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DISTRIBUTION PATTERN OF RICE (*Oryza sativa* L.) ROOTS UNDER DIFFERENT TIMING AND DURATION OF WATER DEFICIT

Pola Distribusi Akar Padi (*Oryza sativa* L.) pada Perbedaan Waktu dan Durasi Cekaman Air

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Abstact: In Indonesia, Rice (*Oryza sativa* L.) is the most important food crop. In rice cultivated areas, there is a major problem of water deficit. The objective of this study was to investigate the effects of different timings and durations of drought stress on root distribution patterns of rice. The experiment was conducted in Greenhouse at Faculty of Agriculture, Gadjah Mada University, Yogyakarta. A rice genotype IR64 was used in the experiment. Drought stress was imposed for 0 (well-watered treatment), 7, 14 and 21 days by withholding watering at vegetative phase, reproductive phase and generative phase. The

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result showed that the root's response was depends on the timing plant growth stages. Under drought stress condition during vegetative growth stage resulted inhibition of root growth and reduced root dry weight. In contrast, under drought stress during reproductive stages, roots grew vigorously below 48 cm of the soil layer. Drought stress during generative stage reduced root dry weight each layer. Drought stress during 7 and 14 days at different beginning times could change the roots grew deeper than under well-watered condition. Dry weight of root in each lower soil layers was higher than under well-watered conditions. In contrast, drought stress during 21 days had reduced root dry weight each soil layer.

Keyword: drought stress, root distribution, root dry weight

Abstrak: Di Indonesia, padi (*Oryza sativa* L.) merupakan tanaman pangan utama. Pada lahan budidaya padi terdapat masalah utama yakni kekurangan air. Tujuan penelitian ini adalah untuk mempelajari pengaruh waktu dan durasi cekaman kekeringan yang berbeda terhadap pola distribusi perakaran. Penelitian dilaksanakan di Rumah Kaca Fakultas Pertanian, Universitas Gadjah Mada, Yogyakarta. Padi yang digunakan dalam penelitian ini adalah varietas IR64. Cekaman kekeringan dilakukan dengan menghentikan pemberian air selama 7, 14 dan 21 hari. Cekaman kekeringan diberikan pada saat fase pertumbuhan vegetatif, reproduktif dan generatif. Kontrol diberikan air sesuai kebutuhan. Hasil penelitian menunjukkan bahwa terdapat perbedaan tanggapan perakaran padi pada pemberian waktu cekaman kekeringan. Cekaman kekeringan selama fase vegetatif mampu menghambat pertumbuhan perakaran dan menurunkan bobot kering akar dibandingkan dengan kontrol. Sebaliknya, cekaman kekeringan yang diberikan pada fase reproduktif memicu pertumbuhan perakaran hingga kedalaman 48 cm. Cekaman kekeringan yang diberikan pada fase generatif menurunkan bobot kering tiap lapisan kedalaman. Cekaman kekeringan selama 7 dan 14 hari juga memicu pertumbukan perakaran yang semakin kedalam dan meningkakan bobot kering akar setiap lapisan dibandingkan dengan kontrol. Sebaliknya, cekaman kekeringan selama 21 hari menurunkan bobot akar setiap lapisan tanah.

Kata kunci: cekaman kekeringan, waktu, durasi, bobot kering akar

1. Introduction

Rice belongs to the genus *Oryza* within the Poaceae family. The genus *Oryza* contains approximately 23 species. Rice (*Oryza sativa* L.), has become a major source of nutrition for about two-third of mankind (Vaughan et al., 2003). In Indonesia, there are about 14.12 million hectares of rice land, which provide around 75.4 million tons of rough rice annually (Anonymous, 2016).

In rice cultivated areas, there is a major problem of water deficit especially in rain-field areas. Drought stress is a serious limiting factor to rice production and yield stability. Drought stress is one of the major abiotic stresses in agriculture worldwide. Plant responses to drought consist of morphological, physiological (Fukai, S. and Cooper, M. 1995; Chutia and Sailen, 2012), and biochemical changes (Mostajeran, A. and V. Rahimi-Eichi. 2009; Jabasingh, 2013). Plant growth and productivity are negatively affected by water stress (Sabar and M. Arif, 2014).

Adaptive mechanisms of plants in response to drought have been reported by several scientists. Most studies have reported on morphological and physiological traits such as harvest index, water use efficiency (Zain et al., 2014), stomatal conductance (Cha-Um *et al*. (2010)), increased proline (Mostajeran, A. and V. Rahimi-Eichi. 2009; Zain et al., 2014) and deep root growth (Henry, 2012). Roots are the principal plant organ for nutrient and water uptake. Root systems form is one of the important components of drought for improving drought resistance in rice. There are significant differences reported in root thickness, depth, and root mass among rice cultivars and there is documented genetic variation for root morphological traits in response to drought (Gowda et al., 2011).

The hypothesis this study is that timing and duration of drought induces responses by root traits such as root distribution pattern and root dry weight. These traits could be possibly relevant to root absorptive ability. The objective of this study was to investigate the effects of different timing and durations of drought stress on root distribution patterns of rice. Results of this study provided a foundation for selection of different timing and durations of drought stress on distribution pattern of rice root. Also, it will be further understanding on the role of roots in response to drought.

2. Material and Method

1. Experimental design and plant materials

The experiment was conducted in Greenhouse at Faculty of Agriculture, Gadjah Mada University. A rice IR64 was used in the experiment. Drought stress was imposed for 0 (Well-Watered treatment), 7, 14 and 21 days by withholding watering at early vegetative phase 0 days after transplanting (DAT), vegetative phase (21 DAT), reproductive phase (42 DAT) and generative phase (64 DAT).

2. Field capacity

Field capacity was measured by gravimetric method. The soils samples were collected and the soil weights were taken immediately (A gram). The soil samples were oven-dried at 105°C until for 48 h or until weights were constant and soil dry weight was determined (B gram). FC_1 content was calculated as;

$$FC_1 = \frac{(A-B)gram}{B\ gram} \times 100\%$$

The polybag were filled with soil samples which were taken from oven-dried. It was watered until first the water drop from polybag. The polybag weight was determined (C gram). FC 2 content was calculated as;

$$FC_2 = \frac{(B-C)gram}{B\ gram} \times 100\%$$

3. *Preparation and watering*

The seeds were germinated in soil box. After 14 days, the plants were transplanted to the polybag. The plants were grown in the polybag with the dimension of 45 cm in height and 35 cm in width. The polybag were filled with dry soil up to height of 40 cm.

Soil moisture contents were maintained at field capacity. The water was first supplied at field capacity and the treatment were imposed at the same time (0 DAT), 21 DAT, 42 DAT and 64 DAT by withholding watering. The durations of drought imposition were 7, 14, and 21 days after holding watering. Well watered treatment was maintained as a field capacity. A continuous maintenance at field capacity, soil was applied by crop water requirement. Crop water requirement (WR) was calculated as the sum of water loss through transpiration and soil evaporation based on

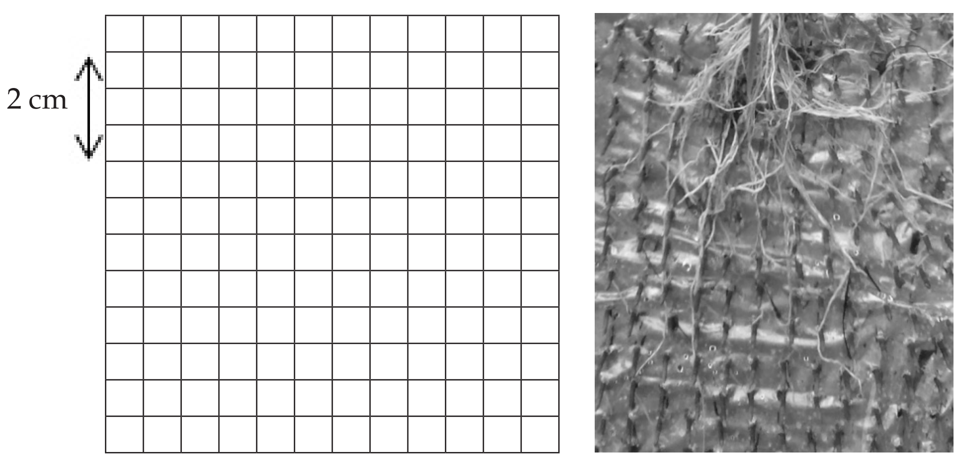
$$WR = \frac{(FC1-FC2)gram}{100\%} \times \text{weight of polybag}$$

4. *Crop management*

Nitrogen fertilizer as urea was utilized at 7 and 14 days after transplanting. Phosphorus fertilizer as SP-36 (50 kg/ha) and potassium fertilizer as potassium chloride (50 kg/ha) were applied at 7 days after transplanting. Weeds were controlled manually.

5. *Root dry weight and observation of root distribution*

The sampling time was done at vegetative, reproductive and generative phase. Needle-board (**Fig.1.**) method with modification was used for observation of root distribution (Kano-Nakata et al., 2012). Spacing of needles was 2 x 2 cm. Each polybag sample was carefully installed to fix the needle-board. The needle-board was installed to fix the root at the same position. It was washed with tap water to remove the soil to visualization of root image. After this process, there root was digitized by taking photographs. The photographs showed distribution patterns of whole roots on needle-board with scale bar compared with well watering and drought stress treatment. The roots were separated into square section units and among treatments were compared for root length and dry weight. The size of square unit was 4 x 4 cm and divided into 14 soil layers at 4 cm intervals from the top to the bottom of needle-board. The samples of all layers were bulked and oven-dried at 80 °C for 48 h or until the weights were constant and root dry weight was measured.



A **B**

Fig. 1. Diagrammatic representation and dimension of needle-board (A) spacing of needle; (B) the image of rice root system

3. Result and Discussion

The results indicated that root dry weight was less in drought stress treatment than those of well-watered. The distribution patterns of whole rice root on needle-board with scale bar under well-watered conditions (**Fig.2.WW; Fig.4.WW**) and drought stress conditions beginning at vegetative, reproductive and generative growth phase (**Fig. 2.**) during 7, 14 and 21 days in three growth stages was observed (**Fig.4.**). The results of root dry weight were showed for soil layers at 4 cm intervals from the top to the bottom of the needle-board.

Rice under drought stress respond by roots depends on the timing plant growth (vegetative, reproductive or generative) stages. An important finding of this study under drought stress during vegetative growth stage caused during stress and could change root distribution patterns of rice. Drought stress condition during vegetative growth stage resulted inhibition of root growth and reduced root dry weight (**Fig. 3a. (a)**). After re-watering, the root growth was higher root percentages in upper soil layers than lower soil layers under field capacity condition (**Fig. 3a. (b), and (c)**). The dry weight root of each layer decreased (**Fig. 3a (a), (b), and (c)**) compared to well-watered (**Fig. 3d. (a), (b), and (c)**) from initiation of water withholding to generative stage although after under drought stress maintained to field capacity.

So far the information on root response to different durations of drought at vegetative growth stage of rice for root distribution has been very limited. Water deficit caused a significant reduction in physiological parameters i.e. growth, chlorophyll fluorescence and biochemical parameters i.e. chlorophyll and protein content at vegetative stage (Sikuku et al., 2012). However, severe drought stress also reduced root biomass about 95% but deep-rooting varieties are more resistant to drought than those with shallow-rooting ones (Asch et al., 2005).

Drought stress during reproductive stages, root growth responded in the same pattern as the distribution pattern of roots grew vigorously below 48 cm of the soil profile (**Fig.3b. (b)**). The results indicated that roots of rice subjected to drought stress during reproductive stage distributed greater proportion of roots in lower soil layers than did roots of rice grown under well-watered conditions. It indicated that roots absorb more water at the deeper profile as soil moisture at the top soil layers was low under drought stress. After drought stress treatments, the soil maintained to field capacity. Under field capacity, the root growth indicated by higher root dry weight in upper soil layers than lower soil layers (**Fig. 3b. (c)**).

Most studies found that water stress was increased the percentage of root at lower soil layer. Root characteristics responses of rice to drought stress with reductions in top growth (height, leaf area and biomass and production tiller abortion), and changes in root dry matter and rooting depth were completely stopped under severe stress (Asch et al.,2005). Siopongco et al., (2005) reported that there was reduction in root growth rate during drought. Henry et al.,(2012) reported lateral root formation increased under drought stress to improve contact with shrinking water columns in the soil. A deep root system has important role for water and nutrient absorption. The ability to grow deep roots is currently the most accepted target trait for improving drought resistance (Gowda et al., 2011).

Drought stress during generative stage reduced root dry weight each layers (**Fig.3c**. **(c)**). Root dry weight indicated by higher in each upper soil layers than lower soil layers. It indicated that the root in lower soil layers was withered. However, the allocation of resources toward the root is high at early vegetative stages but decreases remarkably at flowering and is almost negligible after flowering (Gowda et al., 2011). Well-watered condition, most of root dry weight each soil layers were higher than those under drought conditions (**Fig. 3d. (a), (b), (c)**). It indicated that drought stress disturb root growth although re-watering until field capacity condition.

In this study, drought stress during 7 and 14 days at different beginning times could change root distribution patterns of rice (**Fig.4.**). Rice roots appeared to adapt to drought condition by growing deeper into the soil from vegetative to generative growth stage. Under withholding water for 7 days, roots grew below 20 cm of soil layers at vegetative growth stage (**Fig.5a (a); 5b (a)**). At reproductive stage, both of drought stress during 7 and 14 days resulted that the roots appeared below 40 cm (**Fig.5a (b), (c); 5b (b), (c)**). The roots grew deeper than under well-watered condition. The distribution and architecture of the root systems might be depended strongly on the moisture of the deeper soil layer. Root growth below 40 cm was developed to extracted soil water from soil depth. Dry weight of root in each lower soil layers were higher than under well-watered conditions (**Fig.5d.**). This suggested that the root responses at given periods of drought was determined principally by root dry weight and changed distribution patterns.

Drought stress during 21 days at different beginning times had resulted mainly from inhibition of root growth and reduced root dry weight during vegetative to generative growth stage. Roots grew shorter than under well-watered condition at reproductive growth stage (**Fig.4c.(c)**). At generative stage, the roots grew as long as under well-watered conditions and the root dry weight each layer was lower (**Fig.4c.(c)**). It indicated that the root might wither.

Plant roots responded to soil water by modifying root distribution patterns in root zone. Rice reacted to drought stress with reductions in height, leaf area and biomass production, tiller abortion, changes in root dry matter and rooting depth and a delay in reproductive development (Asch et al., 2005). Siopongco et al., (2005) reported that there was reduction in root growth rate during drought. Likewise, root to shoot ratio and root mass per tiller also decreased under drought. Deep root mass, deep root ratio and specific root length increased under drought conditions. Drought avoidance of rice with a deep root system avoided drought better than rice with a shallow root system (Henry, 2012). Advantages conferred by a deep root system depend on three major factors: duration of the drought period, availability of water at depth, and rate of water uptake. If water is not limited in upper layers of the soil, the plant may not benefit from the formation of deep roots (Gowda et al., 2011).

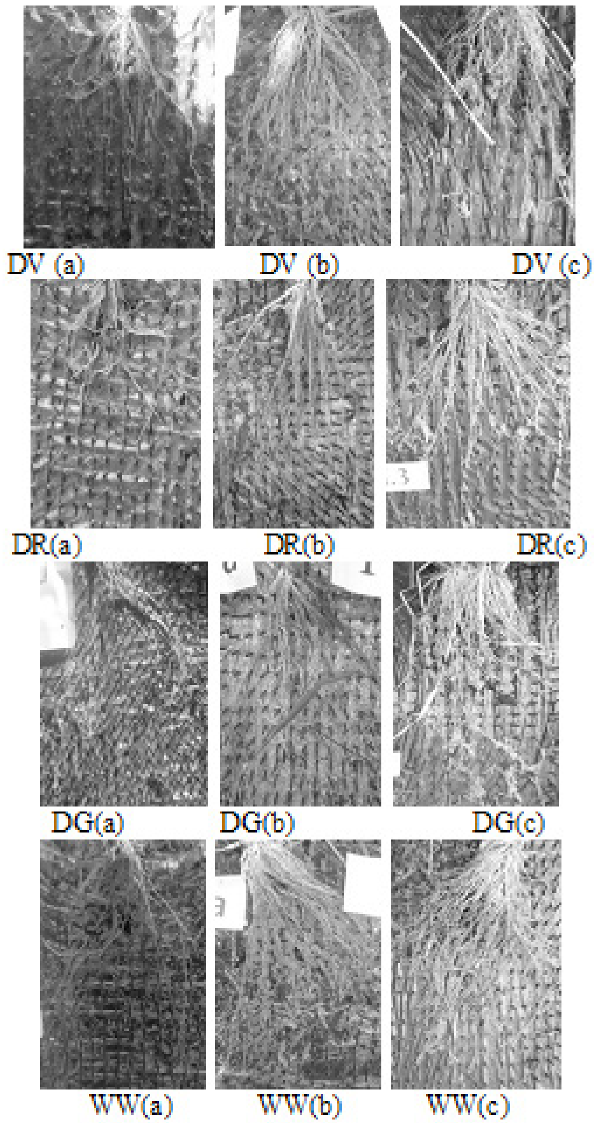


Fig. 2. Root dry distribution under well-watered (WW); withholding watering beginning 0 DATS (vegetative phase/DV), 21 DATS (reproductive phase/DR), and 42 DATS (generative phase/DG) for different durations: in the vegetative (a), reproductive (b) and generative (c) growth phase.

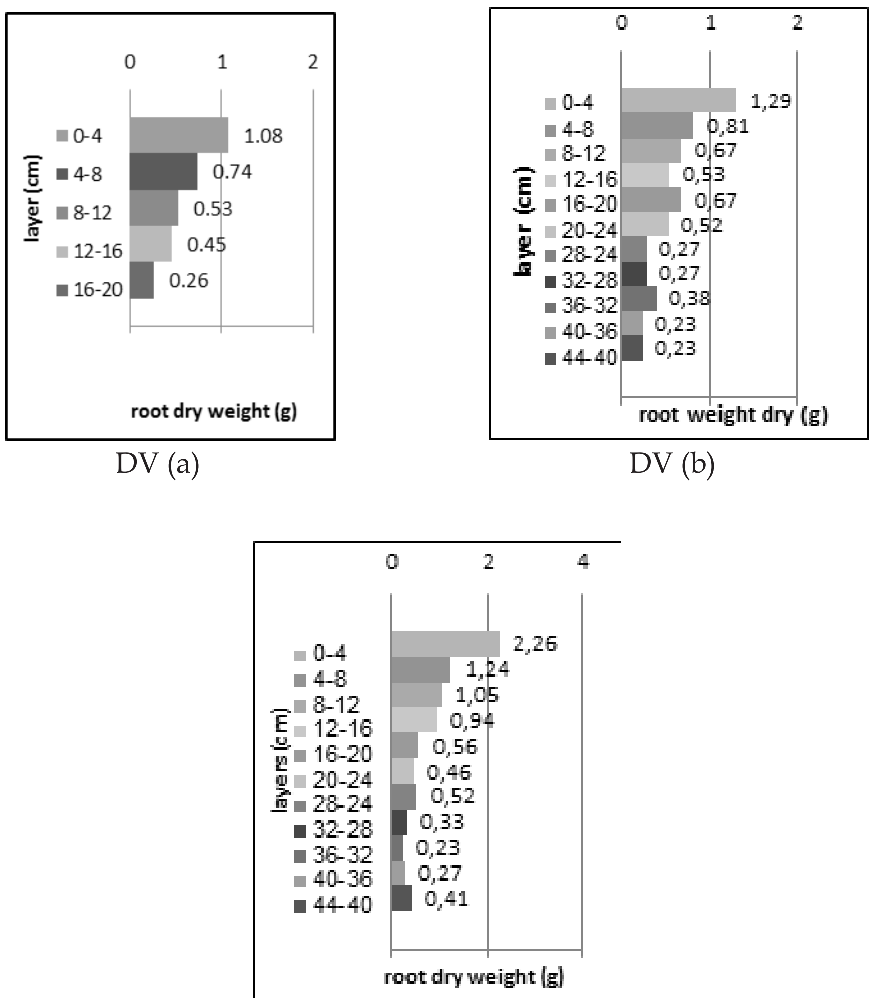
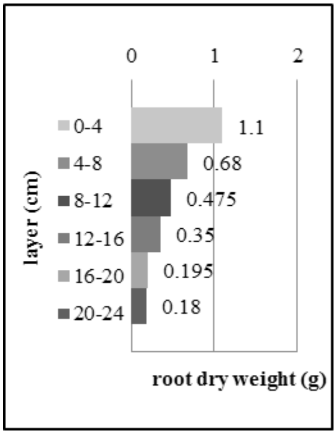
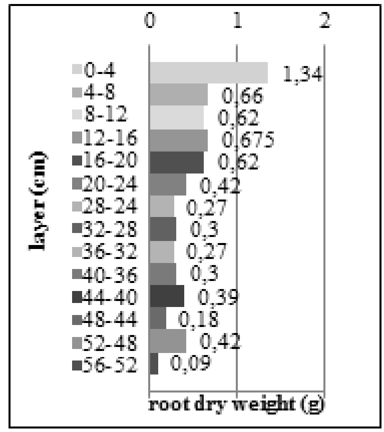


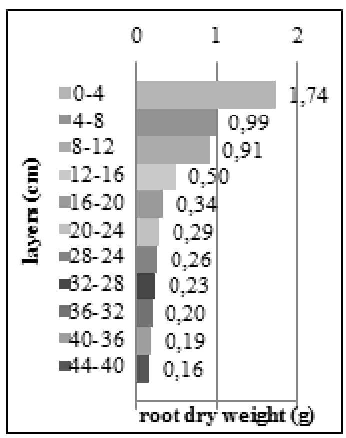
Fig 3a. Root dry weight in different layers under withholding watering at 0 DATS (vegetative phase) for different durations: in the vegetative (a), reproductive (b) and generative (c) growth phase.



DR (a)

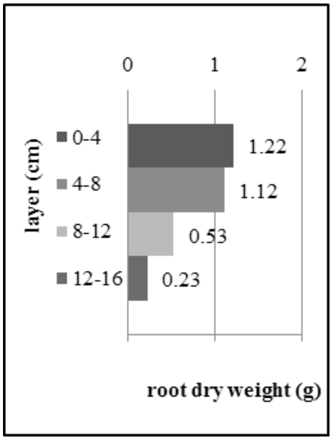


DR (b)

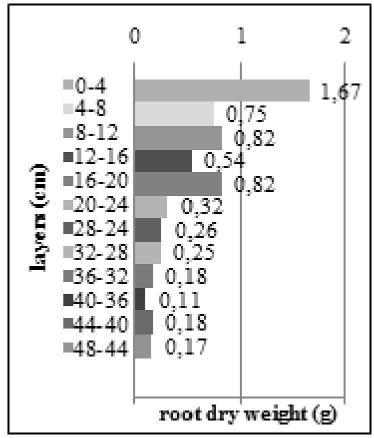


DR (c)

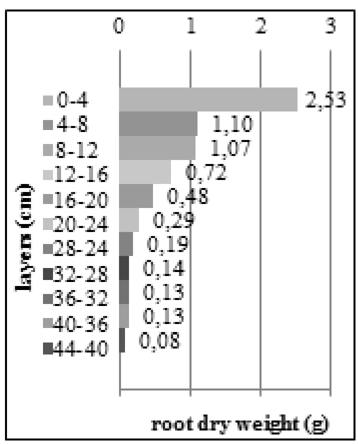
Fig 3b. Root dry weight in different layers under withholding watering beginning 21 DATS (reproductive phase) for different durations: in the vegetative (a), reproductive (b) and generative (c) growth phase.



DG (a)

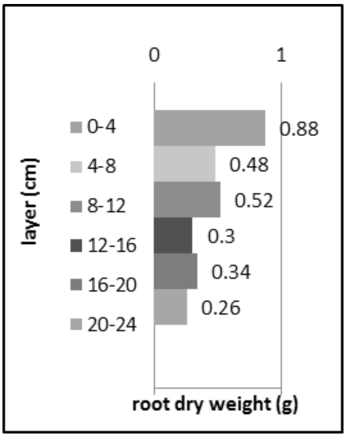


DG (b)

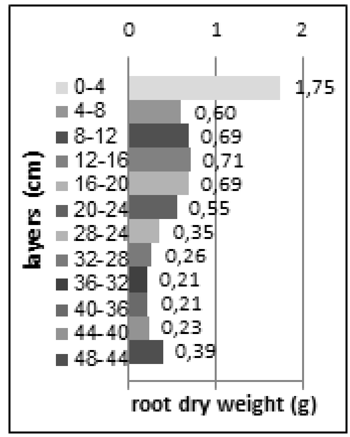


DG (c)

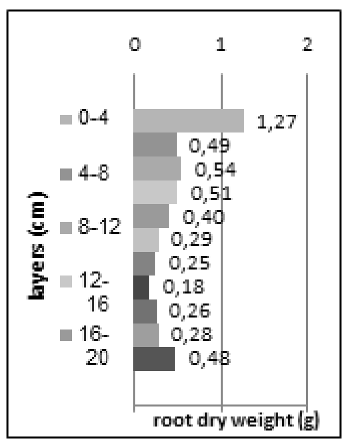
Fig 3c. Root dry weight in different layers under withholding watering beginning 42 DATS (generative phase) for different durations: in the vegetative (a), reproductive (b) and generative (c) growth phase.



WW(a)



WW(b)



WW(c)

Fig 3d. Root dry weight in different layers under well-watered: in the vegetative (a), reproductive (b) and generative (c) growth phase.

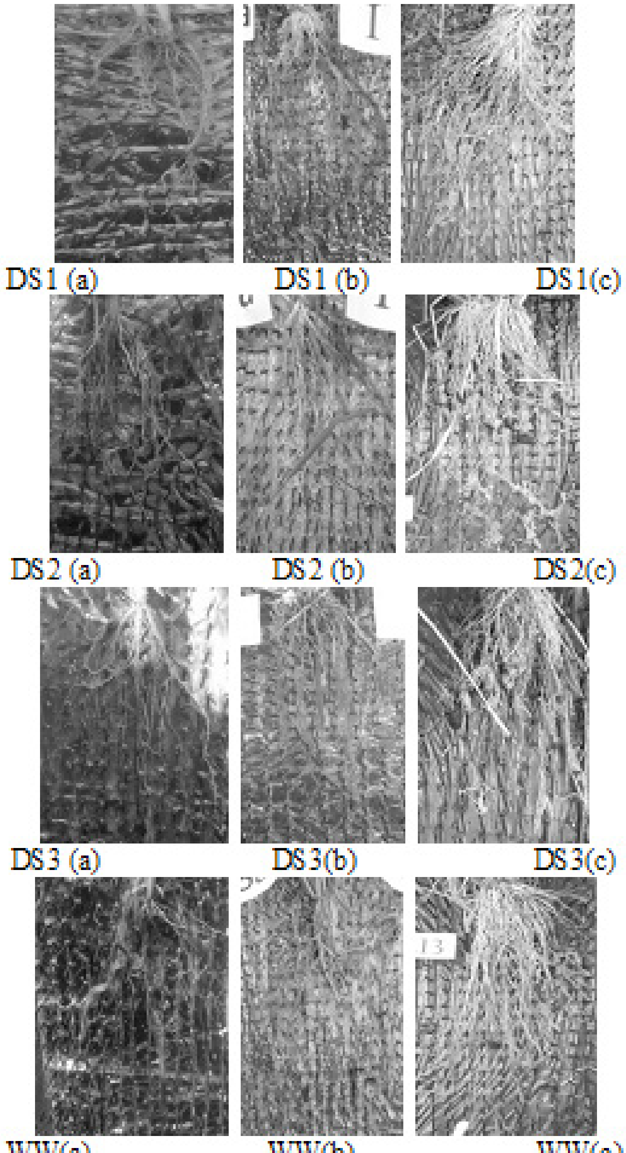
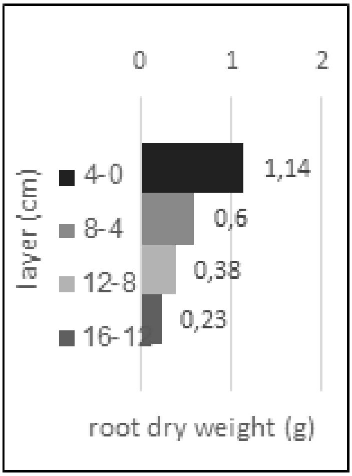
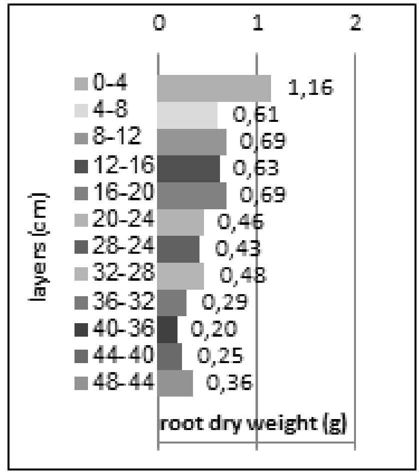


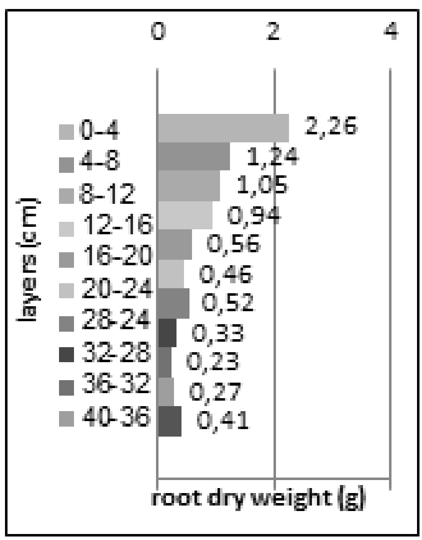
Fig. 4. Root dry distribution under well-watered (WW); withholding watering at different beginning during 7 (DS1), 14 (DS2) and 21 (DS3) days: in the vegetative (a), reproductive (b) and generative (c) growth phase.



DS1(a)

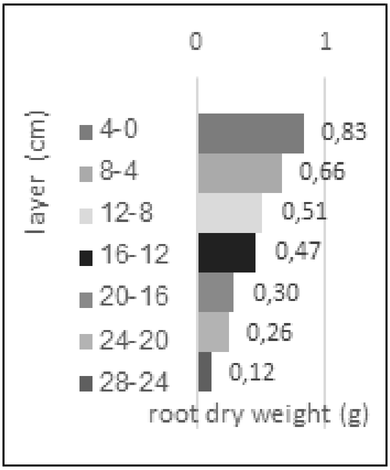


DS1(b)

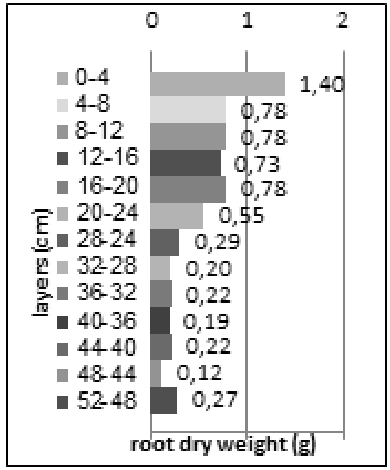


DS1(c)

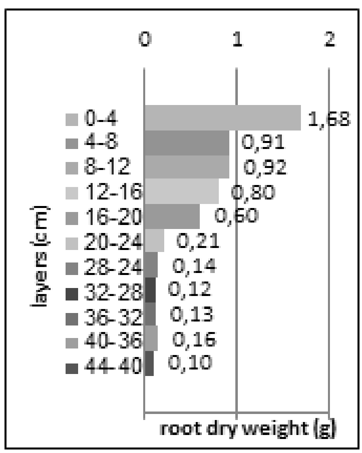
Fig 5a. Root dry weight in different layers under withholding watering at different beginning times for 7 days: in the vegetative (a), reproductive (b) and generative (c) growth phase.



DS2(a)

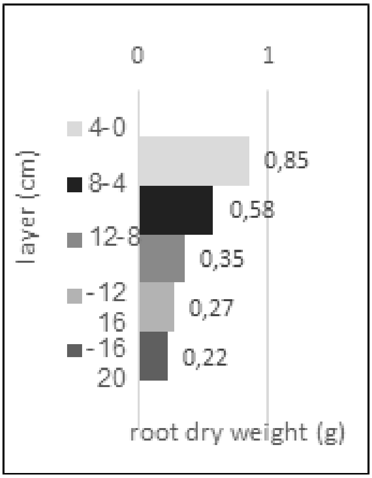


DS2(b)

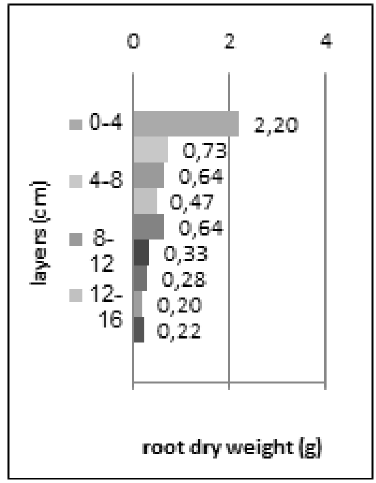


DS2(c)

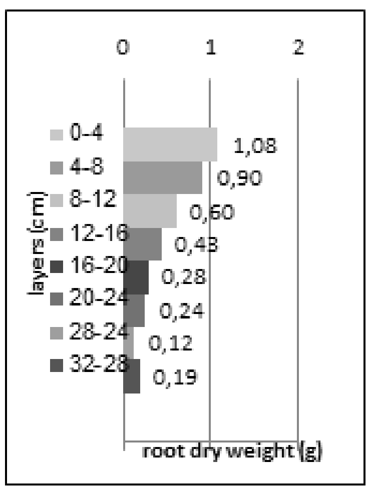
Fig 5b. Root dry weight in different layers under withholding watering at different beginning times for 14 days: in the vegetative (a), reproductive (b) and generative (c) growth phase.



DS3(a)

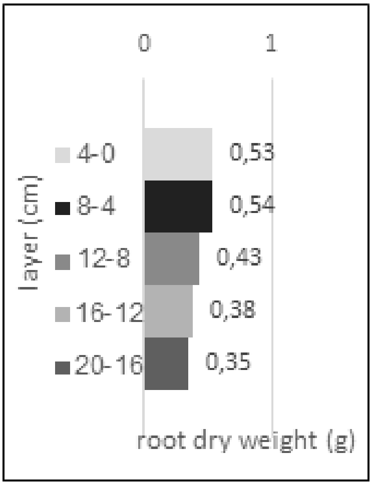


DS3(b)

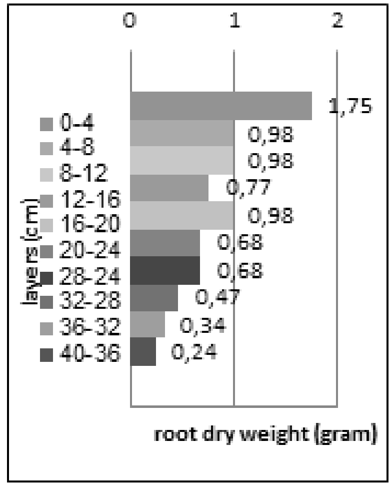


DS3(c)

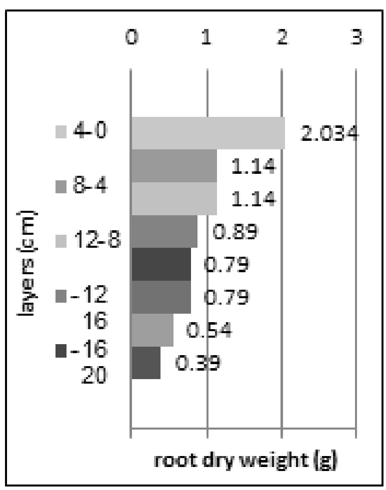
Fig 5c. Root dry weight in different layers under withholding watering at different beginning times for 7 days: in the vegetative (a), reproductive (b) and generative (c) growth phase.



WW(a)



WW(b)



WW(c)

Fig 5d. Root dry weight in different layers under well-watered in the vegetative (a), reproductive (b) and generative (c) growth phase.

4. Conclusion

Rice's root response was depends on the timing plant growth stages. Drought stress condition during vegetative growth stage resulted in inhibition of root growth and reduced root dry weight. In contrast, under drought stress during reproductive stages, roots grew vigorously below 48 cm of the soil layer. Drought stress during generative stage reduced root dry weight each layers. Drought stress during 7 and 14 days at different beginning times could change the roots grew deeper than under well-watered condition. Dry weight of root in each lower soil layers was higher than under well-watered conditions. In contrast, drought stress during 21 days had reduced root dry weight each soil layer.

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