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Grain Yield in Mungbean (*Vigna radiata*) is Associated with Spatial Distribution of Root Dry Weight and Volume

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ABSTRACT

Root system is an important plant organ affecting yield and the degree of influence of roots on yield in different spatial locations in the soil is different. The aim of this study was to research the spatial distribution characteristics of mung bean root and to analyze the correlation between spatial distribution of root and yield. The roots of mung bean in 0-5, 5-10, 10-15, 15-20 and 20-25 cm horizontal soil layers and in 0-20, 20-40, 40-60, 60-80 and 80-100 cm vertical soil layers were collected to analyze spatial distribution characteristics of root volume and root dry weight at full flowering stage and full pod stage. Yield and yield components were measured at maturity. Our study showed that approximately 48.4%~65.2% of the mung bean root were in 0-5 cm horizontal soil layer and about 73.2%~82.3% were in 0-20 cm vertical soil layer. Yield of mung bean exhibited significantly positive correlation with number of pods per plant. The root volume density of mung bean in 20-25 cm horizontal soil layer at full flowering stage exhibited significantly positive correlation with yield. These findings could be used to provide scientific basis for cultivating high-yield mung bean varieties with excellent root system.

Key words: Correlation, Mung bean, Root dry weight density, Root volume density, Spatial distribution.

INTRODUCTION

Legumes are second only to the Graminiae in their importance to humans (Graham and Vance, 2003). Grain and forage legumes account for 27% of the world's primary crop production, with grain legumes alone contributing 33% of the dietary protein nitrogen (N) needs of humans (Vance *et al*., 2000). Legumes can grow in arid and N-deficient soils, acting as pioneers for soil stabilization and fertility and preventing soil erosion and desertification (Mahmoud *et al*., 2019). Mung bean is one of the most ancient and extensively grown legumes with the characteristics of short-term growth, strong nitrogen fixation ability and barren tolerance (Muthu *et al*., 2018; Patil *et al*., 2011). The root of mung bean is tap root system, which contain nodule having the N_2-fixing bacteria Rhizobium spp. (Khan *et al*., 2016). It is deep rooted, much branched just like the roots of black eye (Itefa, 2016).

The relationship between crop yield and root has been studied extensively across different crops under different screening environments. Ehdaie *et al*. (2012) reported that yield of bread wheat showed positive correlation with shallow and deep root dry weight under terminal drought. The study of Kanbar *et al*. (2009) revealed that root dry weight had the largest effect on grain yield of rice under well-watered condition. Izumi *et al*. (2004) showed that root length per unit area exhibited significantly positive correlation with yield in wheat but not in soybean. Kashiwagi *et al*. (2006) reported that root length density at 35 days after sowing showed a significant positive correlation with yield of chickpea in field trials.

The distribution of root system is related to crop yield, but the key spatial location in the soil of root system affecting yield is not clear. Various workers have studied the correlation between crop root indicator and yield, but there are only few reports on the effect of mung bean root distribution on yield (Khurana and Khurana, 2014). We hypothesized that root of mung bean at different spatial locations in the soil had different effects on yield. Therefore, the objectives of this study were to estimate spatial distribution of root system of mung bean and to compute the correlation of yield with root distribution.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at outdoor test site in National Coarse Cereals Engineering Research Center, Daqing, China on June 5, 2016.

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Experimental devices

There were two kinds of devices: horizontal device and vertical device (Fig 1). The horizontal device was a cylindrical metal barrel with a diameter of 50 cm and a height of 50 cm, which was fixed with a cross steel frame with a length of 54 cm on both sides of the metal barrel. The inside of the metal barrel was equipped with a diameter of 10 cm, 20 cm, 30 cm and 40 cm of metal net. The distance between the metal net was 5 cm and the metal net was fixed on the cross steel frame by nylon straps (Fig 2). The vertical device was a cylindrical plastic barrel with a diameter of 30 cm and a height of 150 cm (Fig 3). In order to facilitate sampling, inside the vertical device was a plastic water belt of 30 cm in diameter and the soil was filled in the plastic water belt (Fig 4). The lower end of the plastic water belt was sealed and four round holes were cut using scissors.

Soil characteristics

The soil obtained from fall of the previous year (2015) was used in the experiment. The soil was screened before pouring into the devices to remove grass root, tree root and large granular clods and stones and the filtered soil was

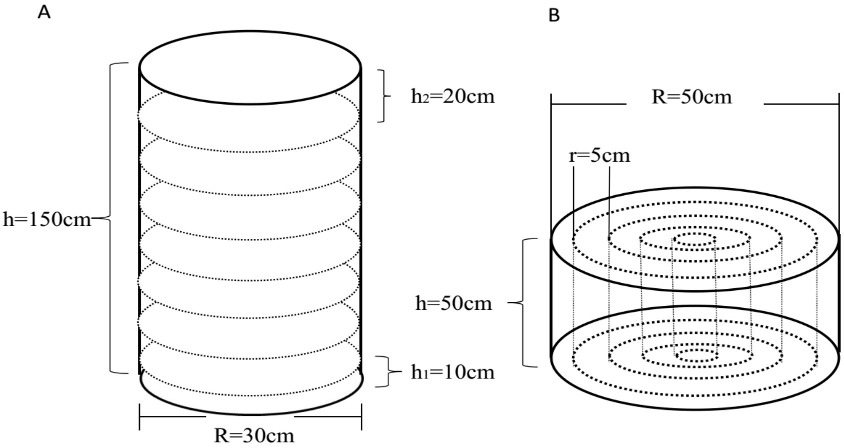

Fig 1: A: Vertical device, which was a cylindrical plastic barrel with a diameter of 30 cm and a height of 150 cm; B: Horizontal device, which was a cylindrical metal barrel with a diameter of 50 cm and a height of 50 cm.

Fig 2: Horizontal device entity.

Fig 3: Vertical device entity.

Fig 4: The plastic water belt of 30 cm in diameter inside the vertical device and the soil was filled in the plastic water belt.

mixed with sand in a 3:1 ratio. Repeated infusion of soil and water was undertaken, so that the soil became tight until soil was not sinking when water was refilled. This water and soil blend was maintained in the field environment during the winter and spring.

Experiment design, species and seeding

Mung bean cultivar Jilv7 and Gonglv2 were planted at five seeds per barrel separately in 48 barrels which included 24 horizontal devices and 24 vertical devices. Two seedlings were retained and grown with four replications per growth stage and type of device.

Root sample collection

Soil samples for root measurements were taken from the devices at full flowering stage and full pod stage. The number of pods per plant, number of seeds per pod and yield were measured at maturity. In horizontal devices, the center of the cross section of the column was taken as the starting point to obtain the mung bean root samples in the horizontal direction i.e. 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and 20-25 cm layers. In vertical devices, the upper soil surface was taken as the starting point to obtain soil samples with root in 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm soil layers in vertical direction. The plants were clipped at cotyledons by scissors before sampling. Soil samples containing root were soaked in a plastic bucket filled with water until the soil became soft and then filtered. The obtained root samples were washed with clean tap water and then placed in a plastic, sealable bag and the bag was placed in a refrigerator for further use.

Data collection

The harvested root samples were placed in a clear glass tray filled with water. The roots were washed to remove soil particles and other dirt that could hamper efficient scanning of root samples. The glass tray was placed on a scanner (Epson V700) and digital images were generated at 400 dpi. Digital image analysis of mung bean root samples was conducted using WinRHIZO (version 2014a, Reagent Instruments Inc., Quebec, Canada) and the data included root volume, from which root volume density (RVD) was estimated as follows:

$$RVD = V/V_0$$
$$V_0 = \pi r^2 h$$

Where,
V is the root volume, V_0 is the soil volume, r is the radius and h is the height.

After scanning, the roots were removed from glass tray and subsequently were placed in an oven at 105°C for 2 hours, then drying to constant weight in 75°C oven. The dry weight of roots was obtained by analytical balance and the root dry weight density (RDWD) was estimated as:

$$RDWD = M/V_0$$
$$V_0 = \pi r^2 h$$

Where,
M is the root dry weight.

Statistical analysis

Pearson Correlation Analysis was used to evaluate the relationships between different traits by SPSS 22. Figure preparation was carried out by MicroCal Origin software 2017 (OriginLab).

RESULTS AND DISCUSSION

The spatial distribution of root volume density

Root volume is an important factor in drawing up moisture and nutrients from the soil for the plants, reflecting the size of rooting systems (Fageria, 2005). In horizontal devices, mung bean had the largest root volume density in 0-5 cm horizontal soil layer. With the increase of distance from the main root, the root volume density decreased gradually. The root volume of Jilv7 in 0-5 cm horizontal soil layer were 18.4% and 21.0% of the total root volume at full flowering stage and full pod stage, respectively. And Gonglv2 had 18.1% and 29.1% of the total root volume in 0-5 cm horizontal soil layer at full flowering stage and full pod stage,

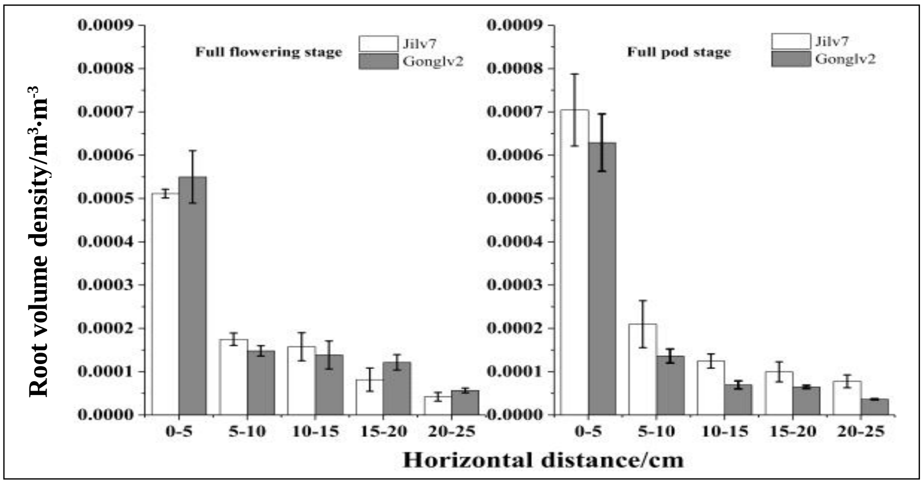

Fig 5: Changes in different horizontal soil layers of root volume density of two mung bean cultivars Jilv7 and Gonglv2 at full flowering stage and full pod stage. Bars represent standard error.

respectively. Compared with full flowering stage, the ratio of root volume in 0 - 5 cm horizontal soil layer to total root volume of both two mung beans increased at full pod stage (Fig 5).

In vertical devices, the maximum root volume density of mung beans was found in 0-20 cm vertical soil layer. 20-40 cm and 40-60 cm vertical soil layers also had a large proportion of root volume. The root volume of Jilv7 in 0-20 cm vertical soil layer were 67.5% and 60.5% of the total root volume at full flowering stage and full pod stage, respectively. For Gonglv2, 71.0% and 62.1% of total root volume were found in 0-20 cm vertical soil layer at full flowering stage and full pod stage, respectively. This agrees with Gan *et al*. (2011) who found that 59% of the total root volume of pulses were in 0-20 cm soil layer. From full flowering stage to full pod stage, the proportion of root volume in deep soil layer increased (Fig 6).

The spatial distribution of root dry weight density

Root dry weight density can be used as an indicator to express root extension and distribution (Adiku *et al*. 2001). In horizontal devices, the maximum root dry weight density of mung beans were found in 0-5 cm horizontal soil layer. 48.4% and 56.8% of total root dry weight of Jilv7 were found in 0-5 cm horizontal soil layer at full flowering stage and full pod stage, respectively. Gonglv2 had 53.7% and 65.2% of total root dry weight in 0-5 cm horizontal soil layer at full flowering stage and full pod stage, respectively. This agreed with the study of Gao *et al*. (2010) in soybean and maize. Compared to other soil layers, the root dry weight density in 20-25 cm horizontal soil layer were the minimum (Fig 7).

In vertical devices, the maximum dry weight density of mung beans were found in 0-20 cm vertical soil layer. With the increase of soil layer depth, the root dry weight density decreased gradually. In 0-20 cm vertical soil layer, 82.3% and 75.5% of total dry weight of Jilv7, 74.0% and 73.2% of total dry weight of Gonglv2 were found at full flowering stage and full pod stage, respectively. Similar results were reported by Benjamin and Nielsen (2006) in soybean. The proportion of root dry weight of two mung beans in deep soil layers at full pod stage decreased compared to full flowering stage (Fig 8).

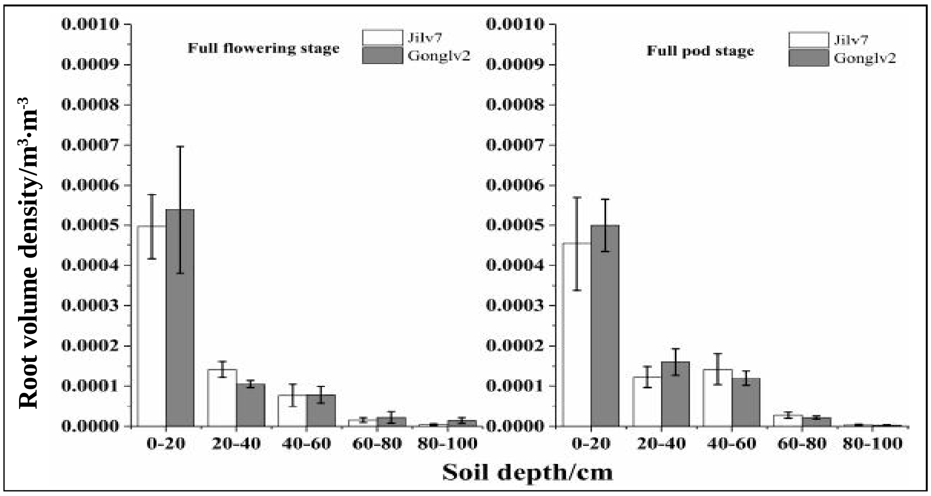

Fig 6: Changes in different vertical soil layers of root volume density of two mung bean cultivars Jilv7 and Gonglv2 at full flowering stage and full pod stage. Bars represent standard error.

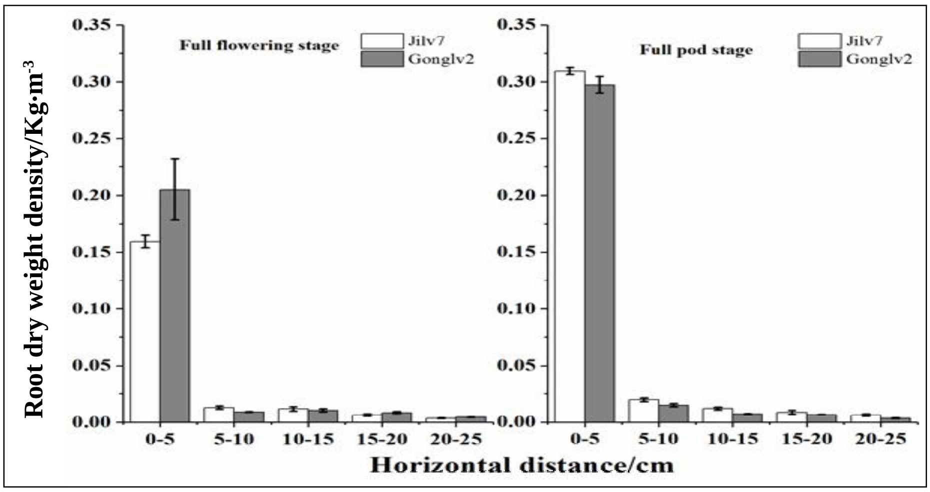

Fig 7: Changes in different horizontal soil layers of root dry weight density of two mung bean cultivars Jilv7 and Gonglv2 at full flowering stage and full pod stage. Bars represent standard error.

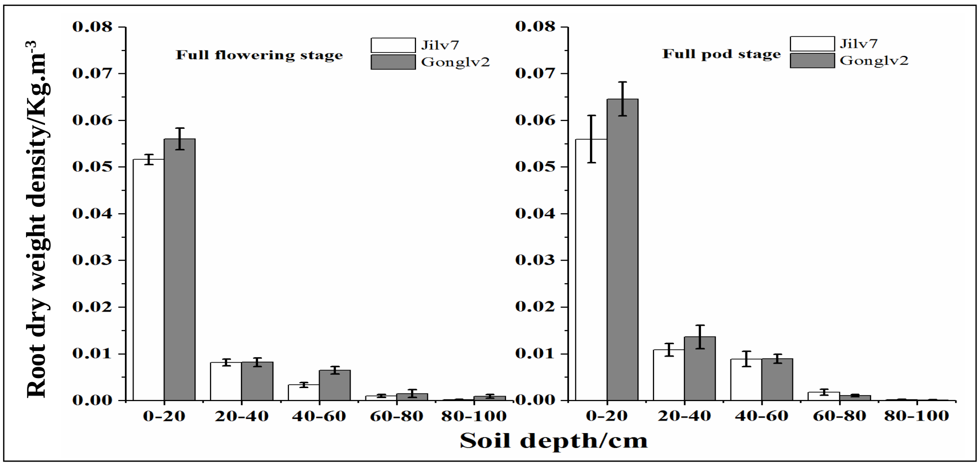

Fig 8: Changes in different vertical soil layers of root dry weight density of two mung bean cultivars Jilv7 and Gonglv2 at full flowering stage and full pod stage. Bars represent standard error.

Table 1: Correlation coefficients between yield and yield components of mung bean cultivars Jilv7 and Gonglv2.

Trait	Number of pods per plant	Number of seeds per pod	Yield
Number of pods per plant		0.399	0.964**
Number of seeds per pod	-0.589		0.268
Yield	0.871**	-0.215	

The upper right corner are correlation coefficients of Jilv7, the lower left corner are correlation coefficients of Gonglv2; * = significant at P<0.05; ** = significant at P<0.01.

Table 2: Correlation coefficients between yield and root volume density ($m^3\ m^{-3}$) and root dry weight density ($kg\cdot m^{-3}$) of mung bean cultivars Jilv7 and Gonglv2 in different horizontal soil layers at full flowering stage and full pod stage.

Cultivar	Root indicator	Growth stage	Horizontal distance(cm)				
			0-5	5-10	10-15	15-20	20-25
Jilv7	Root volume density	full flowering	0.769	0.924	0.632	0.551	0.960*
		full pod	0.850	0.116	-0.674	-0.699	0.109
	Root dry weight density	full flowering	0.144	0.670	0.661	0.938	0.024
		full pod	0.457	0.603	0.219	0.929	0.816
Gonglv2	Root volume density	full flowering	0.549	0.701	0.976*	0.815	0.982*
		full pod	-0.266	0.349	0.098	0.742	-0.359
	Root dry weight density	full flowering	-0.026	0.936	0.819	0.843	0.848
		full pod	0.616	-0.25	0.257	0.535	0.954*

*= significant at P<0.05; **= significant at P<0.01.

Table 3: Correlation coefficients between yield and root volume density ($m^3\ m^{-3}$) and root dry weight density ($kg\cdot m^{-3}$) of mung bean cultivars Jilv7 and Gonglv2 in different vertical soil layers at full flowering stage and full pod stage.

Cultivar	Root indicator	Growth stage	Soil depth(cm)				
			0-20	20-40	40-60	60-80	80-100
Jilv7	Root volume density	full flowering	-0.112	0.662	0.141	0.148	-0.164
		full pod	0.843	0.891	0.988*	0.806	0.422
	Root dry weight density	full flowering	0.634	-0.51	-0.769	-0.433	0.108
		full pod	-0.263	0.173	0.911	0.907	-0.651
Gonglv2	Root volume density	full flowering	-0.343	0.932	-0.666	-0.068	0.879
		full pod	0.948	-0.299	-0.183	0.758	-0.525
	Root dry weight density	full flowering	0.525	0.827	0.837	0.725	0.075
		full pod	0.037	0.056	0.743	0.395	0.485

* = significant at P<0.05; ** = significant at P<0.01.

Table 4: Yield and yield components of mung bean cultivars Jilv7 and Gonglv2 in vertical devices and horizontal devices.

	Horizontal devices		Vertical devices	
	Gonglv2	Jilv7	Gonglv2	Jilv7
Number of pods per plant	39.4 ± 1.8	52.2 ± 1.3	11.3 ± 0.7	13.0 ± 1.8
Number of seeds per pod	9.1 ± 0.5	10.0 ± 0.5	10.3 ± 0.6	9.9 ± 0.5
Yield (g)	22.7 ± 1.6	24.1 ± 1.1	8.8 ± 0.8	9.1 ± 1.6

Data represent average ± standard error.

The spatial distribution of mung beans' root dry weight density showed that the root dry weight density tended to decrease gradually with the deepening of the soil layer and the increasing of the distance from the taproot.

Correlations

The yield traits such as number of pods per plant, number of seeds per pod and seed yield were measured at maturity (Table 4). Yield of Jilv7 showed significantly positive correlation with the number of pods per plant (r = 0.964**) and yield of Gonglv2 also had significantly positive correlation with the number of pods per plant (r = 0.871**) (Table 1). This was same as the results of Makeen *et al*. (2007) and Tabasum *et al*. (2010). The increase in the number of pods per plant may increase the yield of mung bean.

In horizontal direction, the root volume density of Jilv7 in 20-25 cm horizontal soil layer showed significantly positive correlation (r = 0.960*) with yield at full flowering stage. The root volume density of Gonglv2 in 10-15 cm (r = 0.976*) and 20 - 25 cm (0.982*) horizontal soil layers at full flowering stage showed significantly positive correlation with yield, respectively. The root dry weight density of Gonglv2 in 20-25 cm horizontal soil layer had significantly positive correlation (r = 0.954*) with yield at full pod stage (Table 2). In vertical direction, the yield of Jilv7 showed significantly positive correlation (r = 0.988*) with root volume density in 40-60 cm soil layer at full pod stage (Table 3). These traits were the most important yield contributing traits of mung beans for increasing yield.

CONCLUSION

The highest density of mung bean root was in 0-5 cm horizontal soil layer and in 0-20 cm vertical soil layer. Approximately 48.4%-65.2% of the mung bean root were in 0-5 cm horizontal soil layer and 73.2% - 82.3% were in 0-20 cm vertical soil layer.

The number of pods per plant was the most important yield components of mung bean. The root volume density in 20-25 cm horizontal soil layer at full flowering stage was the most inportant roots morphology indicator of mung bean to increase yield. These traits can be used in high yield breeding of mung bean.

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