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Amelioration of Soil Physical Constraints for Crop Production in Hilly Areas

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ABSTRACT

Soils of the hilly areas in the Himalayan region and elsewhere in the country encounter problems of shallow depth, poor structural status, crust formation, subsurface compactness, clod formation, rapid drying of seed-zone depth, poor seed-soil contact, sub-optimal soil temperature during winter, poor soil-water relations etc. which ultimately limit plant growth and crop yields due to poor root proliferation, nutrient and water use efficiency. In general, the soil structure is more degraded in soils following rice than maize in the cropping sequence. Long-term application of organic amendments like farm yard manure (FYM) and organic materials to these soils helps amelioration of soil physical constraints through improvement in the soil physical environment including the soil-water relations. Application of organic materials as much in the conventional and conservation tillage systems favourably moderates the hydro-thermal regime for better root proliferation, water and nutrient uptake and thereby helps producing higher crop yields. The paper reviews the work done for the last two and a half decades in the identification of physical constraints and their amelioration for crop production in hilly areas of north-west India.

Introduction

In Himachal Pradesh ($30^0$22' to $33^0$22' N latitude and $75^0$45' to $79^0$04' E longitude) and elsewhere in the Himalayan regions the hilly areas encounter the problems of complex topography, high but erratic and uneven rainfall and sub-zero minimum soil temperature during winter. The soils are generally exposed to high degree of erosion leading to shallow depth, degraded soil structure and coarser texture with lot of stones and pebbles. This results in low retentivity of water and nutrients, poor soil-water relations, high infiltration and low unsaturated hydraulic conductivity (Bhagat and Acharya, 1987, 1989; Chenkual and Acharya, 1990). High concentration of total sesquioxides (12 - 15%) and clay give rise to aggregates with large mean weight diameter and problem of clod formation, particularly after rice culture in acidic soils. This generally leads to low crop germination owing to poor seed-soil contact. Thus, proper management of hilly soils aimed at improving their typical physical characteristics can overcome most of the production limitation to a greater extent. The paper discusses the results of various studies conducted by H.P. Krishi Vishvavidyalaya for the identification of physical constraints and their amelioration for crop production.

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Characterization of Soil Physical Constraints

Water stable aggregates

Irrigated paddy is the important crop during *kharif* season in many valley areas of Himachal Pradesh. The crop is followed either by wheat or potato. Soil structure deterioration is a major consequence of puddling during rice cropping. Ploughing of puddled soil after rice results in the formation of large clods and very large amounts of energy and time are consumed in preparing seed beds. Surface soil characteristics under rice-wheat and maize-wheat cropping sequences in Palam valley of the state are given in Table 1. The studies (Chenkual and Acharya, 1990; Bhagat *et al.*, 1994) have shown that inclusion of rice in a cropping sequence deteriorates soil physical properties. Aggregate stability index was higher under maize-wheat than in the rice-wheat cropping sequence with distinct difference in wet sieving (Table 2). This was attributed to the repeated puddling over the years. Bhagat and Acharya (1987) found that 0.30-0.45 m and 0.45-0.60 m layers had minimum (7%) percentage of aggregates of 1-3 mm diameter in comparison to the surface 0-0.15 m depth (20%) in Alfisols of Palampur. Long term application of NPK fertilizers alone in maize-wheat sequence deteriorated the soil physical properties. However, FYM application along with recommended inorganic fertilizers improved the mean weight diameter and bulk density (Acharya *et al.*, 1988). Sharma *et al.* (1994) reported that soils of Soan river valley in lower

Table 1 Surface soil characteristics under rice-wheat (RW) and maize-wheat (MW) cropping sequences

Site	Cropping sequence	Texture	pH	O.C. (%)	*$K_s \times 10^6$ (ms^{-1})
Palampur	RW	Sil	5.9	0.77	5(6)
	MW	Sil	5.7	0.93	13(1)
Malan	RW	Sil	5.5	0.73	3(20)
	MW	SiCl	5.7	1.07	18(1)
Paprola	RW	SiCl	5.7	0.91	2(5)
	MW	SiCl	5.0	0.99	4(10)
Bhadiarkhar	RW	SiCl	5.5	0.95	2(30)
	MW	SiCl	5.6	0.98	3(13)

*k_s the saturated hydraulic conductivity of undisturbed samples; figures in parenthesis give coefficient of variation (Chenkual and Acharya, 1990)

Shivaliks of the state had average mean weight diameter values of 0.37 ± 0.09 and 0.36 ± 0.05 mm.

Bulk density

Bhagat and Acharya (1987) found average bulk density in Palam valley varying between 1.06 Mg m^{-3} in 0.0-0.075 m layer and 1.45 Mg m^{-3} (maximum) in 0.45-0.60 m layer. Bulk density at all depths was higher under rice-wheat than under maize-wheat sequence (Chenkual and Acharya, 1990). Under both cropping sequences,the values increased with increasing depth. Bhagat and Acharya (1989) have reported that soils (Typic Psammquents) along the bank of river Beas in Kullu valley in the state had higher bulk density at the sub surface due to compaction and massive structure. Soan river valley soils had higher bulk density values (1.51±0.11 Mg m^{-3}) which were attributed to coarse textured fraction and low organic matter content (Sambyal and Sharma, 1986; Sharma *et al.*, 1993; Sharma *et al.*, 1994).

Water retention characteristics

Soil structure degradation through high degree of erosion, low organic matter and mismanagement practice have resulted in soils with low water and nutrient retention behaviour in thehills. Most of the soils of the state do not retain enough water following irrigation or rainfall to sustain proper germination and crop growth, thus requiring light but frequent irrigations.

Palam valley soils have poor retention in surface layer in comparison to sub-surface layers (Bhagat and Acharya, 1987). Typical water retention characteristics curve show that at all depths, the water content decreases abruptly with an increase in suction upto 10 kPa and beyond this value the decrease becomes gradual (Fig. 1). Further, the surface layer desiccates rapidly despite the lower layers remaining wet because of low unsaturated hydraulic conductivity of these soils (Chenkual and Acharya, 1990). Under these situations, the crop germination and their subsequent establishment suffers the most. They also reported that soils under rice-wheat (RW) sequence retained higher water than under maize-wheat (MW). This may be ascribed to the increased micro-porosity caused by destruction of soil structure in rice-wheat rotation. Soils of Soan river valley in lower Shivaliks and Beas river bank in Kullu valley possess low water retention characteristics (Sharma *et al.*, 1993 and Bhagar and Acharya, 1989). Soan river valley surface soils retained 13.4±3.4 and 4.7±1.7% at 33 and 1500 kPa matric suctions. Gupta *et al.* (1983) found greater water retention under grass and forest lands of the state in comparison to cultivated soils due to their higher organic matter, silt and clay and CEC values.

Water transmission characteristics

Coarse texture, large mean weight diameter and bouldery nature give rise to high infiltrability and percolation and lower unsaturated hydraulic

Table 2. Mean weight diameter (MWD) and dry stable (DSA) and water stable (WSA) aggregate index (>0.25 mm diameter) under rice-wheat and maize-wheat cropping sequences

Site	Dry sieving				Wet sieving			
	MWD (mm)		DS (%)		MWD (mm)		WSA (%)	
	RW	MW	RW	MW	RW	MW	RW	MW
Palampur	2.7 (0.04)	2.9 (0.02)	93.3 (1.58)	99.1 (0.13)	1.8 (0.05)	2.2 (0.21)	68.2 (1.88)	81.7 (4.92)
Malan	2.6 (0.09)	2.8 (0.03)	92.0 (2.68)	98.4 (0.91)	1.5 (0.09)	2.4 (0.05)	64.9 (2.32)	89.7 (1.73)
Paprola	2.6 (0.07)	2.9 (0.03)	89.5 (2.25)	97.7 (0.84)	0.8 (0.03)	1.3 (0.10)	45.5 (2.75)	54.7 (3.88)
Bhadiarkhar	2.7 (0.07)	2.9 (0.02)	92.9 (2.12)	98.5 (0.45)	1.4 (0.06)	1.7 (0.04)	58.7 (2.30)	68.8 (2.56)
Average for sites	2.7	2.9	91.9	98.4	1.4	1.9	59.3	73.7

Figures in parenthesis give standard deviations (Chenkual and Acharya, 1990)

conductivity of hilly soils. Bhagat and Acharya (1989) reported a basic intake rate of 3.24×10^{-6} ms^{-1} and accumulated intake of 0.58 m after 15 h in soils of Kullu valley. Chenkual and Acharya (1990) found that soil surface conditions in rice-wheat crop rotations were initially more favourable for infiltration (Table 3). This they attributed to the more extensive cracking of the surface soil in rice-wheat which initially favoured rapid entry of water into the soil. Similarly the initial infiltration rate, except at Palampur, was also higher for the sites having rice-wheat than maize-wheat rotation. However, with elapse of time the process reversed and both I (m) and i (ms^{-1}) within about 100 seconds were higher in MW and RW rotation. The greater reduction in infiltration rate in RW rotation was attributed to the formulation of crust at the soil surface through slaking and breaking of water conducting pores. Thus, rate of drainage under RW was slower than MW plots. Despite faster rate of drainage, the MW plots when compared with RW plots retained higher amount of water with increasing profile depths. Similarly, the unsaturated hydraulic conductivity at all water contents was 3 to 10 times lower in RW than in the soil having MW rotation.

Drying behaviour

The drying behaviour of a soil is affected by its retention and transmission characteristics. Chenkual and Acharya (1990) reported that seedzone depth in RW plots rapidly desiccated

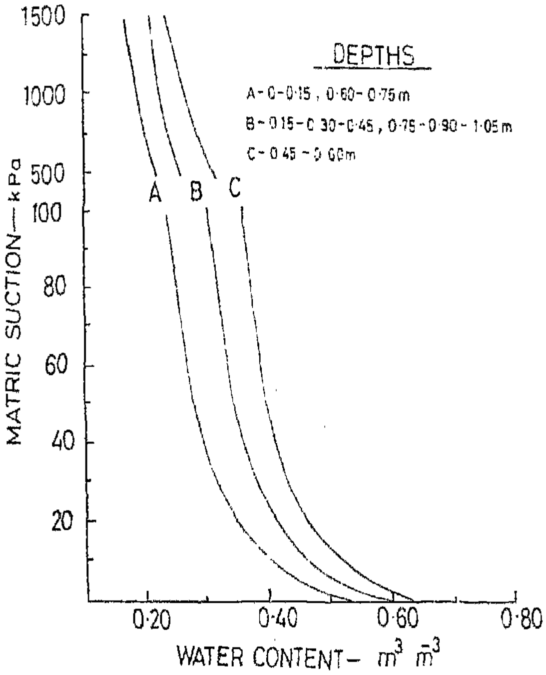

Fig. 1 Soil water retention characteristics (undisturbed samples)

(Fig. 2) despite the lower layers remaining wet because of low unsaturated hydraulic conductivity of the soil. The cumulative water loss over small depth and time intervals was higher in RW plots from surface (0-0.075 m) depth compared with MW plots. However, reverse was true for 0.075-0.15 m depth where RW plots owing to poor hydraulic conductivity showed slower rate of change of water content with time.

Problems associated with the desiccation of the seedzone and consequential formation of large clods require a strenuous manual task of breaking. This can be avoided if the soil is tilled to produce a coarse or medium tilth immediately after the rice harvest instead of keeping it untilled (Chaudhary and Acharya, 1993).

Root growth

Root growth in soils of hilly regions is greatly affected due to their shallow depth, boulder-ridden nature, surface crust formation and sub-surface compactness. These factors influence root growth either directly or indirectly by affecting the soil moisture regime and nutrient availability. Chenkual and Acharya (1990) reported poor root growth of wheat in RW compared with that in MW plots owing to deterioration of soil structure in the former rotation due to inclusion of rice in sequence with wheat (Fig. 3). Acharya and Bhagat (1984) found restricted root growth of maize and wheat crops under zero-tillage without mulch due to formation of compact layer at the surface. This problem, however, was mitigated when no-tillage was done with mulch which moderated the hydro-thermal regime and produced higher root growth (Acharya and Sharma, 1994). Verma and Acharya (1996) also reported higher root growth of wheat with mulch both under conventional and conservation tillage systems by favourably moderating the physical constraints observed after inclusion of rice in the cropping sequence.

Amelioration of Soil Physical Constraints

Conservation tillage

The problems of fast desiccation of surface soil, poor soil water retention and transmission, surface crusting and low minimum soil temperatures can be alleviated by adopting the conservation tillage practice in these soils. The application of tender twigs of wild stage (*Lantana camara* L.) to the previous standing maize helps in conservation and carry-over of moisture for successful sowing of unirrigated wheat crop (Acharya and Kapur, 1993). Sandal and Acharya (1997) found that conservation tillage (minimum tillage + surface cover of wild sage) in maize and wheat crops gave faster and higher seedling emergence and higher crop yields. Conservation tillage conserved soil water, maintained bulk density at optimum level and helped in the build up of soil organic carbon. Acharya *et al.* (1998) found that conservation tillage (minimum tillage + mulch of wild sage in standing maize before recession of monsoon rains) generated friable soil structure owing to 5 times higher population of earth-worms, organic carbon build up and lowered bulk density at sowing of wheat (Table 4). Also 6-10% higher soil moisture was found in the seed zone depth at sowing of wheat with this practice. The presence of mulch of organic wastes like wild sage and eupatorium in the conservation tillage system raised the minimum soil temperature by 0.5 to 2^0C (Fig. 4) which had a favourable effect on root growth and nutrient uptake.

The conservation tillage lowered soil bulk density, increased root mass density by 1.27 to 1.40 times, showed build-up of soil organic carbon and available soil nitrogen (24.9-28.1 kg ha^{-1}) over conventionally tiled soil. The former practice also resulted in higher grain yield of wheat crop. Mulch and conservation tillage have also been reported to moderate the soil physical environment and induce soil moisture conservation in the seed zone depth after harvest of rice which benefitted the following wheat crop (Verma and Acharya, 1996).

Table 3. Time (t) dependent cumulative infiltration (I) and infiltration rate (i) equations under rice-wheat (RW) and maize-wheat (MW) cropping sequences

Site	$I(m) = at^b$		$dI/dt = i\ (ms^{-1})$	
	RW	MW	RW	MW
Palampur	$4 \times 10^{-4}t^{0.52}$	$7 \times 10^{-4}t^{0.63}$	$2 \times 10^{-4}t^{0\ 48}$	$4 \times 10^{-4}t^{0\ 37}$
Malan	$12 \times 10^{-4}t^{0.35}$	$2 \times 10^{-4}t^{0\ 79}$	$4 \times 10^{-4}t^{0\ 66}$	$2 \times 10^{-4}t^{0\ 21}$
Paprola	$19 \times 10^{-4}t^{0\ 40}$	$5 \times 10^{-4}t^{0\ 60}$	$8 \times 10^{-4}t^{0.60}$	$3 \times 10^{-4}t^{0\ 46}$
Bhadiarkhar	$20 \times 10^{-4}t^{0.32}$	$7 \times 10^{-4}t^{0\ 46}$	$6 \times 10^{-4}t^{0\ 68}$	$3 \times 10^{-4}t^{0547}$

Source : Chenkual and Acharya (1990)

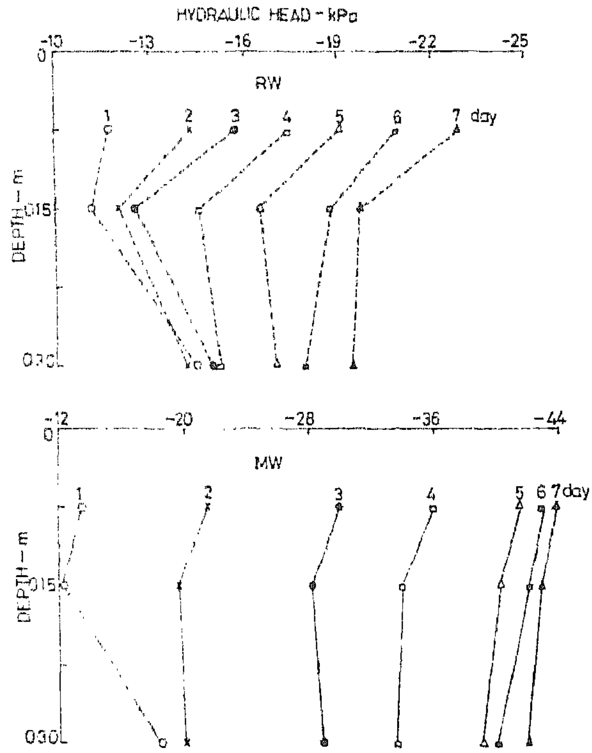

Fig. 2. Changes in hydraulic head during 7 days of continuous drying of soil in rice-wheat (RW) and maize-wheat (MW) rotations

Organic amendments

Use of organic amendments such as FYM, compost, plant residues etc. are known to improve physical properties of the soils. FYM application with recommended NPK under long term fertilizer experiments improved structural index, infiltration rate, water retention characteristics, organic carbon content, available N, P and K status of soil and gave higher maize and wheat crop yields (Acharya *et al.*, 1988). Bhusan (1994) tested compost prepared from eupatorium (*Eupatorium adenophorum* Sprengel) a common weed in hills and reported that this can half substitute the FYM in potato crop. Incorporation of organic residues of wild sage or eupatorium (Sandal and Acharya, 1997; Acharya *et al.*, 1998) improved the physical and chemical properties of hilly soils. Wild sage biomass incorporation in puddled rice soils reflected improvement of structural properties of soil characterized as bulk density, water stability of aggregates, aggregate porosity, soil cracking behaviour and clod breaking strength (Sharma *et al.*, 1995).

Mulching for moderation of hydrothermal regimes

Hilly regions in the country have many wildly growing plants like wild sage, eupatorium, ageratum and many other having no fodder value. These weeds are infesting the grass and common lands. Pine-needle is another forest waste in the hills which if not collected is a fire hazard in the forests. Mulching with these organic materials has been found to conserve soil moisture, prevent soil splash and formation of soil crust, raise minimum soil temperature, decrease fertilizer input, increase water and nutrient use cefficiencies (Kapur *et al.*, 1978; Kapur, 1987; Sharma and Acharya, 1987; Bhagat and Acharya, 1987; Acharya and Kapur, 1993; Gupta and Acharya, 1993; Acharya and Sharma, 1994; Sandal and Acharya, 1997; Acharya and Kapur, 1997 and Acharya *et al.*, 1998). Kapur *et al.* (1978) found that pine-needle mulching raised the minimum soil temperature by 2-3^{0}C, gave higher germination, yield and water use efficiency of wheat crop. Kapur (1987) reported beneficial effects of pine-needle mulch on potato-crop by increasing tuber yield by 44%. Higher dry matter production and total uptake of N, P and K under mulched wheat has been reported largely owing to moderation of hydro-thermal regime which

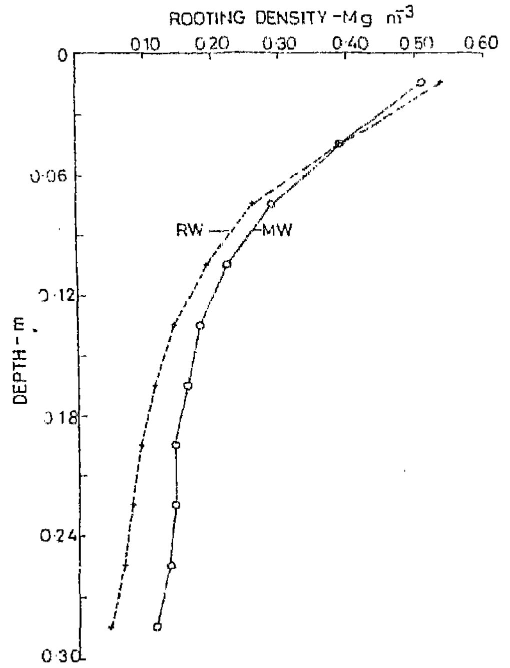

Fig. 3. Rooting density of wheat at small depth increments in rice-wheat (RW) and maize-wheat (MW) rotations

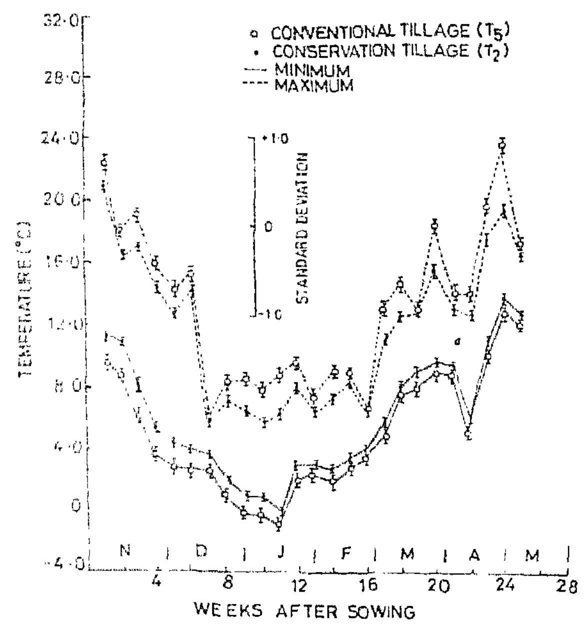

Fig. 4 Soil temperature at 0.05 m depth under conservation tillage with lantana mulch (T_2) and conventional tillage with no mulch (T_5) during growth of wheat. Bar indicates the standard deviation for each data point.

encouraged greater root growth for the uptake of water and nutrients (Acharya and Saharma, 1994; Acharya and Kapur, 1997; Acharya *et al.*, 1998).

Conclusion

Severe soil deterioration through erosion by water and sealing of fertile land for infrastructure development in the hilly areas are decreasing the land for agricultural production. Furthermore, the faulty soil management practices without taking into consideration the long-term sustainability aspects are continuously lowering down the soil productivity. There is need to conduct in-depth diagnostic surveys for identifying various physical constraints under different cropping systems and develop techniques for the build-up of soil organic carbon, a key soil quality indicator linked to physical, chemical and biological aspects of soil fertility. Conservation tillage can lead to carbon sequentration in soil and must be evaluated under different soil types and agro-ecosystems. Wildly growing plants/bushes, having no fodder value, in the hilly areas can serve as alternatives to crop residues (fed to animals) in the conservation tillage system. The problem of clod formation at cultivation

Table 4. Effect of mulch and tillage on soil organic carbon, bulk density and earth worm population in surface (0-0.15 m) layer during wheat crop (1989-92)

Treatment	Soil organic carbon (%)				Bulk density (Mg m^{-3})		Earthworms (No. m^{-2})	
	Sowing		Harvesting		Sowing	Harvesting	Sowing	Flowering
	1989	1991	1990	1992	1989	1992	1991	1992
Mulch-tillage (T)								
T_1	1.06	1.16	0.89	1.06	1.28	1.17	20	8
T_2	0.88	0.99	0.89	1.00	1.29	1.26	21	10
T_3	1.03	1.16	0.90	1.06	1.28	1.18	21	8
T_4	0.86	0.99	0.90	1.00	1.28	1.28	20	10
T_5	0.80	0.81	0.80	0.80	1.24	1.24	4	1
CD (P = 0.05)	0.14	0.14	NS	0.15	NS	0.07	1.7	1.4
Nitrogen (N)								
N_{60}	0.93	1.02	0.88	0.99	1.26	1.25	17	8
N_{120}	0.93	1.01	0.88	0.97	1.26	1.25	17	7
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	0.9

T_1 - Wild sage mulch till sowing of wheat followed by its incorporation with conventional tillage prior to sowing of wheat; T_2 - as T_1 but wheat sown with conservation tillage and wild sage mulch; T_3 - as T_1 but eupatorium mulch instead of wild sage; T_4 - as T_2 but eupatorium mulch instead of wild sage; T_5 - conventional farmer practice of tillage soon after harvest of maize; TxN interactions non-significant (NS).
Source : Acharya *et al.* (1998)

for sowing wheat, particularly after rice, can also be avoided with conservation tillage as it does not require elaborate tillage. The reduction of animal draught power in this system may overcome the problem of acute shortage of fodder in the hilly areas. However, there is a greater need to develop small tools/implements/ seeders for direct sowing of crops under conservation tillage, requiring minimum disturbance of the soil.

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