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Long-term effects of organics, fertilizers and cropping systems on soil physical productivity evaluated using a single value index (NLWR)

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Abstract

Effect of different cropping systems, viz. maize–wheat (M–W), rice–wheat (R–W), soybean–wheat (S–W), and perennial grasses (guinea grass and setaria grass), in vogue since 6–32 years, and long-term use of chemical fertilizers (N, NP, NPK and NPK + lime) and organic materials (FYM, wheat straw, lantana biomass) on physical productivity of medium-textured (silt loam and silty clay loams) soils was investigated using non-limiting water range (NLWR) as the soil physical index. Higher the NLWR better is the soil physical condition for crop growth. The sources of N, P and K were urea, single superphosphate and muriate of potash, respectively. The NLWR was highest in S–W (16.8%), followed by grasses (14.4–15.6%) and M–W (13.1–15.4%), and lowest in R–W (7.5–11.0%). Under M–W system (32 years), NLWR was highest in NPK (13.1%), followed by NP (12.2%), NPK + lime (9.4%) and control (9.0%), and lowest in N (7.7%). Application of organics increased the NLWR in both M–W and R–W (6–18 years) systems; the NLWR values with and without organics were 18.0 and 17.1% in M–W, and 14.1–15.9 and 15.7–17.2% in R–W system. The NLWR was linearly, significantly and positively correlated with wheat grain yield ($r = 0.646^{**}$, -0.706^{**}). The NLWR:PAWC (plant available water capacity) ratio (higher the ratio, better is the soil physical condition), which was 0.58 in control, decreased with N (0.49) but increased with NP (0.72) and NPK application (0.77); use of organics further improved the ratio. The NLWR:PAWC ratio was highest in S–W (0.97), followed by grasses (0.88–0.91), M–W (0.77–0.86) and R–W (0.54–0.68) system. Thus, long-term use of urea alone deteriorated, while NPK at recommended rates improved soil physical productivity over the control of no fertilizer application; the effect further improved when NPK were combined with organic sources. Among different cropping systems, the soil physical productivity followed the order: S–W > grasses > M–W > R–W system.
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Keywords: Cropping system; Manures and fertilizers; Non-limiting water range; Physical productivity; Plant available water capacity

1. Introduction

Decline in factor productivity has put sustainability of agricultural production systems at stake. Deterioration in natural resources, mainly soil and water, in both qualitative and quantitative terms, due to unscientific management practices is largely responsible for it. Increasing demographic pressures for food and fiber have necessitated research in soil quality of which soil productivity is a vital component. Assessment of soil productivity is thus essential to determine soil quality and sustainability of production system.

Soil physical productivity (soil physical properties in relation to crop yields) may be assessed in broadly two ways: one, by establishing quantitative relationships between commonly measured soil physical properties

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and crop yields, and two, by using single-value soil physical indices. Measurement of few selected physical properties may not serve the purpose of physical characterization of soils with respect to crop performance because of wide spatial and temporal variability in soil physical properties, their strong interdependence, and variable response of crop cultivars and phenological stages to soil physical properties. The use of a single value soil physical index may avoid these constraints provided that the physical index incorporates all or most of the critical measurable sources of stress that the soil imposes on growing plants. The non-limiting water range (NLWR) is such an index, introduced by Letey (1985), which can be effectively used for characterizing soils for their physical productivity (da Silva et al., 1994; Topp et al., 1994; da Silva and Kay, 1997a,b; Carter et al., 1999; Sharma and Bhushan, 2001; Benjamin et al., 2003).

Soil physical productivity is significantly affected by cropping systems and management practices, including tillage and organic residue management (Sharma et al., 1995; Sharma and Acharya, 2000; Bhushan and Sharma, 2002, 2005). It has been observed that continuous use of chemical fertilizers in imbalanced form deteriorates soil physical properties (Biswas et al., 1971; Prasad et al., 1983). Detrimental effects of chemical fertilizers even in balanced form on soil physical properties are also being observed. For example, decline in soil organic carbon and associated decline in system productivity under rice–wheat system with the long-term use of recommended NPK was observed in some field studies (Nambiar, 1994; Abroal et al., 2000; Yadav et al., 2000). The widespread stagnation and occasional decline is rice–wheat productivity over the last about three decades have become a matter of serious concern, as rice–wheat is the major cropping system in south Asia, feeding more than 400 million people world-over (Ladha et al., 2003). Decline in soil physical productivity, among several other factors, is being considered responsible for it.

Land use pattern also has a significant effect on soil physical properties (Sharma and Aggarwal, 1984). The cropping systems that provide maximum ground cover, add organic litter to soils and require minimum soil disturbance through tillage and intercultural operations are expected to maintain good soil structure and productivity, and vice versa.

The objective of the present study was to investigate long-term effects of different cropping systems, and use of chemical fertilizers with and without organic manures on soil physical productivity, using NLWR as a single value soil physical index. Long-term field experiments under four cropping systems, viz. maize (*Zea mays* L.)–wheat (*Triticum aestivum* Linn. Emend. Fiori & Poal), rice (*Oryza sativa* L.)–wheat, soybean (*Glycin max* L.)–wheat, and perennial grasses, viz. guinea grass (*Panicum maxium* Jacq.) and setaria grass (*Setaria italica* L.) were selected for study. These are some of the most common cropping systems followed in north-western Himalayan region.

2. Materials and methods

2.1. Experimental site

The present investigation was carried out in different on-going long-term experiments under different cropping systems (perennial grasses, soybean–wheat, maize–wheat and rice–wheat) at the experimental farm of Himachal Pradesh Agricultural University, Palampur (32°6′N, 76°3′E, 1290 m above mean sea level). The area represents the high rainfall mid-hill wet-temperate zone of North-West Himalayas. The mean annual rainfall (1974–2005) around Palampur is about 2.312 ± 618 mm, with the wettest months being June to September. The annual mean maximum and mean minimum temperatures are about 23.2 ± 0.8 and 13.4 ± 0.5 °C, respectively. The mean monthly rainfall, evaporation and air temperatures at Palampur (HP) for the period 1974–2005 are illustrated graphically in Fig. 1. The experimental soils were silty loam to silty clay loam in texture and classified as Typic Hapludalf (Verma, 1979) as per the taxonomic system of soil classification (Soil Survey Staff, 1975). The soils in the region owe their origin to the fluvio-glacial parent material developed from rocks like slate, phyllites, quartzites, schists and gneisses. The soils are acidic in reaction (pH 5.2–6.2).

2.2. Treatments

Some treatments with and/or without organics in different on-going long-term field experiments under different cropping systems at the university farm were selected (Table 1) for assessing soil physical productivity using a single value soil physical index, called the non-limiting water range (NLWR) (Letey, 1985). All field experiments were arranged in randomized complete block design.

2.3. Non-limiting water range (NLWR)

The NLWR was computed as the difference between the soil moisture content at which the air-filled porosity (f_a) was 10% and the moisture content at which the soil

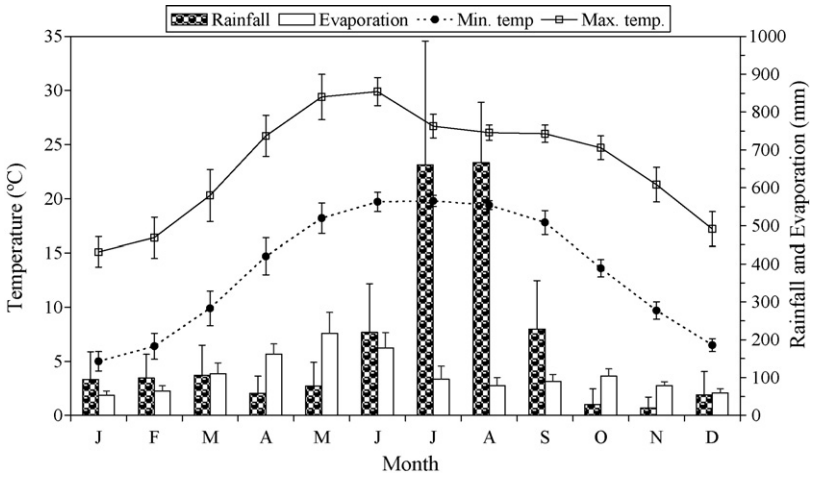

Fig. 1. Mean monthly rainfall, PAN-evaporation and air temperatures at experimental site (1974–2004) (bars indicate standard deviation).

penetration resistance (SPR) was 2 MPa at 0.15–0.18 m soil depth. The value of 2 MPa SPR was used based on previous studies (da Silva et al., 1994; Sharma and Bhushan, 2001). At this SPR, the root mass density of wheat was reduced to about half. The f_a and SPR were determined simultaneously and frequently at regular intervals, starting immediately after rainfall, by using the procedures as described below. The measurements, however, were not linked with the crop stage.

2.4. Air-filled porosity

The air-filled porosity (f_a) was determined at 0.15–0.18 m soil depth at frequent intervals starting after a heavy rainfall during the *rabi* season. Air-filled porosity was determined using the following equation (Hillel, 1980):

$$f_a = f - \theta$$

Table 1
Fertilizer treatments under different cropping systems

Cropping system	Duration (years)	Treatments	Remarks
Maize–wheat	32	Control 100% N 100% NP 100% NPK 100% NPK + FYM 100% NPK + lime	Recommended doses of fertilizers (N:P:K) in kg ha^{-1} 1. Wheat—120:26:25 2. Maize—120:26:33 3. Rice—90:26:33 4. Soybean—20:26:33
Maize–wheat	13	100% NPK	5. Grasses—80:26:25
Soybean–wheat	18	100% NPK	Sources
Rice–wheat	18	100% NK 100% NK + lantana	Nitrogen: urea Phosphorus: single super phosphate
Rice–wheat	14	Control 100% NPK 50% NPK + FYM 50% NPK + wheat straw	Potassium: muriate of potash
Rice–wheat	6	100% NPK 100% NPK + lantana	
Rice–wheat	6	100% NPK 75% N 100% PK + 25% N (lantana)	
Guinea grass	7	100% NPK	
Setaria grass	6	100% NPK	

where f_a, f and θ refer to air-filled porosity (%), total porosity (%) and volumetric water content (%), respectively. Volumetric water content was obtained by multiplying gravimetric moisture content with the bulk density of soil layer. Bulk density was determined by collecting soil cores at 0.15–0.18 m depth, using 0.03 m long and 0.054 m internal diameter metal cores. These cores were also used to determine soil water retention. For determining gravimetric moisture content, soil samples were taken with the help of a tube auger. Air-filled porosity was plotted against time as well as moisture content to determine the time of arrival and moisture content at 10% air-filled porosity.

2.5. Soil penetration resistance (SPR)

The SPR was determined as a function of soil moisture content at 0.15 m soil depth at frequent intervals starting after a heavy rainfall during wheat crop. A Proctor penetrometer, having 0.18 m long probe with a flat tip of 2.61×10^{-4} m^2 surface area, was used for SPR determinations (Davidson, 1965).

For determining SPR at 0.15–0.18 m soil depth, auger hole (with a tube auger) was made up to 0.15 m depth. The probe of the penetrometer was inserted into the hole and pushed down to 0.18 m depth. After recording the SPR value, soil sample from the same layer (0.15–0.18 m) was collected with the help of a tube auger for determining gravimetric moisture content, which was then converted into volumetric moisture content. The SPR versus volumetric moisture content values were plotted. The relationship was used to determine moisture content at 2 MPa SPR.

2.6. Soil–water retention

Soil cores were collected at 0.15–0.18 m depth to determine water retention at zero (saturation), −0.06, −0.10 and −1500 kPa matric potential using a pressure plate apparatus (Soil Moisture Equipment Co., Santa Barbara, USA) (Singh, 1980). The plant available water capacity (PAWC) was determined as the difference between moisture contents at −10 and −1500 kPa matric potentials. Water retention data at saturation and −0.06 kPa was used to determine water transmission pores (>50 μm) using the capillary rise equation.

2.7. The NLWR:PAWC ratio

The NLWR:PAWC ratio was computed to determine the departure of NLWR from PAWC, the classical concept of soil water availability to plants. The NLWR was also correlated with wheat grain yield.

2.8. Statistical analysis

The data for air-filled porosity, soil penetration resistance, NLWR, PAWC and NLWR:PAWC were subjected to standard ANOVA of randomized block design (Gomez and Gomez, 1984) and the means of the treatments were tested for significant differences at L.S.D. = 5% using the IRRISTAT data analysis package.

3. Results and discussion

3.1. Air-filled porosity

Air-filled porosity at 0.15–0.18 m soil depth as a function of soil moisture content under maize–wheat cropping system is shown in Fig. 2. Air-filled porosity at any given moisture content was lowest in N, control and NPK + lime, followed by NP and NPK, and highest in NPK + FYM. The volumetric soil moisture content at 10% air-filled porosity was 35.4–35.9% in N, control and NPK + lime, 37.1–37.5% in NP and NPK, and 39.2% in NPK + FYM treatments.

Air-filled porosity as a function of time after saturation is shown in Fig. 3. The 10% air-filled porosity was reached in about 14, 12, 11, 9, 8 and 5 days after saturation in N, control, NPK + lime, NP, NPK and NPK + FYM treatments, respectively.

The effect of fertilizer and FYM on air-filled porosity was manifested through changes in bulk density and pore-size distribution of soil. The bulk density of 0.15–0.18 m soil layer was 1.33, 1.32, 1.24, 1.23, 1.20 and 1.27 Mg m^{-3}, respectively, in control, N, NP, NPK, NPK + FYM and NPK + lime treatments. The water transmission pores (>50 μm) were statistically the same in control, N and NPK + lime (18.8–21.0%), but were significantly higher by about 32, 34 and 40% with NP, NPK and NPK + FYM, respectively. Lower bulk density and higher water transmission pores favoured early arrival of 10% air-filled porosity at relatively higher moisture contents. Similar observations on air-filled porosity as a function of time and moisture content were also made under other cropping systems also to compute NLWR, but for brevity sake the data are not reported in this paper.

3.2. Soil penetration resistance (SPR)

The SPR as a function of soil moisture content at 0.15–0.18 m soil depth under maize–wheat cropping

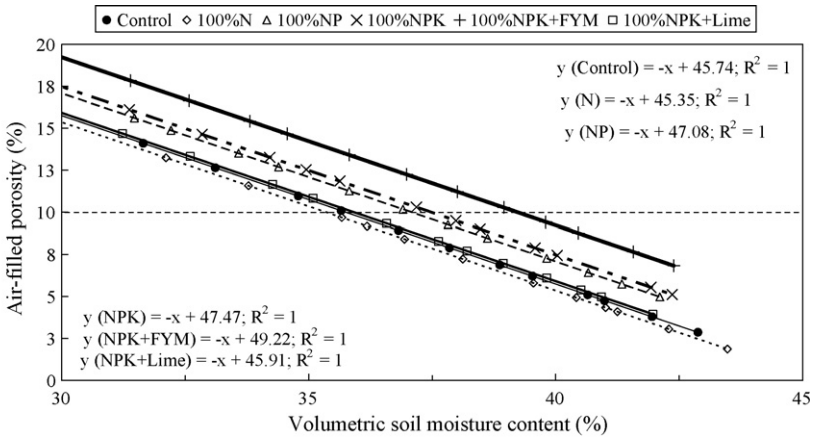

Fig. 2. Effect of chemical fertilizers and amendments on air-filled porosity in relation to soil moisture content during wheat season.

system is shown in Fig. 4. The SPR was linearly, negatively and significantly correlated with soil moisture content. The N treatment had the highest, while NPK + FYM had the lowest SPR at any given moisture content. The SPR in general followed the trend:

N > control > NPK + lime > NP > NPK > NPK + FYM.

The SPR in a given soil depends largely on moisture content and bulk density. The SPR decreases with moisture content but increases with bulk density. Thus, any treatment that decreases bulk density would decrease SPR, other factors remaining the same (Sharma and Bhushan, 2001). In the present study also, the trend in SPR followed changes in bulk density. Lowest SPR was observed in NPK + FYM treatment, where bulk density was also the lowest. Reduction in SPR due to application of balanced fertilizers and organic manures has also been reported in other studies (Obi and Ebo, 1995; Mishra and Sharma, 1997; Whitbread et al., 2000).

3.3. Non-limiting water range (NLWR)

The effect of different cropping systems, chemical fertilizers and organic amendments on NLWR, plant available water capacity (PAWC) and NLWR:PAWC ratio are shown in Tables 2–4. Higher the value of NLWR and NLWR:PAWC ratio, better is the physical productivity of soil.

3.3.1. Effect of cropping systems

The data on air-filled porosity, SPR, NLWR, PAWC and NLWR:PAWC are given in Table 2. The moisture

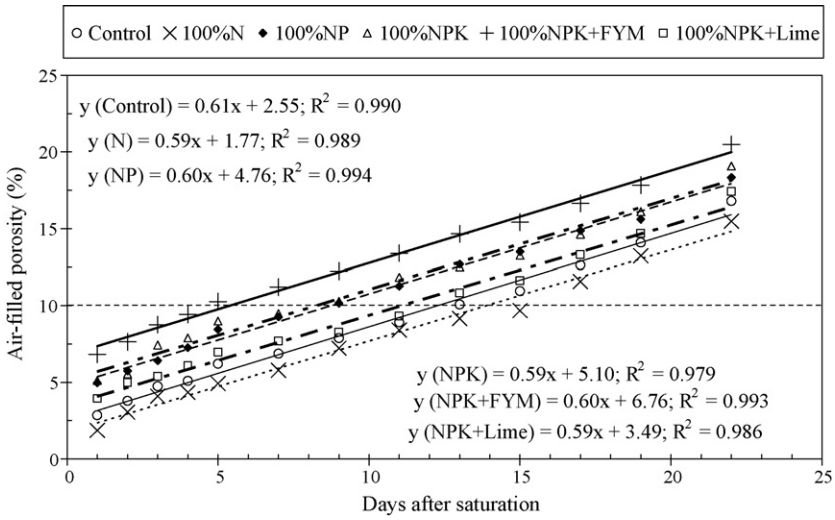

Fig. 3. Effect of chemical fertilizers and amendments on air-filled porosity of soil as function of time during wheat season.

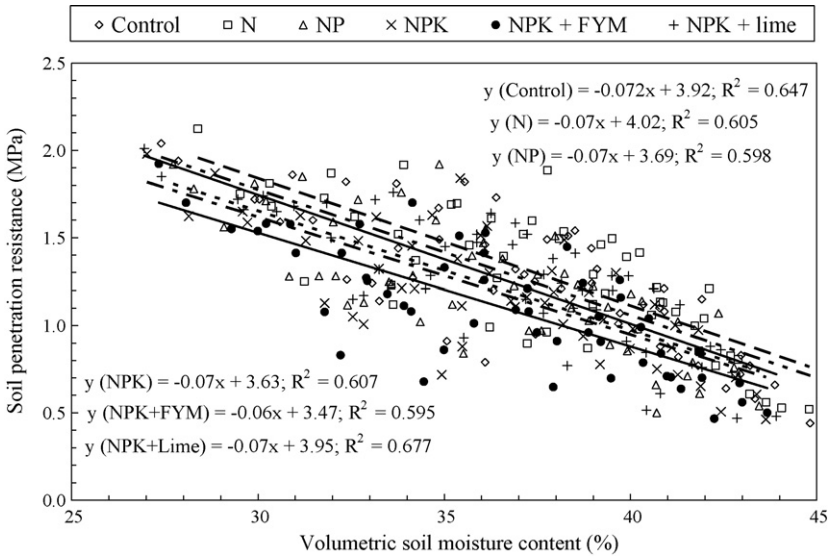

Fig. 4. Effect of chemical fertilizers and amendments on soil penetration resistance as a function of soil moisture content.

content corresponding to 10% air-filled porosity was highest in soybean–wheat (40.7%), followed by grasses (39.8–40.6%), maize–wheat (37.5–39.2%) and lowest in rice–wheat (34.6–37.4%). The moisture content corresponding to 2 MPa SPR was lowest in soybean–wheat (23.9%) and maize–wheat (23.8–24.3%), followed by grasses (25.0–25.4%), and highest in rice–wheat (26.1–27.6%). The differences were statistically significant.

The NLWR was highest in soybean–wheat (16.8%), followed by grasses (14.4–15.6%) and maize–wheat (13.1–15.4%), and lowest in rice–wheat (7.5–11.0%).

The PAWC in maize–wheat (17.1–17.9%), soybean–wheat (17.3%) and grasses (16.2–17.0%) was almost the same, but was significantly higher than rice–wheat system (14.1–16.1%).

The NLWR:PAWC ratio was highest in soybean–wheat (0.97), followed by grasses (0.89–0.92), maize–wheat (0.77–0.87), and lowest in rice–wheat (0.54–0.68). According to NLWR and NLWR:PAWC ratio, soybean–wheat supported better soil physical conditions than other cropping systems under study; the poorest soil physical conditions were observed under rice–wheat system. Soybean–wheat and grass system supported better soil physical conditions probably through regular additions of leaf biomass to soil, as organic residue additions improve soil physical properties (Sharma and Bhushan, 2001). Grass system, being a perennial system, had the additional advantage that it did not require tillage operations. The tillage operations over longer periods deteriorate soil structure by physically breaking soil aggregates and hastening the oxidation of organic matter

Table 2
Long-term effects of different cropping systems on air-filled porosity (f_a), soil penetration resistance (SPR), non-limiting water range (NLWR), plant available water capacity (PAWC) and NLWR:PAWC ratio

Cropping system	Duration (years)	θ (%, $m^3\ m^{-3}$)		NLWR (%)	PAWC (%)	NLWR:PAWC ratio
		10% f_a	2 MPa SPR			
Maize–wheat	32	37.5	24.3	13.1	17.1	0.77
Maize–wheat	13	39.2	23.8	15.4	17.8	0.86
Soybean–wheat	18	40.7	23.9	16.8	17.3	0.97
Rice–wheat	18	34.6	27.1	7.5	14.1	0.54
Rice–wheat	14	36.9	26.8	10.2	15.8	0.64
Rice–wheat	6	37.0	26.1	11.0	16.1	0.68
Rice–wheat	6	37.4	27.6	9.8	15.9	0.62
Guinea grass	7	39.8	25.4	14.4	16.3	0.88
Setaria grass	6	40.6	25.0	15.5	17.0	0.91
L.S.D. ($P = 0.05$)	–	1.3	0.9	1.3	0.7	0.08

Note: Each data set from 100% NPK treatment.

Table 3
Long-term effects of chemical fertilizers on air-filled porosity (f_a), soil penetration resistance (SPR), non-limiting water range (NLWR), plant available water capacity (PAWC) and NLWR:PAWC ratio under maize–wheat and rice–wheat cropping systems

Cropping system	Treatments	θ (%, $m^3\ m^{-3}$)		NLWR (%)	PAWC (%)	NLWR:PAWC ratio
		10% f_a	2 MPa SPR			
Maize–wheat (32 years duration)	Control[a]	35.7	26.7	9.0	15.6	0.58
	100% N	35.4	27.7	7.7	15.7	0.49
	100% NP	37.1	24.9	12.2	16.9	0.72
	100% NPK	37.5	24.3	13.1	17.1	0.77
	100% NPK + lime	35.9	26.5	9.4	16.2	0.58
Rice–wheat (14 years duration)	Control[a]	34.1	27.9	6.2	14.0	0.44
	100% NPK	36.9	26.8	10.2	15.8	0.64
L.S.D. ($P = 0.05$)	–	1.0	0.9	1.4	0.8	0.09

Note: NPK were applied at recommended rates through urea, single super phosphate and muriate of potash (Table 1).
[a] No fertilizer applied.

from soils. Rice–wheat system exhibited poor soil physical productivity due to destruction of soil aggregates caused by puddling for rice (Sharma and De Datta, 1986).

3.3.2. Effect of chemical fertilizers

The data on the influence of chemical fertilizers on air-filled porosity, NLWR, PAWC and NLWR:PAWC ratio under maize–wheat and rice–wheat cropping systems are presented in Table 3.

The moisture content at 10% air-filled porosity under maize–wheat system was statistically the same (35.4–35.9%) with control, N and NPK + lime, but was significantly lower than with NP and NPK treatments (37.1–37.5%). The moisture content at 2 MPa SPR was lowest in NPK (24.3%) and highest in N (27.7%). Similarly, in the rice–wheat system, the moisture content in NPK corresponding to 10% air-filled porosity was higher (36.9%) and corresponding to 2 MPa SPR was lower (26.8%) than control with corresponding values of 34.1 and 27.9%, respectively.

The NLWR ranged between 7.7% (N) and 13.1% (NPK) in the maize–wheat system. The NLWR, compared to control, was lower in treatment with N, same with NPK + lime, and higher with NP and NPK. The application of NP and NPK increased NLWR by about 1.35 and 1.45 times, respectively, over the control. Under rice–wheat system, the NLWR with NPK increased by about 1.6 times over the control (6.2%).

The PAWC varied between 15.3% in control and 17.0% in NPK treatment under maize–wheat cropping sequence. The control, N and NPK + lime were at par with each other with values of 15.3, 15.9 and 16.0%,

Table 4
Effect of continuous application of chemical fertilizers and organics on air-filled porosity (f_a), soil penetration resistance (SPR), non-limiting water range (NLWR), plant available water capacity (PAWC) and NLWR:PAWC ratio under maize–wheat and rice–wheat cropping systems

Cropping system	Duration (years)	Treatments	θ (%, $m^3\ m^{-3}$)		NLWR (%)	PAWC (%)	NLWR:PAWC ratio
			10% f_a	2 MPa SPR			
Maize–wheat	32	100% NPK	37.5	24.3	13.1	17.1	0.77
		100% NPK + FYM	39.2	22.7	16.5	18.0	0.92
Rice–wheat	18	100% NK	34.6	27.1	7.5	14.1	0.54
		100% NK + lantana	37.1	24.3	12.7	15.7	0.82
Rice–wheat	14	100% NPK	36.9	26.8	10.2	15.8	0.64
		50% NPK + FYM	38.0	25.0	13.1	17.2	0.76
		50% NPK + wheat straw	37.2	25.8	11.4	16.2	0.70
Rice–wheat	6	100% NPK	37.4	27.6	9.8	15.9	0.62
		75% N 100% PK + 25% N through lantana	38.3	26.4	11.9	17.2	0.69
L.S.D. ($P = 0.05$)	–	–	1.3	0.8	1.4	1.0	0.12

Note: NPK were applied at recommended rates through urea, single super phosphate and muriate of potash (Table 1).

respectively, while PAWC was significantly higher in NPK treatment. Under rice–wheat system, the NPK increased the PAWC from 14.0% in control to 15.8%.

The NLWR:PAWC ratio in maize–wheat system was the lowest in N (0.48), followed by control and NPK + lime (each 0.59), NP (0.72) and NPK (0.77) treatments. This ratio in control was at par with NPK + lime; NP and NPK were also statistically at par with each other. Under rice–wheat system also the recommended dose of NPK increased the NLWR:PAWC ratio to 0.64 in comparison with 0.44 in the control treatment.

According to these data, applications of chemical fertilizers (NPK) at the recommended rate did not have negative impact on soil physical conditions; they rather improved soil physical productivity over the control i.e. cultivation without fertilizer application, and over the imbalanced use of chemical fertilizers (N or NP). Chemical fertilizers at recommended rates produced higher crop biomass, including the root biomass, than other treatments. The total productivity (grains + straw) of maize–wheat system (2004–05) was 8.72, 0.00, 14.75 and 20.29 Mg ha^{-1}, respectively. It left more organic matter in the form of root biomass in soil, which resulted into improved soil physical productivity.

3.3.3. Effect of organic amendments

The effects of application of organics along with chemical fertilizers on air-filled porosity, NLWR, PAWC and NLWR:PAWC ratio under maize–wheat and rice–wheat cropping system are presented in Table 4.

Application of organics increased the moisture content at 10% air-filled porosity and decreased the moisture content corresponding to 2 MPa SPR either significantly or numerically, and thus increased the NLWR in both maize–wheat and rice–wheat systems. Under maize–wheat system, the NLWR in NPK + FYM was about 1.3 times higher than in NPK. Similarly, under rice–wheat system the NLWR increased by about 1.2–1.7 times in different experiments. Application of organics increased the PAWC and NLWR:PWAC ratio in both maize–wheat and rice–wheat systems.

The beneficial effect of organic residue additions on soil physical properties have amply been reported in literature (Sharma and Acharya, 2000; Sharma and Bhushan, 2001, 2003; Bhushan and Sharma, 2005). The build up in soil organic carbon significantly improves soil structure and hydraulic properties. Consequently, NLWR also improves. da Silva and Kay (1997a) also observed a positive correlation of NLWR with soil organic carbon content and a negative correlation with soil bulk density.

3.4. Relationship between NLWR and wheat yield

The NLWR was linearly, positively and significantly correlated with grain yield of wheat under maize–wheat cropping (Fig. 5).

It has been observed that the soil management practices, which result in an increased NLWR, can maximize the potential of a soil for crop production (da Silva and Kay, 1997b; Sharma and Bhushan, 2001; Benjamin et al., 2003). The NLWR considers only the physical properties. In the present study, however, chemical properties also varied significantly under different treatments. The correlation coefficient, otherwise, would have been still higher. In N-treated plots the grain yield was zero. In these plots the extremely acidic conditions (pH 4.4) resulted in aluminum toxicity and therefore the effect of chemical fertility on grain yield was dominated when compared with physical fertility. In NPK + lime the yields were comparable to NPK + FYM even though the NLWR was relatively low. This might be due to improvement in soil chemical conditions and higher nutrient availability due to increase in pH (6.5). Moreover, the soil moisture contents during critical phenological stages of crop remained well above the critical SPR of 2 MPa.

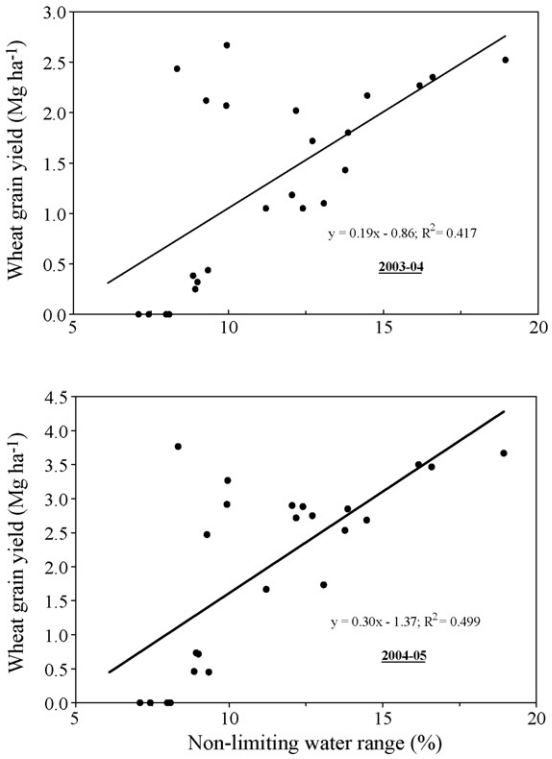

Fig. 5. Relationship between non-limiting water range and wheat grain yield.

4. Conclusions

Soil physical productivity, as assessed by NLWR, was significantly affected by cropping systems, and long-term use of chemical fertilizers and organic materials. Continuous use of recommended NPK as urea, single superphosphate and muriate of potash did not deteriorate soil physical productivity; rather improved it over the control treatment in which no fertilizer was applied. Imbalanced use of chemical fertilizers (N or NP) impacted on soil physical productivity depending on the type of fertilizers used. The continuous use of urea alone (N) significantly decreased NLWR over control, while a combination of urea (N) and single superphosphate (P) showed a significant improvement in NLWR. Application of organic materials along with chemical fertilizers further improved soil physical productivity. Soybean–wheat had better soil physical conditions, followed by grasses, maize–wheat and rice–wheat cropping systems. Positive correlation with crop yield proved sensitivity of NLWR as a soil physical index. Further experimentation, however, is needed to establish critical values of NLWR in relation to crop yields. The studies also suggest that NLWR is a better index for field water management than the classical method of PAWC. Therefore, irrigation scheduling may be based on NLWR rather than PAWC concept. The NLWR:PAWC ratio may be used to numerically assess the extent of decline in soil physical productivity.

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