Differences in drought avoidance root characteristics among several millet species

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Abstract

Deep root penetration may help millet species to exploit soil water more effectively and therefore overcome drought stress. The aim of this study was to evaluate interspecific differences in water uptake abilities by the deep roots of millet species, which can penetrate a hard pan layer. Six millet species were grown in tubes, which consisted of three parts. Top loose soil, middle hard pan layer, and bottom loose wet soil. A vaseline layer prevented water movement between the hard pan and bottom layer. Soil moisture was adjusted to well-watered and drought conditions in the top and hard pan layer, while the bottom layer was always kept wet. Drought imposed in the top two layers at the end of the heading stage reduced the photosynthetic rates in common millet and foxtail millet, but did not in the other four species (pearl millet, barnyard millet, finger millet, Job's tears). The root penetration in the four species was not decreased by the hard pan layer, and their root water extraction efficiency in deep roots was increased significantly by drought. Although roots in common millet were able to effectively penetrate the hard pan layer, root water extraction efficiency in deep roots was not significantly increased. In contrast, roots in foxtail millet could not effectively penetrate the hard pan layer. Interspecific differences in both the root penetration ability through the hard pan layer and the deep root water uptake efficiency were clearly demonstrated indicating these traits offer effective drought stress avoidance mechanisms.

Media summary

Interspecific differences in drought avoidance traits associated both hard pan penetration and water uptake efficiency of deep roots were demonstrated.

Key words

Cereals, Root activity, Photosynthesis, Soil water depletion, Transpiration, Water uptake

Introduction

The efficiency of soil water extraction and use are important factors determining crop productivity in semi-arid regions. Generally speaking soil water availability and root water uptake efficiency determines the ability of plants to withdraw water (Eastham et al., 1990). Vertical deep root penetration would help millet species to avoid the drought stress (drought avoidance), however it is often restricted by the presence of a hard pan layer. Moreover, drier soil conditions often promote root elongation and increase the degree of branching, allowing the crop to exploit soil water more effectively (Sharma and Ghildyal, 1977). In these circumstances, drought avoidance of millet species should be considered together with the deep root penetration abilities through hard pan layers; however, there are few studies in millet species that have investigated these aspects. In the present study the water uptake of deep roots which penetrated a hard pan layer under drought conditions was investigated to determine whether interspecific differences in drought avoidance among millet species exist.

Material and methods

Six millet species [foxtail millet (*Setaria italica* B.), pearl millet (*Pennisetum glaucum*), barnyard millet (*Echinochloa utilis* O.), finger millet (*Eleusine coracana* G.), common millet (*Panicum miliaceum* L.), Job's tears (*Coix lacryma-jobi* L.)], were grown in pots of 75 mm diameter and 500 mm height (Fig. 1). Each pot consisted of two parts; the top and bottom compartments were separated by a Vaseline layer (2-3 mm thick) in order to prevent water movement between the two parts. The lower compartments were loosely

filled with sandy soil with a bulk density of 1.33 Mg m^{-3}. In the upper compartments between 18 and 25 cm depth a compact layer was formed with a bulk density of 1.50 Mg m^{-3} and the rest of this tube was loosely filled. The bottom compartments were kept wet (average 35 %). Soil moisture in the top compartments was adjusted every day to 25 and 12 % in the well watered and drought treatments. Adjustments of soil water were applied for 15 days, starting after the booting stage. Until then, all plants were grown under well-watered conditions. During the drought treatment daily water uptake from top and bottom layers was determined gravimetrically. Root length was measured at the end of the heading stage. Root water extraction efficiency (RWE) was defined by a dimensionless ratio as:

RWE = $(WE_L/WE_T)/(R_L/R_T)$ where, WE_L is water extracted from top or bottom layers; WE_T is total water extracted in the whole soil profile; R_L is root length from top or bottom layers and R_T is total root length in the whole soil profile. Root penetration through a hard pan layer was defined as the ratio of root length in bottom layer to root length in top layers.

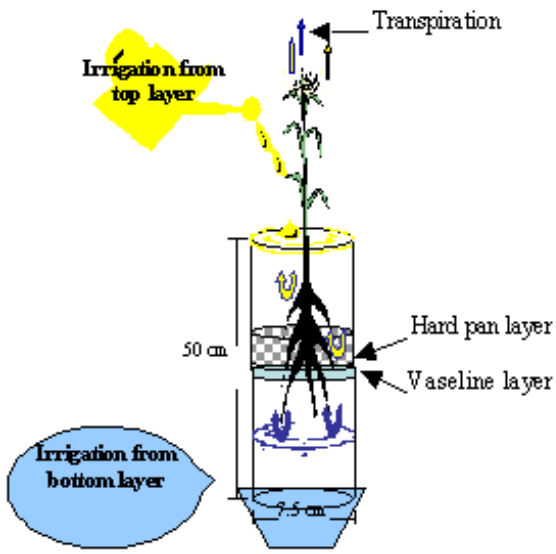

Figure 1. Schematic representation of the pot system.

Results and Discussion

Under well watered conditions at the end of the heading stage barnyard millet, Job's tears and common millet showed lower ability to extract water from deep soil layers while the other millet species showed similar efficiencies at top and bottom soil layers. On the other hand, all species except common millet, increased their water uptake efficiency from bottom soil layers when exposed to drought in topsoil layers (Fig. 2). The root penetration in pearl millet, barnyard millet, finger millet, Job's tears was not decreased by the hard pan layer, which would allow them to maintain water supply to the shoot under drought conditions. Results published elsewhere (Zegada-Lizarazu and Iijima, 2004) indicated that photosynthetic rate of pearl millet, barnyard millet, finger millet, Job's tears was maintained comparable to those of well-watered plants. In contrast, photosynthetic rates in common millet and foxtail millet were significantly reduced by drought. Although the roots in common millet effectively penetrated the hard pan layer, root water extraction efficiency in deep roots was not significantly increased. This could be attributed to the relatively poor tolerance of waterlogging conditions of common millet as compared to the other millet species (Kono et al., 1987). In foxtail millet, however, the roots could not penetrate well the hard pan layer. This would cause much less water supply to the shoot under drying topsoil layers.

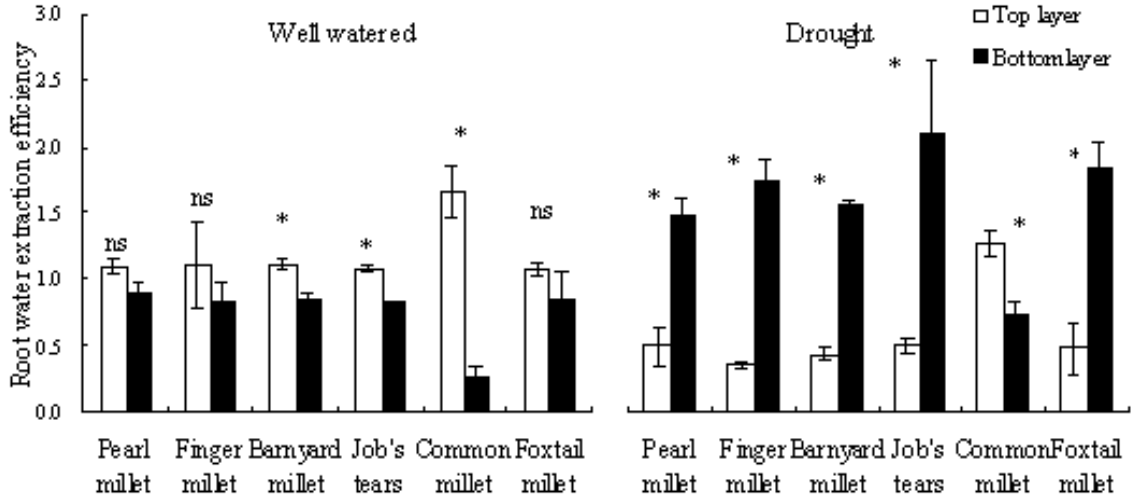

Figure 2. Deep root water extraction efficiency under two different soil water conditions at upper soil layers. Significant difference (*) between the two layers at 5 % level. Values are means of three replications ± SE.

Conclusion

Interspecific differences in both the hard pan penetration and water uptake efficiency of deep roots of millet, and hence drought avoidance characteristics was clearly demonstrated. Drought reduced the photosynthetic rates in common millet and foxtail millet, but did not in other four species. Although roots of common millet were able to penetrate the hard pan layer, root water extraction efficiency in deep roots was not significantly increased. In foxtail millet, roots could not effectively penetrate the hard pan layer.

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