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Restoration of Soil Health for Achieving Sustainable Growth in Agriculture

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I. INTRODUCTION

Total geographical area of Pakistan is 79.61 million hectares (m.ha.). Area under cultivation is 21.59 m.ha.; of which, only 5.34 m.ha. (i.e., 25 percent) is free from soil limitations and is fit for intensive agriculture [Mian and Mirza (1993)]. The remaining agricultural lands have various types of problems including formation of slow permeability, water logging, salinity and sodicity, and wind and water erosion. Thus, on an average, three out of four hectares of cultivated land in Pakistan are in poor health. This in turn is causing temporary or permanent decline in the productive capacity of the land. Therefore, poor soil health is posing serious threat to the sustainable growth of agriculture. The most important on-farm effects of land are summarised in Table 1.

The remaining paper is divided into five sections. Section II gives details regarding water logging and salinity. Section III deals with the nutrient depletion and management. Section IV reviews the causes and effects of soil compaction. Section V is devoted to soil erosion, its causes and effects. Concluding remarks and researchable areas appear in Section VI.

II. WATERLOGGING AND SALINITY

Historically, there has been very little problem of waterlogging and salinity in the Indian sub-continent during the nineteenth and early twentieth centuries under the prevailing barrage controlled irrigation systems. These systems thinly spread water over large agricultural area. Overtime, seepage from canals and field percolation from continuous irrigation have caused the ground water to rise and the salts to move upward through capillary action that resulted into soil salinity or alkalinity and waterlogging.

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Table 1

Causes and Indicators of Resource Degradation

Resource Base	Possible Causes	Effects of Resources Degradation
Increase in Salinity/ Water Logging	Poor design of the irrigation system resulting in high seepage of water	Reduction in yields and fall in factor productivities
	Application of poor quality tubewell water	Reduced land use and cropping intensities
Increased Nutrient Depletion	Continuous practice of the same rotation	Reduction in yield and fall in factor productivities
	Continuous cropping of exhaustive crops	Declining efficiency of various fertilisers
	Reduction in area under leguminous crops	
	Declining organic matter	
Formation of Hard Pan	Increased use of machines	Reduction in yields and reduced factor intensities
	Use of brackish well water	
Devegetation	Indiscriminate cutting of trees	Barren fields and Increased erosion

Pakistan has two principal sources of irrigation that are surface water and groundwater. More than 100 million acre feet (MAF) of surface water is being diverted into the canal systems in the Indus plain. There are thus substantial losses in water in the system. Under the present conditions, the overall water use efficiency of the system is about 59 percent [Pakistan (1988)]. The chemical quality of the surface water shows that the total dissolved salts (TDS) contents commonly fall in the range of 150 to 250 mg/litter, which is excellent for irrigation, drinking and industrial purposes [Ghossemi *et al.* (n.d.)]. On the other hand, the groundwater quality varies depending on the climatic factors, nature of the surface flow, topography, extent of seepage and irrigation practices. The quality deteriorates as one goes across the plain from upstream to down stream towards the Arabian Sea and the TDS values range from 1000 mg/litter to 3000 mg/litter [Ghossemi *et al.* (n.d.)]. The ground water pumpage is about 44 MAF [Mohtadullah *et al.* (1993)]. Of this, about 32 MAF is used for irrigation showing water use efficiency of 73 percent. As regards the quality of ground water, about 25 percent of the tubewell water in Punjab is of marginal quality and 50 percent of the water is not safe for irrigation purposes. The situation is even worse in Sindh but the quantity of underground water used for irrigation in Sindh is much less [Malik *et al.* (1991)]. According to some estimates, about 7500 million tonnes (MT) of salts are present in the upper 100 meters of the groundwater reservoirs of the Indus Plain [ICID (1991)]. About 50 MT of salts are being added to the system every year through the canal irrigation water [Qureshi (1993)]. While 100 MT of salts are being added every year to the soil surface through tubewell irrigation [ICID (1991)]. Unfortunately, present export of salts out of the system is about 10-15 MT every year [Qureshi (1993)]. However, this figure is expected to rise upto 25-30 MT every year on the completion of the Left Bank Outfall Drain (LBOD) stage I project. Despite all this, the problem of salinity/ alkalinity is likely to aggravate further as the addition of salts is much more than the export of salts from the system.

Table 2 shows very serious concerns regarding the present situation of salinity/sodicity in Pakistan. Total affected area with salinity is about 6.2 m.ha.; of which, 4.3 m.ha. is severely saline/saline sodic and 78 percent (3.40 m.ha.) of this area is not even being cultivated. Major portion of this uncultivated area is approximately equally distributed in Punjab and Balochistan provinces. As regards the area with high water table, it is not easy to assess. However, some of the estimates show that the area with water table at 0–5 feet depth is 2 m.ha. in the month of June, but this figure increases to 5.2 m.ha. in the month of October [Pakistan (1997)]. Such a situation is considered disastrous for agricultural growth [Pakistan (1988)].

According to Javed (1991), a study conducted in Sheikhupura district, cropping and land use intensities were found about 11 percent and 62 percent less, respectively, on farms where the water table depth was 0–5 feet as compared to farms where the depth was 10 to 15 feet. The proportionate area under rice was found higher. It was lower for wheat and sugarcane on lands having water table depth of 0-5 feet as compared to other categories—5-0 feet and 10–15 feet. However, the yields of wheat, sugarcane and burseem were 2 to 4 times lower on the farms with high water table. Nadeem (1989), considering different levels of salinity/sodicity in Sheikhupura district, provided the same type of results. Another study by i.e., Mustafa (1991), conducted in the same district concluded that the wheat yield per acre on degraded soils, having PH and EC levels higher than 6.5 and 4.0, respectively, was half of that of the yield on non-degraded soils. Moreover, the use of inputs was found many times lower on degraded soils than that on non-degraded soils. As regards the reasons of land degradation, fifty percent of the farmers considered the scarcity of irrigation water, poor quality of the tubewell water was viewed as a source by 16 percent of the farmers and 10 percent of them blamed the lack of drainage facility. About 31 percent of the farmers mentioned no reason.

Table 2

Extent of Salinity/Sodicity in Pakistan (000 Hectares)*

Province	Slightly Saline/ Saline-Sodic[a]	Moderately Saline/Saline Sodic[b]	Severely Saline/Saline Sodic[c]	Total
Punjab				
Total	472.4	804.8	1390.3	2667.5
Cultivated	472.4	804.8	235.5	1512.0
Uncultivated	–	–	1155.5	1155.5
Sindh				
Total	118.1	324.7	1666.8	2109.6
Cultivated	118.1	324.7	708.2	1151.0
Uncultivated	–	–	958.6	958.6
NWFP & FATA				
Total	5.2	25.7	17.6	48.5
Cultivated	5.2	25.7	0.9	31.8
Uncultivated	–	–	16.7	16.7
Balochistan				
Total	3.0	74.6	1270.3	1347.9
Cultivated	3.0	74.6	31.4	109.0
Uncultivated	–	–	1238.9	1238.9
Pakistan				
Total	598.7	1232.8	1558.6	6173.5
Cultivated	598.7	1232.8	4345.0	2803.8
Uncultivated	–	–	3369.7	3369.7

* The extent is estimated for an area of about 20.6 m. ha. of Punjab, 9.2 m. ha. of Sindh, 9.1 m. ha. of NWFP and FATA and 30.5 m. ha. of Balochistan covered through reconnaissance soil survey.

[a] Includes soils having mainly surface or patchy salinity/sodicity.

[b] The figures given for cultivated area under these soils include a small extent of uncultivated soils which are expected to be brought under cultivation in very near future due to their location within irrigation command.

[c] The cultivated area reported under this category has relatively low discernible salinity but the soils are dense (impermeable) with severe sodicity problem.

In sum, the available empirical evidence shows that the decline in productivity because of salinisation ranges from 25 to 70 percent on moderately salt affected soils and it approaches 100 percent in areas where the problem of salinisation is severe. At the present stage of our development and in the face of explosive population growth, Pakistan economy cannot afford to see its crop yield declining with low crop germination rates and poor crop establishment in the fields. Restoration of soil health from the menaces of water logging and salinity deserves highest priority to ensure sustainable food security to the fast growing population of Pakistan.

In order to estimate the expected benefits from the improvement of degraded soils due to salinity/sodicity, economics of the use of various amendments has been determined. The experimental data used for this purpose were generated by the Department of Soil Science, University of Agriculture, Faisalabad during the period 1980-81 to 1984-85. These experiments were conducted at the farmer's fields for two soil series, i.e., Khurrianwala and Gandhara in Shahkot area of district Sheikhupura. There were four treatments: (1) T1 Control (leaching with saline-sodic ground water); (2) T2 Subsoiling (SS) (50 cm deep, 150 cm apart crosswise furrows); (3) T3 Gypsum (GYP) (@100 percent GR (Gypsum Requirement); and (4) T4 Subsoiling plus gypsum (SS+GYP). There were nine replications making a total of 36 plots each for Khurrianwala and Gandhara series. During the period of these experiments, rice-wheat rotation was practised.

The experimental data thus generated were analysed by using the partial budgeting technique recommended by CIMMYT (1988) and Chaudhry *et al.* (1995). The analyses are presented in Appendices I and II, which show that the best amendment for farmer's practice is gypsum for the reclamation of salt affected soils for Khurrianwala series and gypsum + subsoiling for the Gandhara series.

III. NUTRIENT DEPLETION AND MANAGEMENT

(i) Declining Soil Nutrient Status

There are different crop ecological zones in Pakistan/Punjab. In each zone, specific crop rotations are being practised. For example, in the rice-wheat cropping system, rice and wheat is the dominant crop rotation, where wheat follows the rice crop (Table 3). Traditionally, wheat and rice were grown as single crops in rice-fallow and fallow-wheat cropping patterns. Similarly, in the cotton wheat cropping system, wheat and cotton is the dominant crop rotation.

Table 3

Rotations Followed in the Rice—Wheat System

Rotation	Percent of Total
Rice-Wheat-Rice	71.8
Rice-Berseem-Rice	8.50
Rice-Watermelon-Rice	2.70
Rice-Fallow-Rice	6.50
Others	10.50
Total	100.00

Source: Ashraf (1984-85).

Major proportion of the total cropped area in various crop ecological zones is occupied by exhaustive crops: For example, in the rice - wheat cropping zone about 92 percent of the total cropped area is occupied by wheat, rice and fodder (Appendix III). Pulses, which help in improving the soil fertility, occupy only one percent area of the total cropped area. Similarly, in other crop ecological zones, with the exception of Mungbean-wheat cropping system, the area occupied by the leguminous crops is very small (Appendix III).

Besides the domination of exhaustive crops, the problem of declining soil nutrient status is getting more serious with the increasing cropping intensities in various zones. Table 4 indicates that the overall cropping intensity has substantially increased over the period 1960–1990 in various zones of the Punjab. However, declining trend has been observed during this period in rainfed area.

Table 4

Cropping Intensities in Various Zones of the Punjab Over Time

Zone	Cropping Intensity		
	1960	1980	1990
Rainfed	122	122	117
Rice-Wheat	107	156	173
Cotton-Wheat	103	125	165
Mixed Cropping	116	127	142
Mungbean-Wheat	94	104	112
Punjab		124	141

Sources: Pakistan (1960, 1980, 1990).

The repeated cultivation of same crops and nutrient exhaustive cropping pattern year after year in various crop ecological zones has led to degradation and depletion of land resource. Due to excessive removal and less application, there is a net negative balance of all the major nutrients even when the nutrients are applied at recommended doses of fertiliser [Zia *et al.* (1992)]. In rice-wheat cropping system, the soils are also deficient in Zinc. The use of "Octa" a mixture of crop nutrients (i.e., Zinc, Boron, Manganese, Sulfur, Magnesium and Copper), for increasing the availability of micro nutrients has improved the paddy yield [Ashraf (1984-85)]. Unless adequate amounts of nutrients are applied, it will be difficult to sustain the yield of rice-wheat system in the long-run.

(ii) Poor Efficiency of Applied Fertiliser

Consumption of fertiliser in Pakistan has substantially increased overtime. However, crop yields have not increased proportionately indicating poor fertiliser use efficiency. Empirical work shows that nitrogen use efficiency for rice varies from 25 percent to 80 percent depending upon farmers practices and soil health, while the efficiency of phosphorous is 15 to 25 percent [Zia *et al.* (1992)]. Efficiency of potash is observed about 80 percent under wet land rice, while the zinc is found deficient in 70 percent of the soils and its efficiency hardly exceeds 10 percent [Zia *et al.* (1992)].

(iii) Imbalanced Use of Fertilisers

Imbalanced use of plant nutrients has also been one of the major causes of low productivity of most of the crops. The ratio of nitrogenous fertilisers to phosphatic fertilisers has improved from 8:1 to 4.27:1 over the period 1970–1996 [Pakistan (1997)]. This ratio needs to be further narrowed down to 1:1 in order to obtain higher yields.

(iv) Declining Soil Organic Matter

The major sources of organic matter are farm yard manure, green manures and crop residues. The use of farm yard manure is limited because dung is widely burnt as a source of fuel. As regards the crop residues, wheat straw and rice straw are used for feeding the animals. Further rice straw is also burnt as a source of fuel. Sesbania is one of the most suitable green manure for the wheat - rice rotation provided it is sown around May 20 and allowed to grow for 40 days; while, rice may be transplanted in 2nd week of July [Zia *et al.* (1992a)]. Unfortunately, this practice is very limited.

Addition of nutrients to soil take place through fertilisers, farm yard manure, irrigation water, flood waters, flood silt, rain, etc. These nutrients are basically mined through crops, volatilisation, denitrification, leaching, water erosion, etc. Table 5 indicates very critical situation regarding the nutrient balance for all the provinces in Pakistan. Use of nutrients is more than the addition to the soil and the deficit is increasing over time in all the provinces. Exception is only of Punjab where deficit of nitrogen contents has declined over the years.

Table 5

Provincial Nutrient Balances 1985-86 and 1995-96 (Kg/hac)

	N		P_2O_5		K_2O	
	1985-86	1995-96	1985-86	1995-96	1985-86	1995-96
Punjab	–19.19	–8.57	–10.45	–10.73	–23.69	–27.27
Sindh	–5.0	–6.95	–8.54	–11.72	–7.69	–17.32
NWFP	–9.52	–10.73	–8.35	–10.74	–20.89	–29.73
Balochistan	–21.56	–27.15	–7.43	–11.36	–14.18	–25.57
Pakistan	–15.61	–9.39	–9.78	–10.9	–20.00	–25.79

It is expected that most of our soils under various cropping systems will become still more deficient in major macro and micro nutrients unless appropriate measures are taken to avert this situation. The fertility status and physical condition of these systems can be improved by using green manure that will help in realising high yields of crops [Zia *et al.* (1992a)]. Moreover, legumes also help sustain soil fertility through following ways: (1) potential to make substantial contribution to the nitrogen economy of the cropping system; (2) often exert favourable influence on several other soil fertility parameters through their extensive and deep root systems; (3) have ability to extract nutrients from deep soil layers; (4) utilise insoluble or fixed form of nutrients like phosphorous, and make them available to the succeeding crops; and (5) crops like sesbania and their incorporation improves physico-chemical properties of saline-alkali soils leading to increased growth and yields of subsequent crops [Ladha *et al.* (1996)]. Legumes even save the use of nitrogenous fertilisers and also improve the soil health [Joshi (1996)].

IV. SOIL COMPACTION

Soil compaction is caused by concentration of salts, ploughing at higher moisture levels, frequent use of tractors and implements, increased use of irrigation water and less use of animal and crop wastes. The loss of micro and macro pore spaces, as a result of compaction, reduces infiltration capacity, restricts gaseous exchange in soils and hinders most important biological activities that are essential for plants [Majeed (1989)].

According to Chaudhry (1990), there are three types of hard pans, that are plow pan, clay pan and sodic pan. A plow pan develops due to continuous ploughing at a shallow depth over years. Frequency of these ploughings with tractor varies from 4 to 5 times in fields of various crops [Ahmad *et al.* (1994)]. Plow pan, that develops normally at a depth of 20 cm, restricts water movement and results in accumulation of salts carried with the irrigation water on the upper layer of the soil with the passage of time. As a consequence, plow pan reduce land productivity significantly. The experimental results show that breakage of plow pan using non-conventional tillage practices increases the yield by 5 to 20 percent of wheat sown after the harvest of Basmati 385 (Table 6). Moreover, incremental benefit cost ratio over the control show that the highest returns from the investment were obtained where chisel plow or M. B. plow was used along with other implements (Table 7).[1]

Sodic pan develops in sodic soils or through the use of brackish ground water for irrigation. Development of such a pan results in negligible permeability as the clay sediments seal the soil pores on their downward movement [Sabir *et al.* (n.d.)]. Such a soil behaves like concrete. Results of breakage of such a pan with various treatments are presented in Tables 8 and 9 for wheat crop at a site in Faisalabad district. These results

[1]Razzaq *et al.* (1993) conducted this study at adoptive research farm at Sheikhupura and farmer's fields. Trials were laid out on clay loam soils for wheat after the harvest of Basmati 385 on 10 similar sites with three replicates.

Table 6

Effect of Breakage of Plow Pan with Different Tillage Practices on the Yield of Wheat Crop

Treatment	Yield (Kg/Ha) 1986-87	1987-88	1988-89	1989-90	Av. Yield (kg/hac)	Percent Over Check
Cultivator (5)	1311	1555	1661	1726	1563	–
Rotavator (1) + Cultivator (3)	1354	1656	1690	1845	1637	4.69
Disc. Harrow (2) + Cultivator (2)	1428	1764	1806	1944	1736	11.03
Rotavator (1) + Chisel Plow (2)	1478	1818	1786	2051	1784	14.13
Disc Harrow (1) + Chisel Plow (2)	1528	1832	1850	2288	1875	19.91
M.B. Plow (1) + Disc Harrow (1)	1493	1825	1893	2288	1875	19.91

Source: Razzaq *et al.* (1993).

Table 7

Economics of Breakage of Plow Pan with Different Tillage Practices

Treatment	Gross Expenditure (Rs/Acre)	Change in Cost over Control	Gross Income (Rs/Acre)	Change in Income over Control	Incremental Cost Benefit Ratio
Cultivator (5)	2105.63	–	4181.71	–	–
Rotavator (1) + Cultivator (3)	2106.84	25.50	4377.98	196.28	1:7.70
Disc. Harrow (2) + Cultivator (2)	2154.49	48.97	4643.06	461.35	1:9.42
Rotavator (1) + Chisel Plow (2)	2154.49	89.03	4772.97	591.26	1:6.64
Disc Harrow (1) + Chisel Plow (2)	2191.83	86.20	5014.57	832.86	1:19.66
M.B. Plow (1) + Disc Harrow (1)	2191.83	86.20	5014.57	832.86	1:19.66

Source: Razzaq *et al.* (1993).

Table 8

Dominance Analysis of Field Trials on Sodic Soils with Pans

Treatment	Cost	Benefit	Net Benefit
Cultivator[a]	1289	3441	2152
50 GR + Cultivator[a]	1439	3351	1912 D
50 GR + Subsoiler[b]	1836	4046	2210
50 GR + Chisel Plow[c]	1924	3602	1678 D
50 GR + Disc Plow[d]	2099	3398	1299 D
75 GR + Cultivator	1515	3534	2019 D
75 GR + Subsoiler	1912	4658	2946
75 GR + Chisel Plow	2000	4312	2312 D
75 GR + Disc Plow	2175	4117	1942 D

[a] Tine cultivator treatment includes cultivator (14) + rotavator (1) + disc harrow (1).
[b] Subsoiler treatment includes subsoiler (2) + cultivation (12) + rotavator (1) + disc harrow (1).
[c] Chisel plow treatment includes chisel plow (2)+ cultivator (12) + rotavator (1) + disc harrow (1).
[d] Disc plow treatment includes disc plow (2) + cultivator (12) + rotavator (1)+disc harrow (1).
D. Dominated treatment.

Table 9

Marginal Analysis of Field Trials on Sodic Soils with Pans

Treatment	Total Cost that Vary	Marginal Cost	Net Benefit	Marginal Benefit	MRR
Option I					
Cultivator	1289	547	2152	58	10.60 %
50 GR + Subsoiler	1836		2210		
Option II					
Cultivator	1289	623	2152	794	127.44 %
75 GR + Subsoiler	1912		2946		

show that the wheat yield was about 30 percent higher where gypsum was applied at the rate of 75 percent requirements compared with 50 percent requirements. Based on marginal analyses, option II (75 GR + subsoiler) appears most feasible for farmer's adoption. It promises a return of Rs 127 for every Rs 100 investment (Table 9).

V. SOIL EROSION

Land degradation is also caused by soil erosion. A considerable fertile area has already been abandoned as soil erosion has rendered it unproductive. About 4.8 million hectares are affected from wind erosion (Table 10). Deserts of Thal, Cholistan, Thar and Kharan are the most affected ones [Rashid *et al.* (1998)]. Table 10 further shows that

Table 10

Area Affected by Wind and Water Erosion (Thousands Hectares)

Degree of Erosion	Punjab	Sindh	NWFP+ FATA	Balochistan	N.A.	Pakistan
Wind Erosion						
Slight	2251.4	295.0	13.1	36.0	–	2595.5
Moderate	279.1	70.2	3.8	143.6	–	496.7
Severe to Very Severe	1274.0	273.8	19.6	100.9	–	1668.3
Total	3804.5	639.0	36.5	280.5	–	4760.5
Water Erosion						
Slight (Sheet and Rill Erosion)	61.2	–	156.3	–	180.5	398.0
Moderate (Sheet and Rill Erosion)	896.8	–	853.8	1805.0	25.8	3581.4
Severe (Rill, Gully &/or Stream Bank Erosion)	588.1	58.9	1765.1	829.6	504.2	3754.9
Very Severe (Gully, Pipe and Pinnacle Erosion)	357.9	–	1517.0	–	1571.6	3446.5
Total	1904.0	58.9	4292.2	2634.6	2282.1	11171.8

Source: Mian and Mirza (1993).

about 11.2 m.ha. are affected by water erosion; out of which, 4.3 m.ha. are in NWFP and FATA, 2.6 m.ha. in Balochistan, 2.3 m.ha. in Northern areas and 1.9 m.ha. in the Punjab. Water erosion depletes the soil fertility and accelerates silting up of irrigation system [Qureshi and Muhammed (n.d.) and Mian and Mirza (1993)].

Water erosion depends on different factors like, nature of soil, density of vegetative cover, amount and intensity of rainfall. It is intensified by improper methods of cultivation, overgrazing, burning and activities of rodents. Water erosion can have significant adverse effects on soil productivity: Most of the organic matter and nutrients are present in the upper layers of soil that are mostly lost in the eroding water. Erosion also degrades the soil's structure and diminishes its water holding capacity [Naidu *et al.* (1998)]. Results, though old, of a conservation project showed that the treated or reclaimed lands performed much better than the eroded land requiring conservation in terms of the use of various inputs, output per acre of various crops, gross and net income, etc. Table 11 indicates that the index of inputs use increased from 100 to 332. In terms of output the least increase was observed in case of wheat that was 123 percent and highest increase was observed in lentil, i.e., 382 percent. Per acre net income doubled on the reclaimed (treated) soils. Cropping intensity increased from 32 percent to 119 percent after reclaiming the soil. Another important result was that the proportionate area under grasses and trees increased from zero to 14 percent.

Table 11

Index of Input, Output, and Income on Untreated and Treated Soil Conservation Farms

Items	Untreated Farm	Treated Farm
A. Inputs		
Labour	100	252.40
Capital	100	403.67
Land	100	343.85
Total Input	100	332.36
B. Yield Per Acre		
Wheat	100	223.33
Gram	100	478.76
Lentil	100	481.88
Bajra	100	246.87
Watermelon	100	246.65
C. Income Per Acre		
Gross Income from Crops	100	452.88
Gross Income from the Whole Farm	100	714.50
Net Income from Crops	100	201.46
D. Erosion Free Area (%)	22.78	98.78
E. Cropping Intensity (%)	32.33	118.88
F. Area under Forests and Grasses of Total Farm Area (%)	0	14.16

Source: Ahmad (1968).

VI. CONCLUSION AND RESEARCHABLE AREAS

Land degradation is essentially a serious problem in Pakistan. Various forms of land degradation, i.e., water logging and salinity, nutrient depletion, soil compaction, soil erosion, etc., are resulting in inefficient use of various farm inputs and reduction in cropping and land use intensity, crop yields, farmer's income, employment, etc. Nevertheless there are still many aspects that need to be researched, which include: (1) Impact of different quality tubewell water on soil characteristics, input use efficiency, output of various crops and land use and cropping pattern; (2) Impact of use of city drainage water including industrial effluents on, resource productivity, quality of output, environmental hazards and farm income; (3) Economics of various drainage systems like tile drainage, surface drainage etc. at farm level; (4) Economics of improvement of drainage facilities and drainage effluent disposal; (5) Economics of use of brackish drainage effluent for agriculture and industry; (6) Factors responsible for the adoption of land reclamation technologies such as are Gypsum application, Sub-soiling, Green manuring, Farm yard manure applications, EM technology and other soil amendments;

(7) Studies into the nutrient management on degraded soils which may include economics of alternative crop rotations on degraded soils in various zones, economics of use of macro, micro and trace nutrient elements under various cropping systems, determination of optimum N, P, K etc. ratios for various crops under varied crop ecological conditions and economics of green manuring; (8) Studies on the impact of various types of soil compaction on crop productivities and farm income; (9) Economics of soil conservation with special reference to watershed areas; (10) Economics of growing fruit plants in gullies in different ecological zones of rainfed areas; (11) Economics of gullied land development under different climatic conditions; and (12) Economics of growing of cover crops/legumes for moisture conservation.

Appendices

Appendix I

Partial Budget for the Project Period (1980-81 to 1984-85) Khurrianwala Soil Series

Item	Treatment			
	Control	SS	GYP	SS+GYP
I. Gross Field Benefits				
(a) Wheat Grain				
i. Gross Output (Kg/Acre)	2892	4188	5711	5091
ii. Adjusted Output (Kg/Acre)	2458	3560	4854	4327
iii. Gross Field Benefits @ Rs 6/Kg (Rs/Acre)	14749	21359	29126	25964
(b) Wheat Bhusa (Straw)				
i. Gross Output (Kg/Acre)	2892	4188	5711	5091
ii. Adjusted Output (Kg/Acre)	2458	3560	4854	4327
iii. Gross Field Benefits @ Rs.0.95/Kg (Rs/Acre)	2335	3382	4612	4110
(c) Rice Grain				
i. Gross Output (Kg/Acre)	2052	3193	2979	2488
ii. Adjusted Output (Kg/Acre)	1744	2714	2532	2115
iii. Gross Field Benefits @ Rs 5.55/Kg (Rs/Acre)	9594	14927	13927	11631
(d) Rice Bhusa (Straw)				
i. Gross Output (Kg/Acre)	8699	12153	9358	9908
ii. Adjusted Output (Kg/Acre)	7394	10330	7954	8422
iii. Gross Field Benefits @ Rs 0.12/Kg (Rs./Acre)	887	1240	954	1011
Total Gross Field Benefits (Rs/Acre)	27565	40917	48619	42717
II. Total Costs That Vary				
i. Gypsum @ 76 Bags Per Acre in Treatment GYP @ Rs 29 Per Bag (Rs/Acre)			2204	
ii. Gypsum @ 56 Bags Per Acre in Treatment SS+GYP @ Rs 29 Per Bag (Rs/Acre)				1624
iii. Subsoiling Once (Rs Per Acre)		741		741
iv. Labour Cost for GYP Application 4 Man Days in Treatment GYP @ Rs 70/Man Day (Rs/Acre)			280	
v. Labour Cost for GYP Application (2.83 Man Days @ Rs 70/Man Day in Treatment SS+GYP)				198
Harvesting, Threshing, Cleaning Cost		2100	3771	2814
Total Costs That Vary		2841	6255	5377
III. Net Field Benefits (Rs/Acre)	27565	38076	42364	37340
IV. Average Annual Benefits (Rs/Acre)	6891	9519	10591	9335

Updated data by using latest prices as reported by Ahmad *et al.* (n.d.).

Appendix II

Partial Budget for the Project Period (1980-81 to 1984-85)
Khurrianwala Soil Series

Item	Treatment			
	Control	SS	GYP	SS+GYP
I. Gross Field Benefits				
(a) Wheat Grain				
i. Gross Output (Kg/Acre)	1052	1366	3459	3477
ii. Adjusted Output (Kg/Acre)	894	1161	2940	2955
iii. Gross Field Benefits @ Rs 61/Kg (Rs/Acre)	5364	6967	17641	17733
(b) Wheat Bhusa (Straw)				
i. Gross Output (Kg/Acre)	1052	1366	3459	3477
ii. Adjusted output (Kg/Acre)	894	1161	2940	2955
iii. Gross Field Benefits @ Rs 0.95/Kg (Rs/Acre)	849	1103	2793	2808
(c) Rice Grain				
i. Gross output (Kg/Acre)	2414	2414	4223	4723
ii. Adjusted output (Kg/Acre)	2051	2052	3589	4014
iii. Gross Field Benefits @ Rs 5.55/Kg (Rs/Acre)	11284	11287	19741	22079
(d) Rice Bhusa (Straw)				
i. Gross Output (Kg/Acre)	6344	6466	9865	12739
ii. Adjusted Output (Kg/Acre)	5393	5496	8385	10828
iii. Gross Field Benefits @ Rs 0.12/Kg (Rs/Acre)	647	660	1006	1299
Total Gross Field Benefits (Rs/Acre)	18145	20017	4118	43919
II. Total Costs That Vary				
i. Gypsum @ 152 and 184 Bags for Treatment GYP and SS+GYP @ Rs 29 Per Bag (Rs/Acre)			4408	5336
ii. Subsoiling Once (Rs Per Acre)		741		741
iii. Labour Cost for GYP Application 7.7 Man Days in Treatment GYP and 9.3 Man Days in SS+GYP @ Rs 70/Man Day (Rs/Acre)			539	651
Harvesting, Threshing, Cleaning Cost		373	3725	4009
Total Costs That Vary		1114	8672	10737
III. Net Field Benefits (Rs/Acre)	145	18903	32509	33182
IV. Average Annual Benefits (Rs/Acre)	4536	4726	8127	8296

Updated data by using latest prices as reported by Ahmad *et al.* (n.d.).

Appendix Table III

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