Jour. Agric. Physics, Vol. 1, No. 1, pp. 71-75 (2001)

Characterizing Physical Environment of Rainfed Lands and Their Management for Sustainable Production

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ABSTRACT

The various physical constraints of the soils of dryland areas which limit sustainable crop production include (i) soil crusting and compaction due to beating action of rains, (ii) presence of hard pan below the plough layer and calcium carbonate or iron concretion in the root zone, (iii) low permeability and cracking of black soils, (iv) high permeability and low water holding capacity of desertic soils and (v) soil erosion by water/ wind. Ameliorative measures for redressing these problems, though developed, are yet to reach to the farmers' fields in large scale. Operational research projects are urgently needed to evaluate the strength and weakness of the evolved technology and to transfer the proven technology in the field. Future research thrusts need to be based on the feedback of the operational research. Such studies should be closely linked with dryland watershed development programmes of each state/ region. Dedicated efforts on these lines would be useful to sustain dryland agriculture.

Introduction

In India, the rainfed land areas constitute about 67 per cent of the net cultivable area of 143 Mha and contribute to a significant amount of the total foodgrain (40%), oil seeds (70%), coarse grains (90%), rice (66%) and wheat (33%). While emphasis on intensive agriculture will continue to remain on irrigated lands, the improvement in productivity of the vast majority of dryland areas is urgently needed for sustainable Indian agriculture and reducing socio-economic imbalance between irrigated and dryland areas. Technology developed in recent past has explicitly demonstrated that the production from dryland areas could easily be doubled with the adoption of simple components of the technology such as improved seeds and crops and cropping systems, establishment of timely good crop stand, tillage and soil/moisture conservation measures, balanced use of fertilizers and manures and water harvesting.

Soil Resources of Rainfed Areas

The important physical characteristics of soils under dryland conditions are described below :

Alluvial soils : The alluvial soils under drylands usually have low clay but high sand contents and possess low to medium (10-16% w/w) water holding capacity and medium to high water intake rates (>25 mm h^{-1}) besides variable soil depths. In these soils surface crusting hinders rapid intake of rainfall into the soil profile, enhances runoff and reduces rainfall conservation *in situ* but enhances soil erosion besides hampering germination of seeds. Presence of hard pans at certain depths in the soil profile formed due to binding of soil particles by infiltrating silica or calcareous matter, are often observed in these soils. Such a hard pan usually found below the normal ploughing depths (>10-15 cm) restricts movement of water and penetration of plant roots into the sub-soil. Presence of calcium carbonate concretion in the root zone of these soils reduces water holding capacity and interferes with normal proliferation of plant roots. Sub-soil salinity is common in these soils (Oswal and Khanna, 1983).

Black soils : Dryland black soils occupy about 25 Mha land in the Peninsular India in the states of Maharashtra, Madhya Pradesh, parts of Gujarat, Karnataka, Tamilnadu and Andhra pradesh and receive an average annual rainfall from 500-1500 mm. These soils have medium to heavy texture and high water holding capacity (30-40% w/w) but low available plant water as the water is held by soils with more tenacity. They are prone to soil erosion and even under normal cultivated crops like sorghum and cotton in land slopes of 1-3 percent the erosion could be as high ad 16 t ha^{-1} a^{-1} (Ram Babu *et al.*, 1978).

Due to their low infiltration rates, rainfall runoff ≤ 40 percent of the total rainfall can take place on slopy lands. On account of their high consistency, they have narrow tillage range moisture and therefore, ploughing of such lands is often difficult. Such soils have poor aeration and high resistance to penetration. Consequently, the root growth in these soils is sparse. On slopy lands, soil depths (0.3 - 0.9 m) are usually limiting for plant growth. They may also contain variable amounts of soluble salts.

Desertic soils : These soils are found in most parts of Rajasthan and some parts of Haryana, Punjab, Gujarat and Andhra Pradesh which receive annual rainfall less than 400 mm. The desertic soils are light in texture (sand>70 percent) and possess very low water holding capacity with available plant water ranging from 50-100 mm m^{-1} (Gupta, 1983 and Fayez *et al.*, 1979). They are loose, single grained and structure less and are vulnerable to wind erosion due to low organic matter and clay contents. Because of high infiltration rate and low water retention or storage capacity of these soils about 30-50 percent rainwater is lost from the soil profile as deep percolation. Though water retention at field capacity (10 kPa) is very low, it is held very loosely and is readily available to plants.

Red soils : These soils are extensive (87.6 Mha) in eastern Madhya Pradesh, Bihar plateau, Orissa and parts of West Bengal, Andhra Pradesh, Karnataka, Kerla and TamilNadu. Rainfaill in these areas ranges from 700-2000 mm a^{-1}. Red soils are usually light to medium in texture containing less clay (10-20%) and organic matter and are prone to wind/water erosion. They are generally well drained and possess iron concretion in the top soil. These soils have low water holding capacity, variable depths and high infiltration rates. Medium texture soils develop surface crusts due to beating action of rain. The red soils occurring in rolling and undulating topography suffer from severe soil erosion upto 40 t ha^{-1} a^{-1}. Even under flat topography, soil erosion from 4-10 t ha^{-1} a^{-1} is common (Anonymous, 1987).

Sub-mountainous soils : In the foot hills the lands are slopy and the soil depth is variable and limiting for crop growth. Land slides and soil erosion by water is a real problem interfering with the cultivation of crops in these areas. These soils are usually coarser in texture but medium texture soils are not uncommon. The soils are low in organic matter and possess variable water holding capacity (8-25% v/v). Due to lack of binding materials they are easily dispersed under the impact of rains and develop soil crust and get eroded.

Dryland constitutes a stressed agro-ecosystem. Under tropical climate with highly erratic rainfall sustainable crop production is difficult. The physical parameters associated with different soils which limit sustainable production could be listed as, (i) soil crusting and compaction due to beating rains, (ii) presence of hard pan below the plough sole, (iii) presence of calcium carbonate / iron concretion in the rhizosphere, (iv) high permeability and low water holding capacity of desert soils and low permeability and soil cracking of black soils, and (v) soil erosion by wind and water.

Managing Soil Physical Constraints

Realizing the importance of soil physical constraints in sustainable crop production from rainfed areas, systematic research investigations were carried out by several research organisation to mitigate the adverse effects of various constraints. Some of the important practical findings are highlighted below.

Soil crusting : In alluvial, red and sierozemic soils the crust formation at the surface of soil by the beating action of rain hampers germination of crops, reduces infiltration and enhances rainfall runoff.

Mechanical breaking by hoeing and continuous incorporation of stubbles or crop residues to the land minimises crust formation in soils. Similarly the set line cultivation as prevalent in Saurashtra, where the crops are grown in the same line and fertilizer and manure are applied in the same furrows over the years, minimizes soil crusting. Application of FYM@4 t ha^{-1} or 2 t ha^{-1} wheat straw increased emergence of cotton by 4-10 times while that of pearl millet by 2-3 times. Seed line application of FYM 1 t ha^{-1} immediately after seeding of pearl millet helped emergence of the crop (Table 1).

Table 1. Emergence of pearl millet as influenced by application of FYM

Treatment	Emergence No./m^2
Seed line application (@1 t ha^{-1})	255
Broadcast before sowing (@2 t ha^{-1})	249
Control	191

Sowing of the dryland crops on the shoulders of ridges under ridge-furrow system of cultivation helps lowering the crusting problem to seedling emergence. By this system of cultivation the crust is formed in the furrow as the soil particles responsible for soil crusting are transported from ridge side to furrow bottom with rain water. Also due to inter-row water harvesting of the rain the furrows remain wet for a longer time thus preventing to develop crust strength critical to seedling emergence.

Hard pan : Formation of a hard pan below the ploughing depths restricts infiltration of the rain water into the sub-soil besides restricting root proliferation (Oswal and Dakshinamurti, 1975, Prihar *et al.*, 1973). Mechanical shattering of these hard pans by chiseling or mould board ploughing help in improving infiltration (Table 2) and water storage capacity of the solum besides a good improvement in the yield of crops (Table 3). In black soils addition of gypsum @2-5t ha^{-1} increased infiltration rate by 4-7 times over the control rate of 0.25 cm h^{-1}.

Table 2. Effect of deep ploughing on basic infiltration rate of soil

Treatment	Infiltration rate, cm h^{-1}		
	Desertic	Alluvial	Black
Control	5.2	2.1	0.18
Ploughing with local plough	5.7	2.2	0.20
Deep ploughing	7.6	3.3	0.39

Table 3. Effect of deep ploughing on yield of some dryland crops

Soil type	Crop	Yield t ha^{-1}	
		Local plough	Deep plough
Alluvial	Maize	2.22	2.65
	Pearlmillet	2.24	2.56
	Wheat	2.38	2.81
Red	Castor	4.00	6.00
	Groundnut	1.80	2.40
	Pigeonpea	5.90	7.60
Black	Castor	4.20	6.00
Desertic	Pearlmillet	1.34	1.58
	Mungbean	0.47	0.58

Deep percolation : In light textured soils about 25-40 percent of rainfall can percolate down below the root zone of crops. Consequently, a small quantity of rainfall could be conserved *in-situ*. Under such conditions rainfed crops are unable to sustain even short (>10 days) dry spells. The percolation loss of water, however, could be reduced by treating the sub-soil (below 60 cm depth) with a suitable sealent like hot asphalt emulsion (@14000 1 ha^{-1}), Janta emulsion (a product of Burmah shell) and bentonite clay. The practical feasibility of using these sealents is, however, limited. Mixing of pond silt in the light soils helps retaining more water and reducing the percolation loss (Gupta, 1983).

Soil compaction by giving a few passes of heavy duty roller was attempted by several researchers (Agarwal, 1988) with good results (Table 4). Compaction by 12 passes of half ton roller could increase buld density of top 30 cm soil layer from 1.55 to 1.67 mg m^{-3} and increase yield of pearl millet at Jobner (Rajasthan) by 33 percent over the control yield of 1.43 t ha^{-1}. Similar results were reported with 6 passes of 1.5 t roller from Hisar (Haryana).

Table 4. Crop yield as influenced by soil compaction

Crop	Yield, t ha^{-1}	
	Without compaction	With compaction
Barley	2.28	2.61
Clusterbean	1.00	1.25
Cotton	1.49	1.56
Mustard	0.81	0.94
Pearl millet	1.55	1.86
Wheat	2.28	2.60

Soil erosion : It has been estimated that water erosion is the major problem causing loss of top soil in 140 Mha of land. Wind erosion is a serious problem in the arid and semi-arid regions in the states of Rajasthan, Haryana, Gujarat and Punjab. Destruction of the natural vegetation cover resulting from excessive grazing and extension of agriculture to marginal areas is the main human-induced factor leading to accelerated erosion (Abrol and Sehgal, 1992). Wind erosion is also prevalent in the coastal areas where sandy soils dominate and in the cold desert regions. It was estimated that about 10 Mha land is affected by wind erosion (Kanwar, 1997). Wind strip cropping is a useful practice to contain wind erosion. Under this practice erosion resistant crops like grasses (Lasiurus Sindicus, Cinchrus Ciliaris) are alternated with erosion susceptible crops like pearl millet and grain legumes in the direction perpendicular to prevailing wind.

Soil conservation measures

Various practices have been recommended for soil conservation. Among these, bunds are very important. Since soils are prone to erosion due to their low infiltration rates, high intensity of rainfall and slopes, some kind of mechanical obstacle is essential. For slope about 1.5 percent, contour bunds with surplusing arrangement were very effective in black soils.

Comparison of graded bunds and live bunds (Umrani, 1994) revealed that live bund could reduce runoff by about 34 percent compared to sowing across the major slope. Soil loss was reduced by about 74 percent. Compared to graded bunds the runoff was not reduced due to live bund but the soil loss was reduced by 70 percent (Table 5).

Table 5. Effect of different land treatments on runoff, soil loss and yield of dryland sorghum

Land treatment	Runoff		Soil loss	Sorghum yield
	mm	%	(t ha^{-1})	(t ha^{-1})
Sowing across the main slope	342	24.4	34.9	3.82
Contour sowing along the Leucaena key line	297	21.2	18.1	4.19
Contour sowing along vetiver key line	227	16.2	8.3	4.33
Sowing parallel to graded bund	174	12.4	27.3	4.20

Total rainfall 1400 mm, Runoff causing rainfall 1026 mm

In deep black soils with gentle slopes and other slopy lands surface configuration such as ridges and furrows, tied ridges and compartments helps to hold rain water, increase infiltration, and reduce runoff and soil loss. Beneficial results on soil conservation due to surface configuration have been reported for different land situations.

Soil conservation practices are location specific and need to be adopted on watershed basis. Their piecemeal application has limited value. The Government of India initiated National Watershed Development Programme for soil and water conservation along with conservation and utilization of other resources for Rainfed Agriculture since 1986-87. The programme has now received a big momentum as about 50 percent of the plan outlay for Rural Development got to be utilized for development of these watersheds all over the country.

Undoubtly, the rainfed land resource of India is vast, highly variable and full of several soil physical constraints limiting sustainability of agriculture. Ameliorative measures evolved for redressing these complex problems need to be transferred to the fields which are almost lacking completely. Dedicated operational research programmes are highly needed to evaluate the strength and weakness of the technology under actual farming situations and to transfer the acceptable technology in the field. Such programmes are limited. Further research thrusts based on field scale operational studies by a multi-disciplinary team of scientists are highly required. Such studies should be closely linked with rainfed watershed development programmes of each state/ region funded by the government.

References

Abrol, I.P. and Sehgal, J. 1994. Degraded lands and their rehabilitation in India, In Soil Management for Sustainable Agriculture in Dryland Areas, Bulletin-16, *Ind. Soc. Soil Sci.*, New Delhi. pp : 143.

Agrawal, R.P. 1988. Managing soil physical condition for sutainable production. In Soil Physical Conditions for Crop Growth, Geo-Environ. Academia, Jodhpur. pp : 28.

Anonymous. 1978. Physical properties of soils of India, AICRP, Improvement of Soil Physical Conditions, ICAR, New Delhi.

Anonymous. 1987. Hand Book of Agriculture, ICAR, New Delhi. pp : 1303.

Fayez El. Komos, Oswal, M.C. and Khanna, S.S. 1979. Soil water functional relationship of some soils of Haryana State. *J. Indian Soc. Soil Sci.* 27 : 345-54.

Gupta, J.P. 1983. Soil moisture conservation for increasing crop production in Arid lands. Monograph No. 20, CAZRI, Jodhpur, pp : 43.

Gupta, R.P. 1984. Soil Managament to Increase Crop Production. Consolidated Report of AICRP for Improvement of Soil Physical Conditions to Increase Agricultural Production of Problematic Areas. ICAR, New Delhi. pp : 164.

Kantikar, V.N., Sirur, S.S. and Gokhale, D.H. 1968. Dryfarming in India. ICAR, New Delhi. pp : 726.

Kanwar, J.S. 1997. Soil and water management - The base of food security and sustainability. *J. Indian Soc. Soil Sci.* 45 : 417-28.

Narayan, V.V. and Ram Babu 1983. Estiamtion of soil erosion in India. J. Irrigation Drainage Engg. 109 : 419-34.

Oswal, M.C. and Dakshnimarti, C. 1975. Effect of different tillage practices on water use efficiency of pearl millet and mustard under dryland agriculture. *Indian J. Agric. Sci.* 45 : 264-66.

Oswal, M.C. and Khanna, S.S. 1983. Technology for Dryland Areas of North West India. Bulletin, Haryana Agricultural University, Hisar, India. pp : 46.

Oswal, M.C., Kumar, V. and Malik, R.K. 1987. Soil crusting as related to texture and moisture and its management for increased seedling emergence. Proc. 2nd International Convention of Agricultural Engineers, Institution of Engineers, held at HAU, Hisar from Feb 28 - March 1, 1987.

Prihar, S.S., Gajri, P.R. and Manchanda, M.L. 1973. Effect of dense soil layer at shallow depths on crop growth. *Indian J. Agro.* 18 : 344-48.

Ram Babu, Tejwani, K.G., Agarwal, M.C. and Subhash Chandra 1978. Rainfall, erosion potential and isoerodent map of India. Bulletin No. 2, CSWCRIT, Dehradun, U.P. (India).

Singh, G., Ram Babu, Pratap Narain, Bushan, L.S. and Abrol, I.P. 1992. Effect of different land uses on soil erosion by water. *J. Soil Water Conserv.* 47 : 97-99.

Umrani, N.K. 1994. Soil management and rain water conservation and use III - Vertisoils under medium rainfall, In Soil Management for Sustainable Agriculture in Dryland Areas, *Ind. Soc. Soil Sci.*, New Delhi. pp : 143.