Field Crops Research 166 (2014) 1–9

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Influence of phosphorus and biofertilizers on soybean and wheat root growth and properties

Dibakar Mahanta [a,b,*], Raj K. Rai [a], Shiva Dhar Mishra [a], Arunkumar Raja [b], Tapan J. Purakayastha [a], Eldho Varghese [c]

[a] Indian Agricultural Research Institute, New Delhi – 110 012, India
[b] Vivekananda Institute of Hill Agriculture (ICAR), Almora – 263 601, Uttarakhand, India
[c] Indian Agricultural Statistical Research Institute, New Delhi – 110 012, India

ARTICLE INFO

Article history:
Received 15 April 2014
Received in revised form 8 June 2014
Accepted 9 June 2014
Available online 26 June 2014

Keywords:
Phosphorus inflow rate
Root cation exchange capacity
Root length density
Soybean
VAM
Wheat

ABSTRACT

Alteration of crop root morphology is a new innovative approach to provide food security. Phosphorus is the most important nutrient to influence root properties. Efficient use of P fertilizers has become an important issue of agriculture all over the world due to limited availability of rock phosphate and its non-renewable nature. Hence, root properties and grain yield of soybean–wheat cropping system were evaluated by inoculation of phosphate solubilizing bacteria (PSB) and vesicular arbuscular microorganism (VAM) with 50% recommended P (0.5 P + PSB + VAM) against 100% P (1.0 P), 50% P and control in a Typic Ustochrepts of the Indo-Gangetic plains. The root cation exchange capacity (CEC) of soybean and wheat treated with 0.5 P + PSB + VAM were 3.6 and 4.6% higher than 1.0 P, respectively. The same treatment produced 2.3 and 2.6% higher root length density (RLD) in soybean and wheat, respectively in comparison to 1.0 P. The P inflow rate under 0.5 P + PSB + VAM was 9.2 and 4.6% higher than 1.0 P in soybean and wheat, respectively indicating higher acquisition of P through VAM, although higher rhizospheric P availability was recorded in 1.0 P. The root CEC, RLD and P inflow rate were closely related to P concentration and content in root, shoot and nodule, specific root length, root diameter and internal P requirement. The better root property observed in 0.5 P + PSB + VAM enhanced 4.1 and 4.9% grain yield of soybean and wheat, respectively as compared to 1.0 P. Inoculation of PSB and VAM could substitute 50% P of soybean–wheat cropping system with better root property and higher grain yield in semi-arid sub tropics of the Indo-Gangetic plains.

1. Introduction

Phosphorus (P) may be present in relatively large amounts, but much of it is poorly available because of the very low solubility (Smith et al., 2011) and fixation of soluble P. It is generally accepted that the mechanism of mineral phosphate solubilization by PSB strains is associated with the release of low molecular weight organic acids, which through their hydroxyl and carboxyl groups chelate the cations bound to phosphate, thereby converting it into soluble forms (Chen et al., 2006; Panhwar et al., 2011). Further vesicular arbuscular mycorrhizas (VAM) grow extensively in soil to form a well-developed hyphal network that absorbs inorganic phosphate several centimeters away from the root surface. P is translocated rapidly to the roots overcoming the slow diffusion that occurs in the soil solution. The individual fungal hyphae have much smaller diameters than roots, allowing access to narrower soil pores and hence increasing the soil volume explored and providing a larger surface area for absorption (Smith et al., 2011). VAM are also able to take P from soil solution with low phosphate concentration, where simple roots have difficulties in tapping the ions (Bolan, 1991). VAM-inducible plant PiT genes are expressed exclusively in the colonized cortical cells, which are involved in the uptake of Pi released. Additionally, H^+-ATPases energize the plant plasma membrane surrounding the intracellular fungal structures, facilitating active Pi uptake (Smith et al., 2011). The high effectivity of VAM in phosphorus uptake is not only caused by their small diameter and large surface area, but also the accumulation of polyphosphates in their vacuoles where it serves storage functions and in terms of energy as an alternative to ATP. Polyphosphates are

* Corresponding author at: Vivekananda Institute of Hill Agriculture (ICAR), Almora – 263 601, Uttarakhand, India. Tel.: +91 5962 241005; fax: +91 5962 241250.
E-mail addresses: dibakar_mahanta@yahoo.co (D. Mahanta), r.k.raiiari@gmail.com (R.K. Rai), drsdmisra@gmail.com (S.D. Mishra), agri_arun@rediffmail.com (A. Raja), tpurakayastha@gmail.com (T.J. Purakayastha), eldhoiasri@gmail.com (E. Varghese).

http://dx.doi.org/10.1016/j.fcr.2014.06.016
0378-4290/

presumably also involved in transport of phosphate in the hyphae to the infected root where it is hydrolyzed in the arbuscules and most likely transported as inorganic phosphate across the plasma membrane of the host root cell. Polyphosphates are strongly negative polyanions and also serve important functions in the cation/anion balance of the fungus, and by binding cations such as magnesium, potassium and basic amino acids such as arginine and glutamine also as carriers for hyphal transport of these solutes to the host root cell. The solute transport in the hyphae, other mineral elements and the plasma streaming are the driving force for this transport (Marschner, 1997).

Phosphate solubilizing bacteria (PSB) and vesicular arbuscular microorganisms (VAM) are reported to improve phosphorus nutrients of crop plants (Vance et al., 2003; Yan et al., 2004). However, there is a paucity of information on the individual as well as combined role of PSB and VAM on root morphology, P inflow rate, root cation exchange capacity and internal phosphorus requirement with single superphosphate in soybean and wheat. Again, root studies are undertaken less compared to shoot studies, because root sample acquisition and analysis are tedious and time consuming (Zoon and Van Tienderen, 1990). Additionally, root mass, which is easier to measure than total root length, surface area and diameter has been used to compare root systems (Murphy and Smucker, 1995), but root mass measurements are not indicative of the total absorptive area of the root system and alteration of root morphology can happen without a change in total root biomass (Iman et al., 2006). Plants can dramatically alter their root architecture to optimize growth in a large variety of soil nutrient conditions (Den Herder et al., 2010).

The objective of the study was to investigate the individual as well as combined effects of PSB and VAM along with 50% single superphosphate on root morphology, P inflow rate, root cation exchange capacity and internal P requirement, and yield of soybean and wheat. The hypothesis of the study was that inoculation of PSB and VAM would improve root characteristics and substitute substantial amount of P fertilizer without sacrificing grain yield through better acquisition.

2. Materials and methods

The experimental site was situated in Indian Agricultural Research Institute (IARI), New Delhi, India (latitude: 28° 38′ N, longitude: 77° 09′ E and altitude: 229 m above mean sea level). It has a semiarid, subtropical climate with hot dry summers and cold winters. The mean maximum temperature during the hottest month of July is about 38.9 °C, while the mean minimum temperature in the coldest month of January is as low as 6.3 °C. The annual average temperature is 24.3 °C. The normal onset period of monsoon is in the third week of June. The mean annual rainfall is 614 mm, three-fourth of which is received during July–September and the remaining one-fourth between October and June. The soil of the farm belongs to order Inceptisol, Mahauli series. The soil is sandy loam in texture, well levelled, deep percolating and well drained, hypothermic family of the Typic Ustochrept (old alluvium). The soil was having the following characteristics in 0–15 cm depth: pH 8.36 (1:2.5 soil:water suspension), easily oxidizable ($K_2Cr_2O_7 + H_2SO_4$) organic C 5.8 g kg^{-1}, alkaline $KMnO_4$ oxidizable N 66.7 mg kg^{-1}, 0.5 M $NaHCO_3$ extractable P 6.2 mg kg^{-1} and 1.0 N NH_4OAc exchangeable K 62.6 mg kg^{-1} soil.

The experiment was conducted for two years, which included two crops per year, soybean (July–October) and wheat (November–April) with seven phosphorus (P) management practices, viz, 1.0 P {recommended dose of P (RDP) through single superphosphate}, phosphate solubilizing bacteria (PSB) + Vesicular arbuscular mycorrhiza (VAM), 0.5 P (half the RDP), 0.5 P + PSB, 0.5 P + VAM, 0.5 P + PSB + VAM, and control (without P). The RDP for soybean and wheat were 34.9 and 26.2 kg P ha^{-1}, respectively, which were applied through single superphosphate (6.99% water-soluble P). The inoculum species used for PSB and VAM were *Pseudomonas striata* and *Glomus fasciculatum*, respectively and were obtained from the Division of Microbiology, IARI, New Delhi. The PSB was inoculated at the rate of 500 g carrier ha^{-1} and the population count was 100,000,000 cells g^{-1} of the carrier. VAM was applied as 5 kg carrier (soil) ha^{-1} and the spore count was 30 spores g^{-1} carrier. Single superphosphate was applied as per the requirement of treatment. *Bradyrhizobium japonicum* inoculant was common for all the treatments in soybean. The recommended doses of N (30 kg N ha^{-1} for soybean and 120 kg N ha^{-1} for wheat) and K (33.2 kg ha^{-1} for both soybean and wheat) were applied uniformly to all the plots. Fertilizers used were urea (46% N) for N and muriate of potash (KCl-50% K) for K. The treatments were distributed in a randomized block design with three replications in a fixed plot of size 5 m × 4.5 m.

Soybean genotype "PK 1042" and wheat genotype "HD 2643" were used as seed for experimentation and were released by GBPUAT, Pantnagar and IARI, New Delhi, respectively. These two genotypes are released for commercial cultivation in North Plain zone of India, where the experiment was conducted at IARI, New Delhi is situated. Soybean was sown (80 kg seeds ha^{-1}) in the third week of July each year. The seeds were manually sown in rows 45 cm apart at a depth of about 5 cm. After seeding, a light roller was dragged to cover the seeds. Full doses of N, P and K were incorporated before sowing. Hand weeding was also done to manage the weeds and plant protection measures were applied as needed to control the diseases and pests. Crops were harvested manually 5 cm above the ground at physiological maturity in the second week of October using sickles. After soybean harvest, wheat was sown in the third and fourth week of November in the first and second year, respectively. Wheat was sown by hand (100 kg seeds ha^{-1}) in rows 22.5 cm apart to a depth of about 5 cm. Hand weeding was also done to manage the weeds. Wheat was harvested at 5 cm above the soil surface in the fourth week of April and straw was removed from the plots. Both the crops were cultivated under irrigated conditions.

2.1. Root studies

Root studies with respect to root length and root diameter were carried out during both the years in two stages i.e. at 40 and 80 days after sowing (DAS) for soybean and 45 and 90 DAS for wheat crop. These days were chosen for crops, because the second sampling coincided with flowering stage of respective crops and by that time maximum growth of roots had taken place. After the harvest of above ground plant parts, root samples were collected using root sampling core (15 cm height, 8 cm diameter). Five root sampling cores were used in each plot on each sampling date. The sampling tube was centered over the plant and a sample was taken to a 15 cm depth. These cores were immersed in water to disperse the soil. The roots were obtained by gradually loosening the soil. The remaining soil adhered to roots were washed properly by putting roots on the container with sieves of several mesh sizes to prevent loss of fine roots during washing, following the method of Costa et al. (2000). Each sample was placed in a plastic, sealable bag. Roots were immediately taken to the laboratory and kept in the refrigerator set at 4 °C till analysis. Then these root samples were dried in oven at 70 °C until constant weight and the dry weight was recorded.

2.1.1. Root length and average diameter

Root length and average diameter were measured using a Hewelett Packard scanner controlled by Win-RHIZO Programme V.