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Assessing Different Soil Water Contents on Corn Root Development

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Abstract: Plant roots absorb water and minerals from soil solution. Plant production is a function of root distribution and its activity in soil. By increasing root density in per unit soil volume, roots absorb more water and minerals. This implies that knowledge o f root development is an important factor in crop production. To determine the most efficient amount of water for the maximum development of corn (*Zea mays* L.) root, a greenhouse experiment was conducted in 2006-07. Water was applied in 55, 70, 85, 100 and 110 percent of water demand. The corn root samples were taken from all the pots in three stages: i.e. 8-9 leaves, silking and the dough stage of grain fill. Wet and dry weights, volume, surface area and length of roots were measured in all three stages. In addition, ratio of root dry matter to stem was calculated. Analysis of data revealed an increase in weight, volume, surface area and length of roots by increasing the amount of water applied up to 100% water demand. A significant difference (5%) was found between 85, 100 and 110% water demand treatments in comparison to that of 55% water demand treatment. By an increase in the amount of water applied, the ratio of root to stem decreased. This indicated that when water use is in its optimum level, the root growth is stimulated, otherwise its growth get restricted. It is concluded that optimum efficiency of water application is achieved when 70 percent of water demand is applied instead of 100 or 110 percent.

Key words: Corn (*Zea mays* L.) · Root development · Water demand and water stress

INTRODUCTION

Increasing water use efficiency (WUE) is one of the oldest goals in agricultural sciences, yet it is still not fully understood and achieved due to the complexity of soil-weather-management interactions [1]. The first step in improving effectiveness of water and nutrient management practices is understanding how the plant roots develop [2]. The functioning of the part of the plant aboveground is conditioned very much by the distribution and activities of the root system. Thus, it is obvious that a precise knowledge of root development of cultivated plants, their position, extent and activities as absorbers of water and nutrients at various stages of growth is essential [2, 3].

Root distribution is especially sensitive to soil environmental factors [4]. Soil physical and chemical properties can affect root growth rate, root morphology and ultimately, nutrient uptake [5]. Earlier studies have demonstrated that soil water deficit is the primary limiting factor in crop growth under field condition [6]. Russel [7] showed that in the field condition, a change in water amount is the chief reason for differences in root distribution. Laboski *et al.* [4] reported that soil water holding capacity may control rooting depth when root distribution is not limited by other factors. It was demonstrated that sufficient amount of water in root zone, improved efficiency of the absorption of nutrients. Ziyaeian and Malakouti [8] observed that the time, method and the amount of applied irrigation water affected root distribution pattern. Incorrect methods of irrigation will adversely affect the correlation between soil fertility properties and yield mainly due to poor root development patterns under different management of water applications.

Water stress affects plant metabolism, physiology and morphology. Bingru and Hongwen [9] believed that application of sufficient amounts of water for plants' overall growth stages before appearance of undesirable effects of water stress, plays an important role in

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physiological properties of plants. In another study the effect of soil moisture regimes on growth, yield and water use consumption in wheat investigated by Qajar Sepanloo *et al*. [10]. They found that different water stress treatments decreased the yield of seed, dry weight of aerial body of plants, variety height, the amount of cluster in surface unit and harvest index, significantly.

Adiku *et al*. [11] investigated the patterns of root growth and water uptake of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* (L.) Walp) grown in a mixture under greenhouse conditions. The results showed that under well-irrigated conditions, the root of component plant grew profusely into all sections of the root box and intermingled considerably. Water stress resulted in a decline of maize and cowpea root growth. Some researchers believe that under drought condition, roots grow to the wetter parts of soil profile and produce bigger masses of branches while others do not agree with hydrotropism hypothesis [12]. William's research [13] introduced water stress as a limiting factor for corn and demonstrated that approximately 59 percent of the yield variability in three years resulted from water stress. Bingru and Hongwen [9] reported that drought stress increased root mortality rate in 0 to 20, 20 to 40 and 40 to 60 cm layers.

Corn root distribution assessed at tasseling over a 3-yr period showed an average of 94% total root length within the upper 0.60 m and 85% in the upper 0.30 m of soil. A decrease in the root length was observed as the depth increased [4]. Soil water content above and below optimum both cause problem for roots. In dry soils, mechanical impedance and in wet soils, loss of aeration and accumulation of phytotoxins are dominant stress factors [7]. Dwyer *et al*. [14] found that maximum rooting depth for corn increased as available water decreased.

Little information exists on the relationships between root distribution quantities, soil and plant properties and hidden half of plants which remains mystical [15]. The root system is a vital part of the plant and therefore understanding roots and their functioning is key to agricultural, plant and soil scientists [5]. For the last 20 years evidence has shown that roots are more sensitive to small changes in soil water content than to any change in shoot water relations. Corn (*Zea mays* L.) is an important food crop next to rice and wheat in the world, so the objective of this study was to asses the effect of soil water contents on corn root distribution and to determine the most suitable amount of water for the maximum growth of corn in a greenhouse experiment.

MATERIALS AND METHODS

To determine the most suitable amount of water for maximum development of corn (*Zea mays* L.) root, a greenhouse experiment was conducted from 2006 to 2007 at the agriculture faculty of Tarbiat Modares University in Peykanshahr, approximately 10 Km west of Tehran, Iran. Surface s oil of the experimental farm was collected and mixed with chemical fertilizer based on soil test results [16]. Plastic pots, 30 cm in diameter, were f illed with the soil to a depth of 34 cm. By using weather bureau indices for this location and Penman approach estimated water demand in this study was 7010 m^3/ha. Pot area was estimated and then water demand was determined at pot area. Growth period was 134 days. Daily water demand was ascertained and water treatments were performed during this period. Properties of soil and water are shown in Tables 1 and 2 respectively.

Corn variety 704 was used in this study. The experiment was conducted as completely randomized block with five treatments and three replications. 55, 70, 85, 100 and 110 percent of water demand considered as treatments and compared to 100 percent of water demand as control.

Table 1: Soil chemical and physical properties

Depth of sampling(cm)	Particle size (%) Sand	Silt	Clay	Soil Texture	pH	EC($dS.m^{-1}$)	Total N(%)	OC(%)	K (mg.kg^{-1})	P	Ca	Mg	Fe	Zn
0-30	SL	59.8	21	19.2	7.4	2.85	0.046	0.51	540.0	8.2	495.9	360.9	2.0	1.7

Table 2: Irrigation water chemical properties

HCO_3^- (mg.L^{-1})	SO_4^{2-}	Cl^-	Mg^{2+}	Ca^{2+}	Na^+	Ec$dS.m^{-1}$
121	196.6	43.73	29.09	45.29	69	0.574

The total corn roots were taken from all the pots in three stages: i.e. 8-9 leaves (39 days after planting), the silking stage (84 days after planting) and the dough (117 days after planting). The total yield was measured in third growth stage. Wet and dry weights, volume, surface area and length of roots and the ratio of root by dry matter to stem were measured in all three stages.

Roots were washed on 2 mm sieves and their wet weight measured. Root length was measured with root length measurement system (ΔT Device LTD). For this purpose they were stained with a methyl violet stock solution and measured to obtain their length. Roots volume was measured directly through the displacement of water after root immersion in calibrated vessels (on the basis of Archimedes' principle). Root surface area was measured by using Atkinson method presented below:

$$\text{Root surface area } (cm^2) = 2\ \{[cc, \text{root volume}] \times \pi \times [cm, \text{root length}]\}^{0.5}$$

Roots were oven dried during a 48 hour period at 70°C and then their dry weight was determined. SPSS was used for statistical analysis and diagrams were drawn with EXEL.

RESULTS AND DISCUSSION

The effect of water treatments on wet and dry weights, volume, surface area and length of roots was significant ($p>0.05$). This effect on yield was significant, too ($p>0.01$). Significant effect of water treatments on the ratio of root dry matter to stem was not observed (Table 3). The results showed that weight, volume, surface area and length of roots increased by increasing the amount of water applied up to 100% of water demand, but these increases were not linear. Increasing in the amount of water applied, decreased the ratio of root to stem.

A significant difference ($p>0.05$) was found between treatments 85, 100 and 110% water demand when compared with the 55% water demand treatment.

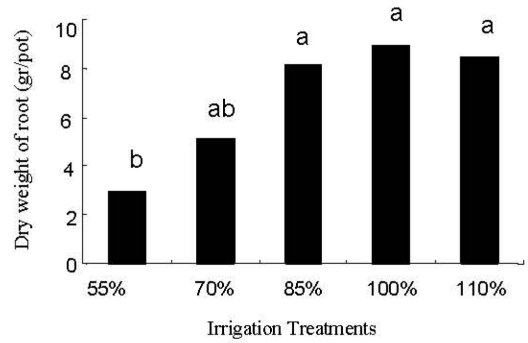

Fig. 1: The relationship between water treatments and dry weight of root in all three stage of sampling

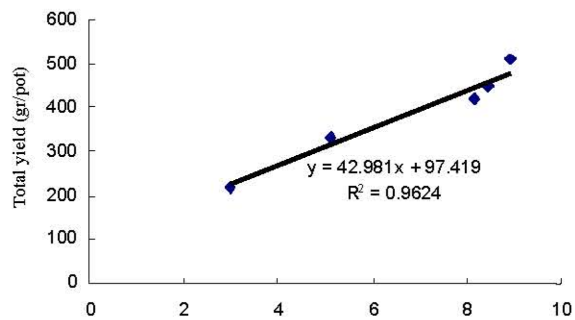

Fig. 2: The relationship between dry weight of root and total yield

The highest amount of the aforementioned parameters was related to 100% water demand treatment and the lowest of them was related to that of 55% water demand treatment (Fig. 1).

In all stages of sampling, the highest values were obtained through the application of 100% water demand. Mean comparisons of all parameters in every stage indicated that the third sampling stage had the highest value whereas the first samplings stage had the lowest value of root's parameters (Fig. 3). There was a linear relation between root parameters and total yield (Fig. 2). It was demonstrated that root parameters significantly affected yield and yield components.

Table 3: Analysis of variance wet and dry weight of root, volume, surface, root length, ratio of root to stem and total yield

Mean square								
Yield	Ratio of root to stem	Root length	Root surface	Root volume	Dry weight of root	Wetweight of root	Degree of freedom	Source of variance
11.832	0.008	349974.148	26360.172	77.089	0.442	215.489	2	Replication (R)
767.026**	0.024ns	47352575.07*	6853288.302*	5040.911*	59.819*	17176.633*	4	Treatment (T)
23.592	0.010	14849339.20	2308328.394	1896.785	18.674	4832.688	38	Error (E)

** Significant in 1% level, * Significant in 5% level, ns is not significant

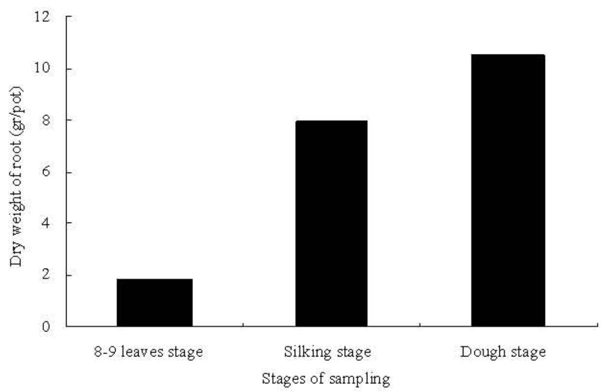

Fig. 3: Mean average of dry weight of root overall stages of sampling

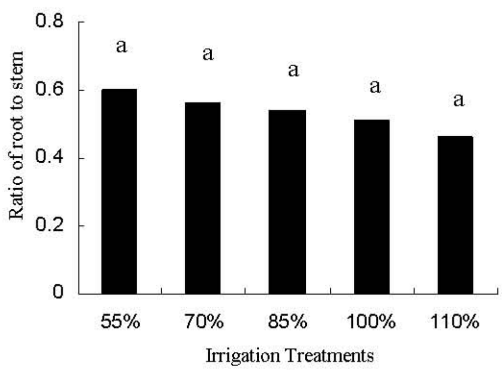

Fig. 4: The relationship between water treatments and the ratio of root to stem in all three stage of sampling

The relationship between water treatments and dry weight of root and the relationship between dry weight of root and total yield have been shown as sample (Fig. 1 and 2). The other parameters such as wet weight of root, length, surface area and root volume, had the same trend and was not showed.

The Ratio of Root to Stem: A negative effect on the ratio of root to stem was observed by increasing the amount of water applied. It changed from 0.65 in treatment of 55% to 0.45 in treatment of 110% water demand but these changes were not significant (Fig. 4). Aboveground parts of plants grew more than roots with increasing water application, therefore the ratio of root to stem decreased. Aboveground parts of plants were affected by water stress prior to roots.

Water deficiency has a more dramatic effect on the aboveground parts of plants since their biomass is always much greater than their root biomass [17]. Mean value of treatments in all three stages of sampling indicated that highest ratio of root to stem belonged to the 55% water

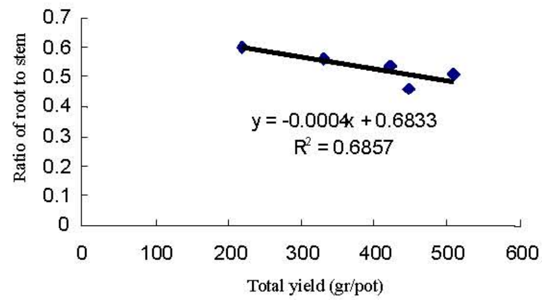

Fig. 5: The relationship between the ratio of root to stem and total yield

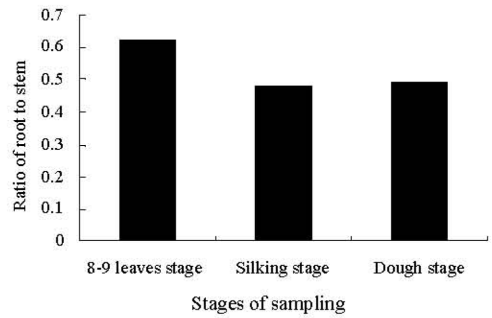

Fig. 6: Mean average of the ratio of root to stem overall stages of sampling

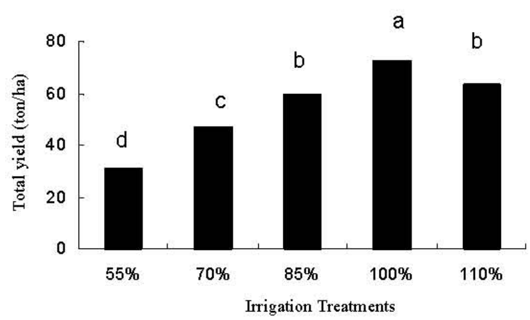

Fig. 7: The relationship between water treatments and total yield in the third sampling stage

demand treatment (Fig. 6). The relationship between total yield and the ratio of root to stem was negative ($r=-0.83$). A reduction in the root to stem ratio was observed when the total yield increased (Fig. 5).

Total Yield: The results showed that increasing water applied had a positive effect on total yield. Significant effect was observed between total yield of corn and treatments ($p>0.01$). Dunckan comparative mean of yields showed that 100% water demand treatment had the highest total yield (72.14 $ton.ha^{-1}$) and 55% water demand treatment had the lowest amount of it (31.12 $ton.ha^{-1}$). The relationship between water treatments and total yield in the third sampling stage has been presented in Fig. 7.

Water stress led to a decrease of wet and dry weights, volume, surface area and root length significantly. These results are in agreement with those reported in literature by Marias and Wiersma [18] and Oliver and Barber [19]. Work from this laboratory and the others showed that optimum level of water stimulated the root growth and deviation from the optimum levels adversely affected its growth. The findings in this experiment also demonstrated that water stress caused a decrease in total yield. Similar results have been reported by William [13] and Wolf *et al.* [20] Asseng *et al.* [21] reported that root growth limited to the upper layer of soil was affected by water stress. Application of water treatments beyond the optimum levels of water demand leads to soil leaching and depletion of available soil nutrients from rhizosphere and decreases the amount of soil oxygen, consequently limiting the soil aeration.

Water stress increased the ratio of root to stem. Therefore shortage of water and mineral elements has a less dramatic effect on roots than the aboveground parts of plants. The root response seems to have an ecological significance when the plant grows under a water deficit. Therefore, shoot growth inhibition helps to save water and to keep tissues hydrated, without significant reduction of plant metabolism. In addition, root growth maintenance improves water extraction from soil at deeper layers. Several studies have revealed that in species like *Betula ermanii, B. maximowicziana, B. platyphylla, P. vulgaris* L. and *Triticcum aestivum* soil water deficit increases the root/shoot ratio due to an increase of root growth and an inhibition of shoot growth [21-23].

It was demonstrated that the roots distributed under inadequate water supply conditions were attenuated, less branched and had lower penetration depth. It was also reported that with increasing water stress, seedling and root elongation rate became restricted. Results showed that the average of measured parameters in dough stage were higher in comparison to other stages, but Dunkan comparative mean analysis indicated that there was no significant difference between the dough and the silking stage. Root elongation rate and the rate of increases in other measured parameters were diminished after silking stage. The results revealed that reproductive parts of plants needed higher amount of water and nutrients after silking stage. After this stage greater amount of water and nutrients move to aerial body and reproductive parts of plants which leads to a diminished root growth rate which is consistence with other reported observations [24].

CONCLUSION

Maximum water use efficiency is obtained when water is applied so that water stress on the crop is minimized and over watering is eliminated. In regard to the lack of significant effect difference among 70, 85, 100 and 110% of water applied treatments, it is concluded that optimum efficiency of water is obtained by using 70 percent of water demand instead of 100 or 110 percent.

It would be necessary to conduct such experiments under field condition with advanced irrigation system to explore the complexity of factors that promote the plant roots system and water relation.

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