Effect of Drought Stress on Soil Water Potential and Leaf Growth in Corn

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Abstract: This study is performed in the method of factorial and split plots in 4 replication and 2 water stress factors with 4 levels as first factor (S3: 25% of S0 treatment irrigation), (S2: 50% of S0 treatment irrigation), (S1: 75% of S0 treatment irrigation), (S0: control, 100% of irrigation at FC point). Growing periods were assumed as second factor with 3 levels (V3: seed filling period), (V2: from end of V1 treatment to end of pollination), (V1: vegetative period (from plant establishment to the appearance of the first double ring). This experiment is performed in 3 crop years (1380 – 81, 79-80, 78-79) in Azad University of Ahwaz. The result showed that water potential of leaf and water potential of plant decreases by decreasing water potential of soil but reduction of water potential of leaf was higher than root water potential, so that by 0.5MPa reduction of soil water potential, root potential decreased 0.7MPa and leaf potential decreased 0.97MPa. Water potential of the leaves decreased 0.1 – 0.6MPa in S1 treatment or moderate stress, but osmotic adjustment was above 0 and leave growing continued until appearance of the first double ring, the leaf water potential was -0.6MPa and the leaf growing didn't stop, but after this step, leaf water potential decreased to 0.15 MPa by applying S2 treatment and leaves growth was zero. In LAI (leaf area index) above 2.7 Reduction of leaf water potential to 0.1 MPa leads to stop leaf growing. LAI showed 2.5 units difference between S0 treatment (control) and S3 treatment (severe stress). Stomata resistance was 7.2 in severe stress and 4.3 in control position until the appearance of the first double ring. But after the first double ring, stomata resistance was above 9.7 in severe stress position. By comparing control position with increasing stress intensity, the absorption of potassium ion increased and K concentration of middle leaves was more than the root and terminal leaves in control treatment (without stress). Potassium transmission from middle leaves to terminal ones was the function of stress intensity. Potassium transmitted from root to middle leaves and from them to terminal leaves to 0.15bar water potential of soil. After 0.10 bar, the process of potassium transmission and accumulation of it stopped in upper leaves of corn. 3 days after applying S2 treatment, K^+ accumulation in was 1.3 – 1.7 higher than control treatment in terminal leaves.

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1. Introduction

Corn Belt region have close correspondence with dry belt due to its physiological characteristics (c_4) that they are seeking for warm areas. These areas provide ideal condition for high performance of this plant except water supply (3).

Most of reports show that performance of corn decreases because of changes in permeability of membrane and changes in absorption process and transmission of necessary nutrient and also because of not providing pressure of osmotic adjustment and all of these cause leaves growth decreasing and severe leaf area index decreasing and stomata resistance increasing against entering CO_2(5).

Water potential (Ψw) of different parts of corn change every day and the plant has maximum content of water when it has maximum water potential (Ψw). The relation between (Ψw) and relative humidity is positive linear regression. At maximum amount of (Ψw), maximum leaf relative humidity is obtained and propagated leaves of corn have higher pressure potential than developing leaves. The speed of leaf growth and photosynthesis decreases severely in (-2) – (-4) and (-6)-(-12) bar leaves water potential (1, 2 and 6).

1. The study was showed that osmotic adjustment potential and osmotic potential in growing leaves of these 2 plants (corn, sorghum) in 24 hours. In the last day it was seen that decreasing water potential to -6 bar increases leaf growth speed because of increasing pressure potential(8).

2. Banziger,M., Betran,F.j., (1997) studied corn and sorghum, they showed that in each step of growth low water potential can close stomata in the leaves which located under the height but this closure isn't complete and stomatal resistance for Ψw=-20bar is 10 sec / cm. in Ψw=-20bar, in reproductive step, leaf stomatal resistance of corn and sorghum didn't

change by changing water potential, so, stomata didn't show sensitivity to water potential. Stomata closure began at Ψw= -8bar. Closing and opening of stomata take 15-20 minutes due to water stress; it means that it is slower than the effect of CO_2 concentration on closing and opening of stomata. That occurs fast and takes 2.5 – 5 minutes.

3. ABA synthesis prevents K+ absorption and releasing of it and causes stomata closure. Water storage excites ABA synthesis and exasperates stomata closure (6).

4. Opening and closing of stomata was more complete than the other growth period due to drought stress and before flowering period and because of this, the effect of water shortage decreased entering CO_2 for photosynthesis (11).

5. By regulating osmotic pressure, K^+ ion entering increases significantly and it causes increasing cells pressure potential. Cells pressure potential of protective cells of stomata is higher than cells around, it leads to stomata closure. However, in non-stress condition, entering water stimulates K^+ ion transmission to protective cells and leads to open the stomata (3, 5and 9).

6. In drought stress condition, potassium absorption will be double higher than desirable conditions (15).

7. Potassium absorption is higher than the other elements in water stress conditions and in plants such as corn and wheat, causes increasing resistance against water shortage. Sinha stated that increasing of potassium absorption process and its storage in plants such as wheat and corn causes higher resistance against water shortage (7, 10).

8. The process of potassium absorption. They said that the reason of potassium absorption in drought stress is an active absorption mechanism of this ion, unlike diffusion phenomenon, the plant increases K^+ concentration in roots and upper parts of to increase resistance against drought by consuming energy. increasing potassium absorption has positive influence on leaf area index, reinforcement of ATP synthesis and NADPH, more synthesis and regulating stomata closing and opening, the number of stomata, increasing water absorption in water stress conditions and making suitable inside condition through regulating osmotic pressure and decreasing transpiration.

Potassium absorption increases in the flowering step through root, or, this element is transmitted from the upper leaves to lower ones so fast to decrease water potential of air parts would decrease more and water could move toward these organs.

2. Methods and Methods

This survey is performed in factorial experiment and split plots in 4 &2 replications in 3 years. In 1st factor, water stress treatment was planned and executed based on various humidity ratio of the field capacity point (FC). 10 samples were selected from 0-30 and 30-60 cm depth of soil before cultivation by sampling drill, then, field capacity and permanent wilting point was calculated: (PWP=14.7) and FC=24.6.

Soil outward special weight was estimated by volumeter cylinder method and Pa = 1.3 gr / cm^3. These 3 parameters were permanent during the experiment. Weight method was used to determine percentage of soil humidity and volume humidity was also calculated by following formula. The amount of input water to each plot is measured by using these calculated parameters and following formula.

By installing parshal flume and locating water meter, the amount of input water to each plot was applied.

2.1 Treatment of different plant growth periods (2nd factor)

3 levels of different plant growth periods were studied as following in 2nd factor:

1. Green phase (V1): this phase was determined through growth system by microscopic observation after germination and third irrigation in field until appearance of the first double ring (DR).

2. Reproductive phase (V2): this phase starts appearance of the first double ring to the end of pollination.

3. Seed filling phase: this phase (V3): this phase starts 3 weeks after appearance of male flowers to the end of growth period and formation of seed black layer.

2.2 Statistical models

Equation (1) shows the statistical model in the study. In this model, factorial experiments were used. The basic design was complete randomize block with 4 replications that two factors have been used:

$$X_{ijk} = \mu + \delta_i + \delta_j + \delta_k + \delta_{jk} + \varepsilon_{ijk} \qquad (1)$$

In this model:

X_{ijk}: Each observed value, μ : The average population, δ_j : The effect of first factor,

δ_K : The effect of second factor, δ_j : The effect of block, δ_{jk} : The interaction between the first and second factor, ε_{ijk} : The experiment error

Because of application these statistical models prevent from compound phenomenon (soil × irrigation effects), also both factors were equal importance.

2.3 Recognition treatments of experimental

In The first factor (S), the amount of water that keeps the field in the field capacity point (FC), 100% considered, then based on the amount of water, water stress treatments were designed. In the second factor (V), Period of growth was studied (Table 1).

2.4 Implementation of water stress treatment

Before sowing by drill sampling, 10 samples of 0-30 and 30-60 cm soil depth were taken. The samples were sent to the soil laboratory.

Table 1. Treatments in experiment

Levels of Drought Stress	Different Growth Period
S_0 : Full irrigation point of FC, control, without water stress	V_1: growing phase, the establishment of the plant stem to the emergence
S_1 : 75% of the amount of irrigation treatments I_0, mild stress	V_2: natal phase: to stem the rise of coffee being resilient and end silk pollination
S_2 : 50% of the amount of irrigation treatments I_0, severe stress	V_3: grain filling phase: the end of pollen grain maturity and the emergence of black layer
S_3 : 25% of the amount of irrigation treatment I_0, very severe stress and point of PWP	-----------

By using pressure plates, permanent wilting point (PWP=14.7%) and field capacity (FC=24.6%) was measured in the field. By the method of cylindrical gauge volume, soil bulk density (Pa=1.3 g/cm^3) was calculated. FC, PWP and Pa parameters during the experiment were considered fixed. These parameters are used in Equation 4. This formula calculates the amount of water input to farm. From equations 2 and 3 were used to calculate percent weight and volume of soil moisture:

$$\%\theta_V = \frac{W_1 - W_2}{V} \times 100 \qquad (2)$$

$$\%\theta_M = \frac{W_1 - W_2}{V_2} \times 100 \qquad (3)$$

$\%\theta v$: Percent volume of soil moisture
$\%\theta m$: Percent weight of soil moisture
W_1: Soil wet weight
W_2: Soil dry weight

Using the parameters calculated above, the amount of water input to each plot (plot of bundles and were built out of water) was calculated from the following formula:

$$V = \frac{\theta_V.A.D_S}{E} = \frac{\theta_m.P_a A.D_S}{E} = \frac{(Fc - pwp)p_a.A.D_S}{E} \qquad (4)$$

V: Amount of water necessary for each irrigation (cm^3)
A: Experimental plate level (cm^2)
E: Irrigation efficiency (0.8%)
D_s: Root penetration depth (trench excavation method was used).

With installation Parshal flume and the water meter, the amount water input to each plot was controlled.

2.5 Estimation of total water potential and osmotic potential of leaf and root

We used Weight method (by using glycol polyethylene), standard solution with different molarity and steam balance through psychometric thermocouple to measure total water potential and osmotic potential of leave and root so that after uniformity seen in results in both methods and more accuracy and speed of this method, we only use psychometric thermocouple method.

The sample was selected from the youngest leaf whose glycol was diagnosable. 5 pieces of the leaf were separated and weighted, then put in standard solution. Total water potential was calculated by the curve and osmotic potential was measured based on Van´t Hoff rule.

Different samples were selected from different depth of the root by using sampling drill and Transhe excavation and total water potential, osmotic potential of the root were calculated.

3. Result

3.1 Water potential of root, soil and the leaf

Considering Water potential of soil, root and the leaves during stress period showed that all water potential (with various levels) decreased and water potential of soil had constant reduction. Root water potential and leaf water potential didn't have constant reduction trend. Root and leaf potential were constant in middle stress by decreasing osmotic potential, leaf tubing and regulation of osmotic pressure. The trend of root and leaf potential changing depends on soil water potential. These 2 potential decreases by decreasing water potential of soil, but decreasing leaf water potential was higher than root water potential reduction. In other words, root water potential decreases -.07MPa and leaf water potential decreases -0.9MPa by decreasing soil water potential. In fact, the root provided a balance between soil water potential and leaf water potential for transmitting more water from soil to the leaves. Increasing water stress, especially in water potential higher than (-0.8MPa) causes water potential of the leaves and root decreasing simultaneity. It occurs when regulation of osmotic pressure and decreasing osmotic potential didn't satisfy the need of osmotic adjustment necessary for growth and metabolism. At this point, when mean water potential of the root was -1.8MPa, mean leaf water potential was -1.3MPa and mean soil water potential was -5.5MPa and the plant started to dejection.

Water potential of soil increased by water injection and root water potential increased at the point that soil water potential was above -0.5MPa. It means that the plant started to absorb water.

Comparing water potential and its component during different growth periods showed that in vegetation period (V1), water potential of the root and leaf changes by changing soil water potential before appearance of double ring.

Water stress, water potential of the leaf and root have similar behavior, the root lost its potential because of decreasing soil water potential and the lack of enough propagation, as a result, the leaves were wilted. This trend occurred in reproductive phase (V2), when the plant has root propagation and also regulation of osmotic pressure and leaf tubing. This trend was also different from vegetative phase (V1) and the root had higher resistance in changing water potential. The changing of water potential of the leaf was less than V1 and V2 at seed filling period and the greatest trend of changing was in water potential of bottom leaves and it might because of the senility of these leaves.

Leaves growth of growth step was max at -0.2 water potential. Leaves growth decreased gradually at lower than -0.2MPa and stopped at -0. 8 MPa so that leaves didn't grow at all in 3- 4 day period. They didn't have any increase in weight by applying water stress treatment (S1: middle stress). Water potential of the leaves decreased to 0.1 – 0.16MPa. At preliminary growth step which the area of the leaves is little and the sweating area is not too much. This water potential reduction of the leaves cannot make osmotic adjustment zero and the leaves continue growing slowly. But at next steps of growing, leaves growing stopped completely by decreasing water potential at 0.5MPa. At preliminary growing step, in addition to low sweating, the root supported by using water potential decreasing and getting some water from the soil and it causes providing osmotic adjustment for leaf growing, but at next steps: (LAI=4), high sweating offsets root support from water supply, especially at germination step that LAI is maximum, even in middle stress, leaf weight growing stopped and it causes early yellowing and infusion of older leaves.

Applying more severe stress, for example 50% of the water that field keeps at FC level (S2 treatment) causes more changes in water potential of the soil, root and the leaves. Water potential decreased 0.2 – 0.3MPa and water potential in upper leaves were higher than the other ones. It shows more severe reduction so that upper leaves had the mean reduction of 0.37MPa and the lower leaves had the mean reduction of 0.28MPa.

1. Considering accumulation trend and potassium transmission
2. Considering stomata resistance

The greatest mean obtained was LDW associated with control that had 90.22 gr (accumulation of dry material) in bush that was higher than S1 = 65.71, S2= 56.93 and S3 = 49.21. In the trend of this period dry material increasing had slow rate until 34 days after cultivation. Increasing of the dry material was faster, after this step. Maximum accumulation of dry material of the leaf occurred in flowering period and after seed formation, accumulation of dry material was limited due to photosynthesis allocation of material for seeds, the accumulation of dry material was limited and the leaves started to infuse and be yellow. All of this was due to reduction of accumulation of dry material in leaves.

Applying water stress in different growth periods of the plant showed that maximum reduction of dry material accumulation occurs when water stress is applied in reproductive period (V2) and after double ring formation. Because, applying water stress leads to reduction of LDW due to fast leaf growing and accumulation of dry material.

4. Discussions

Water potential of the root and leaves decreased by decreasing water potential of the soil. Soil water potential had constant decreasing trend in different levels of water stress treatment and water potential of the root & leaf showed resistance against this decreasing trend, however soil water potential decreased but water and root water potential showed significant resistance until (S2) water stress treatment, but, at more severe water stress, reduction of water potential of the leaves was more than reduction of root water potential. In fact, root resistance against reduction of soil water potential was more than upper organs, especially the leaves. The root makes a modulator role of drought stress effect in itself. It has less changes of water potential than upper organs. Because it is the first organ that is exposed to drought stress and can regulate osmotic pressure by itself and because the root stores some water in itself and also because of being near to water source in soil, but, root resistance ended against water potential reduction in severe water stress (MPa=-0.8) and root water potential decreased significantly (MPa=-1.8) the plant is completely withered. Water potential of root and leaf increased by further water injection at this point. Some of the plant didn't get out of this point. They were placed in permanent wilting point and so they were lost (6, 4 and 13).

The most critical growing period of corn was vegetative (V1). It means before appearance of double ring that couldn't show much resistance against drought. some behaviors such as leaf piping, stomata resistance and osmotic pressure were more than the other periods., so that no adjustment could be done in water stress and also the root system of the plant didn't grow completely, as a result, propagation radius was limited and water absorption was low, but, root support of water supply for upper organs increases in the next growing steps (V2, V3) and also physiologic behaviors such as percentage of leaf piping and increasing stomata resistance and osmotic pressure. Reduction causes adjustment of stress intensity.

Stomata resistance increase in front and back surfaces of the leaves. Stomata resistance increasing was higher at back surface. Stomata resistance off back and front surfaces of V1 period was less than V2 and V3 periods. Andrade,F. H.,Cirilo,A.G.,Uhart,S.A., and Otegui (1996) believes that stomata resistance is not physiologically completed. At the beginning of growth, as a result, they didn't show much resistance against water stress but stomata resistance increased.

Potassium accumulation trend of the plant increased significantly by increasing age and evolution of protective cells and also by applying different levels of water stress in 3 years.

Dow, E.W. 1981 stated that potassium absorption is preferred to the other element in water stress conditions, especially corn that increases potassium absorption to adjust osmotic pressure regulation and resistance to water shortage condition.

We should say that the process of potassium absorption is done actively by using energy. Maximum absorption of potassium was seen at S3 treatment. The process of absorption and accumulation of K^+ was seen in preliminary growth period (V1 treatment). The percentage of K accumulation of V1 treatment had the mean of 2.04 and the mean of 2.5% in growing V1 treatment and 1.58% in V3 treatment. In other words, K absorption showed high absorption and accumulation process since preliminary until the last period. Maximum absorption of this element was seen in flowering period. Most of the reports confirm that this process of K absorption decreased after flowering than V1 and V2 treatment. K as the most stimulus element in plant, showed higher transmission trend than nitrogen, phosphorous and sodium. By applying water stress, K depletion was severe in 70 cm height leaves so that just 20% of total potassium of the bush leaves was seen in 70 cm height of S3 treatment to control. Lopez said that K^+ ion moves toward upper leaves to regulate osmotic pressure and influence on stomata which are in front of direct light in water stress condition so that decreases the percentage of sweating. It was determined in this experiment that the process of K transmission is from lower leaves to upper leaves and maximum accumulation was seen in higher leaves of maize that are exposed to more light in stress conditions.

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