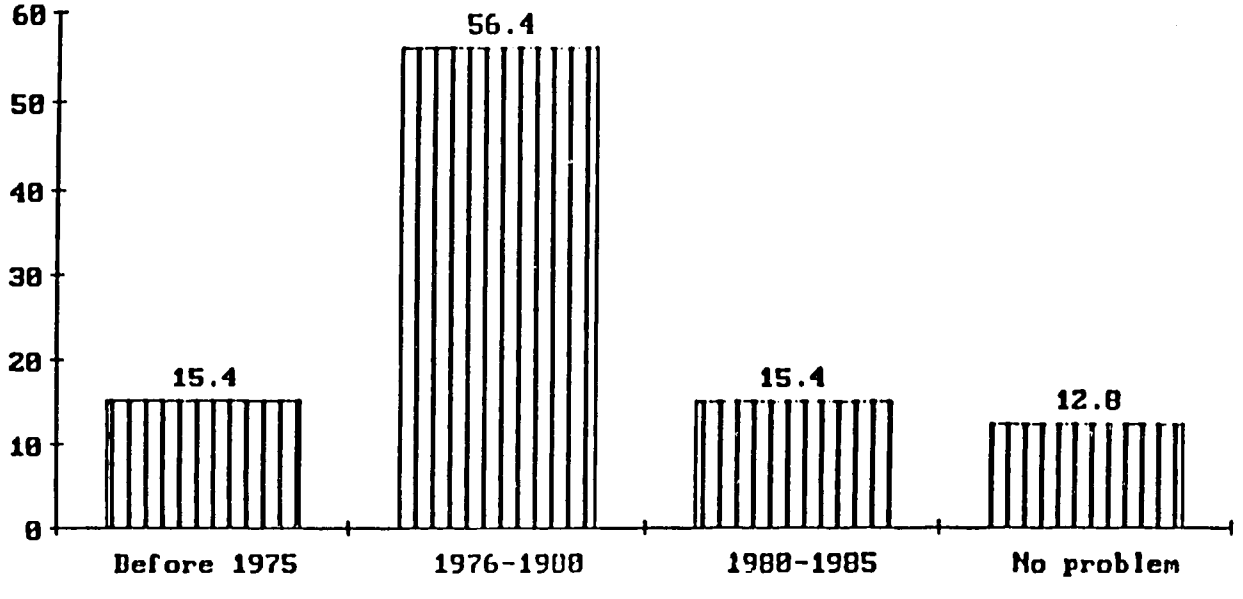
At this stage it is important to define the nature of the problem of salt-affected soil. Soil scientists distinguish between saline, alkaline (sodic), and saline/alkali soils depending upon the nature and concentration of salts present. These distinctions are important because reclamation strategies are different. Indeed it has been argued that lack of precise diagnosis has often led to investment in

Figure 3--Extent of alkaline and waterlogged area on sample farms



Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986

Figure 4--Farmers' perception of the incidence of alkalinity and waterlogging on their fields



Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986

Note: This figure is based on farmers' recall of whether they have ever had a problem and, if so, when the problem first appeared.

ineffective reclamation methods (Abrol and Fireman 1977). Soil samples taken from the plots of farmers were analyzed for acidity (pH) and electrical conductivity (EC).[4]

The results, presented in Table 5, suggest that soil alkalinity (sodicity) is the dominant problem on the study farms. Reclamation of such land requires continuous irrigated cropping, use of organic manures or residues, and application of chemical amendments such as gypsum. Experimental results indicate that in three years' time such soils can be fully reclaimed if recommended practices are followed. It is paradoxical that instead of contributing to containment of the alkalinity problem, irrigation has exacerbated it.

Table 5--Soil reaction (pH) and electrical conductivity (EC mmhos/cm) of soils of sample farms in Gauriganj Block.

Variable	Average	Maximum	Minimum	Coefficient of Variation
				(percent)
pH (1:2)	9.570	10.550	8.050	7.69
EC (1:2)	1.014	2.493	0.126	51.76

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

LAND USE AND CROPPING PATTERNS

Land use changes are examined at two levels. First, the broad land use pattern, at both macro and micro levels, is described. Second, the crop mix under different soil environments at the farm level is examined. The first shows the relatively long-term effects, and the second indicates the kinds of short-term adjustments that farmers make as soil degradation problems emerge.

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[4]These tests were made on 1:2 soil-water mixture and provide an indication of the nature of the problem. More detailed tests are needed for making specific recommendations. Nevertheless, the results presented in Table 5, clearly identify the problem.

In Table 6, data on the land use pattern for Gauriganj Block, where the farm survey was conducted, are presented for two periods, one during the early years of expansion of the canal system and the other for 1985/86.

At the subdistrict level of aggregation, some changes can be discerned. As expected, agricultural use was the dominant category during both periods. However, there was a major decline in land allocated to agriculture even within the short span of seven years. Cultivated land declined at an annual rate of 1.32 percent, falling from 72 percent of the total geographical area in 1978/79 to about 63 percent in 1985/86. Nonagricultural uses grew a modest 2 percent during this period.

Table 6--Land use classification in Gauriganj Block, Sultanpur District

Land Use Category	Percent of Total Geographical Area	
	1978/79	1985/86
Cultivated land	72.1	62.7
Nonagricultural uses	10.3	12.3
Barren and uncultivable land	8.1	4.4
Miscellaneous trees and groves	5.5	2.1
Cultivable wasteland	3.6	1.7
Permanent pastures and grazing land	...	0.8
Current fallows	0.0	9.6
Other fallows	0.4	6.4
Cropping intensity	116.3	157.6

Source: Unpublished records from the office of the Block Development Officer, Gauriganj, Sultanpur.

There was a substantial increase in the relative share of current fallows and other fallows.[5] Fallows increased from 0.4 percent in

[5]Current fallows are lands not used for cultivation for less than three years, and other fallows are lands not used for cultivation for more than three years.

1978/79 to 16.0 percent in 1985/86. This evidence is contrary to the trend in Indian agriculture in general and densely populated regions in particular. Obviously, diversion of area to these less productive uses is mostly at the cost of cultivated land. Over time, most of these fallow lands (which create the impression that excess land is available) will be moved to the uncultivable wastelands category. This trend can be attributed largely to the increase in the area under problem soils, which restricts its use for agricultural purposes.

Part of this loss has been compensated for by bringing into cultivation land from other use categories such as cultivable wastelands, land under trees and groves, and barren and uncultivable land. The shares of all these categories have gone down. While this minimizes the effect on production of a declining land base to some extent, it should be noted that these lands are of poorer quality.

Increase in cropping intensity from 116 percent in 1978/79 to 158 percent in 1985/86 has contributed to vertical expansion of cultivated land. Irrigation has played a crucial role in this. This, and the fact that agricultural production has continued to grow, has led to a relative neglect of the land degradation phenomenon. However, in areas where these problems occur (for example, in Gauriganj Block), the effects are quite dramatic.

To study land use patterns at the farm level, two levels of disaggregation were used. First, the sample farms were divided into "normal" and "problem-affected" categories on the basis of the extent of the alkalinity/waterlogging problem. Farms having less than 30 percent of the area under problem soils were defined as normal and those having a higher incidence were designated as problem-affected. Land use and cropping patterns in these two categories were then compared. Second, land use and cropping patterns on each type of land--normal, alkaline, and waterlogged--were evaluated on the basis of plot data and farmers' categorizations of each of their plots. At this level, the effects are readily discernible.

Table 7 presents information on land use and crop-mix on normal and problem-affected farms. Salt accumulation is significantly more important than waterlogging. On average, 20 percent and 53 percent of the area on normal and problem-affected farms, respectively, is degraded.

On problem-affected farms 29 percent of the farm area is uncultivated as against about 11 percent on normal farms, which bears out the theory that salt accumulation leads to abandonment of cultivated land. As shown in Table 6, permanent fallowing was practically nonexistent until the late 1970s, which is what one would expect in a

Table 7--Average land use and cropping pattern on normal and problem-affected farms

Item	Normal Farms	Problem-Affected Farms
	(hectares)	
Area		
Total farm	0.90	21.93
Net cultivated	0.80	21.37
Fallow land	0.10	0.56
Gross cropped	1.34	1.51
Salt-affected	0.14	0.66
Waterlogged	0.04	0.36[a]
	(percent)	
Cropping intensity	166	110
Share of seasonal fallows		
Kharif	2	32
Rabi	34	57
Share of area under important crops[b]		
Paddy (HYVs)	51	35
Paddy (local)	6	24
Wheat	29	25
Pea	4	4
Mustard/linseed	2	2

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

[a] Includes a very small proportion that is both waterlogged and alkaline.
[b] Area is expressed in percent of gross cropped area.

system dominated by small farms. Salt accumulation and waterlogging erode the already meager land resource base of small farms.[6] Alkalinity was found to be more closely related to fallows. The correlation

[6]On farms where these problems did not exist, the entire farm area was cultivated, and there were no fallow lands.

between fallow area and waterlogged area was not statistically significant, whereas that between fallow area and salt-affected area was 0.467 and highly significant. Waterlogged area can be planted, but highly alkaline soils are uncultivable.

Even on cultivated lands, the land use intensity is adversely affected by alkalinity and waterlogging. In a year with normal rainfall, the entire cultivated area is usually planted in the *kharif* (monsoon) season; *rabi* (winter) cropping is limited by reduced soil moisture. With irrigation, two or more crops can be grown on the same plot of land and land use intensity goes up. Table 7 shows that the cropping intensity is 166 percent on normal, and 110 percent on problem-affected farms. In this area of relatively moderate rainfall, even rainfed farms are usually cultivated at more than 100 percent intensity. Despite availability of irrigation, the intensity level is reduced by alkalinity and waterlogging. The extent of this problem is brought into sharper focus by looking at seasonality in land use under seasonal fallows in Table 7. As expected, more than 98 percent of the land is cultivated in the *kharif* season on normal farms, whereas 32 percent is left uncropped in this season on problem-affected farms. Because irrigation is available, about two-thirds of the cultivated area on normal farms is cropped in the *rabi* season. On problem-affected farms, only 43 percent of the cultivated area is cropped.

Paddy and wheat account for 84-86 percent of the gross cropped area on both categories of farms. A major difference is the lower coverage under high-yielding varieties (HYVs) of paddy on problem-affected farms. On normal farms, about 91 percent of the paddy area is under HYVs; on problem-affected farms, it is only 59 percent. Soil constraints seem to inhibit spread of these varieties. This will be discussed further on.

Disaggregated plot-level data in Table 8 shows how normal, alkaline, and waterlogged lands are used. As expected, normal plots are intensively cultivated: 96 percent of the area is cropped in the *kharif* season and 81 percent in the *rabi*, resulting in an intensity level of 178 percent over the year. On salt-affected and waterlogged lands, cropping intensities are 84 percent and 54 percent, respectively. Even in the *kharif* season, about half of such lands are uncultivated. On alkaline plots, the cultivated area is somewhat larger in the *kharif* season because rains help reduce the concentration of salt in the root zones. Similarly, an early crop of paddy can be grown before the land becomes waterlogged. In winter, cropping options are limited because land preparation and sowing operations cannot be done due to the poor condition of the soil on alkaline plots and continued waterlogging.

Table 8--Land use and crop mix on normal, salt-affected, and waterlogged lands

Item	Normal Plots	Alkaline Plots	Water-logged Plots
		(percent)	
Seasonal fallows			
Kharif	4	47	52
Rabi	19	68	95
Cropping intensity	178	84	54
Share of crop area[a]			
Paddy (HYV)	32	27	47
Paddy (local)	20	34	43
Wheat	28	28	9
Barley	...	3	nil
Pea	6	3	1
Other pulses	3	nil	nil
Mustard/linseed	2	2	...
Other crops	9	3	nil

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

[a] Expressed in percent of gross cropped area.

Note: The ellipses (...) indicate less than 1 percent.

Paddy claimed the largest share of total cropped area in all kinds of soils (Table 8). Where waterlogging existed, 90 percent of the cropped area was under paddy. As the extent of alkalinity and waterlogging increases, the acreage allocated to paddy increases because of its greater tolerance of salts and waterlogging. Few other crops can survive under waterlogged conditions or are as tolerant of alkalinity. Moreover, paddy helps improve sodic soils (Abrol and Bhumbla 1979; Abrol 1985).

The preference for local varieties of paddy for use on salt-affected and waterlogged lands is clear in Table 8. Of the total paddy area, about 56 percent was allocated to local varieties on salt-affected

land, and 48 percent on waterlogged lands. On normal soils, only 36 percent was in local varieties. Thus, while adverse soil conditions do constrain the spread of HYVs, area allocated to HYVs is still significant. In chapter 5, the relative superiority of HYVs for different soil conditions is demonstrated.

Wheat was the most important crop during the winter season in all types of soil, although its relative share declined in waterlogged soils. Prolonged waterlogging precludes the possibility of growing wheat. Pea acreage also declines with deteriorating soils. Barley, a relatively tolerant crop, claims some area under salt-affected conditions.

Crop production choices are severely restricted under degraded soil conditions and the choice is restricted to paddy under waterlogged conditions.[7] Under salt-affected conditions, pulses, sugarcane, potato, and a number of other crops are not grown. The relevant tolerance of crops to alkalinity is as follows (Abrol and Fireman 1977):

Tolerant	Semitolerant	Sensitive
Bermuda grass, para grass, rice, and sugar-beet	Wheat, barley, oats, raya, senji, berseem, sugarcane, millet, and cotton	Cowpea, gram groundnut, lentil mash, mung, peas, maize, and cotton (at germination)

Where soils are alkaline, the choice is severely restricted and confined to grasses and cereals. Exclusion of high-value and nutritious species has implications not only for cash income, but also for household food consumption.

Incidences of alkalinity and waterlogging thus effect land resources in two ways. In extreme situations, they lead to abandonment of cultivation, as shown by the 29 percent of the farm area that was uncultivated on problem-affected farms in the study area. Second, even on cultivated land, the intensity of land use declines substantially as these problems grow. In these situations, the positive intensification effects of irrigation are lost. Moreover, degradation of land resources restricts cropping options severely. Some crops that are crucially important for cash income and family food consumption are forced out of

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[7]About 10 percent of waterlogged area is sown with other crops, but these are late plantings after some fields have dried up. As shown in Chapter 5, productivity is extremely low in such situations.

the cropping system. Thus, both quantitatively and qualitatively, land degradation aggravates land scarcity. In an area where more than 93 percent of the holdings are less than 2 hectares in size and about 87 percent of the population is dependent upon agriculture for its livelihood, land degradation is a serious threat.

INPUT USE AND LAND DEGRADATION

When cultivated area is abandoned and land use intensity decreases the demand for resources is depressed. Where nonpurchased inputs (notably labor and bullocks) are already underemployed, the effects on employment and incomes could be grave. These longer-term effects are not quantified in this report, however.

In this section, resource use per hectare of cultivated normal, salt-affected, and waterlogged land is examined to decipher the short-term effects. Results are first presented on an aggregate basis, followed by results for paddy, wheat, and barley, the most important crops of the area.

In general, the aggregate resource use per hectare was about 21 percent lower under salt-affected and waterlogged conditions than under normal conditions (Table 9). Labor (human as well as bullock and tractor) accounted for about 48 percent of the total cost under normal cultivation. Fertilizers and seeds claimed another 34 percent. The share of labor rose to about 51 percent on salt-affected lands and that of seed-fertilizer went down to 23 percent. The use of inorganic fertilizer declined significantly, while organic manures gained in importance, a practice that is recommended for alkaline soils. Under waterlogged conditions, the share of labor inputs rose to 59 percent. The share of traditional labor inputs--human and bullock--was 39.5 percent on normal soils, rising to about 54 percent on waterlogged plots, which are not easily cultivable by tractors. The contribution of seeds and fertilizers was 23 percent in this case also. Thus, the share of modern inputs--improved seeds, fertilizers, tractors--declines substantially on cultivated degraded soils.

A comparison of absolute levels of inputs confirms these findings. Human labor use is significantly higher on waterlogged plots. As shown earlier (Table 8), this is due to the dominance of human labor-intensive paddy in the cropping pattern. Seed and fertilizer rates decrease, presumably because of poor response. In contrast to normal soil conditions, manure, rather than inorganic fertilizer, is the dominant fertility-enhancing input under problem soil situations. Irrigation costs, because they are levied regardless of soil condition or level of use, remain more or less constant.

Table 9--Aggregate resource use pattern on different types of soil

Input	Normal Soil	Alkaline Soil	Waterlogged Soil
		(Rs/hectare)	
Seed	272	207	119
Manure	126	159	134
Fertilizer	287	141	114
Labor	675	580	777
Bullock/tractor	278	233	140
Irrigation	140	138	141
Other costs[a]	219	122	137
Total	1997	1580	1562

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

[a]Includes machine, pesticides, depreciation, interest, and other costs.

Similar data for paddy, wheat, and barley are presented in Tables 10 and 11. Results for paddy are broadly in line with the aggregate trend. Labor accounts for about 44 percent of the total cost for HYVs of paddy; its share rises to 51 percent on waterlogged lands. As expected, fertilizer's share declines substantially, while that of manure rises on salt-affected plots. In absolute terms, labor use per hectare declines by 23 percent on salt-affected soils and fertilizer use by 62 percent. In aggregate terms, total inputs for HYVs of paddy decline by 23 percent on salt-affected and 31 percent on waterlogged lands. A similar decline is apparent for local varieties of paddy, but the amount is smaller. Total input use goes down 16-17 percent under adverse soil conditions. The use of manure remains stable over all soil conditions, but inorganic fertilizer use declines. On waterlogged soils, about 42 percent less fertilizer is used. This compares with adecline of about 66 percent for HYVs. The use of inputs on traditional varieties thus appears to be less sensitive to adverse soil conditions. This is particularly true for waterlogging, where input use declines by 31 percent for HYVs, but only by 16 percent for local varieties. The taller traditional varieties are better adapted to waterlogged conditions.

Table 10--Input use for paddy under different soil types

Input	Normal Soil		Alkaline Soil		Waterlogged Soil	
	HYVs	Local Varieties	HYVs	Local Varieties	HYVs	Local Varieties
	(Rs/hectare)					
Seed	113	109	113	100	116	115
Manure	235	157	217	177	145	161
Fertilizer	312	157	118	137	107	91
Labor	1,016	963	784	676	815	777
Bullock	91	80	89	93	37	68
Tractor	120	102	121	113	67	101
Machinery	118	68	68	46	49	411
Irrigation	143	143	143	143	143	143
Others	167	136	124	111	112	115
TOTAL	2,315	1,915	1,777	1,596	1,591	1,612

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

Wheat is not grown in waterlogged conditions, as mentioned earlier. This column in Table 11 pertains to lands that are waterlogged only until November or December. Wheat is planted late as these lands become manageable. Seed, manures, and fertilizer account for a larger share of total costs in wheat than in paddy, where labor (human, bullock, and tractor) is the dominant factor. Aggregate input use falls by 18 percent under salt-affected and 34 percent under waterlogged conditions. As in the case of paddy, fertilizer use is lower and manure use higher when growing wheat under salt-affected conditions, though the decline in fertilizer use is 29 percent for wheat, as against 62 percent for HYVs of paddy.

Barley is grown without any fertilizer or manure. Table 11 shows that input use for this crop is least sensitive to changing soil conditions. Aggregate input use under salt-affected condition is only 6 percent lower than that under normal soils. In fact, barley is mainly grown on salt-affected lands (Table 8). Under this situation, its resource needs are about 41 percent lower than those of wheat.

To summarize, this chapter shows that land use and intensity are adversely affected by alkalinity and waterlogging; cropping options are also restricted. Where land is scarce, the adverse implications for farm production and incomes are clear. Use of modern inputs like fertilizers and machines is also lower on such lands. Crops and varieties differ in their sensitivity to adverse soil conditions with regard to the resources used with them. HYVs of paddy suffer most. Resource use on traditional varieties of paddy in the *kharif* and barley in the *rabi* season are most tolerant in this regard. In general, farmers tend to revert to low-output traditional varieties and practices as soil conditions deteriorate. It is important to note that use of soil amendments (mainly gypsum), recommended for reclamation of salt-affected (alkali) soils, was not resorted to by any farmer.

Table 11--Input use for wheat and barley under different soil types

Input	Wheat			Barley	
	Normal Soil	Alkaline Soil	Water-logged Soil	Normal Soil	Alkaline Soil
	(Rs/hectare)				
Seed	399	394	362	396	386
Manure	50	81	40	...	...
Fertilizer	458	324	320	...	...
Labor	286	267	163	199	162
Bullock	129	86	93	67	60
Tractor	267	202	87	150	142
Machinery	96	...	...	...	...
Irrigation	143	143	143	143	143
Others	135	106	87	59	56
TOTAL	1,963	1,603	1,295	1,014	949

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

Note: The ellipses (...) indicate a nil or negligible amount.

5. CROP PRODUCTIVITY AND FARM INCOMES

The effects of land degradation on productivity and profitability are assessed in this chapter. First, farmers' perceptions of how yields decline over time as alkalinity and waterlogging problems grow are considered, followed by a discussion of current yields and incomes from crop cultivation under different soil conditions. Finally, quantitative estimates of the effects of land degradation on gross output are presented.

TREND IN CROP PRODUCTIVITY

In an attempt to ascertain how the yields of major crops--rice and wheat--have behaved over time on affected plots, farmers were questioned in a survey. This information involves systematic recall over a period of time and is therefore subject to bias. However, since no other information is available on the time-path of productivity deterioration, these data are analyzed.

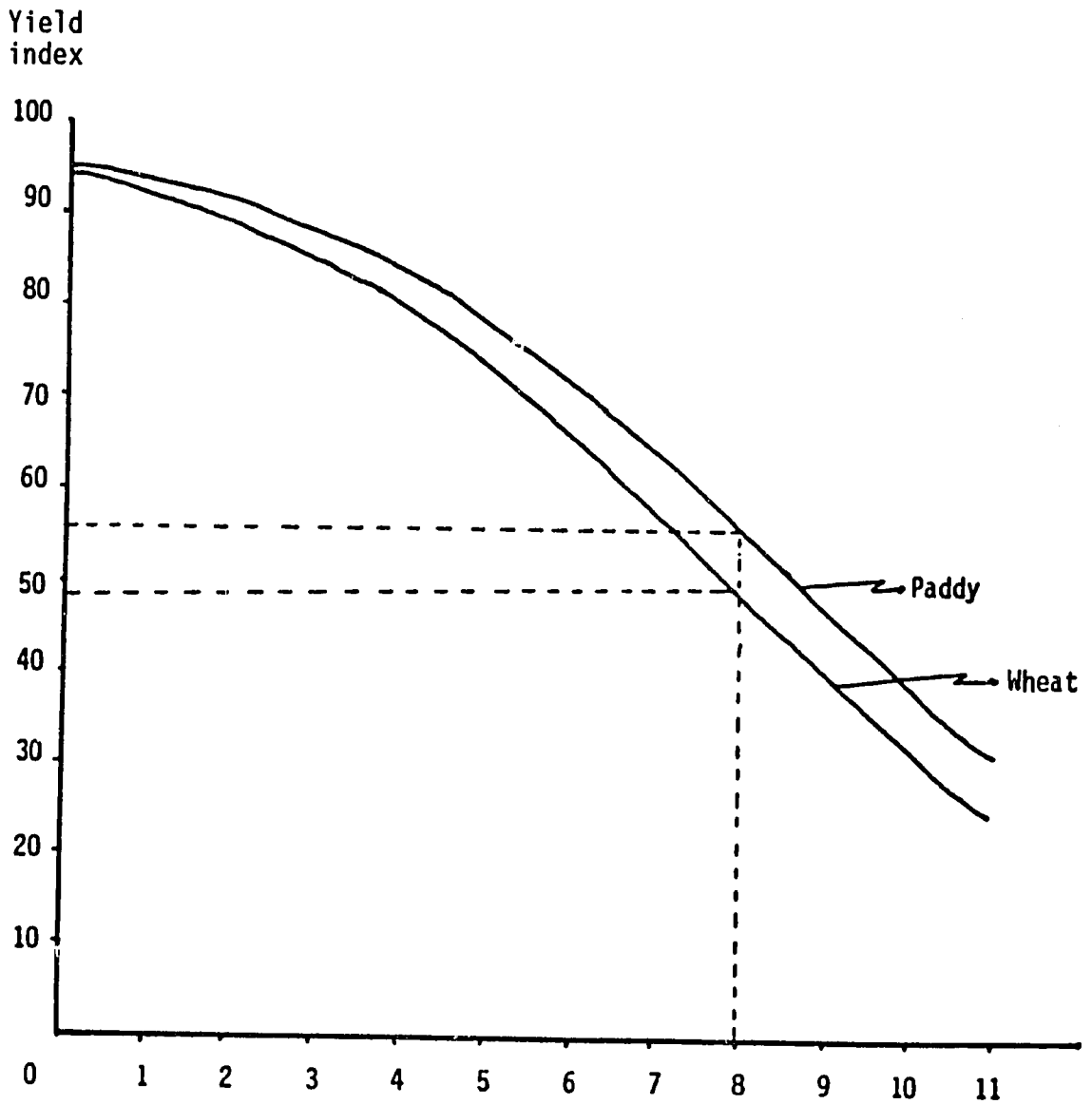
Logistic trend functions are estimated, relating yields on problem-affected plots with time for paddy and wheat. The estimated equations are presented in Appendix Table 20 and the estimated time-paths are plotted in Figure 5.

The figure indicates that the perceived rates of decline are very similar for both the crops, though paddy yields are marginally less vulnerable. This is somewhat at odds with experimental evidence, which suggests that paddy is not only more tolerant to these soil adversities, but that growing paddy on salt-affected land leads to improvements in the condition of the soil (Abrol and Bhumbla 1977). Farmers do not seem to perceive any great difference between the two crops, however.

The estimated equations in Appendix Table 20 indicate that paddy yields on salt-affected plots decline by 61 percent and wheat yields by 68 percent over 10 years' time. Figure 5 shows that yields are halved in about 8 years.

Despite limitations of data, these numbers emphasize farmers' concerns with the problems of alkalinity and waterlogging. Their inability to clearly distinguish intercrop differences in sensitivity of crop yields could be exploited as a useful extension message. However, awareness of these distinctions is reflected in their crop choice--higher area allocations to paddy and barley on salt-affected soils

Figure 5--Decline in productivity of paddy and wheat on salt-affected soils



Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1981.

(Table 8). As mentioned earlier, it is crucial that these micro concerns are reflected in macro policies.

PRODUCTIVITY AND LAND DEGRADATION

Current levels of productivity of major crops on farmers' fields under different soil environments are summarized in Table 12. All are irrigated yields. Average normal yields range between 2.6 and 2.7 tons per hectare for HYVs of paddy and wheat. These, as well as the yields of the traditional varieties of paddy and barley, are reasonable estimates of irrigated yields in the area. As expected, yields are highest on normal plots for all crops. However, the relative decline in yields due to soil degradation varies by crop. It should also be noted that variability in yields is always higher under degraded soil conditions.

Between the two paddy varieties, declines in yield due to deteriorating soils are lower for the traditional types. On alkaline plots, the average yield of HYV paddy decreases by 51 percent and that of local varieties, by 46 percent. Under waterlogged conditions, the corresponding figures are 41 and 26 percent, respectively. As one would expect, the tall traditional varieties withstand waterlogging better. The superiority of HYVs of paddy over the traditional types, though consistent, appears to diminish with soil degradation: on normal soils HYV yields are 42 percent higher than local; on salt-affected and waterlogged plots, the yield advantage is reduced to 26 and 12 percent, respectively. In general, increased sodicity is a more severe constraint than waterlogging for this crop.

The relative decline in yields due to sodicity is about 56 percent for wheat. Yields are dramatically reduced on previously waterlogged plots, mainly because sowing is extremely delayed. Referring back to Table 8, only 9 percent of the cropped waterlogged area was sown in wheat, compared with 28 percent on normal soils. Barley yields were the least sensitive to alkalinity. The relative decline was only 18 percent. Under normal conditions, wheat yields are about 100 percent higher than barley, the competing cereal in the *rabi* season; on salt-affected plots the difference is only 7 percent. The relative profitability of the two crops will be examined in the next section; at this stage it is enough to say that very little area with normal soil is sown in barley.

The actual yields presented in Table 12 appear to be consistent with the trends estimated from farmers' recall information in Figure 5. On average, wheat and paddy yields on salt-affected plots are nearly half the normal plot yields. Figure 5 suggests that it takes about 8-9 years to realize declines of this size. Since the length of time during which plots have been subjected to high salt incidence varies, an

Table 12--Average productivity of major crops on different types of soil on farmers fields in the study area

Crop/ Soil Type	Productivity			Coefficient of Variation
	Average	Maximum	Minimum	
	(kilograms/hectare)			(percent)
Paddy (HYV)				
Normal	2,773	4,200	1,333	26.7
Alkaline	1,349	2,033	727	29.3
Waterlogged	1,630	2,280	857	29.1
Paddy (local)				
Normal	1,958	3,428	960	34.6
Alkaline	1,067	2,300	240	53.6
Waterlogged	1,450	2,639	650	43.7
Wheat (HYV)				
Normal	2,596	3,621	800	27.1
Alkaline	1,139	1,739	571	32.8
Waterlogged	580	831	421	32.5
Barley				
Normal	1,297	1,460	1,190	11.7
Alkaline	1,066	1,400	732	31.3

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

average reduction in yield of 50 percent 12-13 years after the farmers first observed the problem seems reasonable.

Finally, yields vary more when soils are degraded. This is particularly true for local varieties of paddy and barley. Since the HYVs of paddy and wheat are generally grown on better plots, this selectivity helps reduce variability. The remaining plots range widely in fertility and extent of soil degradation.

INCOMES FROM CROP PRODUCTION

In the final analysis, the effects of soil degradation have to be measured in terms of the incomes of farmers. Estimates of losses in earnings are crucial for appraising investments directed toward control and abatement of these problems. This section provides estimates of the returns from production of major crops under different soil environments (Table 13).

As expected, the highest net incomes per hectare are generated by HYVs of paddy and wheat on normal soils in the *kharif* and *rabi* seasons, respectively. On normal soils, net incomes from HYVs of paddy are about twice as high as incomes from traditional varieties. Moreover, this advantage is maintained for all soil conditions. This finding contrasts with the findings based on yields and gross incomes, which show that the physical superiority of HYVs declines under adverse soil conditions. Obviously, the reduced costs more than compensate for the reduced superiority in yields. This is borne out by data on cost per hectare. Fertilizer and machinery costs were shown to be drastically reduced for HYVs (Table 10). In absolute terms, however, net income declines are dramatic for both high-yielding and traditional varieties of paddy.

In the *rabi* season, barley clearly outperforms wheat under salt-affected conditions. On normal soils, net returns from wheat are more than twice as high as those from barely; under sodic conditions, returns from barley are four times higher than those for wheat. Even in absolute terms, barley is more profitable than wheat on salt-affected soils.

When the net return figures are compared with gross output, it is clear that soil degradation affects the economic viability of crop production more strongly. For example, declines in the output of HYVs of paddy on degraded soils range from 41 to 51 percent; net incomes, however, fall 54-80 percent, compared with normal soils. For wheat, net returns decline by 92 percent, while output falls by 56 percent. Again, with an 18 percent decline in physical production and a 30 percent fall in net income, barley stands out as the least affected crop.

Ratios of net income to cost, which indicate of short-term returns to capital investment, show that cultivation of salt-affected plots generate noncompetitive returns ranging from -6 percent for local paddy to 14 percent for HYV paddy. Barley is the only crop that generates an attractive return on investment of 68 percent under salt-affected conditions.

High social costs of land degradation are reflected in sharp increases in production costs. Growing paddy under waterlogged conditions raises unit costs 18-19 percent. The effects of alkalinity are even more dramatic. For paddy, production costs go up by about 60

percent, and for wheat, by 85 percent. An increase of 13 percent is indicated for barley.

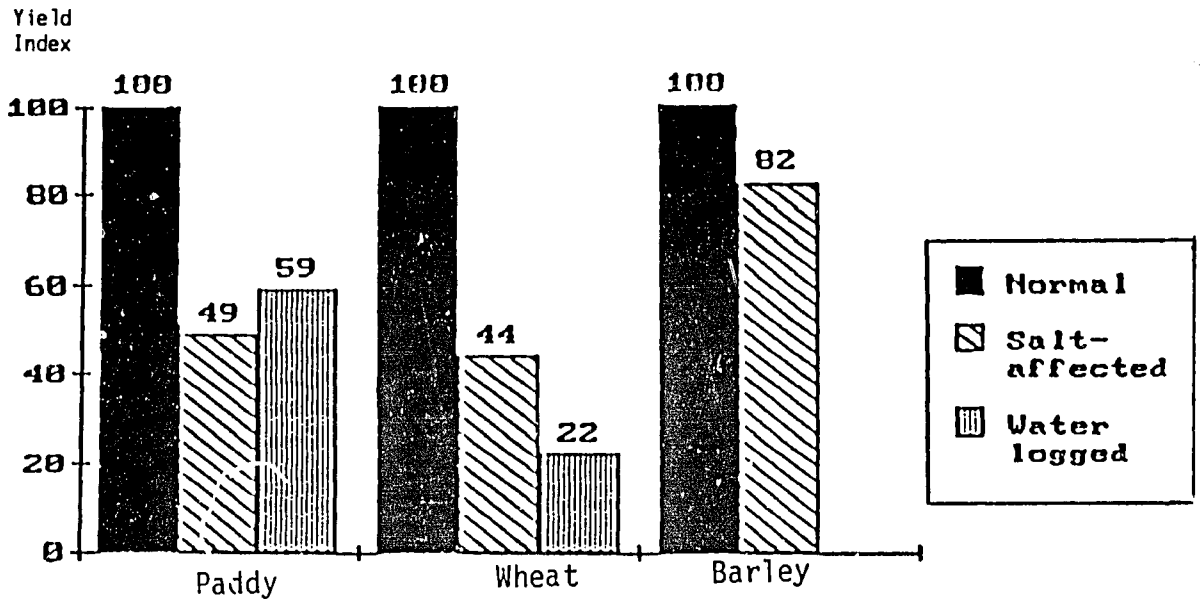
Table 13--Costs and returns from major crops under different soil conditions

Crop (Variety)/ Soil Type	Gross Income	Costs	Net Income	Net Income-Cost Ratio	Cost/ Kilogram
	(Rs/hectare)				(Rs)
Paddy (HYV)					
Normal	4,159	2,315	1,844	0.79	0.83
Alkaline	2,024	1,779	245	0.14	1.32
Waterlogged	2,445	1,592	853	0.54	0.98
Paddy (Local)					
Normal	2,835	1,915	920	0.48	0.93
Alkaline	1,494	1,598	-104	-0.06	1.50
Waterlogged	2,029	1,613	416	0.26	1.11
Wheat (HYV)					
Normal	4,024	1,963	2,061	1.05	0.76
Alkaline	1,765	1,603	162	0.10	1.41
Waterlogged	899	1,296	-397	-0.31	2.23
Barley					
Normal	1,945	1,014	931	0.92	0.78
Alkaline	1,599	949	650	0.68	0.89

Source: Central Soil Salinity Research Institute, survey on farm-level effects of land degradation from irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

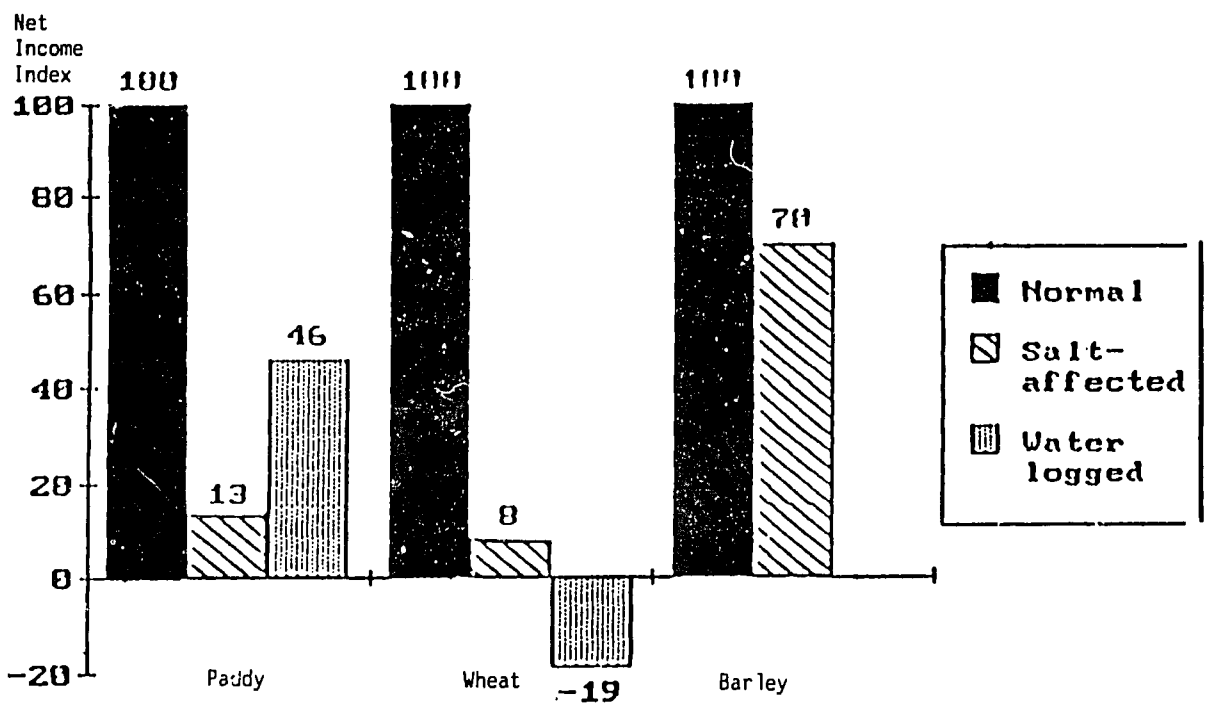
Efficiency losses at the farm level due to alkalinity and waterlogging problems are very large (Figures 6 and 7). In areas where these problems are serious, the positive gains from irrigation are seriously threatened.

Figure 6--Indices of crop yields under different soil conditions



Source: Central Soil Salinity Research Institute, Survey on Farm-Level Effects of Land Degradation from Irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

Figure 7--Net income indices under different soil conditions



Source: Central Soil Salinity Research Institute, Survey on Farm-Level Effects of Land Degradation from Irrigation, Sultanpur District, Uttar Pradesh, India, 1986.

DECOMPOSITION OF CHANGES IN OUTPUT

The preceding analyses have shown that output levels are substantially lower on salt-affected and waterlogged lands, and that farmers cut back the use of production resources on cultivated degraded soils. It is important to sort out the contributions of these two effects in order to discern the true impact of soil alkalinity and waterlogging.

Several analytical approaches have been used to assess these kinds of relationships. Pincock (1969) and the U.S. Environmental Protection Agency (1971) use whole farm budgets to analyze the impact of salinity on net farm incomes. Moore, Snyder, and Sun (1974) use procedures based on linear programming to estimate economic damage on multicrop farms. Variants of this approach have also been applied by Boster and Martin (1978) and Oyarzabad and Young (1978). Dynamic programming models are used by Yaron (1985) and Yaron and Olian (1973) to analyze the long-run implications of leaching of salts with irrigation for annual and perennial crops. Hussain and Young (1985) and Joshi (1987) estimate losses due to soil salinity using a production function approach. Whereas the former use electrical conductivity as one of the variables, the latter estimate the effects with the help of a dummy variable.

In this study an alternative production function approach is used. Separate production functions are estimated for different soil types. These are specified in a log-linear form as follows:

For normal soil,

$$\text{Log } Y_n = \text{Log } A_n + \alpha_n \text{ Log } S_n + \beta_n \text{ Log } F_n + q_n \text{ Log } L_n; \qquad (1)$$

for alkaline soil,

$$\text{Log } Y_s = \text{Log } A_s + \alpha_s \text{ Log } S_s + \beta_s \text{ Log } F_s + q_s \text{ Log } L_s; \qquad (2)$$

and for waterlogged soils,

$$\text{Log } Y_w = \text{Log } A_w + \alpha_w \text{ Log } S_w + \beta \text{ Log } F_w + q_w \text{ Log } L_w, \qquad (3)$$

where Y = gross income in rupees per hectare,
S = value of seed in rupees per hectare,
F = value of inorganic fertilizer in rupees per hectare, and
L = total labor cost in rupees per hectare.

The subscripts n, s, and w denote normal, alkaline, and waterlogged plots; A is the scale parameter, and α, β, and q are output elasticities with respect to different inputs.

Taking the difference between (2) and (1) and between (3) and (1) yields the following:

$$\begin{aligned}\text{Log } (Y_s/Y_n) &= \text{Log } (A_s/A_n) \\ &+ [(\alpha_s-\alpha_n) \text{ Log } S_n + (\beta_s-\beta_n) \text{ Log } F_n + (q_s-q_n) \text{ Log } L_n] \\ &+ [\alpha_s \text{ Log } (S_s/S_n) + \beta_s \text{ Log } (F_s/F_n) + q_s \text{ Log } (L_s/L_n)], \qquad (4)\end{aligned}$$

and, similarly,

$$\begin{aligned}\text{Log } (Y_w/Y_n) &= \text{Log } (A_w/A_n) \\ &+ [(\alpha_w-\alpha_n) \text{ Log } S_n + (\beta_w-\beta_n) \text{ Log } F_n + (q_w-q_n) \text{ Log } L_n] \\ &+ [\alpha_w \text{ Log } (S_w/S_n) + \beta_w \text{ Log } (F_w/F_n) + q_w \text{ Log } (L_w/L_n)]. \qquad (5)\end{aligned}$$

Relations (4) and (5) approximately apportion the differences in gross income per hectare between normal and salt-affected lands and between normal and waterlogged lands, into three components. The first term on the right-hand side indicates the percent change in gross income due to a shift in the scale parameter A. The next term measures the effect of change in slope parameters. These two terms sum up to the total land degradation effect. The third term measures the contribution of changes in input levels between the two situations. Unlike the other approaches based on production functions, this formulation explicitly recognizes that the soil degradation effect has two dimensions--one a pure intercept effect and the other due to changes in response coefficients.

The estimated regression equations for each soil type are presented in Table 14. All three variables--seed, fertilizer, and labor--are statistically significant in the equation for normal soils. In the other two cases, labor is the only significant variable. This indicates that the response to inputs changes significantly as soil conditions deteriorate. The specification used in this model does not adequately capture these differences. The values of adjusted R^2 range from 83 percent for waterlogged soil (equation 3) to 41 percent for salt-affected soil (equation 2). Aggregation over crops and imprecise classification of plots in the three categories could be responsible for these results. Aggregation is addressed subsequently when cropwise equations are estimated. The classification problem cannot be addressed because of data limitations.

Results of the decomposition exercise are reported in Table 15. The estimated model accounts for 88 percent of the difference in mean income between normal and salt-affected soils and 84 percent of that between normal and waterlogged soils. Numbers in the table apportion this explained output difference.

Table 14--Log-linear production functions for normal, alkaline, and waterlogged soils

Soil Type	Constant	Seed	Fertilizer	Labor	$\bar{R}^2$	n
Normal	2.5572	0.9100 (4.675)	0.2433 (3.365)	0.2013 (1.604)	0.43	74
Alkaline	3.3640	0.5655 (1.155)	0.0367 (0.419)	0.4563 (2.129)	0.41	37
Waterlogged	3.3359	0.3394 (0.348)	0.0084 (0.040)	0.6781 (3.922)	0.83	22

Note: Figures in parentheses are t-values.

Table 15--Decomposition of output differences into soil degradation and input change effects

Item	Percentage Attributable	
	Alkaline versus Normal Soil	Waterlogged versus Normal Soil
Source of change		
Alkaline/waterlogged soil	-71.7	-76.8
Changes in inputs	-28.3	-23.2
Seed	-17.8	-33.3
Fertilizer	-2.8	-0.9
Labor	-7.7	+11.0
Total difference explained	100.0 (88.4)	100.0 (83.9)

Note: Figures in parentheses indicate the percentage of the observed difference explained by the decomposition model.

Table 15 indicates that alkalinity accounts for as much as 72 percent of the difference in gross income between normal and salt-affected plots. The corresponding figure for waterlogged soils is about 77 percent. These values indicate that, using the same amount of resources as on normal soils, gross output declines by 72 percent on salt-affected soils and by 77 percent on waterlogged soils. Only 23-28 percent of the output differences can be attributed to curtailment of input use on degraded soils.

Similar results were obtained when the analysis was done for individual crops, though the magnitudes differed. Also, because of an inadequate number of observations, data for alkaline and waterlogged plots were pooled. Thus, there were only two categories of land--normal and degraded--for this analysis. The estimated regressions are presented in Appendix Table 21, and Table 16 shows the results of the decomposition exercise for paddy and wheat.

Table 16--Decomposition of output change for paddy and wheat

Item	Percentage Attributable		
	Paddy (HYV)	Paddy (Local)	Wheat
Source of change			
Salt-affected and waterlogged soils	-88.5	-66.3	-67.3
Changes in inputs	-11.5	-33.7	-32.7
Fertilizer	-5.1	-4.4	-1.2
Labor	-4.1	-19.1	-21.2
Other expenses	-2.3	-10.2	-10.3
Total difference explained	100.0 (83.7)	100.0 (54.3)	100.0 (93.1)

Note: Figures in parentheses indicate the percentage of observed difference explained by the decomposition model.

Again, the bulk of the output difference between normal and degraded lands can be attributed to soil degradation. This effect is most dramatic for HYVs of paddy, where it accounts for more than 88 percent of the output difference. For local varieties of paddy and

wheat, soil degradation contributes nearly two-thirds to the output decline. The HYVs of paddy are more severely affected by alkalinity and waterlogging than the other crops. Unfortunately, it is not possible to isolate individual effects. For local varieties of paddy and wheat, changes in input levels account for nearly a third of the output difference. It should be noted, however, that the model does not give good results for local paddy.

These numbers underscore the extent of damage in productive capacity caused by alkalinity and waterlogging. As discussed earlier, in several cases crop production on such lands has ceased to be economically viable (Table 13). Such lands are eventually taken out of crop production. The growing incidence of permanent fallows perhaps reflects this tendency. With two-thirds to nearly nine-tenths of the output decline attributable to degradation, it is clear that ameliorative responses must focus on arresting and reversing this process.

6. CONCLUSIONS

Irrigation has traditionally been viewed as the driving force behind intensification of agriculture in densely populated agricultural systems. In measuring the farm-level effects of alkalinity and waterlogging in a vulnerable zone within the Sharda Sahayak Canal System, this study indicates that problems of soil alkalinity and waterlogging resulting from imprudent use of irrigation water threaten not only the economic viability of such investments but also the sustainability of production in canal irrigated areas. Precise estimates of the area affected by these problems within the 1.6 million hectares of the command area are not available. Attempts are now being made to collect these data. In this study the primary concern is to demonstrate what happens to production and use of resources at the farm level as these problems assume serious dimensions. Without such data, benefit-cost calculations for irrigation and other land improvement investments cannot take these external diseconomies into consideration.

The study area (Sultanpur district) is dominated by small farms--about 94 percent of the holdings are less than 2 hectares in size. Aggregate data at the district level indicate that agricultural performance over the last decade has been impressive. Production of rice and wheat, the two major crops accounting for 73.0 percent of the gross cropped area, has grown at the rate of 6.3 and 12.0 percent per year, respectively. Mainly as a result of the expansion of canal irrigation under the Sharda Sahayak Canal system, cropping intensity in the Gauriganj Block grew from 118 percent in 1978/79 to 158 percent in 1985/86. These numbers effectively conceal the emerging problems of soil degradation and production decline in affected areas.

Results of this study, based on a survey of 110 farming households in the Gauriganj Block during 1985/86, indicate that the adverse effects of increasing soil sodicity and waterlogging are substantial. During the 12-13 years following the commissioning of the canal system, more than 87 percent of the farms were affected by these problems. The water table rose at an alarming rate. On problem-affected farms, as much as 29 percent of the farm area is uncultivated. Even where alkaline and waterlogged plots are cultivated, the land use intensity is low, despite the availability of irrigation. On these degraded soils, cropping options are also curtailed.

Yields of paddy and wheat are 41-56 percent lower on degraded soils. Net incomes are reduced by 87-92 percent on alkaline lands. In fact, barley is the only crop that yields economically viable returns on

such soils. Paddy is the only option on waterlogged lands, though net incomes are reduced by 54-55 percent, compared with paddy on normal soils. Loss in efficiency is dramatically demonstrated by increases in unit cost of production. For paddy, unit costs rise by about 60 percent, and for wheat, by 85 percent, when cultivation is extended on alkaline lands. On waterlogged plots, unit costs of paddy rise 18-19 percent.

These results are based on a very small sample and cannot even be generalized for the Sharda Sahayak canal system as a whole. More comprehensive studies are needed to validate these findings. Yet the results are so starling that some policy inferences can be drawn.

- The most important first step is to identify and quantify areas that are vulnerable and degraded in the different canal systems of the country. This calls for an inter-disciplinary effort involving irrigation specialists, soil scientists, and others. Sophisticated techniques based on remote sensing and satellite imagery are now available. There is a need to coordinate these efforts with ground-level verification. Soil testing units in the states and within command areas also need to participate in these evaluations, because correct identification of the nature of this problem is crucial for control (Abrol and Fireman 1977). Some initiative in this regard has been taken during recent years (Planning Commission 1985), but not in the coordinated manner outlined above. Strong statistical services at the command area level are also required. The existing reporting system based on administration units is inadequate for this task.

- Strategies to combat these problems fall mainly in the realm of irrigation system design, management, and operation, but first the options relevant to individual farmers need to be examined. Farmers do try to take advantage of differences in the sensitivity of crops to adverse soil conditions. They tend to plant crops that are more tolerant to salt and waterlogging where these conditions exist. There is a need to expand these options through specially directed crop improvement research. This is the main focus of crop improvement research at the Central Soil Salinity Research Institute and an important objective of the All India Coordinated Rice Improvement Project. The following varieties provide good results under conditions of high sodicity (alkaline) stress:

Paddy : IET 10694 (CSR 10), IET 10347 (CSR 12), and IET 10348 (CSR 13);
Wheat : KRL 1 and KRL 2;
Barley : C5B 1, 2, 3, 4, and CS 80-2.

The focus so far has been on these crops. There is a need to expand the crop base of this effort. At the same time, the supply of these seeds to affected farmers has to be ensured. The existing seed

distribution systems, public as well as private, focus on the mainstream HYVs and not on these specialized materials.

In addition to varieties, farmers could also benefit from chemical amendments under certain conditions. Application of gypsum has been recommended for reclamation of alkaline lands and, with current levels of subsidy, is an attractive option. Yet no farmer in our sample adopted this practice, probably because of inadequate extension services and deficiencies in supply of these bulky materials.

Finally, perhaps the most significant strategy for coping with these problems is improved on-farm water management. It is paradoxical that, whereas judicious use of irrigation water is the most critical recommendation for reclamation of salt-affected lands, it is availability of canal irrigation water itself that has aggravated the salt problem. Proper leveling of land and judicious use of irrigation water is crucial for improving and maintaining the productivity of these lands. These strategies--planting of salt-tolerant crops and varieties, use of soil amendments, and land and water management--are not adequately emphasized in extension programs; they remain preoccupied with recommendations for normal conditions. Even under the command area approach, this weakness persists. Thus, both research and extension systems and input distribution systems (for seeds and chemicals used as amendments) need to address these specific problems.

Drainage and improvements in the irrigation system are the most critical system-level interventions. Improvements that contribute toward containment of these problems involve modernizing the canal system by improving the conveyance of water by installing pipes and by lining canals, improving the effectiveness of water application through precision land leveling and advanced application methods. Command area and irrigation authorities need to assign high priority to these goals (Tyagi, Gupta, and Rao 1986).

Controlling the groundwater level by installing drainage systems is crucial in areas affected by waterlogging and alkalinity. Conjunctive use of ground and surface water not only helps to ameliorate the problem but also improves the efficiency of water resource use.

Scientific and technical parameters of the problem are well-understood and so are the solutions. Economic evaluation of these options (such as application of amendments and drainage) indicates that these are viable (Joshi and Agrihotri 1982). This is supported by results from a number of reclamation projects in the country (Joshi 1983; Kahlon and Singh 1983). But, this knowledge needs to be integrated into command area development plans and, of course, supported by additional funding. The economic trade-offs between creating additional irrigation capacity and improving drainage and other

components of existing irrigation systems need to be evaluated. The estimates of losses due to rising water tables and increased alkalinity presented in this study suggest that in the current context of restricted investible resources, the two alternatives could be highly competitive.

APPENDIX: SUPPLEMENTARY TABLES

Table 17--Extent of waterlogging and soil salinity in selected irrigation projects in India

Irrigation Project	State	Extent of Waterlogging	Extent of Soil Salinity
		(1,000 hectares)	
Sriramsagar	Andhra Pradesh	60.00	1.00
		47.62	0.79
Tungabhadra	Andhra Pradesh and Karnataka	4.65	24.48
		1.27	6.69
Gandak	Bihar and Uttar Pradesh	211.01	400.00
		21.11	40.03
Ukai-Kakrapar	Gujarat	16.25	8.29
		4.32	2.20
Mahi-Kadana	Gujarat and Rajasthan	82.00[a]	35.76
		16.81	7.33
Malaprabha	Karnataka	1.05[a]	...
		0.99	...
Chambal	Madhya Pradesh and Rajasthan	98.70	40.00
		20.31	8.23
Tawa	Madhya Pradesh	...	6.64
		...	3.79
Rajasthan Canal	Rajasthan	43.10	29.11
		7.98	5.39
Sharda Sahayak	Uttar Pradesh	303.00[a]	50.00
		28.34	4.68
Ramganga	Uttar Pradesh	195.00	352.42
		32.99	59.62

Source: Joshi, P.K. and Agrihotri, A.K., 1982, Impact of input subsidy on income and equity under land reclamation. *Indian Journal of Agricultural Economics*, 38(3):252-260.

[a] Includes waterlogged and saline area.

Table 18--Progressive development of irrigation potential and utilization in the Sharda Sahayak Irrigation Project

Year	Irrigation Potential	Area Irrigated			Percent Utilized
		Monsoon	Winter	Total	
		(1,000 hectares)			
1974/75	127	13	54	67	53
1975/76	175	388	81	119	68
1976/77	305	55	91	146	48
1977/78	500	73	104	177	35
1978/79	904	105	287	392	43
1979/80	1210	280	400	680	56
1980/81	1410	111	430	541	38

Source: Indian Agricultural Research Institute, *Resource Analysis for Integrated Development, Sultanpur District*, Water Technology Centre, New Delhi: IARI, 1986.

Table 19--Canal irrigation charges in Sultanpur District, 1983

Crop	Irrigation Charges
	(Rs/hectare)
Sugarcane	237.12
Paddy	143.26
Vegetables, garden	143.26
Potato	177.84
Tobacco	153.14
Wheat, barley, or mix of wheat and barley	143.26
Cotton	56.81
Fodder	49.40
Green manure	34.58
Other crops of winter season	106.21
Other crops of monsoon season	86.45

Source: Indian Agricultural Research Institute, *Resource Analysis for Integrated Development, Sultanpur District*, Water Technology Centre, New Delhi: IARI, 1986.

Table 20--Estimated logistic trend functions for important crops

Crop	Maximum Yield (k)	Intercept (a)	Rate of Change (b)	r^2
Paddy	1.00	3.04 (0.14)	-0.35 (0.03)	0.34
Wheat	1.00	2.84 (0.21)	-0.36 (0.04)	0.33

Notes: Figures in parentheses are standard errors. All estimated values are significant at the 1 percent probability level.

The estimated equation is $Y_t = k/1 + e^{-(a+bt)}$,

where Y_t is the productivity index in period t, K is the ceiling of productivity (productivity before any problem appears; assumed to be 100 percent), a and b are parameters to be estimated, and t is the time variable expressed in years.

Table 21--Production functions for paddy and wheat on normal and problem soils

Crop	Soil Type	Constant	Coefficient of Fertilizer	Coefficient of Labor	Coefficient of Other Expenses	R^2	N
Paddy (HYV)	Normal	217.3481	0.0649*** (0.0099)	0.3325*** (0.0797)	0.0597 (0.0921)	0.5157	66
	Alkaline/ waterlogged	145.2128	0.0409* (0.0240)	0.2102 (0.1792)	0.1704 (0.2518)	0.1171	27
Paddy (local)	Normal	27.9439	0.1069*** (0.0139)	0.2848** (0.1136)	0.3361*** (0.1205)	0.6892	34
	Alkaline/ waterlogged	8.9263	0.1184*** (0.0283)	0.3769* (0.2131)	0.3629* (0.2031)	0.4768	34
Wheat	Normal	1291.2939	0.1822*** (0.0108)	0.0263 (0.0334)	-0.0110 (0.0858)	0.8117	71
	Alkaline/ waterlogged	0.3186	0.0680** (0.0283)	0.5966*** (0.1773)	0.7190** (0.2603)	0.6891	23

Note: Figures in parentheses are standard errors.

*** Significant at the 1 percent probability level.
** Significant at the 5 percent probability level.
* Significant at the 10 percent probability level.

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