INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2002/04–3–429–437
http://www.ijab.org

Review

Agriculture in the Indus Plains: Sustainability of Land and Water Resources

ABDUL GHAFOOR, MANZOOR QADIR AND GHULAM MURTAZA
Department of Soil Science, University of Agriculture, Faisalabad–38040, Pakistan

ABSTRACT

Pakistan is basically an agricultural country blessed with reasonably good soil, water, environment and man power resources and Punjab is superior one in this respect to the other three provinces. The anthropogenic activities have been and are interacting with other crop production factors and, in general, have put burden on soil and water availability for agriculture. Such interactions have affected adversely the soil and water, and province Punjab is no exception to these interferences. Good quality soils and irrigation waters are the primary requirements of sustainable crop husbandry. In the present paper, issues related to soil and water resources in the perspective of future of irrigated agriculture of Pakistan with special emphasis on Punjab are presented.

Key Words: Irrigated agriculture; Land/water degradation; Management; Policies

1. Land Use Pattern

1.1. Resources. Area under current fallow and not available for cultivation has and will be increasing (Table I), although increase will be small one. Area sown more than once (cropping intensity) is increasing because of which total crop area will also increase. Increased crop area will require more water and agricultural inputs like water (Table III), fertilizers and energy to sustain the crop production which is necessary for feeding the ever increasing population (Table XI) and to maintain its share in national exports and thus the national economy. Since most of the soils suitable for irrigated agriculture have already been put under crops, there stands very little chance to increase crop area cost-effectively except the rehabilitation of salt-affected/degraded soils as well as to keep the salination and sodication of soils under control by adopting required management/reclamation practices. Only 0.25 ha per capita of the crop area (crop area divided by total population) by the year 2014-15 (Table I) which is in-sufficient to support a 5-member farming family.

1.2. Management options

* Protect agricultural lands from non-agricultural uses.
* Initiate the amelioration of salt-affected soils.
* Devise and adopt concerted strategies to decrease the input of salts into soils.
* Develop and implement farmer-friendly as well as soil/environment-friendly policies for the sustainable future of agriculture.
* Awareness campaign on media about such policies and involvement of subject experts in planning, execution and evaluation of such projects has to be ensured.
* Extent of cropped area will purely depend on increasing cropping intensity and protecting land from degradation through salination, sodication, erosion, fertility depletion, urbanization and contamination as well as other non-agricultural uses.

2. Irrigation Resources

2.1. Canal water. Irrigated area is increasing (Table II) but major source of irrigation has become the tube wells in country-sides (Table II) and municipal sewage in urban agricultural area. It is interesting to note that in 1980-81, canal and tube well irrigated areas were almost equal to each other but in 2014-15, the canal irrigated area will decrease to about one forth of the tube well water irrigated area.

Management options

* Large volumes of sewage (e.g. 14 million gallons daily of sewage is available at Lahore and 400 cusecs at Faisalabad), if properly treated at source, could supplement the irrigation supplies. Rules for effluent treatment at source exist but their implementation in letter and spirit has to be ensured which needs immediate attention of the concerned authorities.
* To meet the irrigation water requirements in Punjab by 2014-15, about 103 MAF water will be required provided today's rate of 6.72 feet per acre at canal headwork (Table III) is maintained. This means that 13 MAF more irrigation water will be required. The present rate of 6.72 feet/acre annually is total quantity available at canal headwork, of which about 30-35% are the conveyance losses. Hence additional water resources (conventional/non-conventional) needs exploitation, strong possibilities of which exist as evidenced from Table IV (Anonymous, 2002a).
* There is scope to develop additional surface water storage for drought periods since a plenty of river water is discharging into Arabian sea (Table IV). Such policy issues have to be decided by overlooking the political interests and giving priority to national interests by all the sections of

Table I. Changes in land use in Punjab, Pakistan (mha)

Year	Forest area	Not avail-able for cultivation	Cultivated area		Sown >once	Current fallow	Net area sown	Total crop area	*Per capita (ha)
			C. waste	Total					
1	2	3	4	5(7+8)	6	7	8	9 (6+8)	10
Pakistan									
1980-81	2.85	19.91	10.86	20.30	3.92	4.89	15.41	19.33	0.30
Punjab									
1980-81	0.44	2.88	2.13	11.59	3.01	1.13	10.46	13.47	0.28
1990-91	0.46	2.99	1.84	11.81	4.26	1.01	10.80	15.06	-
2000-01	0.50	3.02	1.69	12.31	4.98	1.28	11.03	16.01	0.30
2014-15p	0.50	3.06	1.46	13.06	6.01	1.68	11.38	17.49	0.17

p= Projected. *Column 6 divided by population given in Table XI (Source: Anonymous, 2000)

Table II. Area irrigated (mha) by different sources in Punjab, Pakistan

Year	Canal	Wells + Tube wells +Others	Total
Pakistan 1959-60*	8.73	1.60	10.33
Punjab 1980-81	4.58	5.82	10.40
1990-91	4.31	8.32	12.63
2000-01	3.93	9.92	13.85
2014-15p	3.36	12.32	16.68

p= Projected. (Anonymous, 1998*, 2000)

Table III. Irrigated area and water requirement in Pakistan

Year		Pakistan*	Punjab	Canal water available in Pakistan (MAF)		T/W water available (MAF)	
				Headwork	Farm gate	Pakistan	Punjab
1960-61	mha	10.41	-	-	-	-	
1970-71	mha	12.94	-	-	-	-	
1980-81	mha	14.9	10.5	103.3	66.23	36.25	31.24
1990-91	mha	16.75	12.63	109.75	75.64	43.98	38.30
	maf	114.40	81.50				
2000-01	mha	18.09	13.85	84.58	83.37	49.91	44.55
	maf	126.40	90.00				
2014-15p	mha	21.30	15.30	-	-	-	53.93
	maf	144.40	102.80				

p=Projected. (Source: Anonymous, 1998*, 2000 , 2001)

society including the politicians, policy makers and the techno-crates.

* The river water diverted into canals is expected to decrease to about half in 2015 of that in 1980-81 (Table V), which will not be enough to meet the crop requirements. Hence tube wells have to be installed, storage of surface water to be created and on-farm water conservation practices devised carefully and implemented strictly .

2.2. Exploitation of ground water. Canal water supplies has become short to cope with the crop requirements because of droughts, silting of water reservoirs, competition between agricultural and non-agricultural demands and increased cropping intensity. As a result, pumping of ground water has increased tremendously over the years (Table VI). Due to canal water shortage, partly because of silting of the existing water reservoirs (Table VII), number of tube wells is increasing at an alarming rate. Unfortunately, the pumped ground water is unfit for irrigation, about 70 % tube wells were and are pumping hazardous water owing to high EC, SAR and/or RSC during the period of 1995 to 2000 (personal communication from Directorate of Soil Fertility Res. Inst., Lahore). Irrigation with these waters has to promote soil salination/sodication, deteriorate the produce quality/shelf life, and create environment concerns. In addition, sub-soil drying due to draw-down of water table depth is another future concern (Anonymous, 2002b) and must be addressed immediately. More and more pumping of ground water helped lower the water table and alleviation of waterlogging (Table XI) but simultaneously has to deteriorate the ground water quality since it is rule of thumb that as one goes deeper into subsoil and away from rivers, ground water quality becomes poorer and poorer.

The shortage of quality irrigation water in Pakistan has attracted the international interest. Some money making private organizations are trying to market their recipes without proper testing to prove validity/usefulness under local agro-climatic conditions. Such technologies include Sulphurous Acid Generator by Sweet Water Solution of USA, EM/BM technology from Japan, RISTECH technology from UK, and Electro-Magnetic Membrane

Table IV. River inflow at rim station and escape below Kotri and Panjnad (MAF)

Year	Season		Escape below	
	Kharif	Rabi	Panjnad	Kotri
1980-81	115.61	25.22	15.51	20.10
1990-91	138.91	37.11	21.71	42.33
1996-97	143.60	30.34	30.70	45.40

(Source: Anonymous, 1998)

Table V. Season-wise history of canal with-drawls into Punjab (MAF)

Year	Kharif	Rabi	Total
1979-80	35.67	20.13	55.80
1990-91	35.90	22.30	58.20
1995-96	31.10	21.10	52.20
2014-15	16.30	18.10	34.40

(Source: Anonymous, 1998)

Table VI. Year-Wise increase in no. of tube wells and pumpage in Punjab, Pakistan

Year	Tube wells in Province Punjab				Tube wells in Pakistan	
	Public (No.)	Private (No.)	Total (No.)	Pumpage (MAF)	Tube wells (Total No.)	Pumpage (MAF)
1980-81	10205	161867	172072	31.24	199673	36.25
1990-91	10425	285522	295947	38.30	339840	43.98
2000-01	8234	465433	473667	44.55	531344	49.98
2014-15	4948	735300	740248	53.90	818600	58.88

(Source: Anonymous, 2000)

technology from Germany. Novel claims of these technologies are to desalinate the brackish water, convert sodium into nitrogen, change in soil texture over a period of 2-3 years, and bacteria in these recipes eat salts as well as sodium present in water or soils. But unfortunately, none of them could demonstrate at any university or research farm but it is learnt that they are be-fooling the farmers at very large scale and are making money. Government should give attention immediately to stop their business and save the hard earnings of the farmers since farmers are drowning and try to catch a straw to save themselves.

Management options

* It is must to consider and adopt preventive measures immediately to avoid the disaster of soil salination and sodication in response to poor quality tube well water irrigation. The best economical solution to high sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) waters is to soil-apply gypsum along with farm yard manure or green manure before each crop considering the delta of water of crop and gravity of SAR and/or RSC problem.

* Blended/mixed use of canal and brackish waters is not possible under our conditions since the canal water supplies are not at the disposal of farmers. The cyclic (alternate irrigation, or one crop with canal and other with brackish water) are already in practice intentionally or un-intentionally. Farmers should try to avoid irrigation with brackish water at critical crop growth stages and to use good water on good soils and poor quality water on poor soils.

* There is immense need to initiate the tube well water analyses for appropriate and site-specific advice by the Agricultural department at its own, and simultaneously it must be made mandatory and legal for the tube well owners to get the water analyzed and act upon advice.

* Assuming 70 % pumped ground water hazardous which require addition of gypsum @ 4 $mmol_cL^{-1}$ of irrigation water, 400 kg for each acre-foot and 15.6 million tons gypsum for 39 MAF tube well water annually will be required, i.e. 234 million tons quality gypsum will be essential to soil-apply in order to mitigate the adverse effects of high SAR/RSC tube well water during the period of 2000-01 to 2014-15. This could only sustain the crop area given in Table I. For a door-step supply of this much gypsum has to be ensured on credit for sustainability of irrigated agriculture since the salt-stress land and tube well owners might not be in a position to purchase gypsum on cash payment.

* The potential of virtual use of water could be exploited at regional/provincial/national levels. The idea of virtual use of water compares the amount of water embodied in a crop that can be purchased at regional/provincial/international levels with the amount of water that should be required to produce that crop natively. For example, transferring every kilogram of wheat into water stress area means to transfer about 1000 L of virtual water at a much less price than the price of the same quantity of water from the native water resources in the area itself.

* In-service training of extension staff and refresher courses for farmers are also essential.

* There is significant loss in storage capacity of water reservoirs (Table VII) which is increasing gradually and this loss will become about 33 % of the designed capacity by the year 2020. It is suggested that additional storage facility be developed, and decrease the silt load of in-coming water into existing dams through controlling/promoting vegetation with or without the help of engineering structures in the catchment areas.

3. Land Degradation

Degradation is the process whereby a compound is transformed into simpler products, although such products may be even more complex than the starting material. Hence soil degradation is the transformation of soil by different agencies resulting in a soil having properties less favourable for agricultural uses. Soil degradation could be natural or caused by intensive cultivation following unsuitable techniques. It usually leads to damage of soil properties, like structure, water retention, porosity, EC, SAR, and soil flora and fauna. Prior to land use planning and project execution, land degradation must be characterized for effective management and sustainable agriculture because preventive measures are easy and cost-effective than to reverse degraded soils.

When a man is confronted with cold, hunger and/or

Table VII. Storage decline in water reservoirs in Pakistan

Reservoir	Completion year	Storage capacity (MAF)					
		Initial	1995	2000	2010	2020	Loss (MAF)
Mangla	1967	5.3	4.6	4.5	4.2	4.0	1.3
Chashma	1971	0.7	0.4	0.3	0.2	0.1	0.6
Tarbela	1975	9.3	8.3	8.0	7.3	6.6	2.7
Total	-	15.3	13.3	12.8	11.7	10.7	4.6
Loss MAF			2.0	2.5	3.6	4.6	-

(Source: Haq et al., 1997)

Table VIII. Year-wise salt-affected area of Punjab, Pakistan

Year	Area surveyed (mha)	Salt-affected			
		Uncultivated (mha)	Cultivated (mha)	Total (mha)	%
1945-46	4.84	0.42	0.49	0.91	18.80
1955-56	5.96	0.54	0.69	1.23	20.64
1965-66	6.88	0.44	0.68	1.12	16.28
1975-76	7.34	0.37	0.61	0.98	13.35
1985-86	7.57	0.30	0.58	0.88	11.62
2000-01	7.92	1.16	1.51	2.67	33.71
2014-15	8.26	2.02	2.44	4.46	53.9

(Source: Ahmad and Chaudhry, 1997)

Table IX. Area underlain by different water table depths in Punjab (000 ha)

Year	June		October	
	0-5'	0-10'	0-5'	0-10'
1980	891	3853	1276	4815
1990	711	3094	-	-
1995	475	2821	901	3566
2015	Nil	1789	526	2317

(Anonymous, 1998)

Table X. Pollution load from towns/cities in Punjab, Pakistan

Constituent	Value*	2000	2015
BOD, 5 days Av.	4 tons/day/105 persons	3071 tons/day	3200 tons/day
TSS	3 tons/day/105 persons	2304 tons/day	2400 tons/day
N	900 kg/day/105 person	691 tons/day	720 tons/day
P	200 t/day/105 person	153600 tons/day	16x104 tons/day

(Source: * Misra and Mani, 1991; Computed for respective year on the basis of Punjab population)

Table XI. Area required for household units in Punjab (ha)

Population	Year									
	1972		1981		1998		2000		2015	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Punjab (million)	28.4	9.18	34.2	13.1	50.6	23.1	52.72	24.06	71.20	32.50
Residential require-ment (ha)	8048	2599	9693	3697	14324	6536	14924	6811	19436	8860
Area required (ha)	10647		13390		20860		21735		28296	

(Computed on the basis of data provided by the Faisalabad Development Authority)

sickness, simply to save what is left of life or to keep his children alive, clutches at any thing to satisfy his hunger and destroys everything headless of the morrow. This narrates that two major factors, *man and severity of climate*, could be held responsible for soil degradation. The impact of these processes could be aggravated by the negligence of planners and policy makers and vested interests of governments as well as the society.

3.1. Salination and sodication. Under arid and semiarid climates, salination/sodication of soils are natural processes, particularly when low quality water is used for irrigation. High temperatures induce evapo-transpiration at rates much higher than the rainfall resulting in accumulation of salts in surface layer of soils rendering them unproductive and consequently the production cost of crops goes higher.

The extrapolated extent of 53.9 % (4.46 mha) Punjab soils to be salt-affected in 2014-15 seems very high (Table VIII) but because of the mushroom growth of tube wells in private sector during the last 3-4 years justify it since 70-80% of the pumped ground water (90% of pumped water in

Table XII. Nutrients removed (kg ha^{-1}) by crops to realize a designed yield in Pakistan

Crop	Yield (kg/ha)	N	P	K	Mg	S
Wheat	2400	170	74	175	30	30
Maize	2400	121	49	121	40	25
Rice	2400	99	49	160	20	10
Potato	1600	175	79	309	40	20
Sugar beat	1600	190	74	341	64	-
Cabbage	2800	370	84	480	59	79
Carrot	1200	126	54	200	30	--
Cauliflower	2000	250	99	351	30	--
Okra	800	59	25	90	35	10
Onion	1400	121	50	160	15	20
Reddish	800	121	59	121	30	--
Tomato	2000	141	64	190	25	30
Peas	800	124	35	79	15	--

(Source: Computed from existing data)

Table XIII. Nutrient balance for 1985-86 and 1995-96 in Pakistan (kg ha^{-1})

Province	N			P_2O_5			K_2O			NPK
	1985-6	1995-6	2014-5	1985-6	1995-6	2014-5	1985-6	1995-6	2014-5	2014
Punjab	-19.2	- 8.6	-21.2	-10.4	-10.7	-11.0	-23.7	-27.3	-30.9	-63.1
Sindh	- 5.0	- 7.0	- 9.0	- 8.5	-11.7	-14.9	- 7.7	-17.3	-27.7	-51.6
NWFP	- 9.5	-10.7	-11.9	- 8.4	-10.7	-13.0	-20.9	-29.7	-30.5	-55.4
Baloch.	-21.6	-27.2	-32.8	- 7.4	-11.4	-15.4	-14.2	-25.6	-37.0	-85.2
Pakistan	-15.3	- 9.4	-18.8	- 9.8	-10.9	-12.0	-20.0	-25.8	-31.6	-62.4

(Source: FAO, 1988)

Table XIV. Province-wise NPK fertilizers consumption in Pakistan (000 Nutrient ton)

Year		Punjab	Sindh	NWFP	Baloch.	Pakistan	N:P in Pakistan	N:P in Punjab
1979-80:	N	552.0	197.0	53.0	4.0	806.0	3.55:1	3.47:1
	P_2O_5	159.0	54.0	13.0	1.0	227.0		
	K_2O	5.0	3.0	1.0	-	9.0		
1989-90:	N	1046.0	322.0	85.0	14.0	1467.0	3.83:1	3.67:1
	P_2O_5	285.0	77.0	18.0	3.0	383.0		
	K_2O	29.0	9.0	2.0	0.2	40.0		
1999-2000:	N	1500.0	518.0	144.0	55.0	2217.0	3.73:1	3.60:1
	P_2O_5	416.0	132.0	33.0	15.0	596.0		
	K_2O	11.2	6.7	0.6	0.0	18.5		
*2014-15:	N	2184.0	812.0	232.5	116.5	3345.0	3.65:1	3.57:1
	P_2O_5	612.5	214.5	55.5	33.0	915.5		
	K_2O	2.3	2.9	0.0	0.0	5.2		

(Source: Anonymous, 1988, 1998, 2000)

Table XV. Province-wise share (%) in eroded lands of Pakistan

Type/degree of erosion	Punjab	Sindh	NWFP	Baloch.	Pakistan (000 ha)
a) Water Erosion					
Slight (sheet and rill)	18.7	*	81.3	*	328.0
Mod. (sheet and rill)	24.7	*	24.2	51.1	3,635.0
Severe (rill/gully)	10.4	1.0	40.2	48.3	5,640.7
Very severe (")	10.4	*	89.6	*	3,446.5
Total	14.6	*	49.8	35.1	13,050.2
b) Wind Erosion					
Slight	86.7	11.4	0.5	1.4	2,595.5
Moderate	56.2	14.1	0.8	28.9	496.7
Severe to very severe	41.3	54.7	0.6	3.3	3,081.3
Total	61.6	33.2	0.6	4.5	6,173.5

NWFP includes FATA, PATA and Northern Areas. * Negligible extent. (Source: Mirza & Ahmad, 1998)

few villages in Faisalabad was unfit as noted by the author) is of hazardous quality for irrigation. Mostly farmers do not get the water analyzed for proper advice and soils are being salinated/sodicated gradually. Therefore, it is of prime priority to provide advisory service to farmers and required inputs like gypsum at subsidized rates on credit to sustain the future of irrigated agriculture.

The estimated extent of salt-affected soils is further stemmed from the fact that salt addition through irrigation water was about 55-60 million tons against a removal of only 25-28 million tons out of the Indus Plains in 1997. By the year 2014-15, the salt addition must be much higher due to more application of poor quality tube well waters while removal to be much lower because of decreased volume of drainage effluent compared to the above quantities.

Management options

* Salt-affected soils must be characterized through laboratory tests or profile description to start amelioration or their other agricultural utilizations first of low problem soils followed by those having greater problems as these soils are quite variable in time and space.
* To cope with the problem of soil sodicity (80-85 % salt-affected soils in Punjab and 55-60 % those of Pakistan are saline-sodic in nature and require an economical external source of calcium like gypsum), 3.0 million tons per annum of quality gypsum (assuming 10 tons per ha) has to be made available at farm at affordable price on credit. The quantity of gypsum come to about 45 million tons during the 15-year period from 2001 to 2015.
* Inclusion of green manure crops, mainly as a source of organic matter, has to be promoted for which some kind of incentives to growers must be offered. This is essential because salt-affected soils are quite low in organic matter otherwise which is considered the blood of soil.
* Another way to combat the salinity/sodicity of soils is saline agriculture approach, i.e. cultivation of salt tolerant forest plants on high problem soils while agricultural crops on marginal problem soils using good or brackish water for irrigation. Such salt tolerant tree species could act as biological drainage pumps for temporary/permanent waterlogging, although little required at present.
* Microbiological and soil fertility aspects of salt-affected soils has not been properly treated in past. Thus this field needs an immediate attention of researchers and administrators.
* For technology transfer pertaining to amelioration of salt-affected soils and imparting training to extension staff as well as farmers, demonstration cum research farm level experiments under different agro-ecological zones should not only continue but also strengthened.
* Research into development of low cost reclamation and saline agriculture technologies must be continued rather strengthened since gravity and extent of problem is increasing day by day.
* Under the prevailing scenario of agro-climatic conditions, gypsum should be considered a life saving drug for sustainability of soil, water and crop health and thus productivity. Every effort must be made on the promotion of its use by all the sections of the society to save our future.

3.2. Waterlogging. With the introduction of surface irrigation canals during the last century, water table started rising and reached within 5' in 1960s in an area 900000 ha (Table IX) and hampered the crop production very badly, for the control of which huge cost-intensive drainage projects were initiated.

It is estimated that area in Punjab with water table < 5' will be almost finished while that with <10' will decrease to half that of 1980 by 2015 assuming the agro-climatic conditions of 2001-2002. Water table 10 feet deep is world-wise considered quite safe for health and production sustainability of soils and crops. Hence no additional drainage facilities might be required but maintenance of the existing infra-structure will remain a must for sustainability of the irrigated agriculture.

3.3. Soil contamination. With social and economic development of any society, its pollution impacts and contaminant load both in type and quantity increases (Table X) as mostly the waste effluent from dwelling sites are discharged into sewage system and ultimately are disposed into rivers from where it again reach into the irrigated fields. Farmers consider the use of sewage for irrigation as cost-effective while administrators take it as a viable option for sewage disposal although sewage water irrigation contaminate the soils and crops with heavy metals in addition to high salt contents.

Management options

* If the city effluents are properly treated at source, it will not only supplement irrigation water, but also large quantities of plant food nutrients will become available free of cost. Hence effluent treatment will become cost-effective and environment friendly. It is a general law that every industrial unit will dispose the waste effluent after its treatment at source. However, practically this has never been complied/observed by the industry owners. But now the water availability scenario warrants implementation of rules and regulations in letter and spirit. The defaulters must be dealt with seriously and action must speak.
* On the other hand, a change in cropping pattern will be useful, i.e. vegetables should not be grown with sewage water rather other crops (fodder/fuel plants etc. and plants having hyper-accumulating habit for heavy metals) be cultivated to dilute the risks of heavy metal entry into the human food chain.
* Even the government with the participation of end users should initiate to install effluent treatment plants since the volume of disposable effluent is too large which otherwise could provide irrigation for millions of hectares of land if properly treated.
* Another option could be devotion of some down stream areas solely for effluent disposal but does not appear feasible since the land is non-renewable resource of the country which already has squeezed below the critical limits. Experience of WAPDA on evaporation ponds and Indian experience in Hisar state in this respect has not shown encouraging results.
* A novel approach could be to collect rain flood water, water from domestic uses and that from industry processing food items separately for agricultural uses. These might not require any pre-treatment.

3.4. Urbanization. Shelter is the primary requirement of every living being in this universe. As the population increases, area under house-holds naturally has to increase. In Punjab, rural plus urban population will increase to about 104 million by the year 2015 which will require about 28296 ha area for house holds (Table XI). Unfortunately, significant area of very good agricultural lands (Class I & II) is being consumed by residential units which is really a permanent loss to agriculture.

Management options

* It is necessary that residential colonies as well as industry be developed on marginal lands in stead of the very good agricultural lands, for promotion of which living facilities like electricity, gas, water and other social services could be used as incentives by the Government.

* Another option could be construction of multi-story houses (vertical growth) to save horizontal area but the construction expenses will become more.

3.5. Depletion of soil fertility. Plant food nutrients availability is very good index of crop growth. Every crop differ in its requirements for various elements for any designed economic yield (Table XII). In Pakistan including Punjab, the fertilizer nutrients (NPK) as well as some micro-nutrients (Zn, Fe, Cu, Mn, B etc.) are removed by plants at rates higher than their addition, i.e. negative nutrient balance leading to decline in soil fertility. It is estimated that by the year 2014-15, depletion of soil fertility will be very critical unless proper measures are not adopted. This alarming situation will be further aggravated in most of the tube well water irrigated soils since an increase in soil salinity/sodicity will decrease bio-assimilation even nutrients are present in soils. Today this fact is indicated by stagnant crop yields, the crop yields might start decreasing by the year 2014-15.

The major reasons for low application rates of synthetic fertilizers (Table XIV), claimed by farmers, are higher costs than the purchasing power of farmers, black marketing at peak fertilizer demand periods and adulteration of fertilizers. Some micro-nutrients like zinc, copper, iron, manganese and boron are reported showing response to their application at places by some crops which appears mainly due to the use of nutrient rich synthetic fertilizers, low inherent soil fertility, high yielding varieties as well as lack of the addition of farm yard manure or green manure.

Management options

* It is suggested that general sales tax may be withdrawn from all the agro-chemicals like fertilizers, pesticides, soil amendments etc.

* Quantity and quality of these chemicals should be ensured in time and space.

* Farmers must be ensured the support prices of produce through improving the marketing.

* Credit facility in kind may help improve the situation, particularly if small farmers access to credit is ensured.

* The application of balanced fertilizers (N:P:K::2:1:0.5 at least) is the core point to be addressed/emphasized and advocated to farmers since at present the N to P ratio of 3.7:1 is very wide (Table XIV) without any addition of potassium fertilizers.

* The existing low fertilizer use efficiency must be improved through strategic programmes.

* A strong programme to assess the fertilizer requirements of fruit and vegetable crops must be initiated.

* Similarly fertilizer requirements of different crops on marginal degraded and soils under reclamation, is badly ignored at present, must be addressed at an early convenience.

3.6. Soil and water erosion. According to the data of 1998 (Mirza & Ahmad, 1998), water erosion damages to range/forest/agricultural soils is the highest in NWFP and the lowest in Punjab; reverse is true for wind erosion (Table XV). In a personal communication from the Soil and Water Conservation Research Institute, Chakwal, it is reported that 1.9 and 3.8 mha area in Punjab has been severely affected by water and wind erosion, respectively. Loss of fertile soil through water erosion is estimated to be one billion tons a year in Punjab alone. In areas facing erosion, natural and native vegetation is at risk and even growing crops are damaged by wind storms in parts of Punjab.

Management options

There could be three categories of options solving the problem:

* Plantation of trees ---- has proved cost-effective, sustainable and affordable.

* Development of water resources (wells, ponds, mini/small dams) ----remained cost-intensive.

* Masonry structures (spillways, outlets and retaining walls) ---- remained cost-intensive.

* Practically some cost-effective and farmer friendly conservation practices must be adopted, develop short and long term soil and water conservation plans for sub-catchment areas, promote permanent vegetation cover in high risk areas, use of integrated engineering, cultural, and biological soil/water conservation methods, initiate ecologically compatible cropping systems, and adoption of compatible cropping - livestock production systems.

* Lot of research and man power development (short/degree level) is required in this specialized area which is not possible with allocated funds at present. Thus enhanced financial allocation is recommended since vast area is facing this problem and its control is necessary.

4. Policy Issues

For creation as well as solution of problems of any society, policies could be primarily important and responsible, and thus the policy makers are the vital organs (for details see Anonymous, un-dated). In developing countries including Pakistan, policies have been formulated and faced implementation problems. In the following section, the policies are critically analyzed.

4.1. Missing/Un-implemented Policies in Crop Sector for Healthy Land Use Changes (LUC)

Type of policy and measures	Impacts
'Barani' areas neglected in green revolution package	Gullying; soil erosion. Stagnant yields of crops helped LUC.
Delay in decision on allocation of Indus water among provinces.	Excessive flood irrigation to create water rights, leading to waterlogging and saline effluent. Yield and income depressed and compelled LUC.

4.2. Policies for Soil/Water in Irrigated Agriculture for Healthy LUC

POLICIES

*Decrease in salination, sodication and waterlogging of soils.

*Decrease in deterioration of soil structure.

*Halt urbanization on good (Class I & II) agricultural soils.

*Prevent processes inducing soil degradation.

MEASURES

*Identify and demarcate areas requiring high priority for regeneration from the salt-affected and waterlogged soils, i.e. soils within canal commanded areas.

*Considering gypsum as soil life saving drug, make available at subsidized price on credit.

*Correct sodicity and deteriorating soil structure in areas irrigated with high SAR/RSC tube well waters.

*Legally bound the farmers to get the tube well waters analyzed.

*Encourage shallow tube wells.

*Recycle tile drain/city effluent locally for reclaiming salt-affected soils using amendments.

*Promote land levelling to increase water use efficiency and decrease patchy salination/ sodication of soils.

*Develop farming systems that retain/absorb farm labour.

4.3. Policies for Waterlogging Control for Healthy LUC

POLICIES

*Give priority to increasing irrigation efficiencies with allowance for salinity/sodicity control.

*Move towards a demand based irrigation water supply.

*Equalize water charges to the O & M cost.

*Promote water use associations (WUA) and thereafter Federation of WUA.

*Maintain the existing drainage infrastructure with site-specific emphasis on new projects.

*Strengthen the advisory service to farmers.

MEASURES

*Take incremental but specific measures towards volumetric consumption as the ultimate basis for water charges.

*Undertake studies in community management of a few distributaries on a pilot basis.

*Address problems of water table draw-down by holistic approaches, encompassing both the demand management and methods to increase water recharge.

*Recycle effluent with canal water at/near source or develop fisheries in such areas.

*Promote farmer education and extension activities as well as in-service training of staff.

*Review funding, goal should be 60:40 ratio for research : administration.

*In kind credit facility for gypsum in time and space, particularly to small farmers.

*Make it legal for farmers to get their tube well water analyzed, mobile teams of experts be organized to collect, analyze and advice solutions for tube well water quality.

4.4. Policies for Soil/Water in Rainfed Agriculture for useful LUC

POLICIES

*Halt over-use of prime soils/land resources.

*Check/reverse soil degradation.

*Manage water run-off/shortage to prevent soil erosion.

*Restore and improve fertility/structure of degraded soils.

MEASURES

* Develop soil and water conservation plans for each sub-catchment area.

* Protect, under permanent vegetative cover, high risk erosion areas.

* Use integrated engineering, cultural and biological soil/water conservation solutions.

* Adopt ecologically compatible cropping systems and compatible cropping-livestock production systems.

* Encourage adoption of effective soil and water conservation practices.

4.5. Conclusions and Recommendations/Suggestions for Future

1. Available data sources are secondary ones, develop primary data basis.
2. Farmers involvement in the process of assessing LUC must be encouraged.
3. Links between farmers, extension staff, scientists and policy makers needs strengthening.
4. Farm income must be ensured through insurance, support pricing, timely payments from intermediaries for farmer/environment/nation friendly LUC.
5. The existing very good farm-level infra-structure of agricultural establishments should take the task to collect and analyze water from all the tube wells and to provide management strategies in light of their expertise and experience. At the same time, it must be made legal obligation for farmers to get their tube well waters tested from laboratory.
6. The imported technologies from abroad must be validated before adoption. None of the private agency and NGOs should be allowed to market such technologies unless it is tested and approved by a multi-disciplinary team of local agricultural experts. It is a high time to wave our blind faith in foreign recipes.
7. The technologies based on research by the private organizations/NGOs in isolation without the involvement of local and concerned experts during the investigations must be banned.
8. At village level, farmer refresher courses before every crop season should be organized where a team of agricultural experts (Soil Scientists, Entomologist, Agronomist, Plant Pathologist etc.) should help them solve the crop related problems.
9. In order to save the future of agriculture, the government should recognize agriculture as an industry to provide the same type and level of benefits as the other industry is enjoying.

10. An acid-based technology to treat the poor quality waters or soils must be discouraged since the long term effects of acids are not yet known but theoretically could not be expected favourable for native soils.

11. The world-wide recognized as the most safe and economical soil and water amendment, gypsum locally available in plenty must be made available in time and space on easy terms and conditions (subsidized rates) but in all the situations the credit facility must be in kind. Small farmers are major section and must be ensured such credit benefits which is lacking badly at present.

12. The farmers must be charged Abiana on the basis of allocated canal water volume but not on cropped area since farmers are growing crops with cost-intensive tube well water as well. Similarly, GST on all the agro-chemicals must be withdrawn without further delay.

13. The adulteration and black marketing of fertilizers, insecticides, herbicides etc. must be checked by all means and the culprits must be dealt strictly so that the action may speak. Similarly marketing of agricultural produce is another area that needs comprehensive reforms and the experience of years (2001/2002) wheat, cotton, sugar cane and rice sales should be enough to devise some feasible and sustainable strategy to avoid repetition.

14. Efforts and resources must be diverted to develop additional water storage facilities as long term measure against the situation being faced for the last some years.

15. To sustain irrigated agriculture, construction of water desalting plants could be considered as are being in operation in USA, Saud-i-Arabia and many other countries at government level which will also help solve poor quality effluent disposal problems in an environment friendly manner in addition to increase the water availability for agriculture.

16. There is a strong need for holistic efforts for imparting training to the staff working in extension departments dealing with some specialized area of activities. For example, extensionists working in salt-affected areas need special training in management options for soil/water salinity/sodicity, staff working in Barani and erosion problem areas need special training in soil/water conservation techniques, and those working in fertility and plant nutrition related fields must be up-dated with the technologies related to their assignments. Such training programmes should be a continuous activity and it should be mandatory for the staff to get special training in his field of working after every five years.

17. In addition to all the efforts mentioned above, the weak link of researchers/subject experts with farmers and extension workers should be strengthened. The political and administrative will to promote and improve the existing agricultural system is a pre-requisite.

18 Funds for research should be increased to the level of 60:40 for research : administration.

19 There is a strong need to place agricultural education, research and extension under one authority for better interactions and effective services delivery to farmers.

20 Under the prevailing scenario of agro-climatic conditions, gypsum should be considered a life saving drug for sustainability of soil, water and crop health and thus productivity. Every effort must be made on the promotion of its use by all means to save our future. Since extent of cropped area will purely depend on increasing cropping intensity and protecting land from degradation through salination, sodication, erosion, fertility depletion, urbanization and contamination etc.

REFERENCES

Ahmad, N.C. and M.R. Chaudhry, 1997. *Review of Research on Reclamation of Salt-Affected Soils in Pakistan.* Publication No. 175, IWASRI, WAPDA, Lahore.

Anonymous, Un-dated. *The Pakistan National Conservation Strategy*. Environment and Urban Affairs Division, Govt. Pakistan, Islamabad.

Anonymous, 1988. *Report of the National Commission on Agriculture*. Ministry of Food and Agriculture, Govt. of Pakistan, Islamabad.

Anonymous, 1998. *50 Years of Pakistan in Statistics Growth*, Vol. II (1947-1997). Federal Bureau of Statistics, Statistics Div., Govt. Pakistan, Islamabad, Pakistan.

Anonymous, 2000. *Agricultural Statistics of Pakistan 1996-97*. Food, Agri. and Livestock Div., Ministry of Food, Agri. and Livestock, Govt. of Pakistan, Islamabad, Pakistan.

Anonymous, 2001. *Economic Survey of Pakistan*. Economic Advisor's Wing, Finance Division, Govt. of Pakistan, Islamabad, Pakistan.

Anonymous, 2002a. Pakistan Statistical Year Book 2002. Federal Bureau of Statistic, Statistic Division, Govt. Pakistan, Islamabad, Pakistan.

Anonymous, 2002b. *Economic Survey of Pakistan*. Economic Advisor's Wing, Finance Division, Govt. of Pakistan, Islamabad, Pakistan.

FAO, 1988. *Plant nutrition for sustainable agricultural development in Pakistan*. Agron. Report. MTF/PAK/003/FIA, Field Document No. 3.

Haq, A., B.A. Shahid and A.S. Shakir, 1997. Indus basin water resources: Sustainability concerns and optimization strategies. p. 61-76. *In: Proc. Int. Symp. Water for the 21st Century: Demand, Supply, Development and Socio-environmental Issues (Vol. II). June 17-19, 1997*. Lahore, Pakistan.

Mirza, M.Y.J. and M. Ahmad, 1998. *Pakistan's agricultural land resource, its potential and degradational trends*. *Country Report Presented at Int. Seminar "Soil Degradation: Processes, Management and Economic Analysis"* Oct. 19-24, 1998, Univ. Agric., Faisalabad.

Misra, S.G. and D. Mani, 1991. *Soil Pollution*. Ashish Publishing House, 8/81 Punjabi Bagh, New Delhi, India.

(Received 01 May 2002; Accepted 22 June 2002)