Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.8, No.5, 2018

Evaluation of the Effects of Water Stress and Relative Water Content on Maize (Zea mays L.)

Abayneh Wubetu
College of Agriculture and Natural Resources, Debre Markos University, PO box 269, Debre Markos, Ethiopia

Abstract

An experiment was conducted from April 1 to June 30 to evaluate the effects of water stress and relative water content on maize (Zea mays L.) crop under green house conditions which have two replication and two treatments. The first two pots were stressed after two months from sowing gradually until clear wilting symptoms were observed and the rest two pots were well irrigated as per the crop water need. Results of this study illustrate that, all vegetative growth of crops were significantly affected by water shortage in the soil profile. However, maize is tolerant than cool season crops due to its C4 metabolism nature and/or tropical adaptation behavior. Even after one week stress maize can recover quickly as it gets a shower of water. Vegetative growth, especially leaf expansion, and reproductive growth are very sensitive even to relatively moderate water stress. This sensitivity was related with cell turgidity and expansion. Highest relative water content (RWC) and leaf moisture content (LMC) was observed in fully irrigated treatments. From this result it is concluded that water stress reduce vegetative growth of the crops which can later reduce yield and quality of those crops. So that, management of appropriate soil moisture within plant root zone and adjusting of the crop water need or irrigation water requirement for better irrigation scheduling is a crucial recommended activity.

Keywords: Relative water content, Leaf moisture content, water stress, cell turgidity, maize, sensitivity, tolerance.

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops used in the human diet in large parts of the world and feed component for livestock. It is also used in processed to food, fuel wood, biogases, and in brewers industries [17]. The per capita consumption of maize is 60 kg per year Ethiopia [18]. Maize is therefore a major crop for Ethiopia in the short, medium term, and the Growth and Transformation program (GTP) purposes' as maize can result doubling of field crops production by 2015 [7].

Leaf water content declined more in maize than in sorghum, attaining low values of leaf water potential [19]. In addition, the relative water content in leaves of different maize cultivars decreased significantly and with drought stress the membrane permeability of the leaf cell markedly increased [15]. Furthermore, water stress decreased the relative water content in seedlings of a drought- sensitive cultivar [14]. Song *et al* (1995) also reported that maize leaves with a drought-tolerant cultivar had relatively high water content. Nevertheless, most of the investigations in pot trials were limited to spatial growth of the root conditions, making it difficult to apply the conclusions to an agro-ecosystem under field conditions. In addition, most experiments applied the stress to either 24 hr or longer of water stress [13, 14], or a certain stage of growth such as the maize seedling [15] and the booting stage [24].

It has been known for many years that plant growth and leaf area are reduced by water stress [8]. Vegetative growth, especially leaf expansion, and reproductive growth are very sensitive even to relatively moderate water stress [11]. These reductions have been observed both in field-grown and laboratory or green-house-grown plants [2]. There is considerable controversy over whether the reduction in leaf area is due to reduced cell division, reduced cell expansion, or a combination of both. McCree and Davis (1974) suggested that reduced rates of cell division were at least as important in reducing leaf area in Sorghum bicolor as was reduced cell expansion. Cell multiplication in sugar beet (Beta vulgar is) leaves was inhibited by water stress, while cell volume was affected very little [26].

Wilson and Ludlow (1983) found leaf expansion to be very sensitive to low water potential and stated that even when some positive turgor was maintained in stressed plants, the cell size appeared to be markedly reduced. They believed this might be due to an increase in the wall rigidity of stressed plants.

Field-grown plants usually reacted differently to stress than greenhouse-grown plants, because the field-grown plants were not affected as quickly by water stress as plants grown in pots [3]. Maize grown in growth chambers experienced a rapid decline in leaf extension, whereas maize grown in the field and stressed much more severely showed no decline in leaf extension [27] to reopen stomata, are important to a plant's ability to withstand stress [28]. The beginning of stomata opening after re-watering was delayed until a minimum solute potential was reached [10]. Gradual stomata closure during stress was reversed by irrigation [5]. Plants can become acclimated (i.e., they can slowly adapt to lower soil water potentials), and therefore become more efficient water users. Short photoperiods produced no recovery, yet long photoperiods produced almost complete recovery. The leaf area of plants recovers from stress within a relatively short time after re-watering. Research on cassava (Manihot carthaqinensis) suggested that leaf expansion re-covered in excess of leaves produced by control plants after severe stress was imposed [5]. Recovery of leaf area was due to the recovery of the plant's water status and could be seen by measurement of the water potential of the leaves after the release from stress [4].

Physiological responses of plants to a gradient of soil moisture content can help in determining at what soil moisture level plant water deficit stress is initiated, which then can be used to determine how much water can be reduced without affecting major physiological processes that contribute to crop growth and yield. A major effect of soil moisture reduction in plants is reduction in photosynthesis [4]. Responses of photosynthesis and photosynthetic pigments content, chlorophyll fluorescence, relative water content and other physiological parameters are often used to determine the effects of soil moisture stress in plants [6].

Little is still known about drought stress over the whole maize growing processes in the study area. Hence, additional information on investigating the possible responses and adaptations as well as the physiological mechanisms of maize to changes of soil water levels under prolonged and increasing drought stress conditions is required. Since field water deficit experiments are difficult to conduct in sub-humid regions because of erratic rainfall and inadequate instruments, a large modified green house was devised to reduce the risk of rain interference with the experiments, along with controlled water applications, that provide proper water supply for the crops. Therefore, this work was initiated with the objective to evaluate the effects of water stress and relative water content on growth and development of maize crop under green house.

2. Material and Methods

2.1. Experimental Location

The experiment was conducted at Debre Markos in 2016 cropping season under green house. The site is situated in Western Ethiopia, Amhara national regional State, and East Gojjam zone at Debre Markos town. It is geographically located about 295 km North West of Addis Ababa, the capital city of Ethiopia, which lies between 10° 20' N latitude and 37° 43' E longitude at an elevation of 2,446 meters above sea level. The town has minimum and maximum temperatures of 15^0C and 22^0C respectively. The annual rainfall was 1300 – 1460 mm (average 1380mm) and the dominant soil type of the area is nitisol. Debre Markos town is one of the high land areas of the country and its climate is generally regarded as sub-humid.

2.2 . Experimental Materials and Treatments

The experimental unit includes 4 pots with 17.2cm × 19.5 cm dimension, inorganic fertilizer and BH-660 improved maize variety was used for the experiment. Also12 kg of soil, watering can, sticker, hand book, metering tape, graduated cylinder, square paper de-ionized water, Scalper, marker ,absolvent paper, sensitive balance, Pipettes, Petri-dishes refrigerator and drying oven were used. The treatment consists of two parameter of process which was contained two treatments and two replications (two pots were grown under water stressed conditions and other two pots were well irrigated). In each of the pots 3kg of soil were added and they were watered before sowing and after sowing continued up to seedling growth and development and more leaf numbers for data record was attained.

2.3. Experimental procedure

The pots were simply arranged randomly in straight line across the slope in green house. Each pot was filled with soil taken from green house which was weighing 3kg each. Four seed of maize were sown per pot, which were arranged randomly in greenhouse and the total numbers of 16 seeds were sown. The seed were started to germinate 5 days after sowing and were thinned out after 15 days keeping two seedlings per pot. Stressing was started after one month and the watering gaps of for the stressed was gradually increased and lastly watering was stopped completely until it shows a clear wilting symptoms. However, the two pots left for well watering were regulated according to their water need. Then from each pot three leaves were taken and measured their fresh weight immediately and put into refrigerator for 16 hr in de-ionized water tight and taken out of it with the container. After putting in room temperature for two hour leaf weights were taken and put in oven dry for 24 hr and also dry weight were taken. Lastly the data were calculated and the results were compared and described.

3. Result and Discussion

- ✓ LMC = leaf moisture content
- ✓ RWC = Relative water content
- ✓ SMC = Soil moisture content

Table1: Total data recorded and results of the experiment

Treatments	Cane wt	Sample wt	Oven dry	SMC	Leaf Fresh wt	Leaf turgid wt	Leaf dry wt	LMC	RWC
T1r1	11.58	41.945	36.62	0.21266	5.24	9.79	1.03	4.21	0.480594
T1r2	11.58	41.945	35.12	0.289932	4.909	10.551	0.906	4.003	0.415034
T2r1	11.58	41.945	31.894	0.494782	18.359	20.701	2.026	16.333	0.874592
T2r2	11.58	41.945	32.58	0.445952	20.959	23.946	3.816	17.143	0.851615

3.1 Determination of soil moisture contents.

3.1.1 Average Mass of soil in well irrigated pots was:

- Weight of can=11.58g } for both sample equal amount
- Mass of wet soil sample=30.365

Wt. of Dry Soil (g) (oven) = Wt. of Dry Sample and can minus Wt. of can
=33.474g-11.58g
=***21.894g***

Wt. of Water (g) = Wt. of Wet Sample minus Wt. of Dry Sample
=30.365g-21.894g
=***8.471***

Moisture Content (%) '= (Wt. of Water /Wt. of Dry Soil) 100%
= (8.471g/21,894)*100
=38.69%

3.1.2 Average Mass of soil in stressed pots was:

Wt. of Dry Soil (g) (oven) = Wt. of Dry Sample and can minus Wt. of can
=36.623g-11.58g
=***25.043g***

Wt. of Water (g) = Wt. of Wet Sample minus Wt. of Dry Sample
=30.365g-25.043g
=***5.322g***

Moisture Content (%) '= (Wt. of Water /Wt. of Dry Soil) 100%
= (5.322g/25.043)*100
=21.25%

3.2 Relative water content (RWC)

RWC= [(FW-DW) / (TW-DW)] *100%

Where,
FW – sample fresh weight
TW – sample turgid weight
DW – sample dry weight.

Table2; Data recorded for relative water content of maize.

Type of application	Nº of treatments	Fresh weight(g)	Oven Dry weight (gm)	Turgid weight (gm)
Stressed	T1	5.24	1.03	9.55
	T2	4.909	0.906	10.79
Watered	T3	18.35	2.03	20.70
	T4	20.96	3.82	23.95

3.2.1 Average Relative water content for stressed sample

✓ $RWC\ (T_1)=[FW_{T1}-DW_{T1}]/[TW_{T1}-DW_{T1}]$
=[5.24-1.03]/[9.55-1.03]
=4.21/8.52
=48.36%

✓ $RWC\ (T_2)=[FW_{T2}-DW_{T2}]/[TW_{T2}-DW_{T2}]$
=[4.909-0.906]/[10.79-0.906]
=4.003/9.884
=40.49%

Average RWC of stressed sample= $[RWC_{T1}+RWC_{T2}]/2$
=[48.36+40.49]/2
=44.43%

3.2.2 Relative water content for watered sample

✓ $RWC (T_3)=[FW_{T3}-DW_{T3}]/[TW_{T3}-DW_{T3}]$
$=[18.35-2.03]/[20.70-2.03]$
$=16.32/18.67$
$=\underline{87.41\%}$

✓ $RWC (T_4)=[FW_{T4}-DW_{T4}]/[TW_{T4}-DW_{T4}]$
$=[20.96-3.82]/[23.95-3.82]$
$=17.14/20.13$
$=\underline{85.15\%}$

Average RWC of stressed sample= $[RWC_{T3}+RWC_{T4}]/2$
$=[85.15+87.41]/2$
$=\underline{86.28\%}$

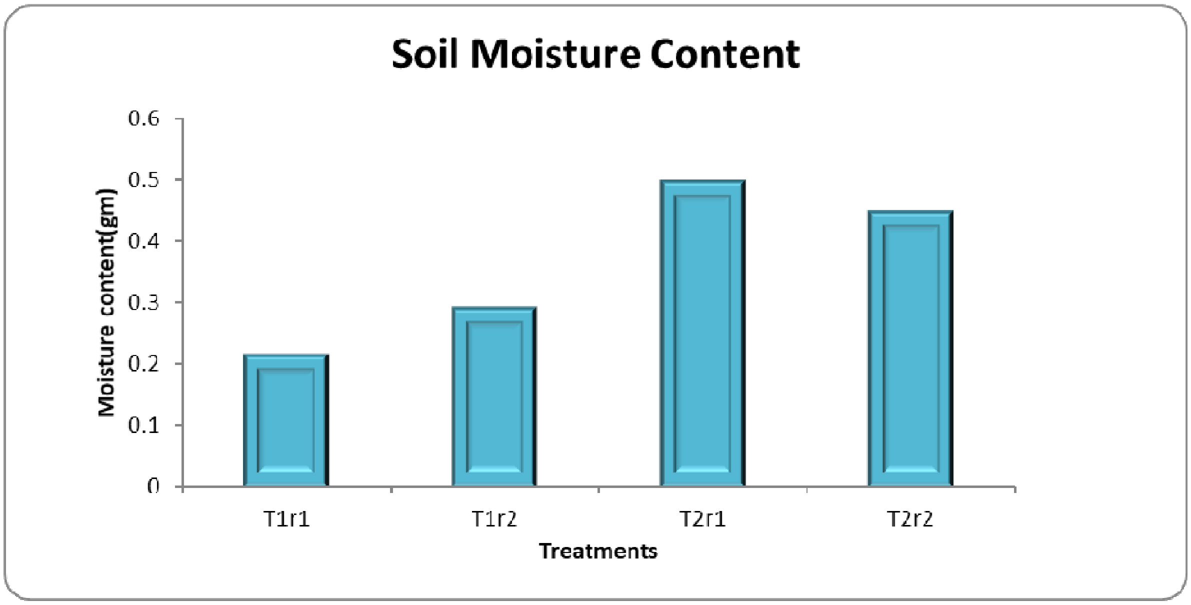

Figure1. Soil moisture contents of the experiment.

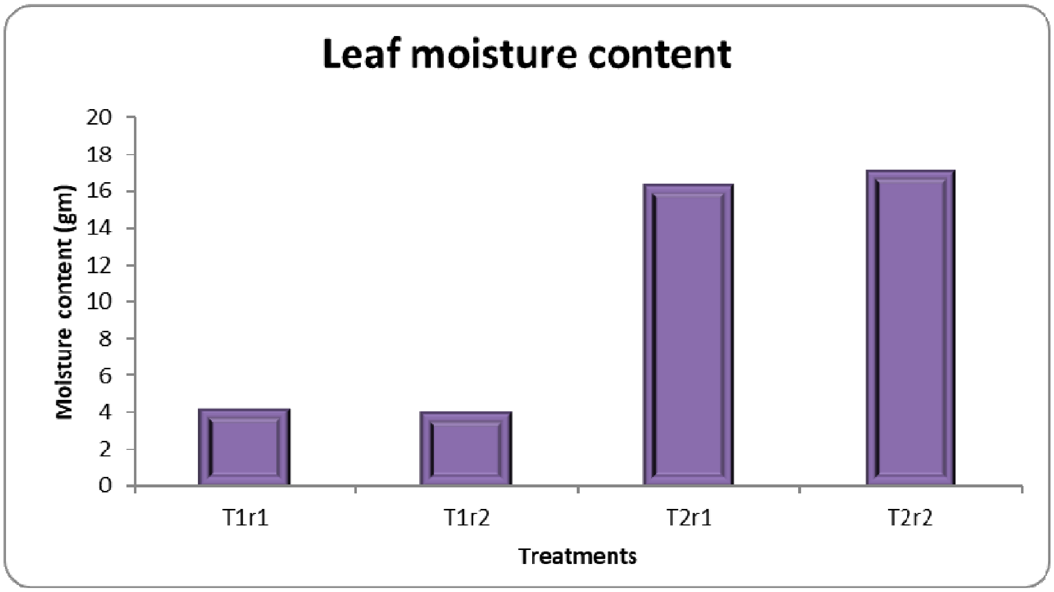

Figure2. Leaf moisture content of the experiment

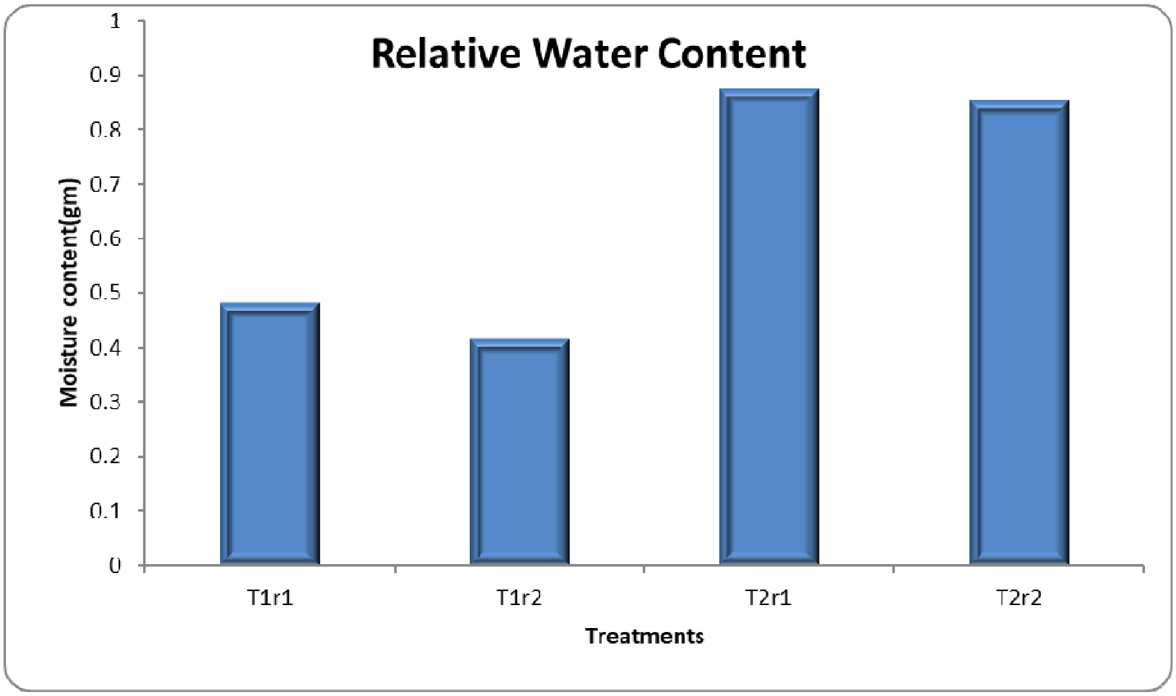

Figure3. Relative water contents of maize.

3.3 Effect of soil moisture status

$$\text{Soil moisture content} = \frac{\text{wet weight (g)} - \text{dry weight (g)}}{\text{Dry weight (g)}}$$

The soil moisture of all pots from stressed was very low and the weights of the stressed soil before and after dry were more similar. That means there is no sufficient water found in the pot before oven dry (Fig1). However, the soil moisture of well irrigated pots was much higher and the difference between the weight of wet sample and oven dried were more significant. This shows that there was more water in the sample that was removed by oven-dry (Fig1). Water is a key determinant in field crop productivity globally though its availability is highly variable. Challenging climate scenarios of unprecedented spatio-temporal temperature and rainfall patterns does translate into the availability of water to crops [9]. Accurate water content estimation is required to make decisions on management schemes and also crop yield estimations in agricultural studies [20].

3.4. Effect of water stress on Leaf moisture content of maize.

Fresh weights of the irrigated plants were slightly higher than the stressed plants even though the stressed plants were slightly longer than the watered plants. The mean for irrigated plants and for water stressed was 5.125 g and 19.452g respectively (Fig2). The effects of water stress on the maize has less risk than other cool season crops, because maize is a stress tolerant crop due to its C4 metabolic nature, but the reduction in leaf area during stress was most severe in younger plant leaves. This result was agreed with Lisa R. (1986), who suggests the leaf moisture content of stressed melon were reduced than irrigated. This indicates, Water is the most important and vital commodity on which whole life depends. It constitutes 80-90% of living protoplasm of plant cells [26]. Due to water deficits, the physiology of crop is disturbed which causes a large number of changes in morphology and anatomy of plant. These changes have an extensive effect on growth and thus ultimate yield of the crop [1].

3.5. Effect of water stress on RWC of maize.

The relative water content (RWC) determination technique, formerly known as relative turgidity, was originally described by Weatherley (2001) and has been widely accepted as a reproducible and meaningful index of plant water status. Relative water content may be accurately estimated using the ratio of tissue fresh weight to tissue turgid weight, termed here relative tissue weight. That relative water content and relative tissue weight are linearly related is demonstrated algebraically.

Relative water content (RWC) was measured on the last day of watering (before stress occurred) in the greenhouse plants revealing a RWC of the water stressed/recovered plants very similar to the irrigated plants (Fig 1). Six days after imposing stress a drastic symptom of wilting had occurred in the RWC of the water stressed while the RWC of the irrigated one is equal and higher than that of the stressed (Fig1). Moisture content of a feed usually is calculated as the weight lost by material during application of heat to a sample.

4. Conclusion

The effect of water stress on maize is less visible than cool season crops; those require high moisture content, high humidity and low temperature for well growth and development. Results of this study illustrate that, all vegetative growth of maize crop was significantly affected by water shortage in the soil profile. However, relatively maize is a stress tolerant crop due to its C4 metabolism nature. The reduction in leaf area during stress was most severe in younger plant leaves. Relative water content may be accurately estimated using the ratio of tissue fresh weight to tissue turgid weight, termed here relative tissue weight. Due to water deficits, the physiology of crop is disturbed which causes a large number of changes in morphology and anatomy of plant. These changes have an extensive effect on growth and thus at maturity ultimate yield losses of the crop.

Inappropriate watering and the deficit of water from the plant root zone is drastically affects the plant growth and development. So that, management of appropriate soil moisture within plant root zone as much as possible or adjusting of crop water need and irrigation water requirement for better irrigation scheduling is the crucial recommendation.

5. REFERENCE

[1] Ashraf, M. and J.W. O'Leary. (1996). Effects of drought stress on growth, water relations and gas exchange of two lines of sunflower differing in degree of salt tolerance. Int. J. Plant Sci. 157:729-732.

[2] Begg, J.E. (1980). Morphological adaptations of leaves to water stress. Adaptation of Plants to Water and High Temperature Stress. John Wiley and Sons, New York. pp. 33-42.

[3] Berlin, J.D., J.E. Quisenberry, F. Bailey, M. Wood-worth, and B.L. McMichael. (1982). Effect of water stress on cotton leaves I. An electron microscopic stereological study of the palisade cells. Plant Physiol. 70:238-243.

[4] Blum, A. (1996) Crop Response to Drought and the Interpretation of Adaptation. Plant Growth Regulation, 20, 135- 148. http://dx.doi.org/10.1007/BF00024010

[5] Connor, D.J. and T.R. Jones. (1985). Response of sunflower to strategies of irrigation. II. Morphological and physiological responses to water stress. Field Crops Res. 12:91-103.FDRE. (2011).

[6] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S.M.A. (2009) Plant Drought Stress: Effects, Mechanisms and Management. Agronomy for Sustainable Development, 29, 185-212

[7] FDRE (The Federal Democratic Republic of Ethiopia), (2011) Five Year Plan for Growth and Transformation. Addis Ababa, Ethiopia: Ministry of Finance and Economic Development.

[8] Hsiao, T.C. (1973). Plant responses to water stress. Annue Rev, Plant Physiol. 24:519-570.

[9] IPCC, (2007) IPCC Fourth Assessment Report: Climate Change 2007. Cambridge University Press,

[10] Kim, J.H. and O.Y. Lee-Stadelmann. (1984). Water relations and cell wall elasticity quantities in Phaseolus vulgaris leaves. J. of _ Exp. Bot. 35(155):841-858.

[11]Kramer, P.J. (1980). Drought, stress, and the origin of adaptations. In N.C. Turner, P.J. Kramer eds. Adaptations of Plants to Water and High Temperature Stress. pp. 7-20.

[12] Lisa R. Matthews, (1986). The Effect of Water Stress on the Leaf area of uCcumis melo, Thesis in Biology PP1-36

[13] Li, L. and Van Staden, J. (1998). Effects of plant growth regulators on drought resistance of two maize cultivars. South African Journal of Botany. 64: 116-120.

[14] Li, L., Van Staden, J. and Jager, A. K. (1998). Effects of plant growth regulators on the antioxidant system in seedlings of two maize cultivars subjected to water stress. Plant Growth Regulation. 25: 81-87.

[15]Liu, L. and He, R. T. (1995). Effects of water stress on membrane damage and changes of some related enzyme activities in leaf of maize seedling. Journal of Guangzi Agricultural University (in Chinese). 14: 195-200.

[16] McCree, K.J, and S, D, Davis. (1974) Effect of water stress and temperature on leaf size and on size and number of epidermal cells in grain sorghum. Crop Sci, 14:751-755,

[17] McDonald, AH. Nicol, JM, (2005) Nematode Parasites of Cereals. pp. 131-191.In: Luc, M., Sikora, R.A. and Bridge, J. (Eds). Plant parasitic nematodes in subtropical and tropical agriculture, 2nd edition. Wallingford, UK, CABI Publishing.

[18] Mosisa, W., Legesse, W., Berhanu, T., Girma, D., Girum, A., Wende, A.,Getachew, B. (2012). Status and future direction of maize research and production in Ethiopia. Proceedings of the Third National Maize Workshop of Ethiopia, 16-20 April 2012 AA, Ethiopia (pp. 17-23).

[19] Nagy, Z., Tuba, Z., Zsoldos, F. and Erdei, L. (1995). CO_2-exchange and water relation responses of sorghum and maize during water and salt stress. Journal of Plant Physiology. pp539-544.

[20] Peñuelas, J., I. Filella, C. Biel, L. Serrano and R. Save, (1993). The reflectance at the 950-970 regions as an indicator of plant water status. International Journal of Remote Sensing 14(10), 1887-1905.

[21] Prasad, P.V.V., Pisipati, S.R., Momčilović, I. and Ristic, Z. (2011) Independent and Combined Effects of High Temperature and Drought Stress during Grain Filling on Plant Yield and Chloroplast EF-Tu Expression in Spring Wheat. Journal of Agronomy and Crop Science, 197, 430-441.

[22] Reisdorph, N.A. and K.1. Koster. (1999). Progressive loss of desiccation tolerance in germinating pea (Pisum sativum) seeds. Physiologia Plantarum. pp105:266-271.

[23] Song, F. B., Dai, J. Y., Gu, W. B. And Li, H. Y. (1995). Effect of water stress on leaf water status in maize. Journal of Jilin Agricultural University (in Chinese). 17: 5-9.

[24] Song, F. B., Dai, J. Y. and Huang, G. K. (1996). Injurious effect of water stress at booting stage on the female inflorescence of maize. Journal of Jilin Agricultural University (in Chinese). 18: 1-6.

[25] Subrahmanyam, D., Subash, N., Haris, A. and Sikka, A.K. (2006) Influence of Water Stress on Leaf Photosynthetic Characteristics in Wheat Cultivars Differing in Their Susceptibility to Drought. Photosynthetica, 44, 125-129.

[26] Terry, N.C, L.J. Waldron, and A. Ulrich. (1971). Effects of moisture stress on the multiplication and expansions of cells in leaves of sugar beet. Planta 97:281-289. 32.

[27] Turner, N.C. and M.M. Jones. (1980). Turgor maintenance by osmotic adjustment: a review and evaluation. In 70 N.C Turner, P.J. Kramer eds. Adaptation of Plants to Water and High Temperature Stress. John Wiley and Sons, New York. pp. 87-103.

[28] Wilson, J.R. and M.M. Ludlow. (1983). Time trends for change in osmotic adjustment and water relations of leaves of Cenchrus ciliaris during and after water stress. pp 10:15-24.