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Soil Related Constraints and Their Remedial Interventions in North-Western Tract of India

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ABSTRACT: *The green revolution has transformed agriculture in irrigated regions in India but had little influence on the rain fed agriculture in the semi-arid tropics. In such areas agricultural productivity is low and natural resources are degraded. The north-west region of India is characterized by undulation terrain with slope ranging from 0-36 per cent and ill distribution of rainfall in time and space. The major problem associated with the region is soil degradation by soil erosion. Some estimates showed that soil loss occurred to the magnitude of 25-225 t/ha/yr on a small to large watershed. Such variations in soil loss occurred due to differences in topography, land use, rainfall amount and intensity, soil type and following different land and soil management practices. Land modifying measures commonly recommended are minimum tillage, mulching, cover cropping, contour/field bunding, graded bunding, bench terracing, minor land leveling, provision of field outlets for safe disposal of excess runoff water and in-situ rainwater conservation. Minimum tillage reduces surface disturbance, mulching, cover cropping and mixed cropping reduces sediment yield by reducing the rain drop impact. Contour/field bunding, graded bunding, bench terracing and field levelling conserve more moisture by providing more opportunity time to infiltrate. Also the provison of proper outlets in channel can help in reducing soil erosion and sediment transport. The paper suggests important options for maintenance or amelioration of soil physical properties, improving soil moisture, reducing runoff, soil loss and help in conserving the soils depending upon slope steepness, soil types, crop management practices and climatic conditions for a location.*

Keywords: *Soil erosion, minimum tillage, mulching, cover cropping, contour/field bunding, terracing, land leveling*

INTRODUCTION

The research and development efforts in the previous three to four decades in the country have resulted in generation of resource conservation technologies which reduced the risk of land degradation, improved the productive potential of soils and help in sustaining the agricultural productivity. Land and water are the basic and precious resources of the country which must be carefully conserved and judiciously utilized to sustain the human and livestock population. In order to meet the demand of food, fiber, fuel and fodder due to exponential increase in population pressure, people are cutting the forests indiscriminately and following intensive land cultivation practices. It thus leads to unabated soil loss and land degradation both in the country and state. Some of the human activities viz. mining, intensive cultivation, road construction, shifting cultivation and urbanization etc. have aggravated the problem.

Soil erosion by water and wind is the major land degradation process in the arid and semi arid regions of the world. Globally, an estimated 1.96 billion hectare land is subject to some kind of degradation. Of this, 1.094 billion hectares are subject to soil erosion by water and 549 million hectares of land to soil erosion by wind (UNEP/ISRIC, 1991). In North-western tract of India, water erosion is the major problem causing loss of top soil and/or terrain deformation in about 148 million ha representing 45% of the total geographical area of the country (Source: www. nbsslup.nic.in). In the country, some estimates indicated that 188 m ha or 57% of geographical area is seriously affected by various land degradation problems (Table 1). This showed that 141 m ha of area is affected by water and wind erosion and another 34

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m ha is degraded through water logging, alkalinity, salinity, ravines and gullies, shifting cultivation and torrents etc (Singh and Sharma 1998).

Table 1
Land Degradation Due to Erosion in India

Type of degradation	*Area (m ha)*
Water erosion	148.9
(i) Loss of top soil	132.5
(ii) Terrain deformation	16.4
Wind erosion	13.5
(i) Loss of top soil	6.2
(ii) Terrain deformation	4.6
(iii) Terrain formation over moving	2.7
Physical deterioration (water logging)	11.6
Total degraded area	164.0

Source: Singh and Sharma (1998)

Deforestation and associated soil erosion has caused desertification of land in the Shiwalik hills in the Hoshiyarpur district of the Punjab state. The extent of degraded land in this area was 194 km^2 in 1852, 2000 km^2 in 1939, while it increased to 20 000 km^2 in 1981 (Patnaik, 1981). Soils of this region are coarse in texture and have low water retention. The area receives an average annual rainfall of 1000 ± 304 mm, 80% of which is received during the monsoon season. Rains are highly erratic and are often of high intensity. Summer monsoon rains produce 20–30 rainstorms, out of which 8–12 create runoff (Hadda and Sur, 1987). Also some estimates in the state of Punjab showed that soil loss occurred to the tune of 25-225 t/ha/yr on a small to large watershed (Sur and Ghuman, 1992). The shrinking forest and cultivated land resource have further aggravated the problem of land degradation and pose the challenge of resource conservation. For example, India supports 15% of the world's population but it has only 2% as the forest area. The per capita availability of forests in the country is only 0.08 ha against the worlds' average of 1 ha. However, the total cropped area has steadily increased from 132 m ha in 1950-51 to 188 m ha in 1994-95. However, the availability of arable land has declined from 0.45 ha in 1950-51 to 0.20 ha in 1980-81 and further to 0.14 ha by 2000 (Sharda, 2002). Such a rapid decline in man to land ratio suggest for a serious cause of concern to increase productivity of arable land.

Some estimates indicated that 5334 m tons of soil is being lost through erosion annually, constituting about 16.4 t ha^{-1} yr^{-1} (Dhruva Narayana and Ram Babu, 1983). Of it, 29 per cent is lost into sea, 10 per cent is deposited in reservoirs and remaining 61 per cent is displaced from one place to another causing various land degradation problems. The soil loss estimate under different management practices are given in table 2. Such variations in soil loss resulted due to differences in topography, land use, rainfall amount and intensity, soil type and following different land and soil management practices. However, soil erosion depends on the erosivity of the rainfall and erodibility of soil. The soil erodibility depends primarily on the physical characteristics of the soils viz., nature and amount of soil aggregates, organic matter content and particle size distribution. Gully erosion is most prevalent type of water erosion as it dissects the fields, impedes the tillage operations, damages agricultural, residential and recreational land and causes environmental pollution.

Soil erosion affects the crop production and public life by Loss of productive soil, due to runoff most of the water is lost to rivers and canals which results in incidence of flood and drought, deposition of sand on fertile land in downstream and Silting of lakes and reservoirs.

Table 2
Annual Soil Loss Estimates in Different Regions of India

Land Resource Region	*Area(000 km^2)*	*Soil loss(t km^{-2})*	*Majorland use*
Northern Himalayan forest region	131.7	207	Forest
Punjab Haryana alluvial plains	101.2	330	Agriculture
Upper Gangetic alluvial plains	200.0	14.4 – 3320	Agriculture and wasteland
Lower Gangetic alluvial plains	145.5	287 – 940	Agriculture
North-Eastern forest region	101.0	2700 – 4095	Shifting Agriculture
Gujarat alluvial plain region (including ravines)	62.7	240 – 3320	Agriculture
Red soil region	68.8	240 – 360	Agriculture
Black soil region	67.3	2370 – 11250	Agriculture
Lateritic soils	61.0	3930	Agriculture

Source: Sharda (2002)

MANAGEMENT OPTIONS FOR MITIGATING SOIL EROSION

The options for mitigating soil loss and improving soil physical sustainability depends on activities which are explicitly aimed at its maintenance and if necessary, any activities needed to ameliorate or control damage already done is depicted in Table 3. But the few strategies are universally applicable in detail for example, minimum soil disturbance may, after several years, enhance sustainability in temperate USA and semi-arid Australia whereas tillage experiments in Africa and Asia support conventional and even deep ploughing etc for enhancing sustainability. Various available options for reducing soil loss are discussed below.

In-situ Rainwater Conservation

By construction of earthen bunds (0.10 m^2 cross sectional area) around the rice fields with appropriate surplus arrangements (an average of 5 years data) revealed that by providing outlet in the field bund for disposal of rainwater excess at 15-20 cm resulted in increasing the yield of transplanted rice by 35 per cent as compared to no impounding. This practice helps in conserving rainwater which reduces both runoff and soil loss (Joshi *et al.*, 1989).

Table 3
Important Options for Maintenance or Amelioration of Soil Physical Properties

Maintenance *: prevention of physical degradation*	
Crop choice	• Rotations + sequential cropping
	• Mixed cropping
	• Relay cropping
	• Alley cropping + agroforestry
Crop cultural practices	• Tillage + residue management
	• Time of planting
	• Seed quality and soil organism symbioses
	• Inorganic fertilizers
	• Organic matter management
	• Cultivar : ground cover, complementarily with other crops
	• Biological pest + weed management
Inter-crop ley and fellow	• Cover crop
	• Pasture ley
	• Maintenance of surface litter in absence of living vegetation
Mulches	• *In situ* live mulch
	• Green manure crops
	• *In situ* dead residues
	• Transported residues
	• Animal wastes, composts
	• Industrial wastes
	• Inorganic covers e.g. gravel
Amelioration to control damage	
Management of water erosion	• Contour ploughing
	• Graded channels
	• Bunds
	• Grassed waterways
	• Ponds
Management of wind erosion	• Wind-breaks + interplanted with trees
	• Shrub + tree revegetation
	• Soil coverage
	• Ridges
Soil surface management	• Coverage with residues, transported waste, etc.
	• Also Inter-crop ley and fallow and Mulches
Compaction	• Deep tillage, subsoiling
	• Deep-rooted “natural plough” plants

Land Modifying Measures

Land modifying measures commonly recommended are contour/field bunding, graded bunding, bench terracing, minor land leveling, provision of field outlets for safe disposal of excess runoff water and in-situ rainwater conservation (table 4).

Table 4
Area Affected by Different Types of Water Erosion on Untreated and Treated Fields with Land Modifying Measures

Type of water erosion	*Untreated*	*Treated*
	– – *Per cent* – –	
Sheet	80.0	15.0
Rill	11.0	2.0
Gully	3.6	Nil

Source: Hadda and Sur (1987)

Contour Cultivation

In slopes cultivation should be done on contour lines. A contour line is an imaginary line which connects all the points of land located at equal height. If the land slope is only vertical (horizontal plain being flat) ploughing just across the slope automatically gives the furrow which is exactly on the contour. If the horizontal plain is also sloppy, furrow should be bent in such a way as it follows contour line. When all the normal cultivation operations e.g. ploughing, sowing/planting, inter-cultural operations, are carried out across the slope or on approximate contours, furrows and ridges so created serve as small barriers to the flow of runoff by retarding the velocity of flow and increasing the residence time of infiltration. The effectiveness of these varies with slope, crop cover and soil texture. The contour cultivation remains most effective on moderate crops ranging between 2-6 per cent, but this practice is least effective both on steep as well as flat slopes. In case of heavy storms on steeper slopes, ridges sometimes break resulting in excessive soil loss (Table 5). The maize grain yield increased significantly by 9.3, 17.6 and 52.3 per cent through T_2, T_3 and T_4 respectively over the treatment T_1 as indicated by study (Singh, 2000) in the foothills of lower Shivaliks at Zonal Research Station on Kandi Area, Ballowal-Saunkhari, Nawanshahr (Table 6). In treatment T_4, more than 50 per cent increase in grain yield may be attributed to favorable soil moisture regime and higher nutrient use efficiency over the steeply sloping lands which were low in their fertility level over the leveled lands. Also the better top soil thickness might have been formed in the levelled land that improved the available moisture status.

Table 5
Effect of Contour Cultivation on Runoff and Soil Loss in Silty Clay Loam soil at 8 % Slope

Crop cultivation practice	*Rainfall (mm)*	*Runoff (mm)*	*(Per cent of rain)*	*Soil loss ($t\ ha^{-1}$)*
Maize up and down cultivation	1239	670	54.1	28.5
Contour cultivation	1239	511	41.2	19.3

Source: Tejwani (1980)

Table 6
Effect of Different Treatments on Maize Grain Yield

Treatment	*Maize grain yield (kg ha^{-1})*	*Per cent increase in yield*
Cultivation along the slope with application of recommended dose of inorganic fertilizers (T_1)	1965	–
Contour bunding and cultivation across the slope with application of recommended doses of inorganic fertilizers (T_2)	2148	9.3
Cultivation of levelled land with application of recommended doses of inorganic fertilizers (T_3)	2310	17.6
Cultivation of levelled land with application of recommended doses of inorganic fertilizers + farm yard manure (T_4)	2993	52.3
LSD < 00.05	174	–

Source: Singh (2002)

Zero Tillage and Mulch in Maize-wheat System

A study conducted through runoff plots of size 100 m x 20 m with 4% slope in maize crop (var. Ganga 5; rows 90 cm apart) on contours with treatments: zero tillage, zero tillage + mulch, normal tillage + mulch indicated that the runoff and soil losses were in order of : zero tillage with mulch < normal tillage + mulch < zero tillage. Soil moisture storage after maize increased to 11.4 per cent with normal tillage + mulch and 10.1 per cent in zero tillage + mulch over zero tillage without mulch. Although mulched plots gave slightly lower yield of maize than zero tillage, but sowing and weeding cost alone (Rs.700/ha) was more than the reduction in yield (Table 7). Bhardwaj and Sindwal (1988) reported that zero tillage/no tillage + weed mulch had only 3 Mg ha^{-1} soil loss whereas normal tillage + weed mulch and zero tillage alone, had 7 and12 Mg ha^{-1} soil loss, respectively.

Tillage and Surface Mulching

Tillage operations should be carried out very cautiously as they can do both harm and good to a

Table 7
Effect of Zero Tillage and Mulch on Soil Erosion, Crop Yields and Soil Moisture Storage

Attribute	*Zero tillage without mulch*	*Normal tillage with mulch*	*Zero tillage with mulch*
Runoff (as per cent of rainfall)	41.8	31.2	21.6
Soil loss (t/ha)	11.9	7.0	3.3
Maize yield (kg/ha)	1853	1618	1543
Wheat yield (kg/ha)	2236	2947	3409
Soil moisture (mm) after maize	287.6	320.5	316.6

Source: Bhardwaj (1988)

soil. The minimum tillage concept developed recently speaks of only that much tillage which is just enough to pulverize the soil. It emphasizes on the least possible tillage. Mulching is a practice of putting straw, plant residues, leaves or grass on the soil surface to reduce evaporation, erosion and fluctuation in soil temperature. Materials used in mulching, act as physical barriers to movement of water in the soil. Immediate objective of mulching is to reduce loss of moisture from the soil is surface by the process of evaporation and protect the soil against the strokes or rain and wind. After decomposition mulching material incorporates organic matter in the soil which enhances erosion resistant power of the soil.

The effect of mulch rate was more pronounced in decreasing sediments than runoff. For example, an application of mulch @ 4 t/ha decreased runoff by 57.6 per cent and soil loss by 71.7 per cent. The effect of mulch was greatly modified by tillage treatment. It was indicated by an interaction between mulch rates and tillage for both runoff and soil loss. For example, a significant decrease in runoff was caused in untilled plots by a mulch @ 4t/ha, whereas in tilled plots mulch rate required was 8 t/ha. Less effectiveness of mulch in tilled plots is owing to the increased concentrated flow in furrows in these plots which provided greater hydraulic radius by decreasing wetted perimeter of the flow (Table 8).

Bhatt and Khera (2006) investigated the effect of tillage and different modes of mulch application on soil erosion losses with two levels of tillage, viz. minimum (T_m) and conventional (T_c) and five modes of straw mulch application, viz. mulch spread over whole plot (M_w), mulch spread on lower one-third of plot ($M_{1/3}$), mulch applied in strips (M_s), vertical mulching (M_v) and unmulched control (M_o). Rate of mulch application was 6 t ha^{-}1 in all modes. Compared with M_o, M_w reduced runoff by 33% (table 9). Runoff and soil loss were 5 and 40% higher under T_c than under Tm. Though other modes of straw mulch application ($M_{1/3}$, M_s and M_v) controlled soil loss better than M_o, their effectiveness was less than M_w. Tm was more effective in conserving soil moisture than T_c. Compared with M_o, M_w had 3–7% higher soil moisture content in the 0–30 cm soil depth under T_m. Minimum tillage with fully covered plots (Mw) was the most effective and conventionally tillage with no residue (Mo) was the least effective in reducing the soil erosion.

Graded Bunding

Graded bunds (channel) terraces are mostly recommended in high rainfall areas receiving annual rainfall greater than 600 mm and these are mostly employed for disposing excess water out of the fields. In these structures, water is moved out of the fields

Table 8
Effect of Tillage Treatments and Mulch Rates on Runoff and Soil Loss (Rain 77 mm)

Treatments	*Mulch rate (t/ha)*			
	0	*2*	*4*	*8*
	Runoff (mm)			
Untilled	35.6	21.4	14.6	10.6
Tilled	31.0	19.0	13.6	10.3
	Soil loss (kg/ha)			
Untilled	5124.3	2778.5	1428.8	636.6
Tilled	4443.2	2194.2	1277.3	441.0
LSD < 0.05	**Runoff (mm)**		**Soil loss (kg/ha)**	
Tillage (T)	NS		32.9	
Mulch (M)	0.80		177.0	
T x M	10.2		218.3	

Source: Hadda and Sur (1989)

through a graded channel, constructing it on a higher side of the bund at a non-erosive velocity and finally disposed off into a graded waterway. The grades to be provided range between 0.1 to 0.6 per cent which is almost one tenth of the original land slope. In case the length of the bund is between 150 m to 225 m, a uniform grade is provided and if it exceeds upto 400 m, a variable grade is recommended. Thus, in order to retain in-situ as much rainwater as possible, contour cultivation is followed in inter-bunded area (DhruvaNarayana 1993). The efficacy of mechanical measures on sloping cultivated lands (4.0 per cent slope) in large field size (100m x 20 m) plots, it was observed that up and down cultivation produced maximum runoff followed by graded bunds in channel terrace, channel terraces with contour farming and contour farming alone. Maximum soil loss per mm of rainfall was observed in up and down cultivation while it was least in case of channel terrace with graded furrows (Tejwani *et al.,* 1971).

Bench Terracing

Terrace is a design or shape given to the land in order to reduce length of the slope. In the lands of high degree and length of slope, erosion is serious problem. Terraced structure of the field permits little erosion as the degree and length of the slope are considerably reduced. Terraces act as earthen embankment across the slope which reduce the rate of run-off and thus minimize soil erosion. This method involves making of wide step like platforms, known as bench terraces, along the contour on the sloppy lands. Bench terracing has made possible the growing of cultivated crops in mountainous regions. In high rainfall areas, channel type of terracing is recommended which permits the controlled removal of water. The important feature is to dig a channel for carrying the water. They are also suitable for the areas with low permeability of water.

In the steep hill slopes, mere reduction of slope length does not affect the intensity of storing of runoff. Bench terracing converts the original sloping ground into level step like fields which reduce the length as well as the degree of slope. The bench terracing is mostly recommended in the slope range of 16-33 per cent and help in slope reduction, reducing soil loss, uniform distribution of soil moisture and ultimately higher productivity. Renovation of rain fed bench terraces sloping outwardly has been found cost effective as compared to complete leveling (Juyal *et al.*, 1988). Renovated bench terraces when put under improved management practices resulted in increasing yields over the traditional terraces (Table 10).

Table 9
Effect of Tillage and Mode of Mulch Application on Soil Loss (Mg ha^{-1})

Mode of mulch application	*Soil loss(Mg ha^{-1})*		
	Minimum tillage T_m	*Conventional tillage T_c*	*Mean*
M_w	2.1	3.1	2.6
$M_{1/3}$	6.3	6.8	6.5
Ms	8.1	10.0	9.0
Mv	15.5	21.4	18.4
M_o	17.2	25.0	21.1
Mean	9.8	13.2	
LSD (0.05)	Tillage = 2.3		
	Mulching = 1.0		
	Tillage X Mulching = 1.5		

Table 10
Effect of Renovated and Traditional bench Terrace on Yield of Crops

Crop	*Yield (t/ha)*		
	Renovated bench terrace	*Traditional bench terrace*	*Per cent increase in yield*
Rice	2.05	1.29	60
Wheat	1.72	1.21	42.1
Maize	3.68	2.60	41.5
Millet	0.80	0.49	63.2
Ragi	0.98	0.58	68.9

Source: Juyal *et al.* (1988

Contour/field Bunding

It comprises of constructing narrow based trapezoidal/parabolic shaped bunds on approximate contour for impounding runoff water behind them so that all the water is retained into the soil profile for use by the crop. This practice is used in permeable soils up to 6 per cent slope for areas receiving low rainfall. Ghumare (1962) has given speciation of bund for soils of different depth ranging from shallow to deep (Table 11).

Table 11
Bund Specification for Various Soil Depths

Soil depth	*Base width (m)*	*Top width (m)*	*Height (m)*	*Side slopes*	*Area cross section (m^2)*
Shallow soils (7.5 – 22.5 cms)	2.67	0.38	0.75	1.5 : 1	1.14
Medium soils (22.5 – 45.0 cms)	3.12	0.60	0.85	1.5 : 1	1.56
Medium deep (45.0 – 90 cms)	4.25	0.60	0.90	2 : 1	2.18

Source: Ghumare (1962)

Land Configuration for Moisture Conservation

Runoff farming on conservation bench terracing was tested in the ratio of donor and receiving area having maize and rice crops, respectively. The conducted study carried out at CSWCRTI, Dehradun for six years revealed that on 2.5 per cent slope, 3:1 ratio of donor to receiving areas has been found to increase the total dry matter as well as ear-bearing tillers and grain yield (Table 12). Due to increased soil water contents at panicle emergence stage rice grain yield increased by 8.8 per cent over control (Singh *et al.* 1987).

Table 12
Effect of Different Ratios of Contributing and Recovering Areas in Conservation Bench Terracing on Rice Yield

Land configuration ratio (sloping : flat)	*Total dry matter (t/ha)*	*Grain yield (t/ha)*	*Per cent increase in yield of rice*
0 : 1	5.1	1.6	–
1 : 1	5.9	1.9	21
2 : 1	6.8	2.3	47
3 : 1	8.2	2.9	88

Source: Singh *et al.* (1981)

Mixed Cropping

Growing of the same kind of crop for years in the same field is a wide spread practice in our country. This practice is not desirable as it depletes certain nutrients and organic matter from the soil. Addition of a densely grown, deep rooted, erosion resisting crop is necessary. An erosion resisting crop must be grown at least once in two years. All the commonly grown pulse or leguminous crops and grasses are erosion resisting in nature. Their extensively grown and dense root system, keeps the soil knitted and bound together. Widely spread foliage of legumes and grasses dissipate the force with which rain drops or wind hit the soil. Some of major objectives of mixed cropping offers better and continuous cover of the land, good protection against the beating action of raindrops, a complete protection against soil erosion and assurance of one or more crops to the farmer. A study by Singh *et al.* (1981) showed that combination of 2 rows of maize (60 cm apart) alternated with 8 rows of soybean (30 cm apart) resulted in optimum production of both the crops (Table 13).

Sub-soiling

In slightly sloppy fields containing hard clay pan in lower layers of the soil, sub-soiling or deep soil turning is a useful practice. Sub- soiling revives the productivity of land. In this method hard sub- soil is broken deeply by means of an instrument called sub-soiler and soil is partially turned or shaken. This process promotes absorption of rain water in the soil and makes the soil loose enough to permit unhindered growth of root system.

Table 13
Yield of Maize and Soybean under Different Crop Mixtures

Treatments	*Average yield (kg/ha)*	
	Maize	*Soybean*
Pure maize	3690.4	–
8 rows of maize + 2 rows of soybean	3254.1	285.2
6 rows of maize + 4 rows of soybean	2722.2	357.9
2 rows of maize + 8 rows of soybean	2054.4	1654.4
Pure soybean	–	2070.9

Source: Singh *et al.* (1981)

CONCLUSION

Erosion control measures commonly recommended are minimum tillage, mulching, cover cropping, contour/field bunding, graded bunding, bench terracing, minor land leveling, provision of field outlets for safe disposal of excess runoff water and in-situ rainwater conservation. Minimum tillage reduces surface disturbance, mulching, cover cropping and mixed cropping reduces sediment yield by reducing the rain drop impact. Contour/field bunding, graded bunding, bench terracing and field leveling conserve more moisture by providing more opportunity time to infiltrate. Also the provision of proper outlet channel helps in reducing soil erosion and sediment transport. The maintenance or amelioration of soil physical properties help in improving soil moisture, reducing runoff, soil loss and also help in conserving the soils depending upon slope steepness, soil types, crop management practices and climatic conditions for a location.

REFERENCES

Bhardwaj, S. P. (1988), Effect of zero tillage and living mulch on rainfall, deposition and erosion at 4 per cent slope. *Annual Report*, Central Soil and Water Conservation Research and Training Institute, Dehradun, 262 p.

Dhruvanarayana, V. V. (1993), *Soil and water conservation research in India*. ICAR, New Delhi, 454 p.

Dhruvanarayana, V. V. and Babu Ram (1983), Estimation of soil erosion in India. *J. Irrig.& Drainage Engg.* 109 (4) : 419-434.

Ghumare, N. R. (1962), Studies on the behaviour of contour bunds. *J. Soil & Water Cons. India*, **10** : 12.

Hadda, M. S. and Sur, H. S. (1987), Effect of land modifying measures on erosion, nutrients, water storage and yield of *pearl millet* fodder.*J. Indian Soc. Soil Sci***. 35**: 480-486.

Hadda, M. S. and Sur, H. S. (1989), Effect of mulch rates on runoff, sediment and nutrient losses from a sandy soil under untilled and tilled conditions. *J. Res. Punjab Agric. Univ.* **26** (1) : 37-46.

Joshi, B. P., Singh, P. N., Gurmel Singh and Bonde, W. C. (1989), *Water management in high rainfall north-west foothills*. Bull. Training Institute, Dehradun, India, T-21/D-17, Central Soil and Water Conservation Research and Training Institute, Dehradun, 33 p.

Juyal, G. P., Katiyar, V. S., Gupta, R. K. and Sewa Ram (1988), Renovation of rain fed terraces in Garhwal Himalayas. *Indian J. Soil Cons*. **13 (1)** : 10-15

Sharda, V. N. (2002), Strategies for soil conservation and watershed management. In: *Resource Conservation and watershed management: Technology Options and Future Strategies*. (eds. Dhyani et al.). Indian Association of Soil and Water Conservationists, CSWCRTI, Dehradun.

Singh, Dapinder Pal (2002), Top soil depth and soil management practices in relation to soil erosion in the foot hills of Shivaliks. *M.Sc. Thesis, Punjab Agricultural University, Ludhiana*, 87p.

Singh, Gurmel, Koranne, K. D., Bhushan, L. S., Sumer Chand and SandipGhosh (1981), *Advances in Rainfed Farming*. Bulletin R-10/D-8, Central Soil and Water Conservation Research and Training Institute, Dehradun, 106 p.

Bhatt, R. and Khera, K. L (2006), Effect of tillage and mode of straw mulch application on soil erosion in the submontaneous tract of Punjab, India. *Soil. Till. Res.* 88 : 107–115.

Sur, H. S. and Ghuman, B. S. (1992), Soil and water management in medium rainfall alluvial soils. Paper presented at the *57th Convention of Indian Society of Soil Science held at Hyderabad* w.e.f. 26-29, Nov., 1992.

Tejwani, K. G. (1980), A quarter century (1955-79) of soil and water conservation research in India. In: *Proceedings of the National Symposium of soil conservation and water management in 1980's*. Indian Association of Soil and Water Conservationists, CSWCRTI, Dehradun, 48 p.

UNEP/ ISRIC, (1991), Global assessment of soil degradation (GLASOD), Nairobi, Wageningen.

Patnaik, N. (1981), Role of soil conservation and deforestation for flood moderation. In: *Proc. Conf. on Flood Disasters*, New Delhi, India.

Bhardwaj, S. P., Sindwal, N. S., (1988), Zero tillage and weed mulch for erosion control on sloping farmland in Doon valley. *Indian J. Soil Conserv*. 26, 81–85.