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SHORT COMMUNICATION

Root Phenotyping of Two Soybean (*Glycine max* L.) Cultivars in a Vertisol of Central India

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Abstract The root system architecture (RSA) is a highly plastic trait and in evitable for plant growth because of its role in water and nutrient acquisition. Soybean, an important economic leguminous crop of India, but its RSA is largely unknown. The RSA of two popular soybean cultivars grown in central India viz., JS-335 and JS-9560 was investigated to compare their root phenotype in a clay soil under laboratory condition. It has been observed that root length, root surface area and root volume of JS-9560 were significantly higher than that of JS-355; whereas root diameter of JS-9560 was significantly lower compared to JS-335. Further, in JS-9560, number of nodes, primary roots, secondary roots, length of primary roots and secondary roots were 17, 8, 20, 24 and 16% higher than JS-335. Primary and secondary root insertion angle was observed to be 33 and 11% narrower in JS-9560 than in JS-335. Based on the findings, JS-9560 showed superior RSA over JS-335 and thus, the cultivar may be consider for further physiological and molecular studies for its adaptability to moisture stress condition.

Keywords Soybean · Root phenotypes · RSA · Drought tolerant traits

The first 'green revolution' has significantly impacted agricultural practices in many parts of the world. But now, the research is increasingly pointing towards "root system architecture (RSA)" as the key factor for improvement in productivity of the future crops [1]. The plant root plays important role in supplying water and nutrient to the crops. The RSA, the spatial configuration of a root system in soil, is a fundamental component of plant productivity and varies among and within crop species, subjects to genotype and environment interaction [2]. It determines the capacity for a plant to search for, and acquire, resources in the dynamic and variable soil environments [3]. Furthermore, increased drought and changes in climate will also increase stress on crops and hence cultivars need to adapt themselves in sustaining yields under changing climatic scenarios. Much of this adaptation is anticipated to the below ground parts, since they are the sites of soil–plant interactions [4].

A typical RSA has several aspects: root typology, topology, geometry of root elements and their spatial distribution in soils [5]. A range of root architectural traits have been linked to plant performances in specific environment [4]. Root length and surface area play an important role in the uptake of both immobile and mobile soil resources [6], whereas rooting depth has an important role in reducing nitrogen losses through leaching and improving drought tolerance [7]. Ge et al. [8] demonstrated that root angle and the resulting orientation of the root system greatly influenced the phosphorous uptake, while Hammer et al. [9] showed that changes in RSA had a direct effect on exploitation of soil water, which consequently affects the cereal yield and biomass. Roots of different orders such as primary and secondary roots play important role in absorbing (radially) and transporting (longitudinally) water and nutrients [10]. Therefore to understand crop root basic functions such as water and nutrient extraction, it is needed to understand the root architectural patterns of different crops and their cultivars. In India, a few studies have been conducted to analyze root system in terms of root length density and its relationship with water-nutrient uptake in

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soybean [11, 12], but very scarce information is available on root architectural parameters such as root diameter, root surface area, root angle, primary and secondary root etc. of crops. Hence, the study was undertaken to characterize RSA of two contrasting soybean cultivars i.e. JS-335 and JS-9560 with a view to identify their rooting traits in vertisol under laboratory condition.

The current inability to measure root architecture under field conditions is a major impediment to root studies [13]. Therefore, a twenty-day laboratory study was conducted in acrylic tube of size 25 cm height and 5 cm diameter with six replicates per cultivar (Figs. 1, 2). The soil used to pack the tubes was collected from the research farm of ICAR-Indian Institute of Soil Science, Bhopal and has the following characteristics: clay 52%, silt 30%, sand 18%; pH 7.8, cation exchange capacity 49 cmol (p+) kg^{-1}, organic carbon 4.9 g kg^{-1}, inorganic nitrogen 22 mg kg^{-1} and available phosphorous 4 mg kg^{-1}. Before packing into the tube, the soil was air dried and sieved to <2 mm. Individual pre germinated seeds were planted 30 mm deep in tube. Each tube was secured at the base with perforated cover, to allow free drainage and air entry. Cylinder walls were covered with black plastic to exclude light. Plants were grown under controlled conditions in the laboratory at a mean temperature of 26 °C with a 12 h illumination. After twenty-days, the soil was carefully removed from the cylinders using 10% sodium hexa meta-phosphate solution and gently washed away from the root system with a fine jet of water. The whole root system of each plant was preserved in a solution of 40% methanol, 5% formaldehyde and 5% glacial acetic acid. Length and number of individual root axes and laterals i.e. primary and secondary root length, root nodes and root angles were measured using scale and protractor; whereas root

Fig. 1 Soybean crop growth in acrylic tube

surface area, root volume, root diameter was measured using Delta-T imaging system. Root penetration rate was calculated by root main axis length divided by total number of days of experiment. For calculating the root biomass, fresh roots were placed in drying oven at 65–70 °C until they attained a constant weight.

The RSA study revealed that phenotypical characteristics such as root length, root surface area and root volume of JS-9560 were significantly higher than JS-355; whereas root diameter of JS-9560 was significantly lower than JS-335 (Table 1 and Figs. 1, 2). Total root length, surface area and volume are known to influence the kinetics of water and nutrient uptake [14], whereas fineness of the root system i.e. root diameter—one of the most important input parameters for rhizospheric modelling-influences net ion influx into roots [15]. Therefore higher root length, surface area, volume and finer root diameter indicated that JS-9560 is a more efficient cultivar compared to JS-335 in terms of better acquisition of water and nutrients. Fitter [16] suggested that thinner root diameter increases water and nutrients uptake in plants. Comparing two cultivars of soybean, it has been observed that lateral root branching parameters such as number of nodes, primary roots, secondary roots, length of primary roots and secondary roots were significantly (17, 8, 20, 24 and 16%, respectively) higher in JG-9560 compared to JS-335 (Figs. 3, 4). Fenta et al. [13] suggested that a soybean cultivar with higher lateral branching density is more suitable for drought prone area. Hence, by virtue of higher root branching density, JS-9560 may be considered to grow in moisture deficit condition. Root biomass of crop cultivar is an important architectural characteristic to assess the overall plant health. A crop/cultivar investing higher biomass in their roots could be healthier than others. In this study, JS-9560 had significantly 23% greater root biomass than JS 335, suggesting robustness of JS 9560 under the studied condition (Table 1). Saxena et al. [17] and Krishnamurthy et al. [18] identified several chickpea genotypes with drought tolerance through increased root biomass. Herrera et al. [19] reviewed genotypic variation in root traits and found higher correlation among root biomass, drought tolerance and nutrient uptake. Sheshshayee et al. [20] have also identified root biomass one of the most relevant trait for drought tolerance and productivity.

The knowledge of the root angle spread at an early growth stage can be useful to predict the root distribution and root biomass of mature plants [21]. Between the two cultivars compared, 33 and 11% narrower primary and secondary root insertion angles were observed in JS-9560 compared to JS-335 (Table 1). The root angle influences the relative exploration of shallow and deep soil domains [22]. Manschadi et al [23] reported

Table 1 Comparison of various root architectural parameters of soybean cultivars

	Root length (mm)	Root biomass (mg)	Mean diameter (mm)	Equivalent surface area# (mm^2)	Equivalent volume# (mm^3)	Primary root insertion angle$ (degree)	Secondary root insertion angle$ (degree)	Rooting depth (cm) after 20 days	Root penetration rate (cm/day)
JS-335	2362.81 (1.25)	34.50 (1.50)	0.79 (0.03)	3446.95 (64.76)	476.12 (62.23)	60	50	20.6 (0.91)	1.0 (0.01)
JS-9560	2664.62 (10.92)	45 (2.00)	0.67 (0.02)	4499.31 (98.29)	775.34 (24.68)	45	45	22.1 (0.90)	1.11 (0.03)
Significant level	$^{**}p = 0.0013$	$^{**}p = 0.045$	$^{*}p = 0.036$	$^{*}p = 0.012$	$^{*}p = 0.046$	–	–	$^{**}p = 0.001$	$^{**}p = 0.004$

Significance level was determined using ANOVA ($^{**}p < 0.01$, $^{*}p < 0.05$) and difference between treatment means was determined using the LS means Student's *t* test

Value in parentheses () indicate standard error

Assuming perfectly cylindrical geometry of all roots

$ Root angle represented as mode

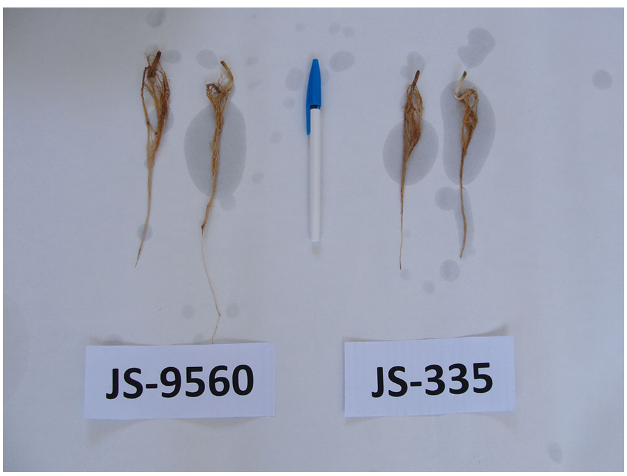

Fig. 2 Root system of two soybean cultivars

narrower root angle of wheat cultivar promotes water use efficiency compared to wider root angle. The vertically oriented roots of wheat crop cultivar were able to extract significantly more water from deeper soil layers by increasing their root length, and thus potentially increasing the amount of accessible soil water when the water availability in the upper soil layers was limited [24]. In the present investigation, narrow root angle of cultivar JS-9560, with higher rooting depth and root penetration rate (Table 1 and Figs. 1, 2), indicated higher capabilities of the cultivar to extract soil water from the deeper layers of soil. Lynch, [25] also suggested that deep soil foraging is important for the acquisition of water and nitrate.

From this investigation, it may be concluded that JS-9560 exhibited a better RSA over JS-335. The rooting behaviors of JS-9560 suggested some favorable traits that

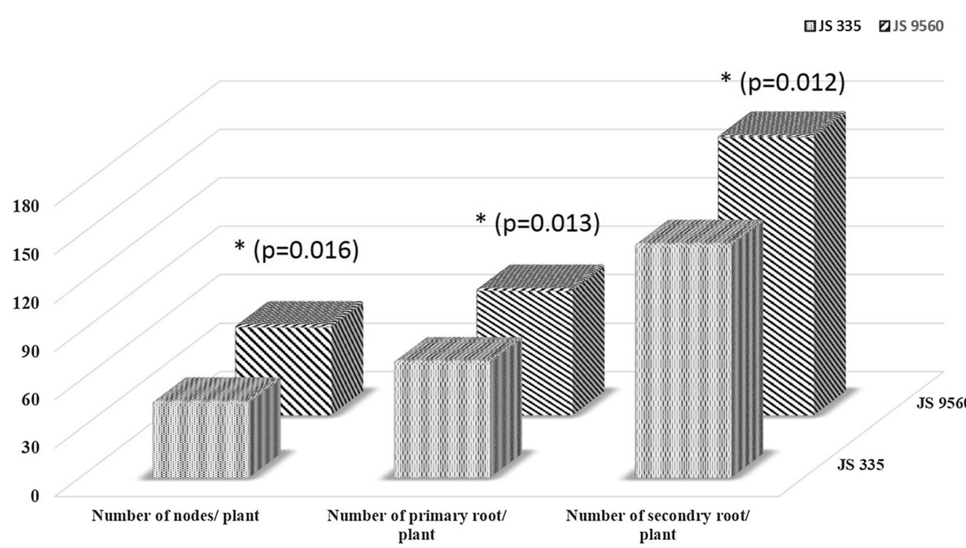

Fig. 3 Comparison of number of nodes, primary roots and secondary roots of soybean cultivars (significance level was determined using ANOVA ($^{**}p < 0.01$, $^{*}p < 0.05$) and difference between treatment means was determined using the LS means student's *t* test)

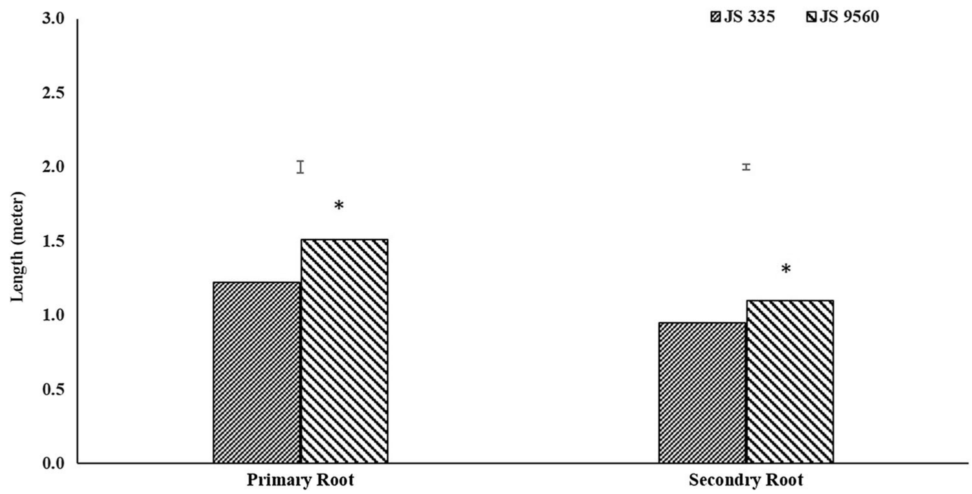

Fig. 4 Comparison of length of primary and secondary roots of soybean cultivars (significance level was determined using ANOVA (*$p < 0.05$) and difference between treatment means was determined using the LS means student's *t* test); error bar indicates the actual *p* value

can be adapted under water stress situation. However other physiological and molecular characteristics related to water stress in plant could be correlated with the rooting behavior of JS-9560 to consider it for drought situation.

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