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Root-shoot ratio of maize (*Zea mays* L.) as influenced by different levels of water deficit under two different climatic conditions

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Abstract

In order to determine the effect of water stress on biomass accumulation of root and shoot, and their ratio of two maize hybrids (*Zea mays* L.) under the effect of three different irrigation levels, two different field experiments were conducted in a silty clay soil during the autumn season of 2014 and spring season of 2015 at the Agricultural research station of Qlyasan – University of Sulaimani. A split plot design with three replications were used. Three different levels of irrigation were applied, I_1 represented the water requirements of the two hybrids along the growing season from seedling to physiological maturity, I_2 breaking one irrigation after each two irrigation during the vegetative growing season only, but I_3 applied with breaking one irrigation after each two irrigations during the vegetative and reproductive growing season till physiological maturity. Effect of water deficit levels on the growth and development of root and shoot as well as the root-shoot ratio were determined. The root-shoot ratio of the two hybrids was increased with the extended growing period through the growing seasons. The effect of I_3 level of maize root- shoot ratio was greater in comparison to I_1 and I_2. There were differences in response of H_1 and H_2 to irrigation levels, the ratio of root to shoot for the H_2 was greater than H_1 in both seasons.

Introduction

Water deficit occurs when moisture around the roots is reduced to the level that cannot be absorbed by a plant. Root growth mainly affected by the status of soil and water and the proportional decrease of shoot biomass than the proportional decrease in root biomass, leads to an increase in the root:shoot ratio as water deficit stress increased at all growth stages. [1, 2, 3, 4]. Root growth of the un-watered plants was also maintained as the severity of water stress increased, a mild degree of water stress resulted in a net increase in root growth compared to the situation in well-watered plants. In field studies, roots continue in elongation while shoot growth inhibited in plants is subjected to a water deficit situation. [5,6]. Higher grain yield will depend on the factors that control the dry matter accumulation and its partitioning between the root and shoot, the root-shoot ratio may be indicate to the optimum environment of root growth and supporting other parts of the plant, [7, 8, 9]. Response of maize genotypes to water deficit condition can be evaluated by root - shoot dry matter ratio[4]. Root growth and an increase in the root-shoot ratio by plants growing in conditions of low water availability may therefore be interpreted as an important adaptive feature. Root growth

characteristics may be a function of the capacity of a plant to accumulate solutes and maintain turgor in its roots when subjected to a soil drying cycle, reducing dry matter products under such drought conditions [10,11,12, 13]. Result of a research by Kim et al., 2015 [14]showed a 56% decrease in accumulated dry matter of roots of corn plants that exposed to severe water deficit conditions, while corn root growth under moderate water deficit condition during the vegetative stages had been shown to differ among hybrids with contrasting root morphology [15]. Plant drought can cause numerous structural, physiological and biochemical modifications, including reduction in leaf area, stem extension, root proliferation, reduced water use efficiency [16]. Response of maize plants to water deficit stress was differ according to growth stages from vegetative to seeking and post silking, comparing two growth periods. Differences were found in the rate of decreasing in root dry weight from 24% to 47% in response to the severity of water stress and the growth periods. [17, 18, 19], alteration in metabolic activities [20], inhibition of enzymatic activities, imbalanced ionic concentration and interruption in accumulation of various solutes [21,22].
Amos and Walters, 2006 [23] found that the average root:shoot ratio varied from 0.68 at plant emergence to 0.16 at physiological maturity for unstressed plants. Changes in the root-shoot ratio was observed with water shortage, but more decreasing trend in shoot weight of drought than root weight was realized. Effect of environmental changes on a shoot is so much slower than plant roots [24, 25]. Shoot-root ratios in various crops increase with aging [26, 27, 28], and the environmental stresses increase relative weights of roots compared to shoots [29, 30]. The objective of this study was to determine the effect of water deficit on root - shoot ratio of two maize hybrids and its influence on the dry matter accumulation and its partitioning to root or shoot.

Materials and Methods

The study was conducted to investigate the effect of water deficit on the growth of root and shoot, and their ratio through the determination of accumulated dry matter and its partitioning to these two parts at two different seasons. The study was implemented through conducting two different field experiments in silty-clay soil at the Agricultural Research Station-Qlyasan, Faculty of Agricultural Sciences, University of Sulaimani during the summer season of 2014 and spring season of 2015. Two maize hybrid (H1 & H2) were cultivated under three different irrigation levels of the regulated water deficit system as, I_1 = Full irrigation of crop water requirement. I_2 = One irrigation breaking after each two irrigations during the vegetative growth period only. I_3= One irrigation breaks after each two irrigations during the vegetative and reproductive growth periods till physiological maturity.

The field experiment was laid out in Split-Plot design, in which the irrigation levels considered as the main treatment and the two hybrids as the sub-plot treatment with three replicates. They were cultivated on the rows of 0.7m apart and 0.25m between the plants within the rows. The hybrids were planted on July 17th 2014 (for Autumn season) and on April 9th 2015 for the spring season. For both seasons nitrogen and phosphorus were applied as recommended, other agricultural processes were behaved when required, except the irrigation schedule which implemented as mentioned above. For proper irrigation schedule, the field capacity and wilting point of the experimental soil was estimated by using tensiometer. Representative samples were taken from the field. The soil samples were air dried and passed through a 2 mm sieve. About 20 kg of the sieved soil was added into a plastic container and the tensiometer cup was embedded at the depth of 15 cm and the water was applied to saturate the soil. Destructive sampling of entire plants were taken from inner rows of all experimental units each 10 days [from V4(Vegetative growth stage no.4) to R6(reproductive growth stage no.6 or stage of physiological maturity(PM)], Ransom, (2000), of the two maize hybrids.. The samples were separated to shoot (leaves and stem) and root. Fresh weight was taken for both parts and oven dried at 60^{o}C till complete dryness then they were waited. For determining the Root-Shoot ratio the following equation was used:

$$\text{Root-Shoot Ratio} = \frac{\text{Weight of root system (g)}}{\text{Weight of shoot (g)}}$$

The data of the two different field experiments were statistically analysed by using Microsoft Excel, and all possible comparisons among the means were conducted following Least Significant Different test (L.S.D) at significant level of 0.05.

Results and Discussions

Shoot Dry Weight (g):

Fig.1, reveal the effect of water deficit levels on the dry matter accumulation and partitioning to shoot at the autumn season for the period from V4 to R6(August 10 to November 17) and spring season V4 to R6 (from May 10 to July 23). In autumn season there was significant exceeding of DM accumulation of (I_1) on October 13, November 5 and November 17 in comparison to other water deficit levels with 174.217, 172.903 and 170.487 g pl $^{-1}$ respectively, while (I_2) showed significant exceeding in DM accumulation on August 10 and August 31 recording 13.085 and 108.588 g pl $^{-1}$ respectively. The third level (I_3) showed the minimum value of dry matter accumulation partitioned to shoot on August 31, October 13, November 5 and November 17 with 79.785, 124.103, 117.057, and 107.463 g respectively. At spring season there were significant differences among all water deficit levels of dry matter accumulation except May 20 and May 31. There is exceeding of I_1 on May 10, June 9, June 18, June 30 and July 12 in comparison to other water deficit levels, giving the values of 5.722, 71.900, 152.802, 202.682, and 215.572 g, respectively, while (I_2) showed significant exceeding in July recording 144.363 g, but the third level (I_3) showed the minimum amount of dry matter accumulated on May 10, June 9, June 18, June 30, July12 and July 23 with 4.133, 55.472, 70.032, 139.725, 146.085 and 92.195 g respectively.

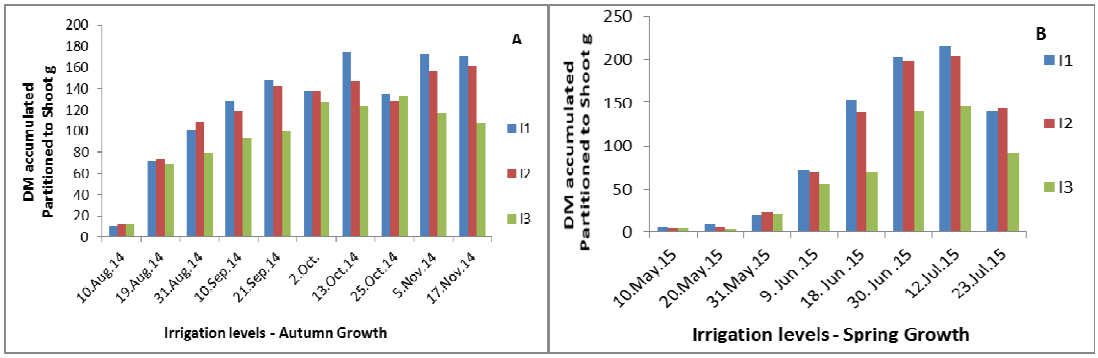

Fig.1, effect of water deficit levels on the dry matter accumulation and partitioning to shoot in

Autumn season (A) and Spring season(B)

The results from autumn season indicate rapid increasing in dry matter accumulation and partitioning to shoot for the period from August 10 to October 13, in which beyond this date, there was a slight declining in the rate of dry matter accumulation till the end of season. The rapid increase of dry matter accumulation is an obvious indication of the effective growth and the linear phase of growth and accumulation of dry matter, but at the end of the vegetative growth (Oct.13) there was no increase in the number of plant leaves and leaf expansion leading to the reduction in accumulated dry matter, [5, 7, 8, 9]. While at spring season the results showed the rate of dry matter accumulation and partitioning to shoot under the effect of three levels of water deficit, they indicate to be increased along the season till July12 with higher rate than other season, this might be due to more favourite climatic condition, especially the temperature, [10, 24, 25, 18, 15]

In both seasons there was significant differences in the effect of irrigation treatments (I_1, I_2, and I_3), which might be resulted from the unstressed condition under the (I_1) that fully irrigated along season, (Amos and Walters 2006), while the other treatments (I_2 and I_3) which reveal water deficit condition from moderate to severe conditions were showed minimum values due to corn plant responses to the water deficit conditions, that agree with the works of previous researches [10, 29, 1, 12, 14, 5].

Hybrids:

Fig.2, reveal the response of two maize hybrids to the rate of dry matter accumulation partitioned to shoot at both seasons, there was exceeding of the first hybrid (H_1) at the period from September 21 to November 17 showing 147.903, 149.772, 162.387, 144.968, 172.850 and 164.98 g pl^{-1} respectively. While the second hybrid (H_2) recorded the minimum value showing 112.617, 118.588, 134.818, 119.668, 124.557 and 128.291 g pl^{-1} respectively.

At spring season there were no significant differences in the effect of the two hybrids on dry matter accumulation at the beginning of the season, while the first hybrid (H1) exceeded H2 at the later stages (June 18 and June 30), showing 146.047 and 200.169 g, while the second hybrid (H_2) recorded the minimum value with 95.540 and 160.029 g respectively.

There was significant, exceeding of the first hybrid growth compared to the second at both seasons, the first hybrid showed better growth performance (34.58%) than the second along the growing season, that may relate to genetic differences performing different tolerant ability to the condition of water deficit. These results agree with previous works conducted by Rezaeieh and Eivazi, 2011 [31].

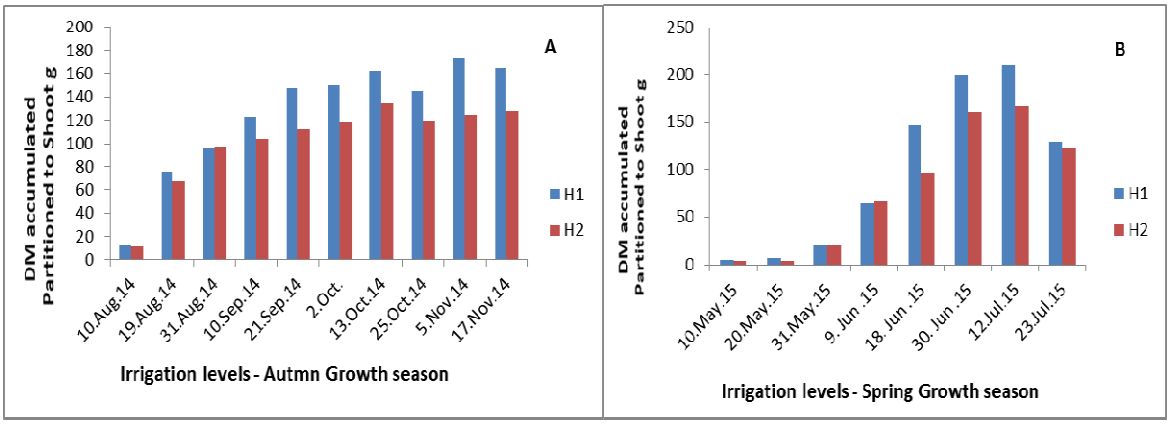

Fig2, Response of two maize hybrids to the rate of dry matter accumulation partitioned to shoot in Autumn season (A) and Spring season(B)

Root dry weight (g):

Fig.3, represent the effect of water deficit levels on the dry matter accumulation and its partitioning to root for the period from August 10 to November 17 at autumn season and May10 to July 23 at spring season. In autumn season there were significant exceeding of I_1 and I_2 in most growth stages, while I_3 showed the minimum amount of dry matter that allocated to root that may relate to lower quantity of water irrigation that provided to the corn root zones that influenced the physiological processes and dry matter accumulation [17, 21, and 22]. Full irrigation (I_1) showed significant exceeding for root weight at post silking stage on September 21 and October 13 (Table 1), in comparison to other deficit levels with 28.142 g and 29.375g respectively, while (I_2) showed high and significant root weight on August 19, August 31 and October 2

recording 8.976, 15.435 and 30.948 g respectively. The minimum values of dry matter accumulation and its partitioning to root was for the third level (I_3) that represents severe water stress on August 31, September 21 and October 02, recording 12.252, 19.467 and 21.422 g respectively.

At spring season there were steadily exceed in root weight for I_1 on May 20, June 18 and June 30 with 0.618, 22.073 and 40.820 g respectively. While I_2 showed significant exceeding on May 10 with 0.596 g, however I_3 level showed the minimum weight of dry matter accumulation partitioned to root on May 10, May 20, June 18 and June 30 g recording 0.353, 0.371, 8.820 and 21.552 g respectively, Exceeding of the effect of I_1 and I_2 level during the period around silking demonstrates the abundant and moderate water condition that corn roots adapted, while under the sever condition of I_3 level the minimum dry matter allocated to roots rather than shoot system or other parts of the plants, [27, 4].

Table 1, Effect of water deficit levels on the periods of growth stages in both seasons

Irrigation	No. of days to 50% tasseling		No. of days to 50% silking	
	Autumn season	Spring season	Autumn season	Spring season
I_1	53.5	64.833	59.5	70.833
I_2	52.823	62.167	59.333	69
I_3	51.667	63.333	58.667	69.5
L.S.D 0.05	1.459	1.94	N.S	1.358

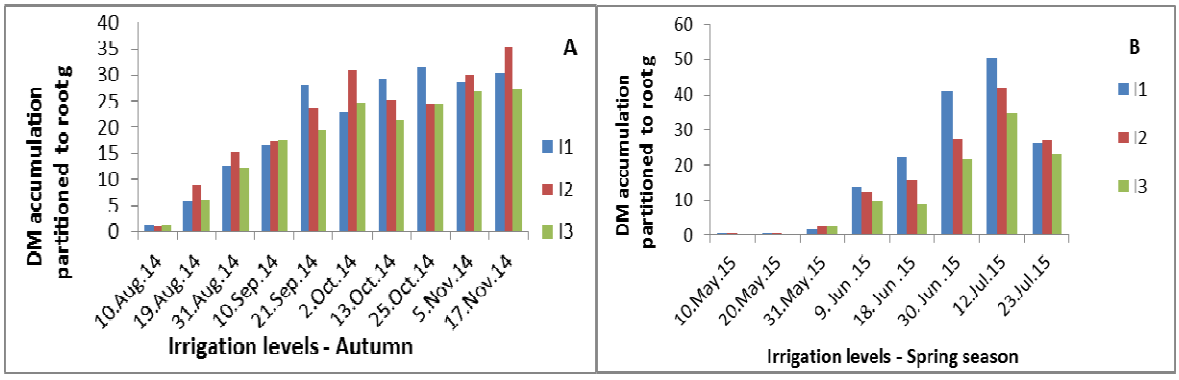

Fig.3, effect of water deficit levels on the dry matter accumulation and its partitioning to root in Autumn season (A) and spring season(B)

Hybrids:

Fig. 4, shows the effect of two maize hybrids on dry matter accumulation and its partitioning to root at both seasons. For an autumn season there was significant superiority of the first hybrid (H_1) in dry matter accumulation on August 19, August 31 and September 21, giving 8.622, 16.688 and 27.449 g, respectively, while the second hybrid H_2 was exceeded H_1 only on September 10 with 19.391 g. The second hybrid (H_2) recorded minimum weight on August 19, August 31 and September 21 g with 5.456, 10.210 and 20.114 g, respectively, in which the first hybrid was recorded the minimum weight only on September 10 giving the value of 14 .816 g.

At spring season there were significant differences in dry matter accumulation between the two hybrids during the mid season. There was exceeding of the dry matter for the first hybrid (H_1) on June 9,June 18 and June 30 with 13.361, 18.563 and 36.480 g, respectively, while (H_2) showed significant exceeding at post silking on July 23 recording 27.804 g.

In both seasons the superiority of dry matter accumulation and its partitioning to root was for H_1, especially during the linear phase of pre-silking growth, indicating the presence of genetic differences between the two hybrids. The growth performance of H_1 was better in both seasons at the vegetative growth stage. In which there was a higher dry matter partioning to the roots for H_1 while in the later stages post silking the H_2 hybrid showed higher rate of dry weight especially during the spring season. These results are in agreement with those of Mohammedi et al., 2012 and Reynolds and Antonio,1996 [2, 30].

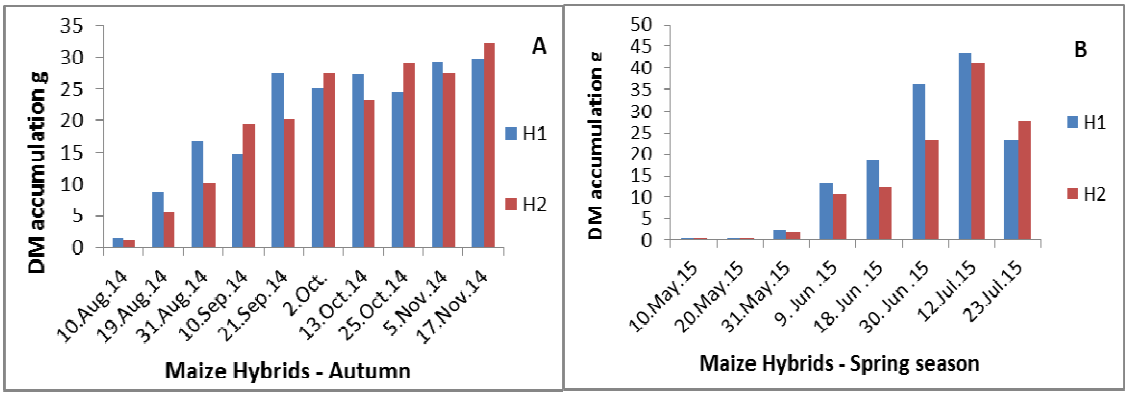

Fig. 4, effect of two maize hybrids on dry matter accumulation and its partitioning to Roots in Autumn season (A) and spring season(B)

Root-shoot ratio:

Fig.5, indicate the differences in the effect of water deficit levels on root-shoot ratio at both seasons, in autumn, although the level I_1 recorded the minimum value of root-shoot ratio at different growth stages in compare to other water deficit levels due to normal growth of maize hybrid roots under the effect of this level, there was increasing in the ratio between the maize root dry weight and that partitioned to the shoot from the beginning to the reproductive growth stage R3 (in which very little root growth occurs after this stage) by 25.96%, while root-shoot increasing of other two levels (I_2 and I_3) for the same period were 39.26% and 22.69% respectively. Results revealed essentiality to growth shifting in roots under the effect of water deficit levels(I_2 and I_3),[11].

In Spring season there were no significant differences in root-shoot ratio among levels of water deficit except at the beginning of the season on May 10 and Jun 30, in which I_2 and I_1 were with the largest value of root-shoot ratio (0.161 and 0.208)respectively, while (I_3 and I_2) showed the lowest ratio of root to shoot at the two mentioned sampling dates by 0.139 and 0.097 respectively. Hence increasing in ratio between the root to shoot in the spring season with favourite environmental factors especially means of air temperature at least during vegetative growth, in the period from seedling to post silking (near R3 stage) were valued 31.72%, 15.26% and 66.83% for $I_{1,I2,}$ and I_3 respectively. There were obvious shifting in dry matter portioning between shoot and root, especially under the effect of I_3 which might be due to the increase of ambient temperature post vegetative growth stage of this season,[96,29,and 27], or may resulted from the alteration in growth development that influenced much more under the effect of I3 level [19, 28, 3].

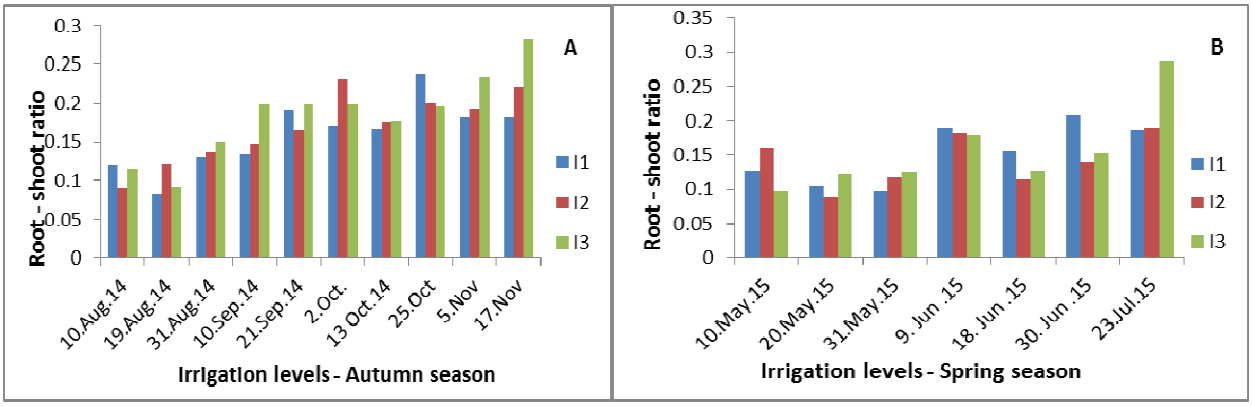

Fig.5, effect of water deficit levels on root-shoot ratio in autumn season (A) and spring season(B)

Hybrids:

Fig. 6, indicates significant differences between the two maize hybrids in root-shoot ratio in both seasons, in autumn season the hybrid H_1 exceeded H_2 in root-shoot raito on Aug.19 and Aug.31 by 0.115 and 0.169 respectively, while H_2 was superior from Sept.10. At spring season, the significant differences between the effect of both maize hybrids on the root-shoot ratio was shown on May 31, Jun 9, and Jul.23 only, in which the superiority was referred to H_1 in May 31, Jun 9 with 0.129 and 0.207 respectively, while on Jul.23 the H_2 exceeded H_1 giving the value of 0.261. There was a variation in hybrid responses to water deficit conditions at different stages of growth seasons that might be adjusted genetically to influenced physiological and biochemical modifications, including shoot biomass decreasing and root dry weight accumulation [31, 13, 20].

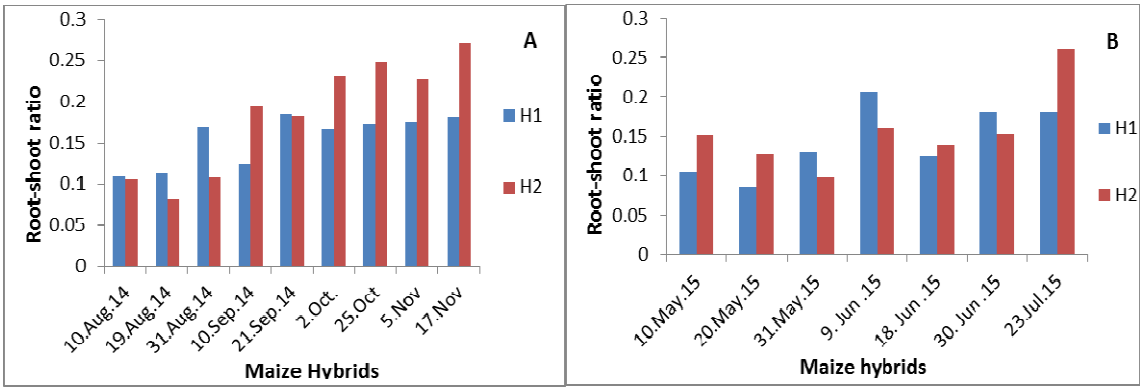

Fig. 6, root-shoot ratio of the two maize hybrids in Roots in autumn season (A) and spring season(B)

Interactions between the water deficient and the genotype:

Table 2 and 3 show the interactions between the effect of water deficit levels and response of two maize hybrids to root-shoot ratio for different growth stages at both seasons. At autumn season the interaction of I_2H_1 exceeded the others in vegetative growth stage pre tasseling on Aug.19 and Aug.31 for the values of 0.157 and 0.195 respectively, but the interaction of I_1H_2 showed the minimum value of root-shoot ratio (0.063 and 0.068, respectively), while the interactions of I_3H_2 exceeded in the period post silking on Oct.25 and Nov.17 recording 0.294 and 0.362 respectively, however the smallest ratio of root to shoot was recorded by I_3H_1 and I_1H_1 recording 0.096 and 0.131 respectively.

For the experiment conducted in spring season there we no significant differences among the effect of interactions between water deficit levels and hybrids responses along the growing season except at the

vegetative growth stage pre tasseling on Jun 30 in which the interaction I_1H_2 exceeded others with 0.230 ratio while the interaction I_2H_2 showed the minimum value (0.086).

Table 2, the interactions between the effect of water deficit levels and response of two maize hybrids on root-shoot ratio at autumn season

Interactions	10.Aug.14	19.Aug.14	31.Aug.14	10.Sep.14	21.Sep.14	2.Oct.	25.Oct	5.Nov	17.Nov
I_1H_1	0.122	0.102	0.189	0.111	0.21	0.139	0.233	0.135	0.131
I_1H_2	0.119	0.063	0.068	0.158	0.171	0.203	0.243	0.229	0.231
I_2H_1	0.089	0.157	0.195	0.121	0.179	0.202	0.194	0.178	0.217
I_2H_2	0.091	0.085	0.077	0.173	0.15	0.26	0.206	0.206	0.222
I_3H_1	0.118	0.085	0.122	0.143	0.167	0.159	0.096	0.216	0.201
I_3H_2	0.11	0.099	0.179	0.254	0.23	0.237	0.294	0.25	0.362
LSD 0.05	N.S	0.0379	0.044	N.S	N.S	N.S	0.074	N.S	0.077

Table 3. The interactions between the effect of water deficit levels and response of two maize hybrids on root-shoot ratio in Spring season

Interactions	10.May.15	20.May.15	31.May.15	9. Jun .15	18. Jun .15	30. Jun .15	23.Jul.15
I_1H_1	0.08	0.059	0.112	0.214	0.134	0.186	0.155
I_1H_2	0.174	0.15	0.082	0.168	0.177	0.23	0.216
I_2H_1	0.169	0.088	0.123	0.205	0.134	0.192	0.196
I_2H_2	0.152	0.093	0.11	0.156	0.093	0.086	0.184
I_3H_1	0.066	0.11	0.152	0.202	0.106	0.163	0.189
I_3H_2	0.129	0.137	0.101	0.155	0.15	0.142	0.382
LSD 0.05	N.S	N.S	N.S	N.S	N.S	0.066	N.S

Conclusions:

The effect of water deficit levels on root-shoot ratio for two maize hybrids resulted from two season cultivation has concluded that the situation of lacking water at root zones created under the effect of water deficit levels (I_2 and I_3) has enabled root development more than that of I_1 treatment for both seasons especially at the later stages of growth or reproductive stage causing reduction in the maize kernel yield. Response of H_2 was more obvious than H_1 to the water deficit conditions, that demonstrated in the effect of interactions between water deficit levels and responses of the maize hybrids which were varied according to the growth stages in both seasons. The maximum ratios of the root to shoot were shown in the interactions(I_3H_2 and I_2H_2) for autumn and spring season at the growth stages post silking and pre-tasseling respectively.

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