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Differential Root Size Distribution and its Relation to Yield in Contrasting Cultivars of Mungbean under Water Limited Environments

V. Maruthi, K. Srinivas, K.S. Reddy and D.G.M. Saroja

ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059, Telangana

Email: v.maruthi@icar.gov.in

ABSTRACT: A Minirhizotron study of two morphologically contrast mungbean cultivars *viz*., ML267 and WGG37 under two water treatments of no stress (field capacity) and stress (33.3% of available water content) conditions was conducted at Central Research Institute for Dryland Agriculture, Hyderabad during 2009-10. CRIDA-Pin board method of root architectural sampling was carried out for subjecting them to WinRhizo analysis (WinRHIZO Regular software) for data on total root length, root size, and its temporal distribution vertically besides the root surface area. The results showed that ML267 performed better under moisture stressed conditions (462 kg/ha) as compared to WGG37 (338 kg/ha), which excelled only with sufficient water availability. It is concluded that 36% enhanced pods per plant and 4% increased seed weight resulted in improved ML267 yields by 22% under moisture stressed conditions over WGG37 attributed to maximum total root length and greater fine root length recorded at flowering stage, increased shift of fine roots to deeper soil layers and reduced root surface area at pod filling stage to enhanced sink filling. Hence, ML267 performed better than WGG37 under water-limited conditions. These above mentioned root traits could be indicators of drought tolerance in mungbean plant types.

Key words: Fine roots, mungbean, root diameter, root size, root surface area, soil moisture stress

Introduction

Water stress is the most important factor limiting the agriculture production worldwide and this is very acute in semiarid tropics of Asia and Africa, where most population depends on the subsistence agriculture (Vadez, 2014). Deficit water conditions affect both above and below ground plant parts as well. However below ground plant part, root system is the first most important part for plant survival followed by reproduction for propagation/ perpetuation. Root system, as a major organ for the exchange of substance and information between above and below ground has a significant influence on crop survival, development and yield (Grant, 1998). Root system gives immediate feedback to any changes in soil moisture, adjusts leaf stomata opening and tries to develop better relationship with water for improved yields. Research on root morphology and distribution has been a subject of great interest in recent years (Cut forth *et al*., 2013). Meanwhile, understanding of dynamics in root growth is of critical importance to investigate crop adjustment to water stress in terms of dry matter partitioning including root size for survival as well as for yield.

Study of plant root systems under field conditions is difficult because the soil limits accessibility for observations (Munrez-Romero *et al*., 2010). This study is further cumbersome under water deficit conditions. Studies on crop root system morphology are extremely crucial and important for understanding root size distribution, which would facilitate acquisition of available soil water (Fageria, 2004) and nutrients. Lack of systematic study on the effect of soil moisture stress on root size, its distribution in relation to the above ground biomass and dry matter partitioning is the reason for conducting this investigation. This could be better understood through a net house study of two contrast cultivars of mungbean grown in minirhizotrons for assessing the varietal difference in root size distribution under water deficit conditions related to yields. Most of the mungbean research work reported in India was on influence of different nutrients, their integrated management on the growth and yield but not much on root studies. Hence this study was taken up on mungbean under limited water conditions in minirhizotrons.

Materials and Methods

Two mungbean cultivars of contrast plant architecture were grown in minirhizotrons under two varied soil moisture conditions as a net house study at in Central Research Institute for Dryland Agriculture (CRIDA) Hyderabad, India during 2010 to compare the root size distribution. ML267 is the most popular short statured cultivar(from PAU, Punjab) while WGG37 a tall variety released from the Acharya N.G. Ranga Agricultural University (ANGRAU), Hyderabad for rainfed conditions were chosen. These two varieties were grown both under field capacity (FC) and 33.3% depletion level of soil moisture from FC.

Soil characteristics : The textural composition of the red sandy loam soil was 75% sand, 3% silt and 22% clay with neutral pH, normal electrical conductivity, and low nitrogen content (171 kg/ha), medium available phosphorus (17.7 kg/ha) and high potassium (307 kg/ha) contents (Table 1).

Table 1 : Physical and chemical soil parameters used in the minirhizotrons

Soil parameter	Soil depths (cm)		
	0-15	15-30	30-45
pH	6.41	6.30	6.57
Electrical conductivity (ds/m)	0.049	0.082	0.047
Organic carbon (%)	0.739	0.710	0.716

Nitrogen (kg/ha)	196	196	197
Phosphorus (kg/ha)	12.3	17.8	13.2
Potassium (kg/ha)	121	298	285
Field Capacity (% by Vol)	14.8	13.0	19.3
Permanent wilting point (% by Vol)	4.6	4.9	7.7
Sand (%)	76.4	71.4	74.4
Silt (%)	3.0	4.0	4.0
Clay (%)	20.6	24.6	21.6

Crop growth and sampling: One plant per minirhizotron was planted and fertilizer was applied as per the recommendation. Plants were sampled at vegetative (22 DAS), flowering (42 DAS) and pod filling (69 DAS) stages. Observations related to above ground biomass and below ground biomass *viz.,* dry biomass in grams were also recorded besides recording leaf area (cm^2) using leaf area meter.

Methodology of sampling for Root Architecture (CRIDA-Pin board methodology): According to Price *et al*. (2002) the minirhizotrons made of glass with very narrow space enables us to collect the whole root sample with minimal disturbance in the root structure or architecture. However, an indigenized acrylic root chambers were made by CRIDA, India for the root study.

Construction of MiniRhizotrons: The Mini Rhizotron was made of transparent acrylic material of 30 cm X 15 cm X 15 cm rectangular boxes, three boxes of the same were arranged one above the other so as to have the total depth of 45 cm (Figure 1). These boxes were fastened with a duct tape to prevent water leakage. Only a wall of one side of the box is movable fixed with hinges and hasps (Maruthi *et al.,* 2013). A drain hole was made to the bottom most boxes to drain excess water. The minirhizotron was filled with 2 mm sieved red sandy loam soil. Mungbean seeds were sown and treatments were imposed after seedling emergence. For measuring water consumption each minirhizotron was weighed daily (Figure 1).

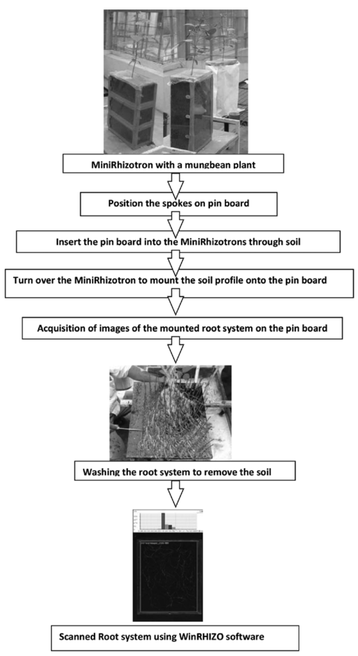


Figure 1 : A flow chart depicting the process of extraction of Mungbean root architecture from a MiniRhizotron

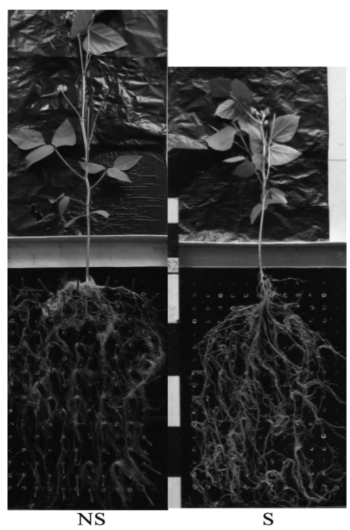
Pin board: PVC board of 30 X 15 X 45 cm dimensions was punched a hole at equal intervals of 2.5 cm and painted black. Spokes (motor bike spokes 16.5 cm length with a screw at the bottom end) were driven vertically into the PVC board.

Sampling protocol: For sampling, the door of each chamber was opened, fitted with the pin board by driving the spokes into soil until it touches the acrylic sheet and turned it over leaving the whole soil profile along with root system onto the pin board. Sampling was done stage wise *viz*., vegetative (25 DAS), flowering (42 DAS) and reproductive (60 DAS).

Root washing: Roots were washed gently by spraying water with adequate pressure. After washing, the mounted root system on the pin board was placed in a water tray for digital photographing.

Photography: The black pin board with root system in the water tray was aligned properly to capture images using a digital camera with high resolution at a perpendicularly fixed object distance using boom stand (Picture 1 & Picture 2).

Picture 1 : Root architecture of ML267 cultivar of mungbean at flowering stage (42 DAS) under no stress (FC) and moisture stressed conditions



Picture 2 : Root architecture of WGG 37 cultivar of mungbean at flowering stage (42DAS) under no stress (FC) and moisture stressed conditions

Root scanning and image analysis: After photography, the roots were subjected to sub sampling and stored in water of glass bottles in a refrigerator at 4 ^{0}C until they were scanned using scanner of STD 4800 and analyzed root traits like TRL (cm) soil profile wise, root diameters, fine root length *etc.* using "WinRHIZO"(Regular 2009c Version). Root scans were saved in JPG format and data were generated in text file, later converting into excel sheet for further analysis. After scanning, the roots were dried at 40 ^{0}C for four days until we get constant weights for weighing root dry biomass.

Statistical Analysis: Complete randomized Block design with one-way analysis of ANOVA was employed with four replications (Gomez and Gomez 1984), to estimate the treatmental differences.

Results and Discussion

Root parameters

Between two cultivars, ML267 recorded either equivalent or reduced TRL at stressed conditions to plant at no stressed conditions (Figure 2). Among the plant phonological to phonological; stages, ML267 recorded maximum total Root Length (TRL) during flowering stage (6559 cm) under water stressed conditions in the root size ranged from 0.1 to 1.0 mm as compared to vegetative (777 cm) and pod filling stages (4551 cm) of the cultivar as normally plants attain maximum TRL at flowering stage declining later at pod filling stages (Brown *et al*., 1985). However, large reduction in TRL due to soil moisture deficits was observed during pod filling stage (43%) followed by flowering (25%) and vegetative stages (4%). Therefore, legumes in general and mungbean in particular suffered from vulnerability to soil moisture deficits at these stages in the same order as mentioned above (Cortes and Suidaria, 1986). In contrast WGG37 recorded maximum TRL at pod filling stage (13378 cm) irrespective of the water regimes, also maximum TRL at stressed conditions (16222 cm) over ML267 as well. No particular trend was noticed in the TRL attainment by WGG37. Greater TRL at pod filling stage as the contrast character of WGG37 in the root size of 0.5 mm to 1.0 mm might have been due to its genetic potential to produce root dry matter as there might be diversion of reduced photosynthates because of soil moisture stress (Uprety, 1989) to roots affecting seed filling as well yields in this cultivar. Kashiawagi *et al*. (2006) in an experiment on chickpea emphasized the beneficial aspects of early stage root distribution in later stage dry matter partitioning.

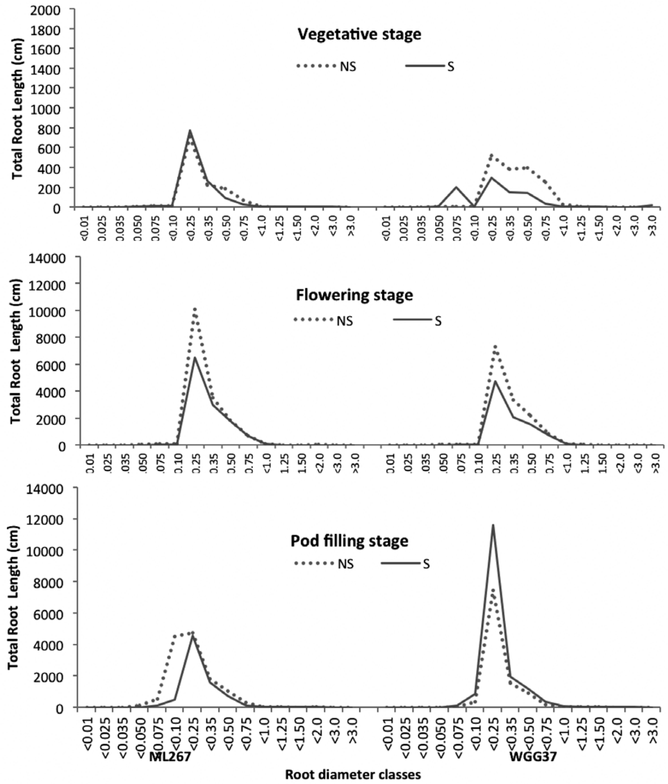


Fig. 2 : Diameter wise root length distribution at all the three stages of two cultivars

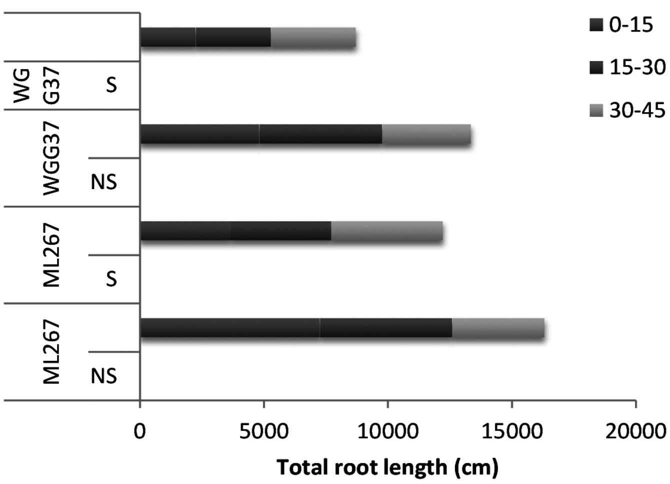
Similar trend as that of TRL was observed in attaining total fine root length (TFRL) in the root size of<0.25 mm as well as in the total coarse root length (TCRL) in >0.25 mm root size (Table 2). As was in TRL, TFRL of ML267 at flowering stage (6701 cm) was greater than TFRL of WGG37 (4879 cm), however augmented TFRL was recorded by WGG37 at pod filling stage (12615 cm) than ML267 (5146 cm). Since dynamics of both TRL and TFRL is positive during moisture stressed stages, they aid in distinguishing drought tolerance in mungbean genotypes as was observed in ML267. Since root diameter is an important morphological trait, which influences the root penetration potential of soil (Materechera *et al*., 1992) as well as account for maximum surface area for water and nutrient absorption (Eissenst at 2002). The maximum TFRL at flowering stage indicated the preferential advantage of ML 267 over WGG37 when exposed to soil moisture deficits to survive, while WGG 37 showed attainment of maximum fine root length at later stage might have affected the source sink relations by increasing the use of photosynthates for more root dry matter partitioning rather than

Table 2 : Phenological stage wise presence of % coarse and fine root length with two water regimes in two mungbean cultivars

	Vegetative stage			Flowering stage			Pod filling stage		
	<0.25mm	>0.25mm	Total	<0.25mm	>0.25mm	Total	<0.25mm	>0.25mm	Total
ML267FC	748	503	1251	10401	6353	16754	9905	3238	13143
ML26733.3% AWC	800	401	1201	6701	5796	12497	5146	2475	7621
Mean	774	452	1226	8551	6075	14626	7526	2856	10382
WGG37FC	549	1076	1625	7511	6712	14223	7856	2678	10534
WGG3733.3% AWC	511	356	867	4879	4655	9534	12615	3606	16221
Mean	530	716	1246	6195	5683	11878	10235	3142	13377
MEAN	652	585	1237	7374	5879	13253	8881	3000	11881

*NS: No Stress of soil moisture (FC); S: Stress with 33% depletion in soil moisture conservation of photosynthates, reducing sink filling. Further it was also explained by Liu *et al*. (2003) that the active cell division in the young ovules and pod expansion gets affected due to moisture deficits, which would sometimes result in floral or pod abortion affecting sink. Therefore, more TFRL is a root trait to be considered as an indicator of drought tolerance in a variety.

Soil depth wise TRL distribution depicted in Figure 3 emphasised the fact that under moisture stress conditions, ML267 registered greater TRL per plant as well as higher TRL at each depth as compared to TRL in each soil depth moisture stressed WGG37. Greater the total root length more is the root surface area. Root surface area (cm^2) is a parameter indicating the root size/diameter indirectly as the increased total root length with soil moisture deficits at 15-30 cm and 30-45 cm soil depths in ML267 compared to 0-15 cm was observed at all the crop growth stages and at respective soil depths of WGG37 as well to counter dry conditions at the top soil depths. Therefore root surface area could be a root trait positively influencing the drought tolerance of a genotype.



Total dry matter, its partitioning and yield, yield attributes

Moisture stress reduced the total dry matter of ML267 and WGG37 by 55 and 26% over no stressed treatments respectively (Table 3). However, higher dry matter accumulation was observed in WGG37 (2.61 g of shoot dry weight and 0.59 g of root weight) over ML267 (1.74 g of shoot weight and 0.32 g root weight), which might have been due to the tall nature of the plant as well as due to enhanced root production at pod filling stage. One another reason might also be 15% reduced leaf area might have reduced the rate of photosynthesis under limited water environments affecting photosynthate assimilation. Therefore, more partitioning towards shoot and root especially seed at later stages of crop growth in WGG37 might be due to reallocation of photosynthates to more dry matter production reducing carbon dioxide assimilation in the sink. Owing to reduced stomatal conductance, assimilation of CO_2 gets reduced as was observed by Reddy *et al*. (2004) and Pandey *et al*. (1984).Hence there was a yield difference of 27% between these two cultivars under stressed conditions, as ML267 recorded 462 kg/ha and WGG37 338 kg/ha (Figure 4).

Table 3 : Effect of two water regimes on above ground and below ground dry matter and yield attributes of two mungbean cultivars

	Leaf area (cm)	Root surface area (cm)	Shoot Dry weight (g)	Root dry weight (g)	Number of pods/ plant[1]	100 seed weight (g)
ML267 NS	221.8	1132	3.90	0.48	15.5	4.23
ML267 S	187.9	617	1.74	0.32	13.0	4.01
WGG37 NS	157.5	971	3.83	0.74	21.5	3.83
WGG37 S	133.4	1081	2.61	0.59	9.5	3.76
SED±	13.16	39.50	0.32	0.10	1.42	0.26
CD at 5%	28.69	86.00	0.70	0.22	3.11	NS

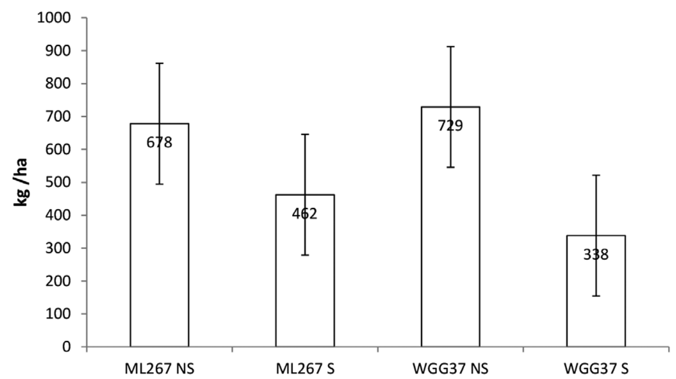


Fig. 4 : Yields of two mungbean cultivars under two soil moisture regimes

Relationship between root diameter, surface area, and yield:

Correlation and regression analysis of root surface area and root size with yield in Table 4 emphasized the positive influence of lower root size (finer roots) on the mungbean yields at flowering stage and the negative influence of greater root surface area on yields at pod filling stage (Figure 5).

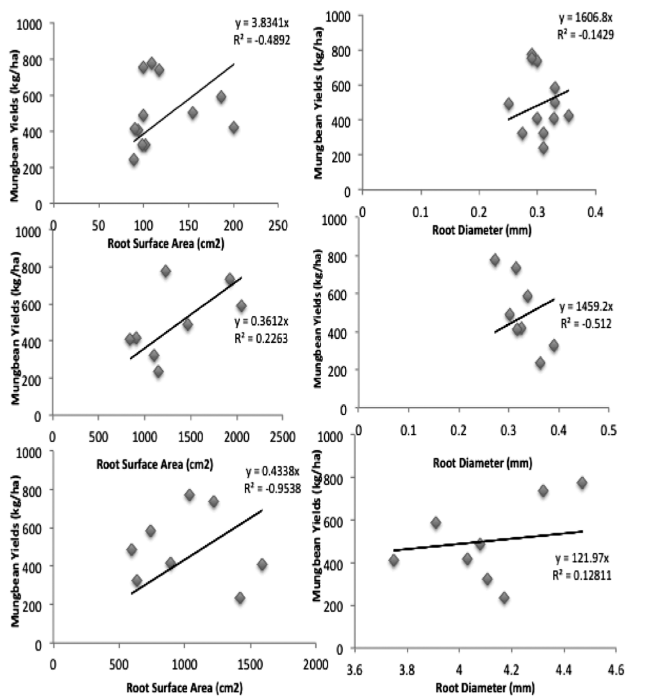


Fig. 5 : Relationship between mungbean yields and surface area, root diameter at three phenological stages of crop growth

Table 4 : Correlation coefficients of different root parameters with seed yields at various crop growth stages of mungbean

Phenological stages	Root surface area (R^2)	Root size (R^2)
Vegetative (22 DAS)	-0.49	-0.14
Flowering (42 DAS)	0.226	-0.512
Pod Filling (69 DAS)	-0.95	0.13

Root size has medium strong negative correlation with mungbean yields (R^2=-0.512) emphasizing the critical importance of low root size (finer roots) for extracting maximum water and nutrients due to increased root surface area. This was true in case of flowering stage, as finer roots have pronounced effect on soil moisture stress management of plant as its assimilation capacity deteriorates due to closure of stomata (Thomas *et al*., 2003). However, the reduced root surface area at pod filling stage has more impact (R^2=-0.95) on realizing seed yields reducing diversion of photosynthates especially at terminal stage, as there might be imbalance between the sink to be filled and source available since new roots consume already reduced photosynthates for maintenance instead of filling the sink.

It is concluded from the present study that under soil moisture deficits up to 33.3% available water content, ML267 performed better than variety WGG37. The improved performance of ML267 under soil moisture deficits was attributed to more total root length, greater fine root length at flowering stage, increased shift of fine roots to deeper soil layers, low root surface area especially at pod filling stage saving photosynthates for sink. All these root parameters reduced negative impact on yield attributes of pods per plant and 100 seed weight. Therefore, these root traits may be considered while assessing the drought tolerance of mungbean genotypes.

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References

Brown EA, Caviness CE and Brown DA. 1985. Response of selected soybean cultivars to soil moisture deficit. *Agronomy Journal,* 77: 274-278.

Cortes PM and Suidaria TR. 1986. Gas exchange of field grown soybean under drought. *Agronomy Journal,* 78: 454-458.

Cutforth HW, Angadi SV, McConkey BG, Miller PR, Ulrich D, Gulden R, Volkmar KM, Entz M H and Brandt SA. 2013. Comparing rooting characteristics and soil water withdrawal patterns of wheat with alternative oilseed and pulse crops grown in the semiarid Canadian prairie. *Canadian journal of soil science,* 93(2): 147-160.

Eissenstat DM and Yanai RD. 2002. Root lifespan, efficiency and turnover. Plant Roots, the hidden half. Waisel Y Eshel A and Kafkafi U (Eds) Marcel Dekker, New York, pp 221-238.

Fageria. 2004. Dry Matter Yield and Shoot Nutrient Concentrations of Upland Rice, Common Bean, Corn, and Soybean Grown in Rotation on an Oxisol. *Journal of Plant Nutrition,* 27(6): 947-958.

Gomez KA and Gomez AA. 1984. Statistical procedures for Agricultural research. Published by John Wiley & Sons, Inc., New York.

Grant RF. 1998. Simulation in ecosys of root growth response to contrasting soil water and nitrogen. *Ecological Modelling,* 107(2-3): 237-264.

Kashiawagi J, Krishnamurthy L, Panwar JD Sand Serraj R. 2006. Implications of contrast in root traits on seed yield of chickpea under drought situations. *Indian Journal of Pulses Research,* 19(2): 193-196.

Liu F, Andersen MN and Jensen CR. 2003. Loss of pod set caused by drought stress is associated with water status and ABA content of reproductive structures in soybean. *Functional Plant Biology,* 30: 271-280.

Maruthi V, Srinivas K, Reddy KS, Reddy BMK, Raju BMK, Purushotham Reddy M, Saroja DGM and Surender Rao K. 2013. Root morphology and architecture (CRIDA indigenous root chamber-pin board method) of two morphologically contrasting genotypes of mungbean under varied water conditions. *Journal of Food Legumes,* 26(3 & 4): 90-96.

Materechera SA, Alston AM, Kirby JM and Dexter AR. 1992. Influence of root diameter on penetration of seminal roots into compacted subsoil. *Plant and soil,* 144(2): 297-303.

Munrez-Romero Veronica, Benitez-Vega Jorge, Lopez-Bellido Luis and Lopez-Bellido Rafael. 2010. Monitoring wheat root development in rainfed vertisol-tillage effect. *European Journal of Agronomy,* 33: 182-187.

Pandey RK, Herrera WAT, Villegas AW and Penletion JW. 1984. Drought response of grain legumes under irrigation gradient. III. *Plant growth,* 76: 557-560.

Price AH, Steele KA, Moore BJ and Jones RGW. 2002. Upland rice grown in soil-filled chambers and exposed to contrasting water deficit regimes. I: Root distribution, water use and plant water status. *Field Crops Research,* 76: 11–24.

Reddy AR, Chiatanya KV and Vivekanandan M. 2004. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology,* 161: 1189-1202.

Thomas R, Fukai MJS and Peoples MB. 2004. The effect of timing and severity of water deficit on growth, development, yield accumulation and nitrogen fixation of mungbean. *Field Crops Research,* 86: 67-80.

Uprety DC and Bhatia A. 1989. Effect of water stress on the photo-synthesis, productivity and water status of Mungbean ((L.) Wilczek). *Journal of Crop Science,* 163: 115-123.

Vadez V. 2014. Root hydraulics: The forgotten side of roots in drought adaptation. *Field Crops Research,* 165: 15-24.

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