Management of soil physical properties of lowland puddled rice soil for sustainable food production

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About 3 billion people who rely on rice as their staple food today will have multiplied to some 4.4 billion by the middle of this century. With rice demand growing at an average rate of about 3 per cent annually, 70 per cent more rice has to be produced in next 30 years compared to present day production levels. More rice has to come from less favorable environments, with less water and nutrients. Agricultural population densities on Asia's rice producing lands are among the highest in the world and continue to increase at a remarkable rate. Rice has widely adapted itself: to the hot Australian and Egyptian deserts, to the cool Himalayan foothills of Nepal. Hill tribes in Southeast Asia plant it on slash-and-burned forest slopes; that's upland rice. However, low lying areas in Asia, which are subject to uncontrolled flooding, are home to more than 100 million poor farmers.

Enormous amounts of water are generally used in rice production. On average, more than 5000 liters of water are used to produce one kg of rice (Bhagat, et al., 1996). A significant portion of the total water requirement for rice production is used in land preparation. Large amounts of water are required during the land soaking phase as huge water losses occur through cracks before the soil saturation is actually reached; surface drainage also contributes to this loss. This causes delays in completing land preparation, low water use efficiency, and a strained irrigation system.

Puddling or wet tillage in rice, decreases total soil porosity only slightly, but markedly changes porosity distribution with both storage and residual porosity increasing at the expanse of transmission porosity. Soil texture plays an important role in soil water retention following soil disturbance. Besides, the textural response, tillage may further influence water retention if it incorporates crop residues or if it alters the distribution of sand silt and clay in soil by mixing particles from different soil horizons (Bhagat, 1990). Tillage operations markedly affect soil hydraulic properties including saturated and unsaturated hydraulic conductivity, soil water content, soil water retention and soil water diffusivity. These properties in turn affect hydraulic processes such as infiltration, water flow through soils, drainage and evaporation.

Surface as well as subsurface soil conditions influence water infiltration. Tillage alters both through the shearing action of tillage tool and may determine the amount of water required for land preparation. Puddling causes destruction of soil structure in rice, which results in a decrease in soil water transmission – a condition often desired for rice. Consequently, puddling decreases percolation and therefore better retains standing water in the field, which may also decrease the irrigation requirement.

Tillage exposes the subsoil to the atmosphere, which increases the rate of water loss from the soil through evaporation. By loosening the soil near the surface, tillage may reduce capillary water rise to the surface and thereby decrease evaporative losses of deeply stored soil water. However, the prevention or the substantive reduction of evaporative losses of water is mostly not cost effective in flooded lowland rice fields.

Rice response to tillage varies with soil texture and climatic water balance. Depending on the soil texture, tillage may induce a gain or loss in soil permeability which may affect rice yield through better retention of surface water. Wet tillage (puddling) and compaction in rice soils decreases water permeability by decreasing the volume of transmission pores. Sharma and Bhagat (1993) have found out that in soils with < 70 per cent sand, puddling as well as compaction are equally effective in decreasing water percolation to satisfactory levels for growing a good crop of rice. The choice between the two methods depends upon factors like susceptibility of rice to compaction levels, residual effects of puddling and compaction on upland crops grown after rice, and regeneration of soil structure after puddled crop. However, in soils having >70 per cent sand, compaction rather than puddling is effective in decreasing water permeability.

One of the requirements of an efficient rice based production system is to decrease energy inputs. Puddled soils shrink on drying, become compact and hard and produce surface fissures of varying size and shape. After rice, preparation of seed beds with fine tilth for wheat is difficult. Plowing of puddled soil after rice results in the formation of large clods, having high breaking strength (Sharma and Bhagat, 1993) and very large amounts of energy and time are consumed in producing fine seed beds. Tillage, irrigation and fertilizer constitute the major energy inputs in a crop production system. As energy costs continue to increase, it becomes imperative to develop energy efficient crop production system. At low yield levels, water and nutrients can substitute for each other and tillage increases efficiency of water and fertilizer use. Interactions among energy intensive inputs of tillage, irrigation and nutrients can be gainfully exploited to combat soil and management related stresses for improved crop performances. Bhagat et al., (2003-unpublished data) have indicated that energy inputs in a conventional tillage was about 276 kwh more than that in a no-till system; however the former system produced more grains per unit of energy consumed.

The foregoing discussion indicated that strategic management of physical properties of rice soils is of utmost importance to have successful production of rice and post rice crops. Major initiatives taken so for in this direction are summarized below:

Incorporation of plant residues coupled with appropriate tillage build up organic carbon status of soil (Bhagat and Verma, 1991). Also use of residue as a mulch has been shown to modify hydro-thermal regime of soils (Bhagat and Acharya, 1888). Field experiments conducted on rice straw management and farm yard manure for five years in humid temperate climate (Bhagat and Verma, 1991; Verma and Bhagat, 1992), have indicated the superiority of addition of rice straw in combination with farm yard manure to wheat in rice/wheat cropping sequence, in improving the soil structure and available soil moisture content (Table 1).

Further studies conducted on long term addition of residue and tillage combinations to typical rice soils in north-western India have shown favorable modifications in soil physical properties (Bhagat et al., 1994, Sharma et al., 1995). These studies have specifically shown that residue incorporation (in the form of lantana (*Lantana camara* L.) leaves and twigs addition) increased water retention in post soils (Fig. 1). Further the drying characteristics of these soils (Fig.2) indicated that residue addition irrespective of the tillage treatments invariably delayed surface drying. In post rice soils, the higher unsaturated hydraulic conductivity of the puddled soils keep the surface soil moist, longer by transferring more profile water upward to the surface. In one of these studies, Bhagat et al. (1994) have observed that residue addition increased infiltration rate of puddled and compacted soil by about 2.5×10^{-7} m sec^{-1} compared to puddled and compacted soils without residue addition (Fig.3).

Further investigations of long term effects of residue addition indicated that although there is build up of organic carbon in soil (although slow), however, much of the organic carbon applied through plant residue (lantana in the present case) remained in soil as discrete particles and only a part of it entered into close association with soil particles/aggregates (Sharma et al., 1995). Consequently, the percentage of organic carbon of the whole soil, especially at 20-30 t ha^{-1} residue application rates was higher than the organic carbon in water stable aggregates. Thus it may take several years of regular additions of plant residues for the added carbon to enter and stabilize micro-aggregates.

Cracking pattern of the soils studied after six years of different levels of regular addition of residue is shown in plate 1. Cracking pattern at a soil surface affects the hydrodynamic properties of soil. Cracking extends the soil-air interface into the soil profile and thereby may increase the moisture loss through evaporation. Besides, it has direct bearing on the extent and size-distribution of clods formed during plowing of land. Deep and wide cracks, arranged in hexagonal pattern, typical of the control plots, are expected to produce large clods, compared to the network of fine and shallow cracks typical of the residue (lantana) treated plots. Further the clods formed in residue treated plots were much weaker than the clods formed in control plots (Table 2).This difference would be reflected in much less energy input in the preparation of seedbed for wheat following rice. Measurements made in the same experiment, revealed that plowing energy after rice harvest was 3.4 GJ ha^{-1} in lantana treated plots as against 5.4 GJ ha^{-1} in control plots (Bhagat et al., 1994).

Some more studies carried out on long term tillage and residue management in rice soils have also indicated improvement in various soil physical parameters (Bhagat et al. 2003; Bhagat et al.,2002; Sharma and Bhushan, 2001). In a long term residue management study, the non limiting water range (NLWR) was determined in the root zone (15-18 cm soil layer) by using data on air filled porosity and soil penetration resistance (SPR). NLWR, which is the difference between moisture contents at 10 % air-filled porosity and 2 MPa SPR, increased with the residue addition. NLWR appeared more sensitive to changes in soil organic carbon and plant available water capacity (PAWC) as shown in table 3. Further since NLWR integrates three important soil physical properties directly influencing plant growth, viz. soil moisture, soil-air and soil mechanical impedance, it correlated linearly, positively and significantly with grain yield of post rice crop (winter wheat). The correlation was better with NLWR compared with PAWC-the classical concept of soil water availability.

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Table 1. Mean values of water stable aggregates, mean weight diameter, bulk density and total porosity to 0-0.15 m depth (*Bhagat and Verma, 1991*)

Structural indices	Treatment*						LSD (0.05)
	Control	SI	SM	SB	FYM	SI+FYM	
WSA>0.25 mm (%)	69.7±5.7	77.3±6.7	76.9±6.1	67.3±6.1	80.7±8.5	81.2±9.0	3.1
MWD (mm)	0.61±0.19	0.74±0.24	0.72±0.22	0.59±0.21	0.81±0.32	0.83±0.28	0.11
Bulk density (Mg m^{-3})	1.32±0.04	1.25±0.04	1.33±0.04	1.32±0.04	1.20±0.05	1.18±0.04	0.11
Total porosity (%)	49.4±2.8	51.9±2.9	48.8±2.7	49.2±2.9	53.8±3.4	54.6±3.9	2.9

*SI=Straw incorporation; SM=Straw mulch; SB=Straw burning; FYM=Farm yard manure
WSA=Water stable aggregates; MWD=Mean weight diameter

Table 2. Effect of six annual applications of Lantana camara on bulk density of soil, aggregates and clods, water stability of aggregates and clod –breaking strength in a silty clay loam soil under rice-wheat cropping
(*Sharma, P.K., Verma, T.S. and Bhagat, R.M., 1995*)

Lantana application (t ha^{-1})	Bulk density (t m^{-3})				Water Stable aggregates >0.25 mm (%)	Aggregate porosity (%)	Mean weight diameter (mm)	Clod breaking strength (kPa)
	Soil		Aggregates	Clods				
	0-7.5 cm	7.5-15 cm	(2-8 mm)	4-6 cm				
0	1.42	1.48	1.54	1.49	72.9	38.2	2.66	419.9
10	1.39	1.48	1.50	1.45	79.0	39.8	3.89	377.2
20	1.34	1.46	1.49	1.44	81.9	40.2	4.18	220.8
30	1.31	1.38	1.48	1.40	82.8	40.6	4.09	215.6
L.S.D. ($p \leq 0.05$)	0.05	0.07	0.04	0.03	3.3	1.04	0.67	87.0

Table 3. Effect of ten annual applications of lantana biomass on bulk density, moisture contents at 10 % air filled porosity and 2 MPa SPR, NLWR and PAWC determined during wheat cropping season (*Sharma and Bhushan, 2001*)

Lantana (Mg^{-1} ha)	Bulk density (Mg ha^{-1})		Soil moisture content (vol. %) at 15-18 cm depth			Water retention (vol%) at water potentials (kPa)		PAWC	NLWR:PAWC ratio
	7.5-10.5 cm	15-18 cm	10% air-filled porosity	2 MPa SPR	NLWR	-33.3	-1500		
0	1.26	1.43	31.2	26.9	4.3	33.5	20.6	12.9	0.33
10	1.22	1.41	32.2	24.8	7.4	33.6	20.2	13.4	0.55
20	1.11	1.37	33.9	23.0	10.9	33.7	20.0	13.7	0.80
30	1.08	1.35	34.7	19.6	15.1	34.8	19.9	14.9	1.01
LSD (0.05)	0.04	0.05	1.0	1.2	1.0	0.9	0.4	1.1	0.17

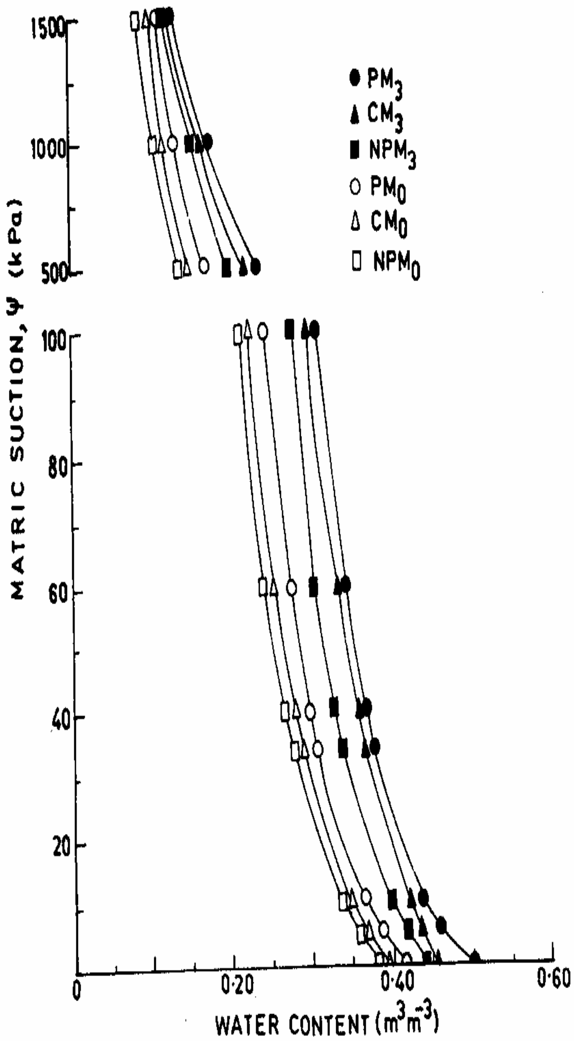

Fig1. Soil Moisture characteristics after rice harvest at 0-0.15 m depth, under various treatments. P=Puddling; C=Compaction; NP=Non puddle; M0= No residue; M3= 30 Mg ha^{-1} residue addition. (*Bhagat et al, 1994*)

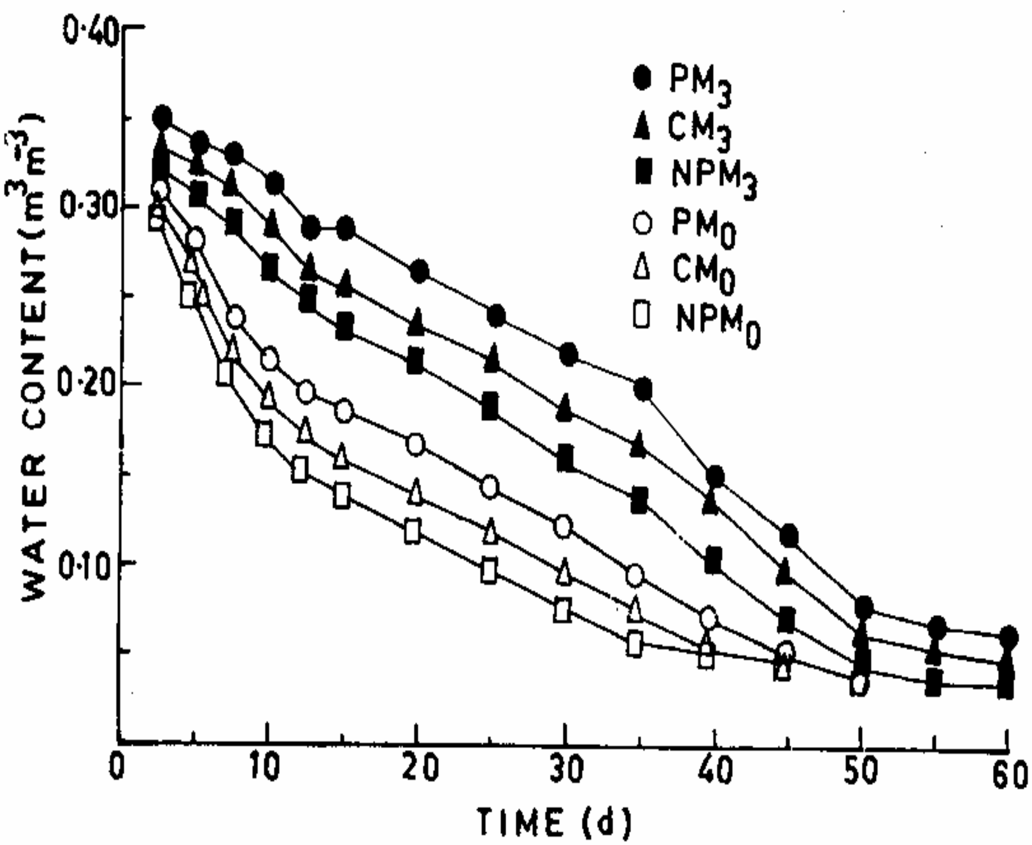

Fig.2 Drying characteristics after rice harvest at 0-0.05m depth, under various treatments. P=Puddling; C=Compaction; NP=Non puddle; M0= No residue; M3= 30 Mg ha^{-1} residue addition. (*Bhagat et al, 1994*)

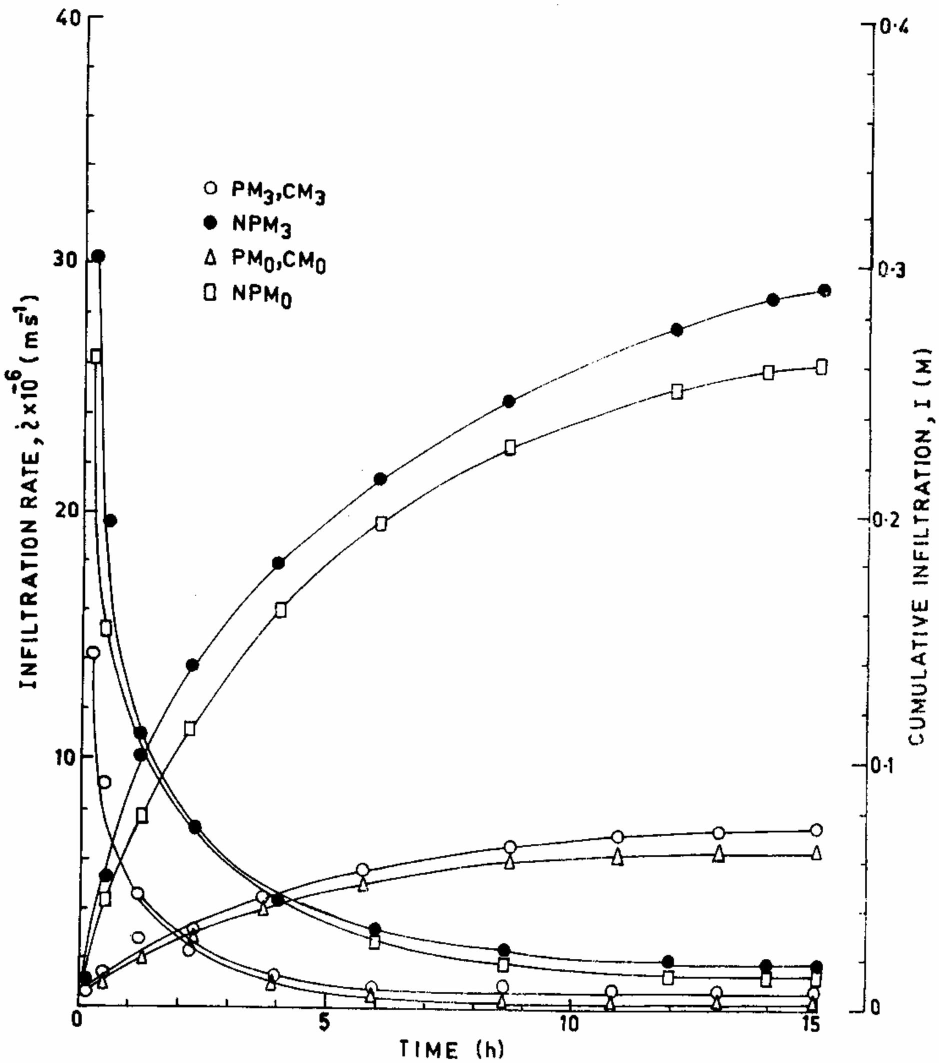

Fig. 3. Infiltration rate and cumulative infiltration vs. time at rice harvest, under various treatments. . P=Puddling; C=Compaction; NP=Non puddle; M0= No residue; M3= 30 Mg ha^{-1} residue addition. (*Bhagat et al, 1994*)

Effect of Lantana residue on soil cracking

Plate 1. Sharma et al. (1995)