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Efficient Soil and Water Management for Sustainable Agriculture

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I feel greatly honoured for being invited to deliver the First "B.P. Ghildyal-ISAP Foundation Lecture". My association with Dr. B.P. Ghildyal dates as back as when he was a student of M.Sc. (Ag.) in Agricultural Chemistry at the then Government Agricultural College (now C.S. Azad University of Agriculture and Technology), Kanpur. After completing M.Sc. (Ag.) successfully, he joined Allahabad University for Ph.D. degree under the able guidance of internationally renowned scientist Dr. N.R. Dhar. Although Dr. B.P. Ghildyal was a student having major specialisation in soil fertility, his subsequent service career in different capacities at the G.B. Pant University of Agriculture and Technology, Pantnagar and at the I.I.T. Kharagpur was marked by notable research contributions in the field of soil physics. Dr. Ghildyal being a scientist of great vision, foresight and brilliance, could visualize the immense importance and potential of deep knowledge and application of soil physics towards much-needed agricultural production. Several students under his unmatchable guidance could generate valuable scientific data on complex aspects of soil physical phenomena involved, particularly in rice culture and brought about outstanding publications in Indian and foreign journals of repute.

Dr. B.P. Ghildyal is an unique example of switching over from specialisation in soil fertility to that in soil physics with utmost competence to the extent that he earned the distinction of a highly esteemed and capable soil physicist. Owing to his eminence in soil physics, his expertise was often sought in a number of high level committees, meetings and consultations. He was a personality of simplicity, easy accessibility, original thinking, frank scientific expression, innovative ideas and urge for practical solution to intricate soil physical processes. Since the chief interest of Dr. B.P. Ghildyal was directed to soil and water management for sustainable agriculture, I have chosen the topic of my lecture as "Efficient soil and water management for sustainable agriculture". I wish to express my gratitude to Dr. D.K. Das, President of the Indian Society of Agro-Physics for giving me an opportunity to deliver this First Foundation Lecture and to pay my tribute to Dr. B.P. Ghildyal.

India has to support about 17% world's human population (over 1 billion) and 15% livestock (about 453 million), but it has only 2.3% land area, 4% fresh water resource, and 1% forest cover. The cropping intensity increased from 111% in 1950-51 to 136% in 1999-2000, while the net cultivated area has remained around 140-142 Mha during the last three decades (approximately 9% of world's cultivated land), and there is no hope of further horizontal expansion. On the other hand, the area under non-agricultural use has increased from 9.4 Mha in 1950-51 to 22.8 Mha in 2001-02 which is likely to touch the figure of 43 Mha by 2050. The required growth in agriculture will, therefore, have to emanate mainly through sustained yield increases from the existing cultivated land. It is irony that despite the limited cultivated land area, the graph of population growth is steadily rising with time and is expected to reach the projected figure of 1.4 billion in 2025 and 1.7 or 1.8 billion in 2050. The average present population density is 324 per sq. km, being maximum in Delhi (9294) and minimum in Arunachal Pradesh (13). More than 65% population depends on agriculture as against only 3% in USA.

Agriculture sector contributes to 24.2% GDP and nearly 16% export income and hence Indian economy being predominantly agriculture-based, sustainability of enhanced productivity with judicious management of natural resources

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*First Foundation Dr. B.P. Ghildyal-ISAP Memorial Lecture delivered on February 17, 2004 especially soil and water without degradation in the wake of mounting unprecedented pressure on the limited and scarce resource bases due to increasing industrialisation, urbanization and globalisation of marketing, has assumed tremendous significance. "The 2020 Vision for Food, Agriculture and the Environment envisages a world where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective and low cost food systems that are compatible with sustainable use of natural resources (IFPRI, 1995)". The Vision statement "India by 2020" released by the Prime Minister on January 3, 2001 on the eve of 88th Session of the Indian Science Congress held at New Delhi defines the future goal as "By 2020, India will be free of poverty, hunger and malnutrition and become an environmentally safe country". Accomplishment of this vision is not possible without sustainable agriculture.

According to FAO sustainable agriculture should involve successful management of the resources to satisfy the changing human needs while maintaining or enhancing the environment and conserving the natural resources. The definition implies prudent use of land resources, maintenance of environmental quality, economic viability, increased and sustained productivity, and risk avoidance. Among the various factors affecting the performance of production system, efficient management of soil and water is central to ensure sustainability of agriculture.

Deceleration of Total Factor Productivity (TFP)

With the green revolution in mid 1960's the agricultural system was based on high input and high productivity technology, wherein large doses of chemical fertilizers, pesticides and weedicides along with improved agronomic practices were employed for cultivation of high yielding, fertilizer responsive and short duration crop varieties with a view to augment the much-needed production for the rapidly swelling population. India has now the largest irrigated area, and ranks third in fertilizer consumption with substantial area under high yielding crop cultivars. The country achieved a record foodgrain production from 51 mt in 1950-51 to 211 mt in 2001-02 with a buffer stock of about 60 mt, surpassing the population growth rate. It has emerged as the largest producer of total pulses, tea, jute and allied fibres, and milk, second largest producer of rice (paddy), wheat, groundnut, sugarcane, fruits and vegetables, and third largest producer of rapeseed, potatoes, and cotton in the world (*Table 1, GOI 2002*).

Table 1. Position of India in World agriculture in 1999

Item	World (mt)	India (mt)	India's rank	Next to
Wheat	584	71	Second	China
Paddy	596	131	Second	China
Total cereals	2064	230	Third	China, USA
Total pulses	59	16	First	
Groundnut	33	7	Second	China
Rapeseed	43	6	Third	Canada, China
Sugarcane	1275	282	Second	Brazil
Tea	287	0.7	First	
Jute & allied fibres	3.3	2.1	First	
Cotton (lint in bales)	18.2	2.1	Third	China, USA
Vegetables	629	59	Second	China
Fruits	445	39	Second	China
Potatoes	294	23	Third	China, Russian Federation
Onion	44	5	Second	China

Despite these impressive achievements, the increase in foodgrain production is not in harmony with the proportionate increase in fertilizer consumption from 0.07 to 19.3 Mt (275 times), net irrigated area from 19 to 59 Mha (3.3 times), net cultivated area under the foodgrains from 97 to 122 Mha (1.3 times), and area under high yielding crop varieties from none in 1950-51 to 76.6 Mha in 2001-02. In addition, there has been considerable increase in the use of insecticides, weedicides, fungicides, energy (human, animal, electricity, machinery) over this period. These data are clearly indicative of low production efficiency of various inputs and marked deceleration of total factor productivity. The crop yields are much lower as compared to many countries. China with much less cultivated area produces much higher quantities of rice, wheat, maize, cereals, fruits and vegetables in comparison to India because of more efficient resource management. Another cause of serious concern is the decline in compound annual growth rate in the yield of most principal foodgrain and non-foodgrain crops during 1990's as compared to 1980's (Table 2, GOI 2002). Even the more popular and dominant rice-wheat cropping system practised over an area of 11.5 mha in India has shown signs of fatigue, especially in the much-acclaimed Indo-Gangetic plains owing mainly to the decline in TFP as a result of fertility depletion and imbalance, toxicity, organic carbon reduction, lowering of water table, and other associated factors. This dismal situation emphasizes the urgent need of accelerating input use efficiency and T.F.P.

Table 2. Compound annual growth rate in yield of important crops in India

Crop	1980-81 to 1989-90	1990-91 to 1999-2000
Rice	3.19	1.27
Wheat	3.10	2.11
Maize	2.09	1.69
Total cereals	2.90	1.58
Total pulses	1.61	0.96
Total foodgrains	2.74	1.52
Sugarcane	1.24	0.95
Total oilseeds	2.43	1.25
Cotton	4.10	-0.61
Non-foodgrains	2.31	1.04
All principal crops	2.56	1.31

Soil Degradation

Soil is the most valuable natural resource, but it is limited, finite and non-renewable. Being the basic medium of life support system for human beings, animals, flora, fauna and other organisms, SOIL is considered as the soul of infinite life. This is amply substantiated by several historical evidences of downfall of civilisations such as Harappan in West India, Malayan in Central America and Mesopotamia in Western Asia resulting from severe degradation of once highly fertile soil base in the past 5000 years. Soil degradation is a complex phenomenon and involves a series of physical, chemical and biological processes, which contribute to reduction in productive capacity. Broadly, the following three factors are of major significance: (1) Natural, (2) Human intervention, and (3) Underlying (population and poverty).

No developing country seems to have evolved precise quantitative indices for defining the degree of soil degradation and also any system of monitoring the soil quality. The changes in the key soil characteristics that accompany degradation, are measured only in some specific areas. Soil degradation has manifold direct and indirect adverse effects, yet despite the enormity of the problem much less well-planned large scale action programme is underway to combat degradation and alleviate consequent social, economic and environmental ill-effects. Very rough and scanty data are yet available on assessment of economic effects of soil degradation. Oldeman (1998) estimated 12.7% lower production in the croplands and 3.8% lower production in pasture lands in the world due to soil degradation.

Over-exploitation and mismanagement with the urgent quest for immediate gains to meet the multiple escalating demands without long-term perspective have caused different kinds of soil degradation at an alarming rate. At the global level about 2 billion ha of once biologically productive land are degraded, which is equivalent to roughly 15 per cent of the total area (13.4 billion ha), two-third of the potentially cultivated land (3.03 billion ha) and 1.33 times the actually cultivated land (1.5 billion ha). The extent of soil degradation in some selected countries of the Asia-Pacific Region (Table 3, Scherr 1999) reveals highest percentage of total degraded land in India followed by Vietnam, Laos, Thailand and China. On the whole, the magnitude of soil loss is greater in the developing countries like India plagued with higher rate of population growth and poverty.

The available data on the extent, kind and severity of land area affected by soil degradation in India differs widely as reported by different sources. As per the estimates of NBSS&LUP out

Table 3. Degraded crop land in selected countries of Asia-Pacific region

Country	Total land area (mha)	Arable and permanent crop land (mha)	Total degraded land (mha)	Degraded land as percent of total land area
Bangladesh	13.0	9.3	0.99	7.4
China	932.6	96.1	280.00	30.0
India	297.3	169.0	148.10	49.8
Indonesia	181.2	21.3	43.00	24.0
Laos	23.1	0.9	8.10	35.0
Myanmar	65.8	10.0	0.21	3.2
Pakistan	77.1	20.7	15.50	17.3
Philipinnes	29.8	8.0	5.00	16.8
Sri Lanka	6.5	1.9	0.70	10.8
Thailand	51.1	22.1	17.20	33.7
Vietnam	32.6	6.6	15.90	48.9
Asia-Pacific region	1710.3	366.1	534.73	31.3

of the total geographical area of 329 Mha, 187.7 Mha (57.1%) are degraded comprising 149.9 Mha by water erosion, 13.5 Mha by wind erosion, 3.7 Mha by nutrient loss, 10.1 Mha by salinisation and 11.6 Mha by waterlogging. According to Prasad and Biswas (1998) 85.65 Mha of cultivated land including 10.77 Mha highly permeable soils, 9.43 Mha slowly permeable soils, 25.62 Mha shallow soils, 20.35 Mha hardening soils, 10.63 Mha soils with high mechanical impedance at shallow depth, and 9.45 Mha others are affected by soil physical constraints. Water erosion is the most dominant degradation process at both global level (56%) and at India level (79.3%) having an array of *on-site* and *off-site* adverse effects on crop productivity and environmental quality.

Based on a study, Singh *et al.* (2001) concluded that in physical terms land degradation is maximum in M.P. (26.2 Mha) and lowest in Punjab (0.9 Mha), but in terms of percentage of degraded land to total geographical area of the state Kerala ranks at the top (67%) followed by M.P. (59%) and J&K has the minimum value (10%). The overall economic loss on account of degradation is around 12% of the value of agricultural output, accounting for Rs. 285.51 billion annually in India and Rs. 4841 million in Punjab state. According to Down to Earth (1996) India incurs a loss of 4.5-6.3% in crop production valued at about 1.9 billion US $. The economic loss of such magnitude has a marked negative impact on the sustainability of agriculture, food security and environmental safety.

The salt affected soils in the world cover more than 950 Mha in about 120 countries, reducing productive capacity of 7-8% of the land surface. In India, the problem of saline/sodic soils recorded from ancient times (Agarwal *et al.*, 1979), is more prominent in the arid and semi-arid regions, though sizeable coastal areas in the humid conditions are also affected mainly due to the ingress of sea water (Yadav *et al.*, 1983). The figures in respect of their extent in India are at a great variance ranging from 7.0 to 26.1 Mha because of different diagnostic criteria and methodologies adopted by different workers in absence of country wide systematic survey (Yadav, 1986). For amelioration of sodic soils addition of some amendment such as gypsum and for reclamation of saline soils provision of adequate drainage to lower the water table and leach out the soluble salts, are basic requirements. With adoption of the technology evolved at the Central Soil Salinity Research Institute, Karnal, more than 1 Mha in the states of Punjab, Haryana and U.P. have been reclaimed and good crops of rice and wheat are grown where no economic crop could be cultivated in the past. Alternative land uses like plantations of tolerant forest species offer vast opportunities especially in the case of community and other government lands (Yadav, 1989).

Removal of soluble salts through leaching below the critical soil depth/root zone is an important aspect for amelioration of saline soils. Leaching with irrigation water is reported to be more efficient when the soil is maintained in an unsaturated condition and the rate of water flow is kept relatively slow (Biggar and Nelson, 1967). Therefore, flood method of irrigation is inferior to sprinkler method in leaching of saline soil. The comparative effect of sprinkler and flood methods (Bresler, 1981) showed almost negligible salt content in the upper soil at the end of irrigation in the sprinkler-irrigated soil due to slower wetting, and also the zone of complete leaching extended to much greater depth. Likewise, in a comparative evaluation of sprinkler and surface methods of irrigation on a sodic soil (pH 10.6, and ECe 2.45 dS m^{-1}) treated with gypsum at 15 t ha^{-1} at Karnal, Yadav and Girdhar (1977) observed a decrease in salt concentration in upper 30 cm soil depth under sprinkler and an increase under surface irrigation (Table 4). The yield of sugarbeet and water use efficiency as well as saving of water were higher under sprinkler. A wetter moisture regime maintained in the upper root zone because of more frequent irrigation in the sprinkler method, resulted in a lower salt flux within this depth.

Table 4. Changes in ECe (dS m^{-1}) of soil under sprinkler and surface irrigations in sugarbeet crop at Karnal

Soil depth (cm)	ECe (dS m^{-1})	
	Sprinkler	Surface method
0 - 3	-0.81	+2.55
3 - 7.5	-0.47	+0.93
7.5 - 15	-0.24	+0.49
15 - 30	-0.03	+0.24
30 - 60	+0.45	-0.35
60 - 90	+0.32	-0.42
90 - 120	+0.24	-0.27

In India, some field experiments have been carried out in saline soils using horizontal subsoil drainage (both open and closed) and encouraging results have been recorded in terms of lowering of water table, reducing salt concentration, and increasing crop yields. In an experiment at Sampla (Haryana) subsurface tile drainage placed at 1.75 m depth and spacings of 25, 50 and 75 m in 1984 by CSSRI Karnal on a highly saline sandy loam soil (ECe varying from 25-80 dS m^{-1} in 0-15 cm layer) having high water table of salty groundwater (EC 10-40 dS m^{-1}), significant salt removal and increased yields of barley, wheat, cotton, mustard and pearlmillet were recorded.

Soil Conservation

Considering the scarcity of soil resource, its vital function to sustain the life support system, unending degradation at unacceptable level, and urgent need to achieve higher production for meeting the varied mounting demands, efficient soil conservation for sustained productivity is inevitable. This has become more important these days in view of the impending threats posed by the swelling population coupled with a host of increasing developmental activities like mining, brick-klin, and road construction as well as the expected climatic change. The government has assigned high priority to soil conservation. Under the Central Sector involving several departments viz. Department of Soil Conservation (Ministry of Agriculture), Department of Wasteland (Ministry of Rural Areas and Employment), Ministry of Environmental and Forests, and Ministry of Water Resources, various schemes related to soil conservation have been implemented. The Ministry of Agriculture and Cooperation undertook schemes like National Watershed Development Project in Rainfed Areas, Soil Conservation in the Catchments of River Valley Projects and Flood Prone Areas, Watershed Development Project in Shifting Cultivation Areas, and externally funded projects on watershed development. Besides, schemes on reclamation of salt affected soils are also in operation. Upto 2000-01, an area of 39.4 Mha has been covered under soil conservation through the Central Sector schemes (GOI, 2002).

Among the various conservation measures, mechanical, cultural and vegetative practices are of great significance, and voluminous data have been generated as a result of these efforts. A positive and linear relationship of the runoff and soil loss with the steepness of slope, and a negative relationship with the length of slope was observed in a long-term study (1986-1999) conducted on Vertisol at Bellary. Maximum runoff and soil loss in the rainfed condition occurred under the sole crop of erosion permitting maize crop, and least runoff and soil loss was recorded when maize was intercropped with sunhemp, thereby indicating the need of intercropping maize with sunhemp or blackgram in the Doon Valley. Four-year average (1997-2001) data relating to the effect of mechanical and vegetative measures in 8% sloping land at Dehradun (Table 5, Ojaswi *et al.*, 2001) show least runoff and soil loss in case of bench terrace and maximum values in case of control fallow. The effect of vegetative barrier of *Panicum maxicum* was next to the bench terrace, especially with respect to soil loss. The performance of graded bund was inferior but superior to the control fallow, thereby validating the bench terrace as the most effective soil conservation practice for 8% sloping lands.

Table 5. Effect of mechanical and vegetative measures on runoff and soil loss from 8% sloping land at Dehradun

Treatment	Runoff (% of rainfall)	Soil loss ($t\ ha^{-1}\ yr^{-1}$)
Bench terrace	5.9	0.57
Graded bund	29.7	11.59
Vegetative barrier	29.3	6.45
Control fallow	36.5	23.49

Efficient integrated watershed management, which involves comprehensive package of practices in a given agro-ecosystem to ensure most optimum and sustained environmental, economic and social change, has gained tremendous importance for soil conservation in recent years. The Central Soil and Water Conservation Research and Training Institute (CSWCRTI) played a prominent role in undertaking watershed development programmes. Initially, a small Sukhomajri village situated 35 km north-east of Chandigarh in the Sivalik foot hills was selected. In absence of any irrigation source, the entire agricultural land (52 ha) in the village used to be put under single rainfed cropping until 1975. Excessive grazing and indiscriminate tree felling in the hilly catchments caused serious soil erosion, resulting in fast siltation of Sukhana lake built in 1958. Within 10 years of its creation more than 65% of its capacity was filled with sediment deposition at the rate of 141 $t\ ha^{-1}\ yr^{-1}$ coming from 4207 ha of the catchment. Social fencing was enforced with the active involvement of local people's participation through a village society 'Hill Resource Management Society', thereby protecting the hilly areas from grazing and illicit tree felling. Four earthen embankments were constructed to collect runoff from the hilly catchments, and the water stored in the four dams was conveyed through underground pipeline to the agricultural fields for providing life saving irrigation to the crops like maize, sorghum, pulses, wheat and gram. The Sukhomajri project not only reduced the soil loss to 5 t/ha/year, enhanced crop production and improved the rural economy but also provided an excellent example of successful watershed management with people's participation.

Encouraged by the commendable success of Sukhomajri model, a number of integrated watershed development programmes were undertaken with multi-disciplinary involvement, multi-resource utilization and multi-facet overall development in several parts of India. The impact of these efforts (Table 6) is reflected in tremendous reduction of runoff and soil loss in a few such watersheds (Samra and Pratap Narain, 1998). The success of various programmes prompted the involvement of several international funding agencies like World Bank, EEC, FAO, DANIDA, IBRD, SIDA and UNDP. In a World Bank supported integrated watershed management project in Punjab hill, the runoff and soil loss, which ranged from 40.3 to 50.4% of rainfall and from 163.5 to 419.0 t/ha/year respectively in the base year of 1994 before imposition of the treatments, dropped in the range of 0.5 to 1.3% and from 2.8 to 5.0 t/ha/year respectively in 1999 in the treated watersheds (Jain *et al.* 2002).

Plant Nutrient Management

Balanced and adequate availability of plant nutrients is crucial for sustained crop productivity. Presently, per hectare application in India is hardly one-third or one fifth of the dose used in countries like Egypt, U.K., Netherland, China, Japan and

Table 6. Impact of integrated watershed management practices on runoff and soil loss

Watershed	Runoff (% of rainfall)		Soil loss (t/ha)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
Fakot (U.P.)	42.0	14.2	11.9	2.5
G.R. Halli (Karnataka)	14.0	1.2	3.5	1.0
Behdala (H.P.)	30.0	15.0	12.0	8.0
Joladarasi (Karnataka)	20.0	7.0	12.0	2.3
UNA (H.P.)	30.0	20.0	12.0	10.0

Korea Republic. There is a big gap of about 8-10 Mt between the nutrients applied and those removed under intensive agriculture, resulting in a negative balance. Estimates indicate that at least 45 Mt of NPK fertilizers against the current consumption of 19.3 Mt will have to be applied to produce the required foodgrains by 2025. Besides, large amount of secondary and micronutrients will also be supplied to support the production systems. In many cases even the use of recommended dose of fertilizers fails to compensate soil nutrient removal and proves to be suboptimal for sustaining the high yielding cropping systems (Tiwari, 2002). On the whole, application of nitrogen is predominant in fertilizer schedule, as most soils are deficient in nitrogen, and the use of high analysis inorganic fertilizers further complicates the situation. It will be difficult to sustain high crop yields in the long term due to micronutrient deficiencies. Very critical consumption ratios of $N:P_2O_5:K_2O$ are used in some agro-ecological regions and cropping systems (Swarup 1998).

Owing to the imbalanced and inadequate fertilizer use coupled with low efficiency of other input management, the response (production) efficiency of chemical fertilizer nutrients has decreased under the intensive agriculture in recent years. The available option is to adopt integrated plant nutrient supply system wherein chemical fertilizers in conjunction with green manure, FYM, crop residues, other organic wastes and biofertilizers are used. This will alleviate the gap between nutrient removal and addition, help balanced nutrient proportion, and augment nutrient production (response) efficiency. Some workers are in favour of organic farming with complete exclusion of chemical fertilizes, but this view is not realistic, as tappable nutrients (N, P_2O_5 and K_2O) are estimated to be only 6.24 Mt in 2010 and 7.75 Mt in 2025 (Tandon 1973). The long term fertilizer experiments conducted in different agro-ecological zones vividly depict that even full application of recommended doses of NPK could not sustain crop productivity, but the conjuntive use of chemical fertilizers and FYM could help achieve higher crop yields (Table 7, Swarup 1998). Even better soils fail to remain productive on a long period without adopting integrated plant nutrient supply system.

Water Management

Irrigation-related Soil Salinisation

Realizing the crucial role of water in enhancing agricultural production, large scale developmental programmes were undertaken to augment irrigation resources in many countries. As a result of these concerted efforts, about 18% of the world's arable land has been brought under irrigation by canals and other sources, accounting for 40% crop production. In some countries like Egypt, Chile, Iraq, Japan, Korea Republic, Korea D.P. Republic, Oman and Pakistan more than 50% of all arable land was under irrigation in 2000 (FAI, 2001-02). In India, more than 50% crop production comes from only 39.2% of net irrigated land. However, management of irrigation water in India is one of the poorest in the world, leading to hardly 2.2 t/ha crop yield, which can be raised easily by 3 or 4 times with efficient management.

Consequent to unscientific use of canal irrigation natural hydrologic equilibrium is disturbed due to the recharge component far exceeding the discharge component of the water balance. The extent and nature of disturbance will depend upon the local topography, soil characteristics, water table, rainfall pattern, evaporative demand, irrigation method, drainage outlet availability, and other related conditions. In

Table 7. Average grain yield of crops (t/ha) over the years in long-term experiments in different soils of India

Soil order	Location	Crop	Control	N	NP	NPK 100%	NPK 150%	NPK+FYM 100%
Inceptisol	Bhubaneswar	Rice	1.6	2.1	2.2	2.8	3.0	3.5
		Rice	1.4	2.1	2.8	3.0	3.3	3.7
	Ludhiana	Maize	0.4	1.4	1.8	2.3	2.4	3.2
		Wheat	1.0	2.7	4.1	4.8	4.9	4.9
Vertisol	Jabalpur	Soybean	1.0	1.2	2.0	2.2	2.2	2.3
		Wheat	1.1	1.4	4.0	4.3	4.5	4.7
Molisol	Pantnagar	Rice	3.4	5.0	5.0	5.4	5.4	6.2
		Wheat	1.6	3.8	3.8	3.9	4.2	4.6
Alfisol	Palampur	Maize	0.3	0.6	2.0	3.2	4.0	4.6
		Wheat	0.3	0.4	1.8	2.5	3.0	3.3
	Bangalore	Finger millet	0.6	0.9	1.4	4.0	4.8	4.6
		Maize	0.4	0.7	1.0	2.3	2.5	2.7

absence of adequate drainage positive addition to groundwater often leads to a rise in water table, as recorded in several irrigation commands ranging from 26 to 120 cm per year (Gupta and Tyagi 1996). Faulty irrigation management in absence of drainage has resulted in development of waterlogging and soil salinity in a number of command areas in India (Table 8, Joshi and Agnihotri, 1984). In Sharda Sahayak project of Uttar Pradesh, Joshi and Jha (1991) recorded 61% decline in paddy yield and 68% in wheat yield in four villages due to soil salinisation and waterlogging over a period of ten years.

At the global level also, about one-fourth of irrigated land was affected by waterlogging and soil salinity (World Watch Institute, 1990), with two-third of the malady occurring in only five countries namely India, China, USA, Pakistan and erstwhile USSR. According to a later publication (Ghessami and Nix 1995), out of total irrigated land of 227 Mha, 45.4 Mha (about 20%) was inflicted by soil salinity (Table 9). Therefore, maintenance of a favourable water and salt balance particularly in the root zone through scientific water management is of vital importance.

Provision of suitable drainage is of paramount importance to maintain the water table below the critical depth and also a favourable salt balance in

Table 8. Extent of development of waterlogging and soil salinity in some irrigation projects in India

('000 ha)

Irrigation project	State	Water-logging	Soil salinity
Sriramsagar	A.P.	60.00	1.0
Tungabhadra	A.P., Karnataka	4.65	24.5
Gandak	Bihar, U.P.	211.01	400.0
Ukai Kakrapar	Gujarat	16.25	8.3
Mahi Kadana	Gujarat, Rajasthan	82.00	35.8
Malprabha	Karnataka	1.05	40.0
Chambal	M.P., Rajasthan	98.70	6.6
Rajasthan canal	Rajasthan	93.10	29.1
Sharda Sahayak	U.P.	301.00	50.0
Ramganga	U.P.	195.00	352.4

the irrigated areas. Despite great emphasis on essentiality of adequate drainage hand in hand with introduction of canal project especially in the arid and semi-arid regions, these two components have not been implemented simultaneously in any canal command in India, resulting thereby in widespread waterlogging and soil salinisation. The essentiality of drainage has, however, received considerable attention in practice

Table 9. Global estimate of secondary salinisation in irrigated land

Country	Cropped area (Mha)	Irrigated area (Mha)	Salt-affected in irrigated land (Mha)	% of affected to irrigated land
China	97.0	44.8	6.7	15.0
India	169.0	42.1	7.0	16.6
USA	190.0	18.1	4.2	23.0
Pakistan	20.8	16.1	4.2	26.2
Iran	14.8	5.7	1.7	30.0
Thailand	20.1	4.0	0.4	10.0
Egypt	2.7	2.7	0.9	33.0
Australia	47.1	1.8	0.2	8.7
Argentina	36.7	1.7	0.6	33.7
South Africa	13.2	1.1	0.1	8.9
World	1473.7	227.1	45.4	20.0

in country like USA. Installation of tile drainage in the Coachella valley in the water district of California was taken up almost immediately after opening of the canal. The tile drainage effluent was carried into the Salton sea. The relevant data relating to the area of irrigated and tiled land, as well as the input and output of salts from the area during 1957 to 1965 (Table 10, Bower *et al.*, 1969), show a favourable salt balance when about half of the irrigated area was tile-drained and about 30% leaching was done. Similarly, in the Imperial Valley about three-fourth of the irrigated land was tile-drained after introduction of All American Canal and the salts through drainage effluent were discharged into the Salton sea. It was observed that the quantity of salts removed was greater than that added through the canal water.

Irrigation with Poor Quality Water

In many arid and semi-arid regions of the world, groundwaters which are generally of poor quality, are the major source of irrigation. The nature and distribution of groundwaters in some parts of India are reported by Yadav (1982). According to Minhas and Bajwa (2001) about 41-84% of well waters in the north-western parts of the Indo-Gangetic plains are brackish. The continuous use of such waters

Table 10. Irrigated and tiled area with salt input and output in Coachella Valley, California during 1957-65

Year	Land area (× 1000 ha)		Salts (× 1000 tonnes)	
	Irrigated	Tile drained	Input	Output
1957	20.9	4.3	369.7	99.9
1959	22.2	7.7	348.5	166.6
1961	21.6	9.9	390.5	277.2
1963	23.1	11.6	391.5	402.7
1965	24.0	12.8	407.0	444.8

for irrigation causes salinity or sodicity in the soil, the effects being more pronounced in the slowly permeable heavy clay soils dominated by montmorillonite mineral than in the light-textured soils dominated by kaolinite or illite mineral (Yadav, 1977), though the climatic conditions, drainability and calcareousness of soil, management practices and kind of crops grown are also important in modifying the effect of irrigation water. Since the crops differ greatly in their tolerance, the limits of salt concentration of irrigation water in bringing about 10, 25 and 50% reduction in the yield of different crops vary according to soil texture (Table 11, Gupta and Yadav, 1986).

Besides, many poor quality groundwaters possess higher proportion of magnesium than calcium, their ratio increasing with an increase in salinity of water. Prolonged irrigation with high Mg:Ca ratio waters creates adverse effects on the physical properties of soil as reflected in an increase in the degree of dispersion and a decrease in hydraulic onductivity (Yadav and Girdhar, 1981). The adverse effect is of much greater magnitude in non-calcareous than in calcareous soil. Depending upon the degree of salinity or sodicity of irrigation water appropriate management practices have been worked out under the All India Coordinated Research Project on the Use of Saline Water in Agriculture.

Judicious Irrigation Application

Judicious irrigation application as per the soil and crop requirement not only provides correct

Table 11. Tolerance limit of some crops in saline water irrigation for a given yield reduction

Crop	Limit of ECiw (dS m^{-1}) for a given yield reduction					
	Sandy loam soil at Agra			Black clay soil at Dharwad		
	10%	25%	50%	10%	25%	50%
Wheat	9.0	12.9	17.6	2.7	7.4	18.0
Sorghum	8.3	12.8	17.8	2.4	6.5	13.4
Safflower	6.2	11.4	-	4.9	12.2	24.7
Mustard	7.9	10.9	14.6			
Pigeon pea	1.8	3.3	6.2			
Cotton				3.3	7.7	15.1
Cowpea				2.0	4.6	8.8

amount of water but also minimises the detrimental effects such as waterlogging, secondary soil salinisation, and nutrient loss. The most important factors that influence the selection of irrigation method, are the soil type (texture and mineralogy), topography, crop to be grown, quantity and quality of water available for irrigation, climatic conditions of the area, and other local variations. Among these factors soil texture is of tremendous significance. Based on the research work conducted for several years at different locations under the All India Coordinated Project for Research on Water Management, it is inferred that depending upon the stream size the dimensions of check basin have to be smaller in the porous sandy soils that are highly prone to deep percolation as compared to the clayey loam or clay soils. In case of border strip method of irrigation, the length of the border is kept generally longer is clay loam to clayey soils and shorter in case of highly permeable sandy soils in view of greater opportunity for water loss in the latter (Table 12, Yadav 1987).

The furrow method of irrigation which is generally used with row crops and vegetables, is adopted on the soils having infiltration rate between 0.5 and 2.5 cm per hour. This method is more advantageous and effective in the areas that are in need of surface drainage. In the areas where irrigation water is scarce, the practice of alternate or skip row irrigation results in substantial saving of water. The sprinkler method is very much suited to sandy soils, shallow soils, undulating land surface, and limited water availability situations. The drip or trickle method which is relatively a recently developed technique, is especially suited to limited water condition, high water evaporative demand, undulating or poorly levelled areas, and porous sandy soils. This method not only saves considerable water and applies water directly to the root zone as per requirement, but is also beneficial to the areas where only saline water of limited EC is available. The relative increase in crop yield and water saving with drip irrigation over the surface method under different

Table 12. Optimum dimensions for border strip method of irrigation

Location	Soil texture	Dimensions of border			Stream size (litre/sec)
		Width (m)	Length (m)	Slope (%)	
Jobner	Sandy	1.5	20	0.3-0.5	3.5
Hisar	Sandy loam	7.5	50	0.1-0.2	14.0
Kharagpur	Sandy loam	3.5	50-70	0.3	6.0-8.0
Karnal	Clay loam	6.0	70	0.1-0.15	10.0-12.0
Kota	Clay loam	6.0	50	0.2	10.0
Navsari	Clay	3.0	90	0.3	4.5

crops at various locations in India is presented in Table 13 (Kumar and Singh, 2002). Considering multiple benefits, the government is giving financial support to promote adoption of drip irrigation method, as a consequence of which about 3 lac hectares of land have been covered under this method in India, with maximum area in Maharashtra followed by Karnataka, Tamil Nadu, Andhra Pradesh and Rajasthan.

Table 13. Relative increase in crop yield and saving of water with drip irrigation over traditional surface irrigation

Crop	Location	% increase in yield	% saving of water
Bottle gourd	Jodhpur	31.9	12.0
Beet	Coimbatore	36.0	79.1
Bittter gourd	Chalakudy	25.6	56.6
Brinjal	Akola	38.5	62.0
Broccoli	Delhi	28.2	14.3
Cauliflower	Pantnagar	37.6	33.3
Chili	NCPA	30.5	61.7
Cucumber	Pune	31.1	55.6
Ladyfinger	Delhi	25.0	38.1
Onion	Hisar	17.0	25.0
Potato	Parbhani	30.4	26.7
Radish	Coimbatore	11.8	76.1
Sweet potato	Coimbatore	28.0	60.3
Tomato	Udaipur	17.7	31.7
Banana	NCPA	34.3	45.0
Grapes	Dharwad	0.0	47.2
Guava	Allahabad	27.3	18.6
Lemon	Delhi	44.4	23.9
Papaya	Coimbatore	43.5	68.5
Pomegranate	Hyderabad	59.5	2.7
Cotton	Rahuri	28.3	37.3
Groundnut	Junagarh	4.5	40.9
Sugarcane	Coimbatore	22.7	32.3

Another area where substantial quantity of water can be saved with efficient management is the rice crop which consumes bulk of irrigation water used in agriculture, but in most inefficient manner under the common practice of deep continuous submergence. The results of field experiments conducted at a number of locations under the All India Coordinated Project reveal that it is possible to withhold irrigation for 1 to 3 days after disappearance of water from the soil surface and to reduce the depth of submergence to 5 cm, thereby saving considerable water without affecting the rice crop yield.

Water Management in Vertisols for Crop Production

The Vertisols, popularly known as black soils, occupy about 72.9 Mha (roughly 22.2% of India's geographical area), and present special management problems for crop production owing to high clay content (more than 40%) dominated by montmoillonite clay mineral. These soils have very low infiltration rate, low hydraulic conductivity, poor vertical and downward water transmission, and swelling as well as shrink properties on wetting and drying respectively. The infiltration rate of these soils recorded at several locations in India (Table 14, Gupta *et al.* 1991) is in the range of 21-54% of the total rainfall, thereby resulting in serious runoff and soil erosion during storms of high intensity, specially in the fallow lands without protective vegetative cover.

Table 14. Infiltration rate of black soils at different locations of the peninsular India

Location	Infiltration rate (mm hr^{-1})
Indore, M.P.	12.6
Jabalpur, M.P.	4.7
Hyderabad, A.P.	0.21
Rahuri, Maharasthra	6.4
Parbhani, Maharashtra	7.0
Satna, M.P.	4.0
Bijapur, Karnataka	2.3
Kovilpatti, Tamil Nadu	29.0

Since a major proportion of the black soils in the semi-arid region is rainfed, it is imperative to employ suitable methods of land configuration modification depending upon the local topography, soil condition, climate and kind of crop to be grown, such that maximum water is conserved *in situ* and utilized for crop production. With the onset of rains the cracks become sealed, often leading to water stagnation and adversely affecting crop growth due to oxygen stress etc. The system of alternate ridges and furrows has given promising results at ICRISAT, Hyderabad in growing upland rainy season crops like sorghum on the ridges.

This system facilitates drainage with disposal of runoff through the furrows on the one hand, and adequate root zone aeration in the ridges on the other. In the areas having assured high rainfall, the configuration system of raised and sunken bed (raised bed of 6-9 m width and 30-35 cm height alternating with 6 m wide sunken bed), helps in collection of runoff from the raised beds in the adjacent sunken beds which are connected with pipe for safe removal of excess water above the desired level into a pond for storage. In the raised beds *kharif* upland crops like sorghum, black gram, pigeon pea and sesame are grown, while in the sunken beds rice is cultivated. The excess rainwater collected in the pond is used for irrigating the upland crops on the raised beds during the period of water stress. The same configuration is utilized in *rabi* season to grow chickpea, linseed or safflower in the raised beds and wheat in the sunken beds. This system facilitates *in situ* rainwater conservation as well as drainage, and gives much higher total productivity than the farmer's traditional flat method. The results of a long term study using this method at Jabalpur are presented in Table 15 (Painuli *et al.* 2002)

Table 15. Productivity of soybean-rice cropping sequence in raised and sunken bed system of cultivation at Jabalpur (kg ha^{-1})

Selected years	Soybean seed yield		Paddy grain yield	Rainfall (mm)
	Raised bed	Flat bed	Sunken bed	
1980	2962	2229	5100	1432
1985	2253	1000	2500	1380
1990	2425	581	3001	1624
1995	1755	1113	4473	1153
Mean of 16 yrs	2281	957	2607	-

The growth of deep-rooted crop like cotton is affected adversely because of poor hydraulic conductivity and low water release characteristic despite high water holding capacity, particularly in the sodic Vertisols. In a detailed study on 29 Vertisols of semi-arid central India, Kadu *et al.* (2003) observed significant negative correlation between the saturated hydraulic conductivity (HC) and exchangeable sodium percentage (ESP), and between cotton yield and ESP (Table 16). On the other hand, a positive correlation was noticed between HC and exch. Ca/Mg, and between cotton yield and exch. Ca/Mg. An improvement in H.C. of Vertisols caused by high exchangeable calcium created favourable available water status and drainage condition for the cotton crop. Reverse was the case when the exchange complex was dominated by Mg or Na. These workers concluded that poor hydraulic conductivity is the important limiting factor in controlling the cotton yield in such soils. The Vertisols with HC > 20 mm hr^{-1} can be considered suitable for growing deep-rooted crops under the rainfed condition and therefore, the sodic Vertisols with HC < 10 mm h^{-1} can be suitable only after HC is improved through removal of subsoil sodicity.

Table 16. Correlation coefficient between soil attributes and cotton yield

Parameter Y	Parameter X	r
sHC (mm h^{-1})	ESP	-0.56*
sHC (mm h^{-1})	Exch. Ca/Mg	0.51*
ESP	Exch. Ca/Mg	-0.40*
Cotton yield (q ha^{-1})	ESP	-0.74*
Cotton yield (q ha^{-1})	sHC	0.76*
Cotton yield (q ha^{-1})	Exch. Ca/Mg	0.50*
Cotton yield (q ha^{-1})	Carbonate clay	-0.64*

*Significant at 1% level; sHC - Saturated hydraulic conductivity

Challenges

- Fast diminishing per capita availability of soil and water resources, and steadily soaring population growth.
- Rapid degradation and pollution of soil and water
- Widespread nutrient deficiencies and toxicities
- Deceleration in input use efficiency and total factor productivity
- Unsustainabilty and low productivity of irrigated agriculture

- Wide regional dispartities
- Need for greater diversification, product quality, and value addition
- Expected climatic change and attendant hazards
- Most farmers are resource-poor marginal and small (< 2ha)

Conclusion

From the available evidence it is abundantly clear that without judicious soil and water management, even the most fertile lands can not remain productive for long and the yield potential of the best crop cultivars can not be realized. The increasing competitive agriculture scenario consequent to globalisation of marketing warrants accelerated cost-effective production in terms of both quality and quantity on a sustained basis from the already strained resources. In the wake of fast degradation rate and rising graph of burgeoning population, sustained high productivity from the diminishing land base has become imperative. Any neglect in efficient management of soil and water resources will be extremely detrimental to accomplishment of the highly cherished Vision 2020 and beyond, at both world and India level, and is bound to cause a dreadful crisis for the mankind.

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