Effects of sodicity induced changes in soil physical properties on paddy root growth

P.K. Srivastava, M. Gupta, A. Pandey, V. Pandey, N. Singh, S.K. Tewari

CSIR-National Botanical Research Institute, Rana Pratap Marg, Lucknow, India

ABSTRACT

A study was conducted to investigate the influence of sodicity induced changes in soil physical properties on paddy root growth in the normal agriculture, semi-reclaimed and sodic soils. The root growth (length, length density, biomass and distribution pattern) were unfavourably affected by the soil physical properties (bulk density, soil aggregate stability, available water content, hydraulic conductivity and soil water retention potential) in the case of sodic soil. The microbial biomass carbon, bacterial, fungal population and dehydrogenase activity showed the lower values in the case of sodosol compared to the normal soil. These soil biological properties tend to sustain paddy root growth in normal and semi-reclaimed soils. Principal component analysis revealed that soil physical properties accounted for 98.2% of total variance in root growth. The study revealed that salt stress induces changes in soil physical properties limiting paddy root growth in the salt affected soils. It is important to reclaim sodosols to alleviate salt induced physical stress for optimum paddy root growth.

Keywords: below-ground biomass; bulk density; sodic soil; *Oryza sativa* L.

Plants require a root system that delivers adequate water and nutrients for maintaining crop yields and to anchor them in the soil for proper growth (Gewin 2010). Root growth in soil is related to physical, chemical and biological properties of the soil. The physical properties of soil affect root growth such as texture (Dexter 2004), moisture content (Laclau et al. 2001), bulk density and penetration resistance (Lipiec and Hatano 2003). Rice is the most important staple food crop in India occupying maximum area under cultivation and contributing nearly to 44% of the total food grain production and provides 43% calorie requirement for more than 70% Indians (Shetty et al. 2013). Globally, rice is cultivated now in 160 million ha with annual production of about 650 million tonnes of rough rice and average productivity of 4.18 t/ha of rough rice (Shetty et al. 2013). The food grain production in India grew on average by 1.4%, which did not match with the food demand of the fast growing population in India during 1990–2010. As per an estimate, about 1.3 million ha area is affected by the salt stress in the Indo-Gangetic alluvial plains of Northern India, which can be reclaimed to provide additional cultivable area for supporting higher production of staple crop like rice. This study investigated the effects of soil physical properties on the growth of paddy roots in sodic, semi-reclaimed and normal agriculture soil. It was postulated that salt stress was likely linked to adverse changes in the soil physical properties influencing paddy root growth.

MATERIAL AND METHODS

A field experiment was conducted with rice (*Oryza sativa* L.) crop during 2011–2012 at three different sites. Site 1 (S_1) was located at the CSIR-National Botanical Research Institute (NBRI), Lucknow, India (80°59'E, 26°55'N; 132 m a.s.l.). Sites 2 (S_2) and 3 (S_3) were situated at a field research station of CSIR – NBRI (80°45' to 80°53'E and 26°40' to 26°45'N; 129 m a.s.l.). The soil of site 1 was clay loam with soil pH 7.8 as a normal agriculture soil. The soil of site 2 was silty clay loam with moderate alkalinity (pH 8.5) as the semi reclaimed sodic soil. Site 2 was reclaimed during 2000 according to the method described earlier by Srivastava et al. (2011). The soil of site 3 was silt clay loam and highly sodic (pH 10.0) with carbonate and bicarbonate of sodium as the dominant anions. The maximum and minimum temperatures ranged from 40°C to 27°C during summers and from 20°C to 8°C during winters. The experiment was established in a randomised complete block design with four replications. The size of individual plot was 6.75 m^2. Seedlings (30 days old) of rice (*Oryza sativa* L. var. Varadhan IET 18940) were transplanted in experimental beds in the first week of July 2011. The seedlings were transplanted at a row spacing of 20 cm with 7 rows across each bed. After 120 days of paddy seedling plantation, root growth measurements were made in carefully harvested plants for root length (cm), root length density (cm/cm^3), specific root length (cm/mg) root diameter (mm) and root dry biomass (g). The measurements for root surface area (cm^2) and root depth distribution (m^2 roots/m^2 soil).

Soil samples were collected at the time of paddy crop harvest. These soil samples were analyzed for different physico-chemical and biological properties. The soil pH, electrical conductivity, cation exchange capacity, exchangeable sodium percentage, bulk density, particle density, porosity (%), water holding capacity were determined according to the methods described by Black (1965). The soil texture was analysed by the hydrometer method of Bouyoucous (1927) and soil aggregate stability was measured by the turbidimetric method (Akhter et al. 1994). The saturated hydraulic conductivity (K_s) was measured by the constant head method of Klute and Dirksen (1986). The soil water content was determined gravimetrically and plant available water (AW) was calculated as the difference between the water contents at 0.03 MPa (field capacity) and at 1.5 MPa (permanent wilting point) by the method of Akhter et al. (2004). The microbial biomass C (MBC), dehydrogenase enzyme (DHA) and bacterial, fungal population was estimated according to the method described earlier by Dick (2011). The results were statistically analyzed for ANOVA using SPSS 10.0 (Chicago, USA).

RESULTS AND DISCUSSION

Results of the study revealed significant ($P < 0.05$) differences among the soil physical properties (Table 1). The lowest values of soil bulk density and porosity were found in the case of sodic soil (S_3) and their highest values were observed in the case of normal agriculture soil (S_1). Overall, soil physical properties were found minimum in the S_3 and maximum in the S_1. The lowest value of saturated hydraulic conductivity (1 mm/day) and available water content (0.15 kg/kg) were observed in the S_3. The soil water retention potential was found lowest 0.21 kg/kg in the S_3 and highest 0.41 kg/kg in the S_1. The MBC was 328.29, 225.7 and 158.9 μg/g in the S_1, S_2 and S_3, respectively. The bacterial and fungal populations were also found lowest in the S_3 and highest in the S_1. Likewise, the DHA was found minimum in the S_3 and maximum in the S_1.

Results indicate that root growth was significantly influenced by the differences in soil physical properties of the three different soils. The root growth of paddy was significantly different among all three soils (Table 2). There was a significant ($P < 0.05$) reduction in root length and root length density in the S_3 and S_2 compared to the S_1. The maximum significant ($P < 0.05$) decrease in root length (34%) and root length density (32%) were observed in the S_3 vis-a-vis the S_1. The root biomass and root diameter were decreased by 69% and 46% in the S_3, respectively. The reduction in root distribution was observed by 56% and 34% in the S_3 when compared with the S_2 and $S_{1,}$ respectively. The PCA (Figure 1) biplot of different soil physical properties influencing root growth in the three soils explained 98.16% of the total variance, which confirms the negative effect of adverse soil physical properties on root growth.

The study revealed a significant reduction in root growth of *Oryza sativa* L. under unfavourable soil physical properties induced by salt stress. The accumulation of excessive sodium ions in sodic soil causes numerous adverse phenomena, such as increase in exchangeable and soluble ions, pH, destabilized structure, unfavourable soil bulk density, and deterioration of soil hydraulic conductivity (Qadir and Schuburt 2002). Soil became compacted due to high bulk density and retarded the development of root due to less space available for proliferation and hampered ability of roots to penetrate in deep soil layers (Whalley et al. 2005). Beulter and Centurion (2004) reported that root length and root distribution of corn, wheat and pearl millet were adversely affected by the soil compaction. Compaction influences soil strength, aeration and water flow, creating interrelated stress which may act simultaneously to influence root

Table 1. Physico-chemical and biological properties of different soil types

Soil properties	Soil type		
	normal soil	semi-reclaimed soil	sodic soil
pH	7.8^a ± 0.06	8.4^b ± 0.08	10.1^c ± 0.06
EC (µS/cm)	154.6^a ± 1.8	287.5^b ± 1.0	718.9^c ± 0.8
ESP (%)	2.90^a ± 1.8	16.6^b ± 1.2	65.0^c ± 1.4
CEC (cmol$_+$/kg)	1.5^a ± 0.06	11.3^b ± 0.03	18.7^c ± 0.05
SAR (%)	1.32^a ± 0.05	5.89^b ± 0.09	55.6^c ± 0.07
Bulk density (g/cc)	0.98^c ± 0.05	1.42^b ± 0.09	1.85^a ± 1.1
Particle density (g/cc)	2.64^c ± 0.02	2.53^b ± 0.01	1.62^a ± 0.06
Porosity (%)	57.09^c ± 1.0	43.78^b ± 1.2	18.28^a ± 1.6
Sand (%)	41^c ± 2.0	36^b ± 1.0	30^a ± 2.0
Silt (%)	30^c ± 3.0	28^b ± 2.0	26^a ± 1.0
Clay (%)	30^c ± 1.0	36^b ± 1.0	44^a ± 3.0
Water holding capacity (%)	44.7^c ± 0.05	34.5^b ± 0.02	25.1^a ± 0.04
Hydraulic conductivity (mm/day)	7.5^c ± 1.1	5.0^b ± 1.8	1.0^a ± 1.4
Soil water retention potential (kg/kg)	0.415^c ± 1.2	0.312^b ± 1.0	0.210^b ± 1.9
Available water content (kg/kg)	0.305^c ± 1.1	0.248^a ± 0.09	0.150^a ± 0.9
MBC (µg/g)	328.9^c ± 11.8	225.6^b ± 10.9	158.9^a ± 11.0
Bacterial population (CFU × 10^5)	23.0^c ± 1.0	20.3^b ± 1.2	8.2^a ± 1.5
Fungal population (CFU × 10^5)	18.0^c ± 1.3	15.0^b ± 1.1	4.5^a ± 0.6
Dehydrogenase enzyme (µg TPF/g soil/24 h)	1.5^b ± 0.07	0.8^b ± 0.09	0.3^a ± 0.04

Mean ± SE values not marked with the same letter in superscript are significantly different at $P < 0.05$ (DMRT). EC – electrical conductivity; ESP – exchangeable sodium percentage; CEC – cation exchange capacity; SAR – sodium adsorption ratio; MBC – microbial biomass carbon; TPF – triphenylformazan

growth and root distribution adversely (Tracy et al. 2011). Higher soil bulk density promotes the dispersion of clay particles which might contribute to breakdown of soil structure by compressing and breaking of soil aggregates, which are necessary for good air and water movement and for better

Table 2. Effect of different soil types on root growth properties of paddy crop

Root parameters	Soil type		
	normal soil	semi-reclaimed soil	sodic soil
Root length (cm)	18.6^c ± 3.9	14.56^b ± 2.3	11.86^a ± 1.9
Root length density (cm roots/cm^3 soil)	31.4^c ± 6.5	24.8^b ± 3.4	18.7^a ± 2.3
Specific root length (cm/mg)	4.6^c ± 2.4	3.3^b ± 1.9	1.8^a ± 1.1
Root diameter (mm)	6.33^c ± 0.5	5.46^b ± 1.0	3.49^a ± 2.4
Root biomass (g)	6.96^c ± 2.6	5.78^b ± 1.0	4.49^a ± 1.2
Root surface area (cm^2)	21.6^c ± 2.5	17.8^b ± 3.0	14.5^a ± 3.4
Root depth distribution (m^2 roots/m^2 soil)	1.15^c ± 0.09	0.92^b ± 0.09	0.52^a ± 0.09

Mean ± SE values not marked with the same letter in superscript are significantly different at $P < 0.05$ (DMRT)

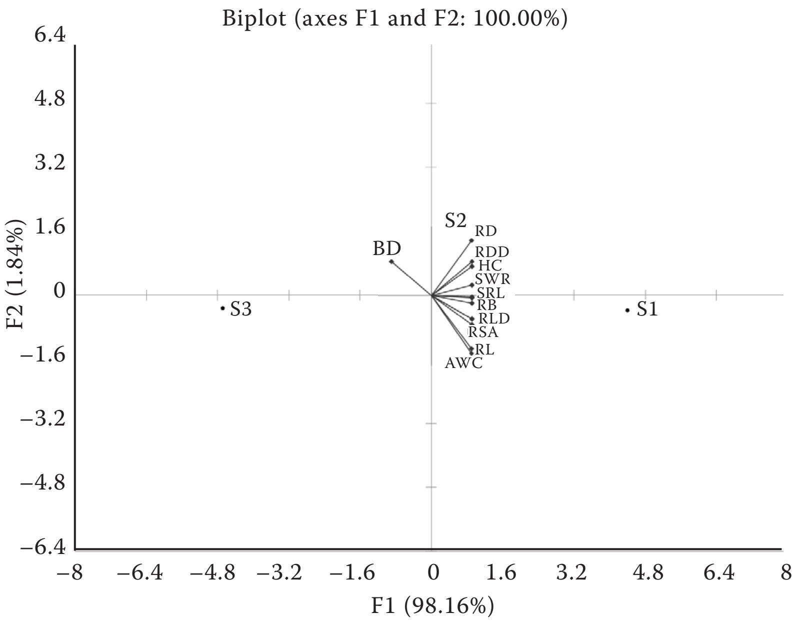

Figure1. Principal component analysis of different physical soil properties influencing root growth parameters in different soil types. BD – bulk density; RD – root density; RDD – root depth distribution; HC – hydraulic conductance; SWR – soil water retention; SRL – specific root length; RB – root biomass; RLD – root length density; RSA – root surface area; RL – root length; AWC – available water content

root growth (García-Orenes et al. 2005). These soil properties may limit root growth due to the insufficient oxygen diffusion to the root tip and supply of too little water for root growth (as the matric potential is too negative; and compaction of the soil is too hard for roots to penetrate rapidly). These are the main reason for limited root growth and development in clay sodosol. Excessive exchangeable sodium and high pH favour swelling and dispersion of clay particles as well as slaking of soil aggregates and decrease in soil permeability or water infiltration rate (Qadir and Schubert 2002). Increase in soil bulk density affects other soil physical properties, like porosity, aeration, hydraulic conductivity and water infiltration rate, and thereby impact the soil micro-biological activity adversely. In sodic soil, microbial activity and soil MBC content were found low with an increase in salt contents and decrease in soil organic carbon. The unfavourable soil physical properties limit biochemical processes in soil, which are important to plant essential nutrient bioavailability in soil (De Neve and Hofman 2000) and considered as sensitive indicators of soil quality. Similar findings were observed in the present study. The microbial biomass carbon, bacterial, fungal population and dehydrogenase activity showed the lower values in the case of sodosol compared to the normal soil. These soil biological properties tend to sustain paddy root growth in normal and semi-reclaimed soils. In the case of S_1, soil organic matter rendered availability of substrates for microbial growth and the dehydrogenase activity which were therefore high along with MBC (Pathak and Rao 1998). It is concluded that salt stress induced soil physical properties cause reduction in paddy root growth. Therefore, it is important to reclaim sodic soils for optimum paddy cultivation as revealed in the study.

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Corresponding author:

Dr. Pankaj Kumar Srivastava, CSIR-National Botanical Research Institute, Rana Pratap Marg, 226 001 Lucknow, India
phone: + 91 522 2297 939, fax: + 91 522 2205 836, e-mail: drpankajk@gmail.com