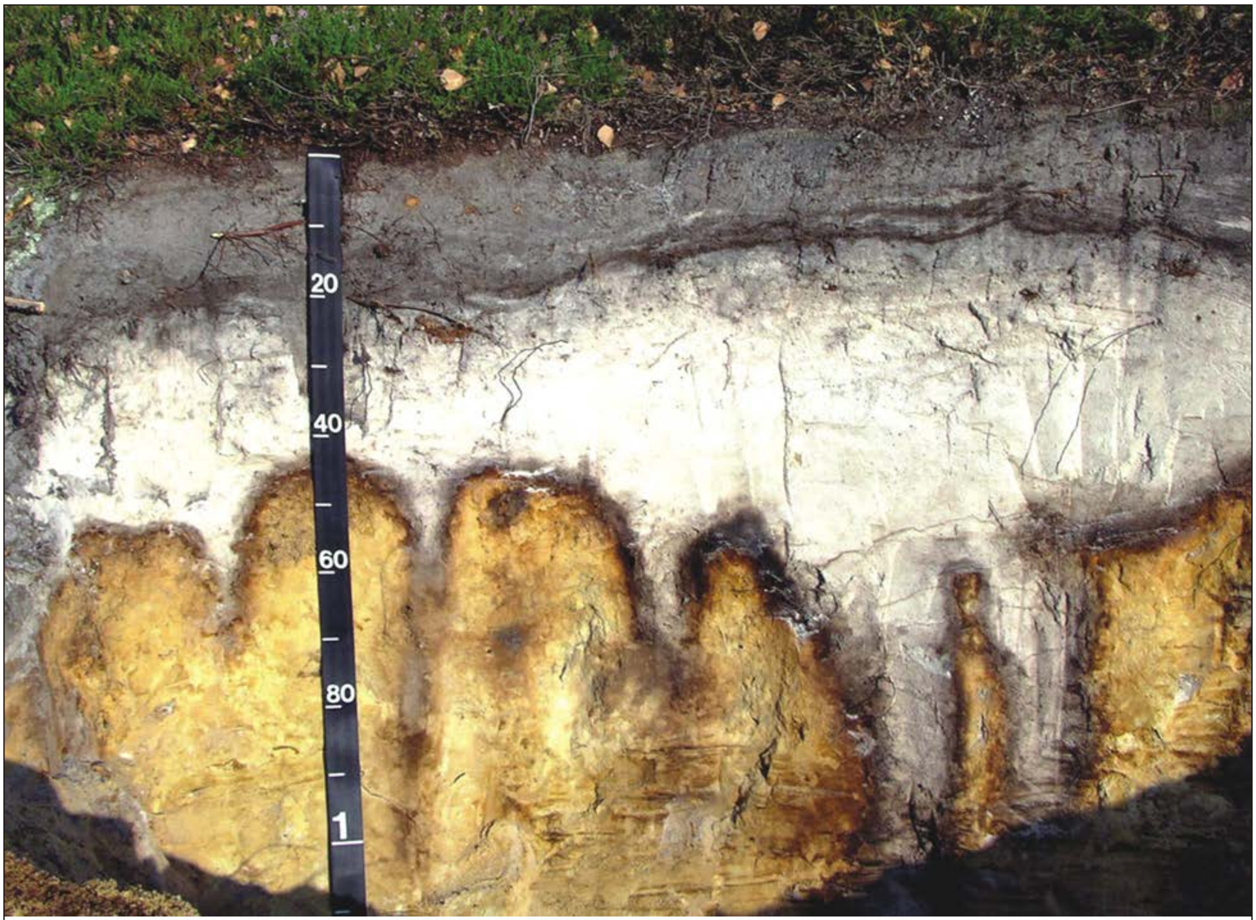

International Journal of
Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 1 (2): 91-107, 2006
ISSN 1816-4978

Soil Physical Response to Multi-Year Rice-wheat Production in India

R.P. Tripathi, Peeyush Sharma and Surendra Singh
Department of Soil Science, G.B. Pant University of Agriculture and Technology,
Pantnagar-263145, India

Abstract: High yields of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) achieved in India following the green revolution have tended to decline after 5 to 8 years of continuous production in the same field. We hypothesized that degradation of soil physical quality was responsible for the yield decline because nutrient, pesticide and irrigation management were relatively well optimized. A soil physical quality assessment model was thus developed using 4 years of data from tillage and crop residue experiments conducted on a silty clay loam (Aquic hapludoll) at the Crop Research Centre, Pantnagar, India. Tillage for rice increased Bulk Density (BD) and Puddling Index (PI) and decreased saturated hydraulic conductivity (Ks), porosity (f) and Infiltration Rate (IR) over the 4 years. Changes in soil properties were significantly higher in the plots puddled by 4 Passes of Rotavator (PR) and in Conventional Puddling (CP) plots than in reduced puddling (ReP) and Direct Seeding Without Puddling (DSWP) plots. The crop residue management and wheat tillage treatments did not significantly influence soil physical properties in the 4 years time but the negative effect of puddling on soil properties was more in the Residue Removed (RR) plots than in the Residue Incorporated (RI) plots. Rice yield was highest in PR, which was at par with that in CP and ReP plots and wheat yield was highest in DSWP, which was at par with that in ReP, irrespective of tillage levels for wheat. Decrease in rice and wheat yields over the 4 years was not significant. Regression of grain yield on soil physical properties showed significant effects of BD and Ks on rice yield and that of IR and f on wheat yield. These relationships were used to develop a Soil Physical Quality Index (SPQI) model. Values of SPQI for treatments with grain yields that were statistically equal to maximum yield ranged from 0.70 to 0.80 for rice soils and 0.75 to 1.0 for wheat soils. Overall, tillage and residue treatments did not significantly degrade soil physical quality during the first 4 years, but projections based on the SPQI suggest they could in 5 to 9 years depending on the practices used for soil puddling and residue management. In DSWP, SPQI for rice was significantly lower from the first year itself (which indicates need for tillage) but was in the optimum range for wheat even under zero tillage. The proposed SPQI model has been verified using the published data on rice-wheat system under different soil conditions across the country.

Key words: Model for soil physical quality index, physical properties, residue management, rice-wheat system, soil physical quality index, tillage for rice wheat system

Introduction

Mission to produce more food, feed and fiber encouraged rapid adoption of new technologies in agriculture without in-depth evaluation of their long-term impact on soil productivity and

---

Corresponding Author: R.P. Tripathi, Department of Land Resources and Environment, College of Agriculture, University of Asmara, P.O. Box 1220, Asmara, Eritrea
Tel: +291-1-164020/162607 Fax: +291-1-162236

environmental quality (Doran *et al*., 1996). As a result of this, high yields of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) observed in India in the initial years have tended to decline in about 5 to 8 years of continuous rice-wheat system (Tripathi, 1992a; Hobbs, 2001), questioning the sustainability of soil quality condition with the existing package of management practices. Whereas nutrient, pesticide and irrigation schedules have been relatively optimized for a cropping system, tillage and residue management, which are highly variable in different soils and environmental conditions, need thorough optimization (Karlen *et al*., 1997; Sharma *et al*., 2004; Tripathi *et al*., 2005). Karlen *et al*. (1997) observed that no-tillage or crop residue application improved soil quality compared with the practice of intensive tillage or crop residue removal. No-till system improved earthworm population, organic carbon sequestration and water stable aggregates but increased bulk density compared to the conventional tillage or reduced tillage (Arshad *et al*., 1999; Tebrűgge and Dűring, 1999). However, Lal (1999) did not find any significant difference in bulk density between no-tillage and minimum tillage or plough tillage in 25 years of no-till system with continuous maize (*Zea mays* L.).

A higher amount of C and N observed in the 0 to 0.3 m layer of the rangeland soils subjected to 11 years of grazing than in the soil prohibited for grazing showed the evidence of improved soil quality due to greater opportunities for plant residue incorporation and less loss through oxidation (Manley *et al*., 1995). Liebig *et al*. (2004) also reported the improved soil quality and agricultural sustainability by residue incorporation with reduced tillage management. Tillage affects organic C, erosion and many physical, chemical and biological properties and processes used as indicators of soil quality (Karlen, 2004).

Larsen and Pierce (1991) defined soil quality as the capacity to function within the ecosystem boundaries and to interact positively with the environment external to that ecosystem. In agricultural context, the soil quality is aimed at maximizing production without adversely affecting the environment. Potential physical, chemical and biological indicators with minimum data set have been suggested to evaluate soil quality (Doran *et al*., 1996; Karlen *et al*., 2001). Efforts have been made to identify critical soil functions, select indicators for those functions and develop appropriate scoring functions to interpret the indicators for various soil resources (Karlen *et al*., 1994). Wander and Bollero (1999) showed that particulate organic matter was a promising indicator of soil quality. Masciandaro and Ceccanti (1999) observed that humic pool, which is often preserved even where most of the labile soil organic matter (>86%) is lost by tillage, was a potential indicator of soil quality. Similarly methane oxidation rate, which is enhanced with structural damage, could also be a potential soil quality indicator (Ball *et al*., 1999). Lapen *et al*. (2004) observed that air-filled porosity based soil quality indicator, such as least limiting water range, was best for maize throughout the growing season. On slopy lands, erosion risk was the reliable indicator of soil quality for sustainable management (Anken *et al*., 2004). Soil quality test kits (Liebig *et al*., 1996; Sarrantonio *et al*., 1996), farmer-based scorecards (Romig *et al*., 1996), soil management assessment framework (Karlen *et al*., 1997), soil resource management programs (Walter *et al*., 1997) and visual soil assessment procedures (Shepherd, 2000) have been developed and used to determine soil quality. Using standardized scoring functions approach, Hussain *et al*. (1999) reported that soil quality index is sensitive to local practices and responsive to inherent soil conditions and therefore, useful for making management recommendations. However, a more systematic approach is needed to objectively select the indicators for determining soil quality (Wang *et al*., 2003). There is no single correct indicator or index value because of inherent differences among soils, crops and climates (Andrew *et al*., 2002; Karlen *et al*., 2001; Sojka *et al*., 2003). Characterization of soil quality in terms of economic yield and changes in soil properties caused by tillage and other management practices is promising (Acton and Gregorich, 1995; Doran *et al*., 1996) but a limited information concerning tillage induced changes on soil properties are monitored (Gantzer and Blake, 1978; Hill, 1990; Hussain *et al*., 1999; Tripathi *et al*., 2003). In this study a method has been described to evaluate soil quality for rice and wheat from soil physical properties and grain yield as affected by tillage and residue management. The chemical and biological quality parameters were not examined due to their dependence on a number of interacting parameters and lack of expertise to separate them.

Materials and Methods

Experiments were conducted to generate data on tillage and crop residue effects on soil physical properties and yield of rice and wheat during 1999 to 2003 at the Crop Research Centre, Pantnagar (28°26'N, 77°29'E, 243.8 m above msl), India, in a silty clay loam of subgroup Aquic hapludoll (Deshpande *et al*., 1971). The area lies as east-west belt adjoining the Himalayan mountains and is characterized by non-saline natural water tables and sub-humid tropical conditions (Tripathi, 1997). The 4-year average rainfall during the rice and wheat seasons was 1715 and 638 mm, respectively. The water table fluctuated between 0.05 to 0.4 m during the rice season and 0.5 to 0.97 m depths during the wheat season.

Experimental Details

Rice experiment was laid out in split plot design in 12×10 m plots in 4 replications. Main plots consisted of 4 tillage treatments viz., PR (puddling by 4 passes of rotavator), CP (conventional puddling by 4 passes of tractor drawn local puddler with cage wheel), ReP (reduced puddling by 2 passes of rotavator) and DSWP (direct seeding without puddling). The subplot treatments were Residue Incorporation (RI) and Residue Removal (RR) in 6×10 m plot sizes. Tillage treatments for wheat were Zero Tillage (ZT) and Conventional Tillage (CT) with RI and RR superimposed over the plots of rice tillage treatments in split-split plot design with rice tillage as main plots and wheat tillage as subplots and residue management as sub-subplots. In ZT, wheat was planted by seed drill without any land preparatory tillage. The CT for wheat included ploughing by one-way disc plough followed by 3 harrowing, leveling, planking and planting by seed drill. The plot size for wheat became 6×5 m. The rice crop was fertilized with 150 kg N ha^{-1}, 26 kg P ha^{-1}, 33 kg K ha^{-1} and 9 kg Zn ha^{-1} and the wheat crop was fertilized with 120 kg N ha^{-1}, 26 kg P ha^{-1} and 33 kg K ha^{-1}. Half of the nitrogen and full P, K and Zn were applied as basal dose and the remaining dose of nitrogen was applied in two splits. The rice crop was irrigated with 75 mm of water 3 days after the disappearance of ponded water from the surface of the PR plot (Tripathi *et al*., 1986). The wheat crop was irrigated based on climate-crop-soil data (Tripathi, 1992b).

The physical properties measured were Puddling Index (PI), Bulk Density (BD), saturated hydraulic conductivity (Ks), Infiltration Rate (IR) and porosity (f). The bulk density was measured by core method and the saturated hydraulic conductivity by constant head permeameter method at 30 Days After Sowing or Transplanting (DAS/DAT) and at harvesting of rice and wheat using soil cores collected from 0 to 0.05 m tilled layer. The infiltration rate was measured at 30 DAS/DAT and harvesting of the crops using double ring infiltrometer. The porosity was determined from BD and particle density data. The puddling index was determined as the volume ratio of soil settled in 24 h in a 100 mL measuring cylinder to that within 5 min after puddling. Harvesting the central 2×2 m area, threshing and air-drying the grain to constant moisture content was grain yield. The 4-year data were analyzed in a split-split plot design taking year as main factor and evaluating significance ($p=0.05$) by F-test (Gomez and Gomez, 1984).

Soil Physical Quality Index Model

A model to calculate Soil Physical Quality Index (SPQI) was developed from the data on soil physical properties and yields of rice and wheat collected during 1999 to 2003. The model utilizes multiple linear regressions of crop yields on soil physical properties to test the relative significance of soil properties on crop yield as

$$Y = a + b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots\ldots + b_nX_n \qquad (1)$$

where Y is grain yield of the crop; X_1, X_2..........., X_n are different soil properties; and a, b_1, b_2, ..., b_n are constants. Those physical properties whose coefficients (b_1, b_2, ...b_n) in Eq. (1) were found significant by t-test were selected for calculating the SPQI. The selected physical properties and yields were then normalized as X'_j by the relation

$$X'_i = \frac{\text{Observed value of the property or yield } (X_{io})}{\text{Maximum value of the property or yield } (X_{im})} \qquad (2)$$

Maximum value of soil physical properties used and experimental maximum yields of rice and wheat are given in Table 1. The X'_j was 1 for the values of X_{io} exceeding X_{im}. The normalization was done to extend the applicability of the model under diverse soils and climates. Since maximum yield is variety, soil and area specific, use of location specific maximum values of the parameters would be more appropriate. The normalized values of the selected physical properties were individually subjected to regression with normalized yields to determine their coefficient of determination, R^2, whose proportionate variation was obtained and expressed as A_i.

$$A_j = R_j^2 / \sum_{i=1}^{n} R_i^2 \qquad (3)$$

where n is number of properties X_i found significant by t-test. The soil physical quality index, SPQI, was then expressed as sum of the products of A_i and X'_j as:

Table 1: Maximum value of soil physical properties and rice-wheat yields used in the calculation of SPQI

	Maximum values (X_{im}) of soil properties and yield	
Soil properties and yield	Rice field	Wheat field
Saturated hydraulic conductivity, Ks (mm d^{-1})	27	-
Bulk density, BD (Mg m^{-3})	1.68	-
Infiltration rate, IR (mm d^{-1})	-	28
Porosity, f (percent)	-	48
Experimental maximum yields (kg ha^{-1})	6500	4500

$$\mathrm{SPQI} = \sum_{i=1}^{n} A_i X_i' \tag{4}$$

Thereafter, SPQI was calculated for the normalized values of the physical properties and plotted against the corresponding normalized yields to determine SPQI at the observed maximum yield. A second-degree polynomial fitted the data. The value of SPQI at the observed maximum yield of the crop and the range of SPQI corresponding to yields statistically similar to the maximum yield represented the optimum range of SPQI. The SPQI of different treatments was then plotted against years to determine soil physical quality projections to follow the temporal trends under different management systems/treatments.

Results and Discussion

Dynamics of Soil Physical Properties

Soil physical properties are responsive to tillage and crop residue management in rice-wheat system (Fig. 1 to 5). Tillage for rice (PR, CP and ReP) caused a significant increase in PI and BD and decrease in Ks, f and IR but tillage for wheat (ZT and CT) and residue management showed no significant effect. Changes in soil physical properties were significantly higher in PR and CP plots than in ReP and DSWP but changes in a treatment with time, due to tillage for rice or wheat and residue management, were not significant in the four years. However, increase in PI from 0.71 to 0.86, 0.69 to 0.81 and 0.57 to 0.71 in PR, CP and ReP, respectively, in 4 years, amply indicates increasing breakdown of aggregates with time depending upon tillage intensity. Residue Incorporation (RI) resisted the aggregate breakdown such that PI and BD in RR plots were always higher than in RI (Fig. 1 and 2). Increased water stable aggregates by residue incorporation and reduced tillage have also been reported by Bajpai *et al.* (1995), Tebrügge and Düring (1999) and Kharub *et al.* (2004). Puddling effects on soil physical properties persisted even in the wheat season and the effects were more in RR than in RI plots and in ZT than in CT plots. Overall changes in physical properties were rapid in the first 3 years.

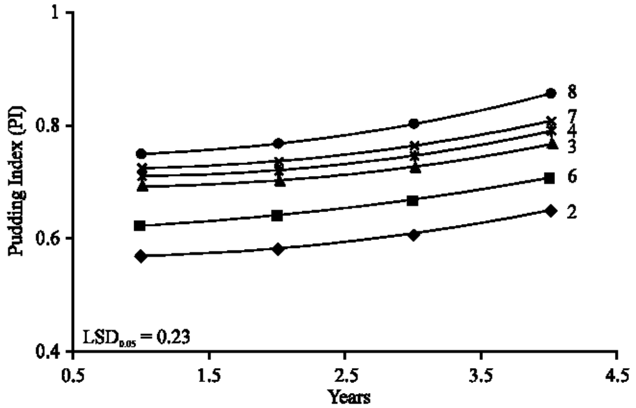

Fig. 1: Puddling index (PI) over the years in 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots of rice

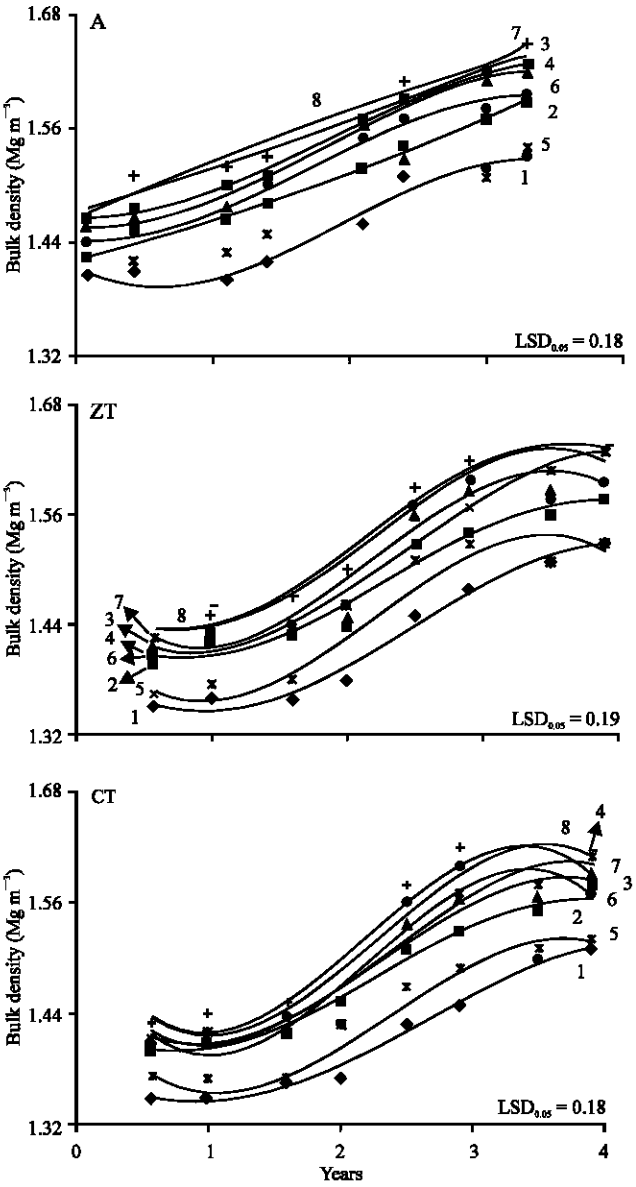

Fig. 2: Bulk density (BD) of the tilled layer over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in 1 (DSWP-RI), 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 5 (DSWP-RR), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots

Dynamics of Grain Yield

Rice yield in PR plot was highest and statistically at par with that in CP and ReP (Fig. 6). But wheat yield was lowest in the PR plot of rice and highest in the DSWP plot in which it was at par

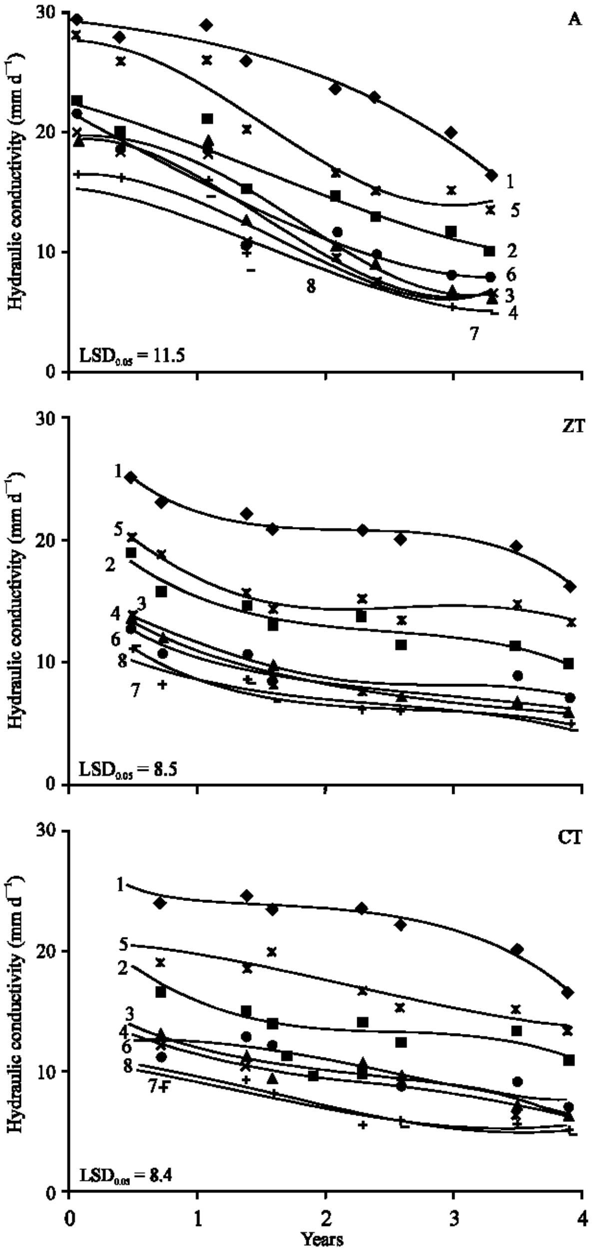

Fig. 3: Hydraulic conductivity (Ks) of the tilled layer over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in 1 (DSWP-RI), 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 5 (DSWP-RR), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots

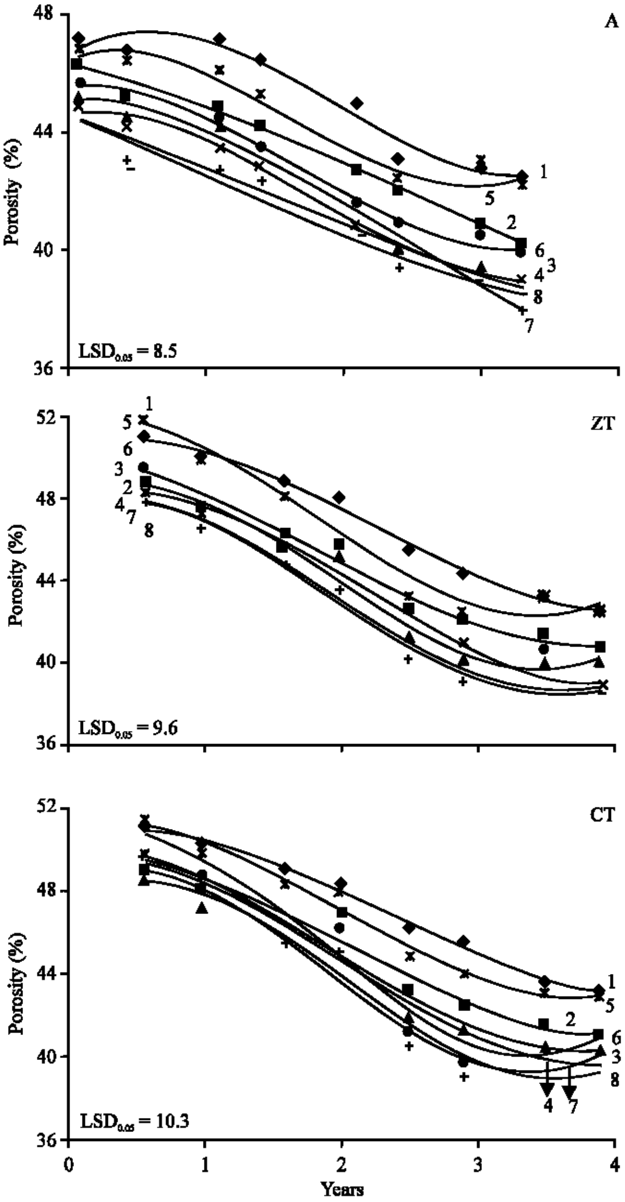

Fig. 4: Porosity (f) of the tilled layer over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in 1 (DSWP-RI), 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 5 (DSWP-RR), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots

with that in ReP. In DSWP, rice yield was significantly lower than in other treatments from the first year itself. Sharma *et al*. (2005) also observed that tillage necessary to maximize rice yield deteriorates soil physical condition for wheat. Total average yield of rice and wheat was highest from RI plots of

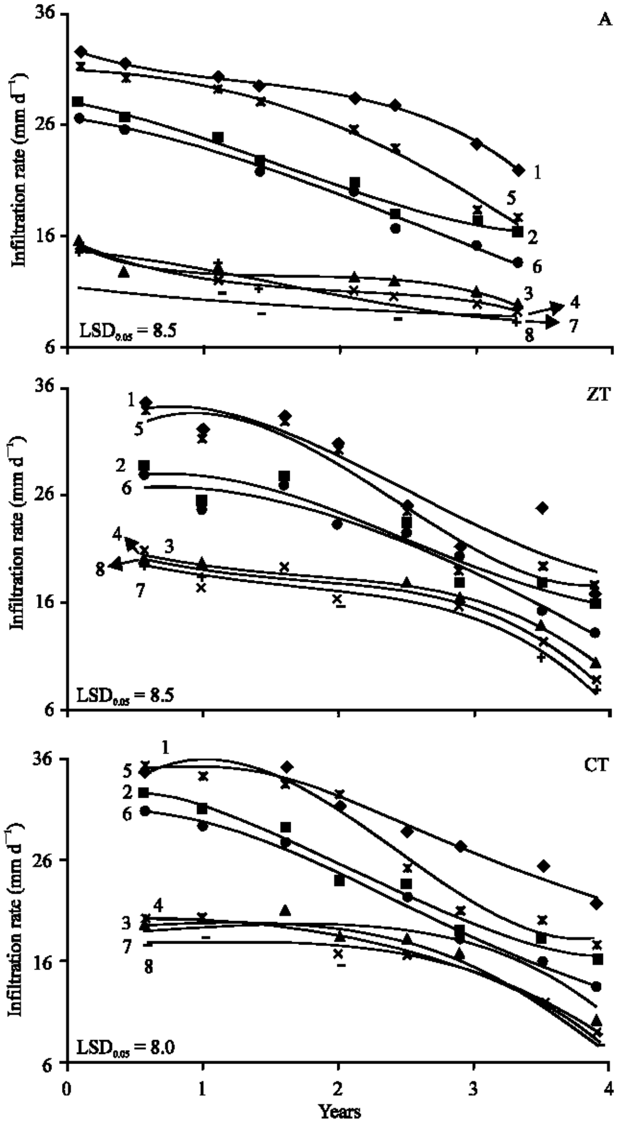

Fig. 5: Infiltration rate (IR) over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in 1 (DSWP-RI), 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 5 (DSWP-RR), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots

ReP-CT treatment combination. Both rice and wheat yields followed a declining trend over the years. The decrease in yield was more in RR than in RI plots. Also, wheat yield decline in CT was greatly slowed down in the fourth year indicating its superiority over continuous ZT.

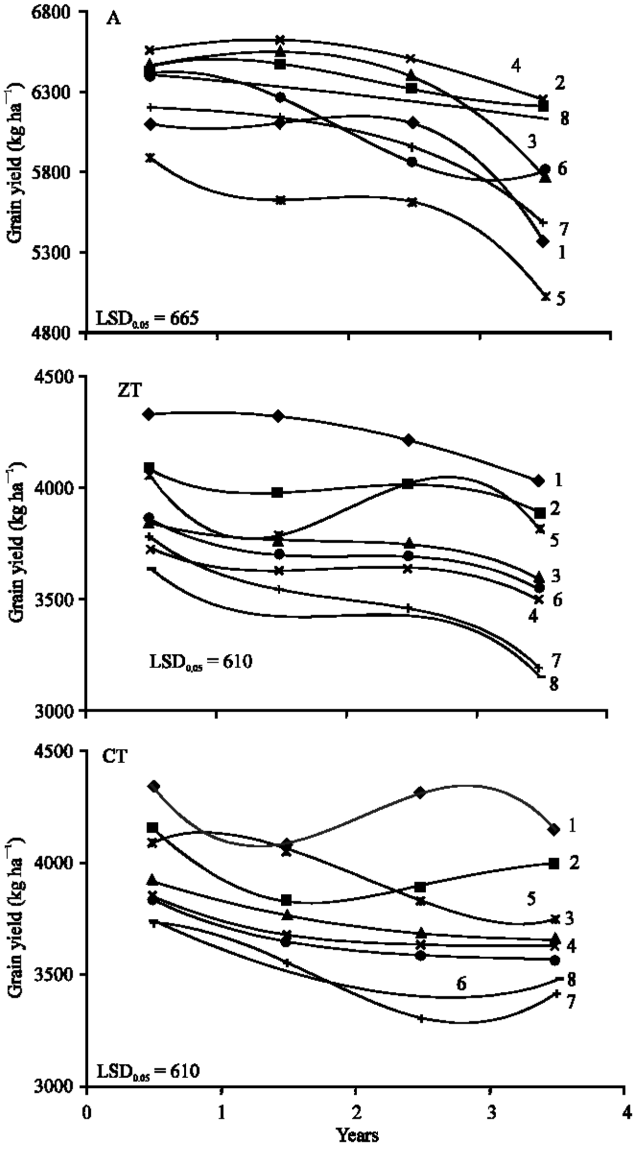

Fig. 6: Grain yield over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in 1 (DSWP-RI), 2 (ReP-RI), 3 (CP-RI), 4 (PR-RI), 5 (DSWP-RR), 6 (ReP-RR), 7 (CP-RR), 8 (PR-RR) plots

Tillage and crop residue effects on soil physical properties and yields suggest that wheat crop liked improvement or preservation of inherent condition of soil aggregates but rice liked puddling that caused breakdown of aggregates into soft mud and soil compaction. Crop residues improved rice-wheat yields and resisted deterioration of soil aggregates. Relative importance of soil physical properties on grain yield as influenced by tillage and residue management was quantified by multiple linear regressions (Eq. 1) as:

$$Y = -5868.8 + 7542.2\ BD + 41.2\ Ks - 9.34\ IR - 5.25\ f + 145\ PI,\ R^2 = 0.60 \text{ for rice} \tag{5}$$

(Calculated t-value for BD = 6.38, Ks = 2.23, IR = 0.40, f = 0.16 and PI = 0.29 and Table value = 2.03; number of observations = 96) and

$$Y = 75.37 - 588.92\ BD + 2.28\ Ks + 58.76\ IR + 18.05\ f,\ R^2 = 0.62 \text{ for wheat} \tag{6}$$

(Calculated t-value for BD = 0.58, Ks = 0.47, IR = 3.78 and f = 4.54; and Table value = 2.03; number of observations = 128)

Analysis showed that combined effects of the properties considered accounted for at least 60% variations in rice yield and 62% variations in wheat yield. The t-test indicated a significant effect of BD and Ks on rice yield (Eq. 5) and that of IR and f on wheat yield (Eq. 6).

Soil Physical Quality Index Model

Equation (5) and (6) formed the basis of the Soil Physical Quality Index (SPQI) model. As described in the methodology, proportionate variation of R^2, obtained from regression of the normalized significant physical properties (Eq. 2) on normalized yields (Fig. 7), was determined (Eq. 3) and expressed as in Eq. (4) to obtain

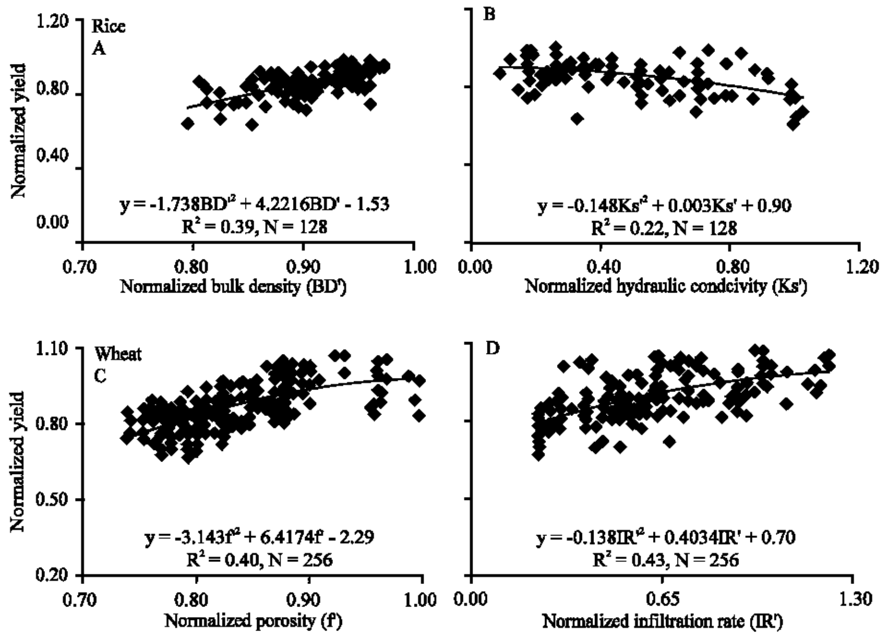

Fig. 7: Relationships between normalized values of (A) bulk density and rice yield, (B) hydraulic conductivity and rice yield, (c) porosity and wheat yield and (D) infiltration rate and wheat yield

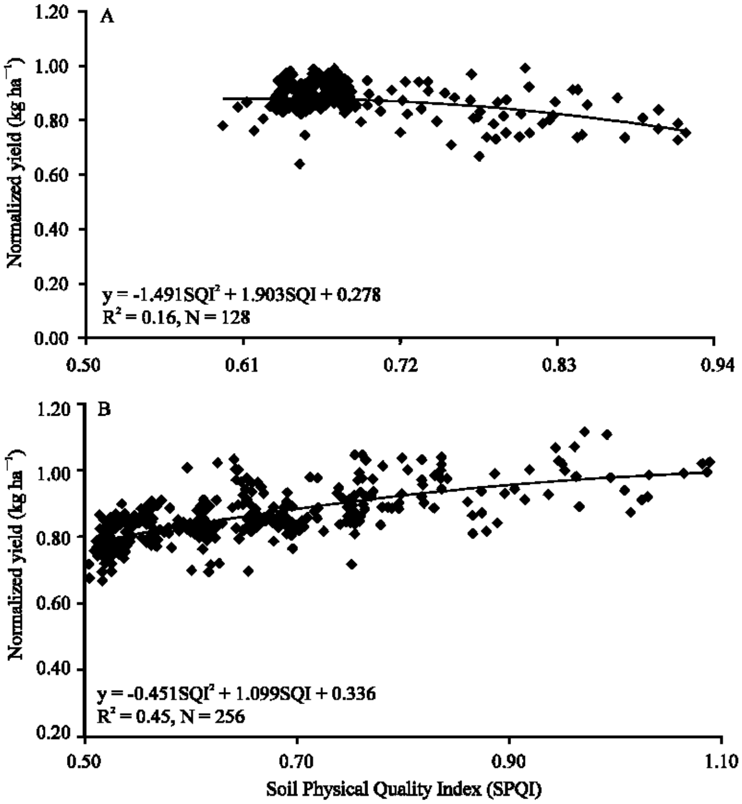

Fig. 8: Normalized yield of (A) rice and (B) wheat as affected by Soil Physical Quality Index (SPQI)

$$\text{SPQI} = 0.65\ \text{BD}' + 0.35\ \text{Ks}', \text{ for rice and} \quad (7)$$

$$\text{SPQI} = 0.52\ \text{IR}' + 0.48\ f', \text{ for wheat} \quad (8)$$

where BD', Ks', IR' and f ' are their normalized values calculated using Eq. (2). Thereafter, SPQI was calculated using Eq. (7 and 8) and plotted against the corresponding normalized yields (Fig. 8) to obtain the optimum range of SPQI as described in the methodology.

As shown in Fig. 8, optimum range of SPQI for optimum yields was from 0.70 to 0.80 for rice soils and from 0.75 to 1.0 for wheat soils. A lower SPQI for rice soils corresponds to higher level of puddling and yield, whereas a lower SPQI for wheat soils corresponds to higher yield and minimum tillage in rice-wheat system. The values of SPQI and rice yield indicate that soil physical quality remained optimum during the 4 years of rice-wheat system in all the puddled plots (Fig. 9). Extrapolation of the curves (equations) in Fig. 9, indicated that soil physical quality for rice would not deteriorate in 8, 6 and 5 years in ReP-RI, CP-RI and PR-RI plots and in 6, 5 and 5 years in ReP-RR, CP-RR and PR-RR plots, respectively. The SPQI for rice in DSWP plot remained in the suboptimal range from the first year itself. But for wheat, it was optimum in all the 4 years in DSWP and ReP plots of rice both under ZT and CT conditions and may remain optimum until 8 and 6 years in DSWP-RI and ReP-RI plots and until 7 and 5 years in DSWP-RR and ReP-RR plots under ZT

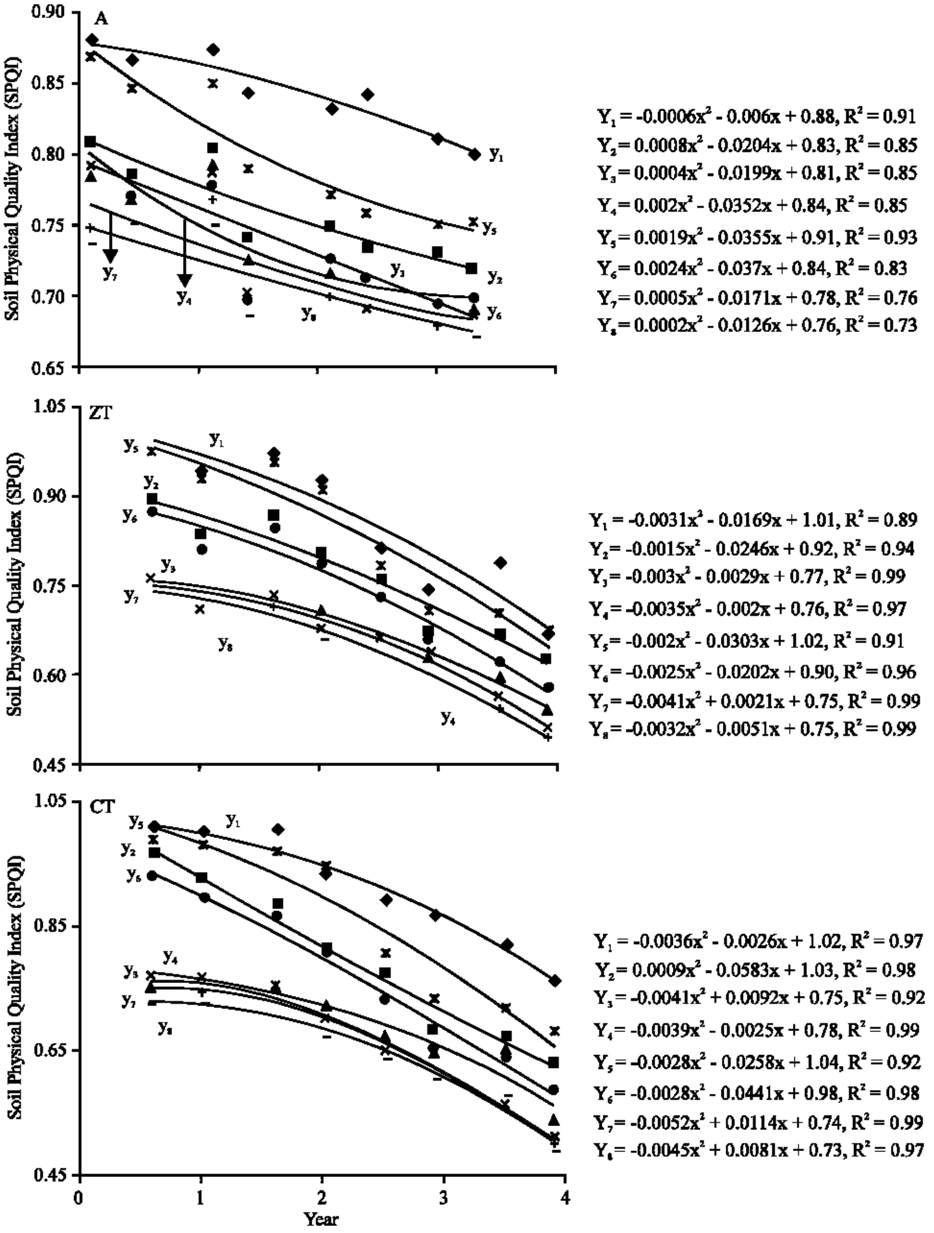

Fig. 9: Changes in Soil Physical Quality Index (SPQI) over the years in different tillage and residue treatments of rice (A) and in zero tillage (ZT) and conventional tillage (CT) conditions of wheat after rice in Y_1 (DSWP-RI), Y_2 (ReP-RI), Y_3 (CP-RI), Y_4 (PR-RI), Y_5 (DSWP-RR), Y_6 (ReP-RR), Y_7 (CP-RR), Y_8 (PR-RR) plots

conditions and until 9 and 6 years in DSWP-RI and ReP-RI plots and until 7 and 5 years in DSWP-RR and ReP-RR plots under CT conditions, respectively (Fig. 9). Results thus show that soil physical quality deterioration was (i) least (not significant) with optimum yields of rice in ReP-RI plot for 8 years and that of wheat in the same plot under CT-RI condition for 6 years, (ii) faster in highly puddled PR-RR and CP-RR plots of rice and in ZT-RR plot of wheat and (iii) resisted by residue incorporation. Karlen *et al*. (1997) and Liebig *et al*. (2004) also reported improvements in soil quality and sustainability of cropping systems by residue incorporation and reduced tillage.

Verification of the Soil Physical Quality Index Model

Equations (7 and 8) were used to calculate SPQI using the data from the experiments on rice-wheat system conducted at New Delhi (Aggarwal *et al*., 1999), Pantnagar (Kumar and Tripathi, 1990; Bharadwaj *et al*., 1994; Bajpai and Tripathi, 2000; Sharma *et al*., 2004; Lal, 2005) and Kharagpur (Kar, 2002). As shown in Table 2, the SPQI for optimum grain yield was in the range of 0.74 to 0.80 for rice soils and 0.77 to 0.98 for wheat soils, which is well within the proposed optimum range of SPQI calculated from the model for rice and wheat soils. Results thus indicate that SPQI in the range of 0.70 to 0.80 for rice soils and 0.75 to 1.0 for wheat soils could be used as indicators of the optimum range of SPQI for optimum productivity and quality of rice and wheat soils.

Table 2: Soil physical quality index calculated from the published data of different locations in India

Locations	Treatments	Rice yield (kg ha^{-1})	SPQI*	Wheat yield (kg ha^{-1})	SPQI*
Pantnagar (Kumar and Tripathi, 1990; Bharadwaj *et al*., 1994)	T_1 (Control)	4647	0.89		
	T_2 (100% NPK)	7452	0.89		
	T_3 (100% NPK+FYM)	7672**	0.79		
New Delhi (Aggarwal *et al*., 1999)	P_0 (No puddling)	1030	0.92		
	P_1 (1 pass of puddler)	1620	0.95		
	P_2 (2 pass of puddler)	2260	0.90		
	P_3 (3 pass of puddler)	2870**	0.80		
Pantnagar (Bajpai and Tripathi, 2000)	T_1 (Puddling)	5895**	0.70	3390 (ZT)	0.70
	T_2 (Non puddling)	5380	0.90	4245 (CT)**	0.77
Kharagpur (Kar, 2002)	T_1 (Puddling by rotavator)	4450**	0.74	2900(ZT)**	0.90
	T_2 (Puddling by power tiller)	4100**	0.78	2425(CT)**	0.89
Pantnagar (Sharma *et al*., 2004)	DSWP	5224	0.81	4030 (ZT)**	0.98
				4007 (CT)**	0.98
	ReP	5658**	0.74	3789 (ZT)**	0.94
				3772 (CT)**	0.94
	CP	5593	0.69	3696 (ZT)	0.74
				3658 (CT)	0.73
	PR	5714**	0.70	3456 (ZT)	0.70
				3517 (CT)	0.71
Pantnagar (Lal, 2005)	T_1 (1-pass of rotavator)	5650	0.82		
	T_2 (2-pass of rotavator)	6125**	0.80		
	T_3 (3-pass of rotavator)	6250**	0.78		
	T_4 (4-pass of rotavator)	6315**	0.78		

*Optimum rang of SPQI for rice soil = 0.70 to 0.80 and for wheat soil = 0.75 to 1.0, **Significantly high yield

Conclusions

A model to calculate SPQI from grain yield and soil physical properties of the tilled layer as affected by tillage and residue management has been developed. The model uses multiple linear regressions to identify significant soil physical properties affecting grain yield and to develop expressions for determining SPQI for soils under rice-wheat cropping system. The parameters have been normalized to enable soil physical quality assessment under diverse soil conditions. The model has been verified on variety of soils in different regions of India under rice-wheat system. Optimum SPQI ranged from 0.70 to 0.80 for rice soils and from 0.75 to 1.0 for wheat soils. The temporal trends in SPQI indicated that soil physical quality for rice-wheat system did not significantly degrade by tillage and residue treatments in the first 4 years but may degrade in 6 to 8 years even in the most optimum treatment combination of ReP-CT under RI in this silty clay loam. The SPQI model can thus be used to determine soil physical quality to keep track of sustainability of the cropping system and changes in soil physical properties resulting from management.

Acknowledgments

Authors are grateful to Indian Council of Agricultural Research and NATP for funding this ad hoc research project.

References

Acton, D.F. and L.J. Gregorich, 1995. Understanding Soil Health, In: Acton, D.F. and L.J. Gregorich, (Eds.). The Health of Our Soils-toward Sustainable Agriculture in Canada, Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ont., pp: 5-10.

Aggarwal, P., R.N. Garg, D.K. Das and A.M. Sharma, 1999. Puddling, soil physical environment and rice growth on a Typic Ustochrept. J. Indian Soc. Soil Sci., 47: 355-357.

Andrews, S.S., J.P. Mitchell, R. Mancinelli, D.L. Karlen, T.K. Hartz, W.R. Horwath, G.S. Pettygrove, K.M. Scow and D.S. Munk, 2002. On-farm assessment of soil quality in California's Central Valley. Agron. J., 94: 12-23.

Anken, T., P. Weisskopf, U. Zihlnann, H. Forrer, J. Jansa and K. Perhacova, 2004. Long-term tillage system effects under moist cool conditions in Switzerland. Soil Till. Res., 78: 171-183.

Arshad, M.A., A.J. Franzluebbers and R.H. Azooz, 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil Till. Res., 53: 41-47.

Bajpai, R.K., M.S. Rawat, R.P. Tripathi and D. Singh, 1995. Effect of Green Manuring and Residue Management on Physical Properties of Soil under Rice-wheat Cropping System, pp: 79-81. In: Proceedings of the National Symposium on Organic Farming for Sustainable Crop Production and Environmental Protection, Published by Agronomy Society G.B. Pant University of Agriculture and Technology, Pantnagar, India, pp: 240.

Bajpai, R.K. and R.P. Tripathi, 2000. Evaluation of non-puddling under shallow water tables and alternative tillage methods on soil and crop parameters in a rice-wheat system in Uttar Pradesh. Soil Till. Res., 55: 99-106.

Ball, B.C., A. Scott and J.P. Parker, 1999. Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland. Soil Till. Res., 53: 29-39.

Bharadwaj, V., P.K. Omanwar, R.A. Sharma and Vishwanath, 1994. Long term effects of continuous rotational cropping and fertilization on crop yields and soil properties-I. Effects on crop yields and nutrient uptake. J. Indian Soc. Soil Sci., 42: 247-253.

Deshpande, S.B., J.B. Fahrenbacher and A.K. Beavers, 1971. Mollisols of Tarai region of Uttar Pradesh, Northern India, I. Morphology and Mineralogy. Geoderma, 6: 174-193.

Doran, J.W., M. Sarrantonio and M.A. Liebig, 1996. Soil health and sustainability. Adv. Agron., 56: 1-54.

Gantzer, C.J. and G.R. Blake, 1978. Physical characteristics of the Le Seur clay loam soil following no-till and conventional tillage. Agron. J., 70: 853-857.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, Inc, New York, pp: 680.

Hill, R.L., 1990. Long-term conventional and no-tillage effects on selected soil physical properties. Soil Sci. Soc. Am. J., 54: 161-166.

Hobbs, P.R., 2001. Tillage and crop establishment in south Asia rice-wheat system: Practices and future options. J. Crop Prod., 4: 19-22.

Hussain, I., K.R. Olsan, M.M. Wander and D.L. Karlen, 1999. Adaptation of soil quality indices and application to three tillage systems in southern Illinois. Soil Till. Res., 50: 237-249.

Kar, S., 2002. Development and Validation of Simulation Models to Predict the Long-term Consequences of Different Tillage and Residue Management Strategies, pp: 26-40. In: Annual Progress Report (2001-2002) Complied by D.K. Painuli and M. Mohanty, Indian Institute of Soil Science, Nabi Bagh, Berasia Road, Bhopal, India, pp: 113.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Eash and J.L. Jordahl, 1994. Long-term tillage effects on soil quality. Soil Tillage Res., 32: 313-327.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris and G.E. Schuman, 1997. Soil quality: A concept, definition, and framework for evaluation (a guest editorial). Soil Sci. Soc. Am. J., 61: 4-10.

Karlen, D.L., S.S. Andrews and J.W. Doran, 2001. Soil quality: Current concepts and applications. Adv. Agron., 74: 1-40.

Karlen, D.L., 2004. Soil quality as an indicator of sustainable tillage practices. Soil Till. Res., 78: 129-130.

Kharub, A.S., R.K. Sharma, A.D. Mongia, R.S. Chhokar, S.C. Tripathi and V.K. Sharma, 2004. Effect of rice (*Oryza sativa*) straw removal, burning and incorporation on soil properties and crop productivity under rice-wheat (*Triticum aestivum)* system. Indian J. Agric. Sci., 74: 295-299.

Kumar, A. and R.P. Tripathi, 1990. Effect of continuous use of manures and fertilizers on physical properties of soil under paddy-wheat-cowpea cropping system. Crop Res., 3: 7-13.

Lal, G., 2005. Effect of puddling on soil properties and performance of rice crop. M.Sc.(Ag.), Soil Science Thesis, G.B. Pant University of Agriculture and Technology, Pantnagar, India.

Lal, R., 1999. Long-term tillage and wheel traffic effects on soil quality for two central Ohio soils. J. Sustain. Agric., 14: 67-84.

Lapen, D.R., G.C. Topp, E.G. Gregorich and W.E. Curnoe, 2004. Least limiting water range indicators of soil quality and corn production, eastern Ontario, Canada. Soil Till. Res., 78: 151-170.

Larson, W.E. and F.J. Pierce, 1991. Conservation and Enhancement of Soil Quality. pp: 175-203. In: J. Dumanski, E. Pushprajah, M. Latham and R. Myers (Eds.), Evaluation for Sustainable Land Management in the Developing World, Vol. 2, Technical Papers; Proc. Int. Workshop, Chiang Rai, Thailand 15-20 Sept. 1991. Int. Board for Soil Res. and Management, Bankok.

Liebig, M.A., J.W. Doran and J.C. Gardner, 1996. Evaluation of a field test kit for measuring selected soil quality indicators. Agron. J., 88: 683-686.

Liebig, M.A., D.L. Tanaka and B.J. Wienhold, 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. Soil Till. Res., 78: 131-141.

Manley, J.T., G.E. Schuman, J.D. Reeder and R.H. Hart, 1995. Rangeland soil carbon and nitrogen responses to grazing. J. Soil Water Conserv., 50: 294-298.

Masciandaro, G. and B. Ceccanti, 1999. Assessing soil quality in different agro-ecosystems through biochemical and chemico-structural properties of humic substances. Soil Till. Res., 51: 129-137.

Romig, D.E., M.J. Garlynd and R.F. Harris, 1996. Farmer-based assessment of soil quality and health, In: Doran, J.W. and A.J. Jones (Eds.), Methods for assessing soil quality. SSSA J Spec. Publ. 49, SSSA, Inc. Madison, WI., pp: 39-60.

Sarrantonio, M., J.W. Doran, M.A. Liebig and J.J. Halvorson, 1996. On-farm Assessment of Soil Quality and Health, In: Doran, J.W. and A.J. Jones (Eds.), Methods for Assessing Soil Quality. SSSA Spec Publ. 49, SSSA, Inc. Madison, WI., pp: 83-105.

Sharma, P., R.P. Tripathi, S. Singh and R. Kumar, 2004. Effect of tillage on soil physical properties and crop performance under rice-wheat system. J. Indian Soc. Soil. Sci., 52: 12-16.

Sharma, P., R.P. Tripathi and S. Singh, 2005. Tillage effects on soil physical properties and performance of rice-wheat cropping system under shallow water table conditions of Tarai, Northern India. Europ. J. Agron., 23: 327-335.

Shepherd, T.G., 2000. Visual soil assessment, Vol. 1. Field guide for cropping and pastoral grazing on Flat to Rolling Country, horizons, mw/Landcare Research, Palmerston North, New Zealand.

Sojka, R.E., D.R. Upchurch and N.E. Borlaug, 2003. Quality soil management or soil quality management: Performance versus semantics. Adv. Agron., 79: 1-68.

Tebrűgge, F. and R.A. Dűring, 1999. Reducing tillage intensity-a review of results from a long-term study in Germany. Soil Till. Res., 53: 15-28.

Tripathi, R.P., H.S. Kushwaha and R.K. Mishra, 1986. Irrigation requirement of rice under shallow water table conditions. Agric. Water Manage., 12: 127-136.

Tripathi, R.P., 1992a. Physical Properties and Tillage of Rice Soils in Rice-wheat System, pp: 53-67. In: Pandey, R.K., B.S. Diwivedi, A.K. Sharma, (Eds.), Proceedings of the Workshop on Rice-Wheat Cropping System, October 15-16, 1990. Project Directorate for Cropping System Research, Modipuram, Meerut, India, pp: 277.

Tripathi, R.P., 1992b. Irrigation timing for wheat based on climate, crop and soil data. J. Irrig. Drain. Div. ASCE, 118: 370-381.

Tripathi, R.P., 1997. Shallow water tables-a potential source of sub-irrigation to crops. J Indian Water Resour. Soc., 17: 42-45.

Tripathi, R.P., M.K. Gaur and M.S. Rawat, 2003. Puddling effects on soil physical properties and rice performance under shallow water table conditions of Tarai. J. Indian Soc. Soil Sci., 51: 118-124.

Tripathi, R.P., P. Sharma and S. Singh, 2005. Tilth index: An approach to optimize tillage in rice-wheat system. Soil Till. Res., 80: 125-137.

Walter, G., M.M. Wander and G.A. Bollero, 1997. A farmer-centered approach to developing information for soil resources management: The Illinoise soil quality initiative. Am. J. Altern. Agric., 12: 64-72.

Wander, M.M. and G.A. Bollero, 1999. Soil quality assessment of tillage impacts in Illinois. Soil Sci. Soc. Am. J., 63: 961-971.

Wang, Z., A.C. Chang, WuL. and D. Crowley, 2003. Assessing the soil quality of long-term reclaimed waste water irrigated cropland. Geoderma, 14: 261-278.