



Management strategy for improving growth and mineral status of Moringa grown under water stress conditions

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Abstract

Water scarcity and drought are the main constraints of crop production. Many technologies have been developed to cope with this environmental problem. So improve crop management under limited amount of available water is a measure issue to maximize the return by unit of water (water productivity). To achieve the aforementioned objectives, a pot experiment was conducted in the greenhouse of the National Research Centre at summer season of 2013 to evaluate the effect of foliar application of potassium sulphate (K_2SO_4), mono potassium phosphate ($KHPO_4$) and ferrous sulphate ($FeSO_4$) at the rate of 1% in addition to distilled water as a control treatment. on growth, and mineral status of Moringa plants grown under different water regimes (irrigation after depletion of 40 % of the maximum water holding capacity of the soil (W.H.C.) i.e. normal water supply, 60 % of (W.H.C.) i.e. moderate soil moisture stress and 80 % of (W.H.C.) i.e. severe moisture stress. However, severe moisture stress cause depression in growth characters i.e. plant height, number of branches, dry weight of stem, leaves, top and whole plant. The highest dry weight of root, stem, leaves, top and whole plant were obtained by irrigation after depletion of 40 % available soil moisture. On the other hand, the dry weight of the root and shoot/root ratio was positively responded with the decreased in availability of moisture before irrigation. Application of foliar fertilizers enhanced all the vegetative growth characters of Moringa plants i.e. plant height, number of branches, root, and stem, leaves and whole plant fresh weight. Data also showed that MKP treatment surpass all the other foliar treatments (except for top/root ratio) which were recorded under Fe treatment. The lowest values were recorded in plants sprayed with distilled water. Moreover, Increasing the percentage of moisture depletion before irrigation, significantly decreased the percentage of phosphorus, potassium and magnesium in Moringa plants. On the contrary water stress treatments significantly increase the content of N, Ca and Na. Application of foliar fertilizers enhancing the content of N, P, K and Mg.

Keywords: Moringa, Water stress, Foliar fertilization, Growth, Mineral status.

1 Introduction

Moringa oleifera L., belonging to the Moringaceae family, consists of only one genus (*Moringa*) and fourteen recognized species. It is a native plant from North of India and it has been cultivated in several tropical countries. Moringa is a multiple-use plant but it has been more intensely used in the industry, medicine and in the feeding human and animal as protein source [1]. Moringa (*Moringa oleifera*) trees have been used to combat malnutrition, especially among infants and nursing mothers. Leaves can be eaten fresh, cooked or stored as dry powder for many months without refrigeration, and reportedly without loss of nutritional value. Moringa is especially promising as a food source in the tropics because the tree is in full leaf at the end of the dry season when other foods are typically scarce [2]. Moringa leaves contain more vitamin A than carrots, more calcium than milk, more iron than spinach, more

vitamin C than oranges, and more potassium than bananas, and that the protein quality of Moringa leaves rivals that of milk and egg [3]. In addition more than its use in water purification, biofuel and pesticides [4].

Globally as well as locally, scarcity of land and water for agriculture facing crop yields decline is of major concern to feed ever increasing population. Water stress affects plants growth and productivity in many ways such as effect on germination [5], cell growth is one of the most drought-sensitive physiological processes due to reduction in turgor pressure [6], photosynthesis, carbohydrate and protein building [7], water adjustment and mineral [8] absorption and oxidative defense [9 & 10].

Potassium is an important macronutrients and the most abundant cation in higher plants. Potassium is the target of many researches mainly because it is essential for enzymes activation, protein synthesis and photosynthesis [11 & 12], and it mediates osmoregulation during cell expansion, stomatal movements and tropism. Furthermore, K is necessary for phloem solute transport and for the maintenance of cation: anion balance in the cytosol as well as in the vacuole. K supply from soil can be rate limiting

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for agriculture production. Potassium nutrition to plants stimulates root growth and hence, efficient exploration of soil water [13]. Further, it decreases the loss of soil moisture by reducing the transpiration and increasing the retention of water in plants [14]. Keeping these facts in view, feasibility of K nutrition in augmenting the performance of the crops namely, mustard, sorghum and groundnut was tested under water stress conditions.

Iron is abundant in most part of the soils, it is insoluble almost in ferric form, hence unavailable to plant [15]. Fe chlorosis is the third field scale disorder after zinc and boron in micronutrients [16]. In Egypt, most of Fe disorder showed at the new cultivated areas especially in calcareous soils. Fe solitary or in combination with other micronutrients or commercial foliar fertilizers was applied for correct Fe deficiency and/or to face the needs of plants to this element in soils with high pH which the plants suffering from less availability of Fe in these soils [8 & 17]. Therefore, this work aimed to investigate the effect of foliar application with potassium sulphate (K_2SO_4), mono potassium phosphate ($KHPO_4$) and ferrous sulphate ($FeSO_4$) on growth and mineral status of Moringa plants grown under water stress condition.

2 Materials & Methods

A pot experiment was conducted in the green house of the National Research Centre in Dokki, Cairo, Egypt. During summer season of 2013 to investigate the impact of foliar application with potassium sulphate (K_2SO_4), mono potassium phosphate ($KHPO_4$) and ferrous sulphate ($FeSO_4$) at the rate of 1 % in addition to distilled water as a control treatment on growth and mineral status of Moringa plants grown under water stress conditions. During the first 35 days of pre-treatment, plants were sufficiently irrigated

and then, subjected to various levels of irrigation. The treatments were as follows:

Irrigation treatments: Irrigation after depletion of 40, 60 and 80 % of available soil moisture represent (normal irrigation, moderate and severe water stress).

Foliar fertilizers: Foliar spraying of potassium sulphate (K_2SO_4), mono potassium phosphate ($KHPO_4$) and ferrous sulphate ($FeSO_4$) at the rate of 1 % in addition to distilled water as control.

The experiment included 12 treatments which were the combination between three irrigation regimes and 4 foliar fertilizers treatments. The design of the experiment was complete randomized block design (CRBD) in 8 replicates. Table 1 shows soil physical and chemical analysis of soil using the methods described by Cottenie *et al.*, (1982) [18]. Each pot received 8 kg soil, 1.80g of ammonium sulphate (20.6%N), 1.5 g calcium super phosphate (15.5% P_2O_5) and 0.5 g potassium sulfate (48.5% K_2O). Moringa (*Moringa oleifera* L.) seeds were sown in the 1st of April, 2013., thinned twice after one and two weeks from sowing, and left one plant/pot in 8 replicates for each treatment. Foliar application treatments were applied at 60 and 90 days after sowing. At 180 day from sowing, three plants were picked from each treatment. The following measurements were recorded: plant height (cm) and number of branches. Plant samples were cleaned dried in electric oven at 70°C, dry weight of root, stem, leaves and shoot (above ground parts). Shoot/root ratio were calculated for each treatment. Leaves samples were ground in stainless steel mill. Dry powder was digested and analyzed for N, P, K, Na, Ca and Mg as described by Cottenie *et al.*, (1982) [18]. Analysis of variance (ANOVA) and least significant difference (LSD) at 0.05 probability level was computed using the Co-Stat program and applied as described by Gomez and Gomez (1984) [19].

Tables 1: Some physical and chemical characteristics of the soil used in this study.

A- Soil mechanical analysis.

Course >200 μ %	Fine 200-20 μ %	Silt 200-2 μ %	Clay <2 μ %	Soil texture
10.2	16.8	29.5	40.6	Clay loam

B- Soil chemical analysis

B- Soil Chemical analysis											
pH 1:2.5	EC dSm ⁻¹	CaCO ₃ %	OM %	Soluble cations Meq/100g soil				Soluble anions Meq/100g soil			
7.87	2.21	2.43	0.97	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	CO ₃ ⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻
				2.43	0.44	2.58	1.24	0.0	0.94	1.96	3.79
Available macro-nutrients%				Available micro-nutrients ppm							
N	P	K		Fe	Zn			Mn			Cu
0.76	0.19	0.98		4.9	3.8			8.6			3.98

3 Results & Discussion

3.1 Effect of water stress and foliar fertilizers on some growth characters

3.1.1 Effect of water stress

Data in Table (2) showed that increase percentage of moisture depletion before irrigation (i.e. increase water stress) led to decrease the growth characters i.e. plant height, number of branches, dry weight of stem, leaves, top and whole plant. Deleterious effects of drought on plant

growth are well known, and have been documented for number of plant species (Farooq *et al.*, 2009) [7]. In this regards, Youssef *et al.*, (2012) [20] revealed that irrigation treatment every fifteen days, in general, was more effective on increasing, plant height, number of leaves and branches as well as number of nodes on the stem followed by irrigation every three weeks compared to other irrigation intervals. Bryle *et al.*, (2003) [21] noticed that with furrow and micro jet treatments irrigation frequency had little

effect on tree development performance with the exception that furrow irrigation every 3 weeks, which produced smaller trees than furrow irrigation every one or two weeks. Inadequate irrigation reduced canopy by development and lengthens the time to reach full production while over-irrigation limits root development and led to groundwater contamination by leaching of soil nitrates and pesticides [22]. Moreover, Campo (2010) [23] found that shoot growth, trunk diameter, leaves area density of olive trees negatively affected by water stress treatment. The highest values of, root stem, leaves, top and whole plant dry mass were obtained by irrigation after depletion of 40 % available soil moisture. These dry weights of plant parts were decreased parallel to the depression in available soil moisture except for root dry weight, the depression was more under the treatment, irrigation after depletion of 80% available soil moisture. This may be due to the effect of water stress on photosynthetic activity [24] and protein building [7]. Zhu *et al.*, (2007) [25] revealed that drought affected growth through its effect on stomatal movement which intern affect photosynthesis as a result of drought through its effect on carbon assimilation which decreased progressively with increase water deficit as a result of both stomatal and metabolic limitation. Nonami (1998) [26] stated that, under severe water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells. Taiz and Zeiger (2006) [6] found that, cell growth is one of the most drought-sensitive physiological processes due to the reduction in turgor pressure. Water deficit affects plant biomass production partly through its negative effects on leaf area, by limiting leaf area development, water deficits reduce radiation interception by the crop and consequently less biomass is produced [27]. Furthermore, water deficits can reduce stomatal conductance, leading to reduced carbon assimilation and consequently give low biomass production [28].

3.1.2 Effect of foliar fertilizers

Application of foliar fertilizers enhanced the vegetative growth of Moringa plants i.e. plant height, number of branches, root, and stem, leaves and whole plant fresh weight. (Table, 2). Data also showed that MKP treatment surpass all the other foliar treatments (except for top/root ratio) which were recorded under Fe treatment. The lowest values were recorded in plants sprayed with distilled water. Similar results were obtained by Baraktuallah *et al.*, (2012) [29]. Potassium (K^+) is an essential element for plant growth and development and is the most abundant cation in plants, making up 3–5% of a plant's total dry weight [8]. This macronutrient is essential for many plant processes such as enzyme activation, protein synthesis photosynthesis, osmoregulation during cell expansion, stomatal movements, solute phloem transport, electrical neutralization, regulation of membrane potential, cotransport of sugars, and the maintenance of cation–anion balance in the cytosol as well as in the vacuole [30]. Potassium is essential to plants, as it increases drought tolerance, stem strength and plant growth. Soil water content is a key factor influencing the diffusion rate,

and so drought conditions may result in limiting K uptake [31].

3.1.3 Interaction effect of water stress and foliar fertilizers

The interaction effect of soil moisture and foliar application of some fertilizers on growth criteria were illustrated in Table 2. Generally, the application of different foliar fertilizers enhanced the dry weight of different Moringa plants parts. The highest values of the whole plant dry mass were achieved by application of MKP. This was true under different irrigation treatments (Table 2). Similar results were obtained by Chen *et al.*, (2011) [32] who mentioned that an appropriate amount of fertilizers could alleviate the negative impact of drought on the growth of *P. vulgaris*. They added that, fertilizer treatments significantly influenced vegetative, dry matter and reproductive parts dry weight. Beside mechanisms for abiotic stress tolerant, foliar spraying of K under drought conditions can improve plants tolerance, it is also improved subsequent growth and yield. Application of K under drought stress enhanced tolerance of wheat and improving the physiological efficiency [33]. Mengel and Kirkby (2001) [34] reported that K improves physiological processes of plant by regulation of turgor pressure and photosynthesis; translocation of cations and enzymes activation. Cakmak (2005) [35] also observed that plant suffering from water stress required more internal K. In legumes, devastating effects of drought can be alleviated by rich K supply [36]. Yield limiting effect of water deficit could be overcome by increasing K supply [37&33]. Potassium ions contribute significantly to the osmotic potential of the vacuoles even under drought conditions [8]. Thus, adequate K fertilization of crop plants may facilitate osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and can improve the ability of plants to tolerate drought stress [38]. Currently, it is evident that crop yields can be substantially improved by enhancing the plant nutrient efficiency under limited moisture supply [39].

3.2. Effect of water stress and foliar fertilizers on mineral status of Moringa plant

3.2.1 Effect of water stress

Data in Fig. 1 showed that the increased in percentage of moisture depletion before irrigation, significantly decreased the percentage of phosphorus, potassium and magnesium in Moringa plants, however the least values (0.72, 2.08 and 0.98% of P, K and Mg respectively) were recorded in Moringa plants subjected to severe water stress i.e. irrigated after depletion of 80% of irrigation water. On the contrary water stress treatments significantly increase the content of N, Ca and Na in Moringa plant. Similar results were obtained by Baraktuallah *et al.*, (2012) [29]. In this concern, Fani (2013) [40] indicated a significant differences in mineral content of leaves of alfalfa under stress conditions. The upward frequency and duration of drought in arid and semi-arid regions in many parts of world and the problems related to the water constraints in water- applying systems and areas may affect the bioavailability and mobility of minerals and mineral-nutrient relations in plants [41].

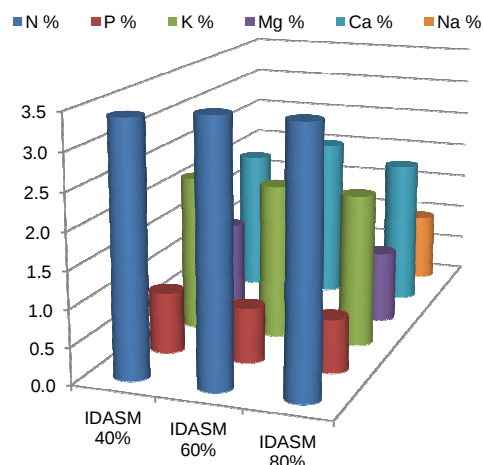


Fig 1: Effect of soil moisture content on mineral status of Moringa plant (LSD 5% N: 0.28, P: 0.05, K: 0.19, Mg: 0.09, Ca: 0.18, Na: 0.07)

Raza *et al.*, (2013) [33] reported that nutrients (N, P, K, Ca and Na) uptake in the plant was considerably affected by the drought stress. The plants under water deficit have high N concentration which may be, because of the free amino acids accumulation that are not synthesized into protein [42] since under drought stress nitrate reductase (enzyme responsible for assimilation of nitrate into amino acid) is adversely affected [43].

3.2.2 Effect of foliar fertilizers

Application of foliar fertilizers enhancing the content of N, P, K and Mg in Moringa plants (Fig 2). Data also showed that MKP treatment recorded the highest values for N and K, while KS application recorded the highest values for P. Application of Fe recorded the highest values of Mg and Ca. Meanwhile, the highest values of Na were recorded in plants sprayed with distilled water. However, the lowest values of N, P and K content were recorded in the control plants. This means that the fertilizers application enhances most of minerals status but decreased sodium concentration. Similar results were obtained by (2012) [20]. Mineral elements are necessary to enable various enzymes for biological responses. Sustainability of life is dependent upon the body's ability to provide balance between the minerals [44]. Youssef *et al.*, (2012) [20] emphasized that foliar fertilizer increased the concentration of different nutrients. They added that N, P and Mn uptake were increased as fertilizer level increase. Nevertheless, the scientific literature shown that many forest species do not response to the application of K^+ suggesting they adapted to reduced availability of this nutrients possibly due to an efficient uptake or and use [45]. The antagonistic relationship between K and Na uptake has been observed by many researcher [46]. Shabala and Hariadi (2005) [47] explained that the ions K^+ and Na^+ compete for the same non-selective cation channels for uptake. It is possible that a surplus of K^+ ions lowered the uptake potential for Na^+ ions and resulted in less Na content in plant tissues. Iron is an essential cofactor for a wide variety of cellular functions

in all organisms. Iron is incorporated in the heme group of some proteins such as hemoglobin, myoglobin and cytochromes, or is associated with non-hememoieties or Fe-S motifs. It is required in essential processes for life such as oxygen transport, respiration, photosynthesis, hormone production and DNA synthesis [48]. This led to concluded that application of foliar fertilizers can improve the drought tolerance of Moringa plants. Iron also acts as a catalyst which is essential for the formation of the chlorophyll molecule. In addition, it is an activating element in enzymes known as a coenzyme. This elemental coenzyme is used as an oxygen carrier for plant respiration [48].

3.2.3 Effect of interaction between water stress and foliar fertilizers

Data presented in Fig. 3 show that the highest values for N and K amounted to 4.18 and 2.40% respectively were recorded in Moringa plants irrigated after depletion of 60% soil moisture and sprayed with NKP. Meanwhile, the highest value for Mg 1.27% was recorded under the treatment of 40% IDASM and spraying with Fe. The same fig also shows that, the highest content of P amounted to 0.91 was recorded under treatment 60% IDASM and spraying with K. On the other hand, the highest content of Na amounted to 1.13 was recorded under the treatment of 80% IDASM and sprayed with distilled water. Similar results were obtained by Hu *et al.*, (2008) [41] who showed that drought reduced the uptake of K, Ca, Mg and P, which may be attributed to decreased transpiration. Increased Na concentration in plants (due to drought) may cause ion toxicity, with the application of K ion toxicity could be reduced because K is involved in osmotic regulation, maintenance of cell turgor pressure and can effectively compete with Na [50].

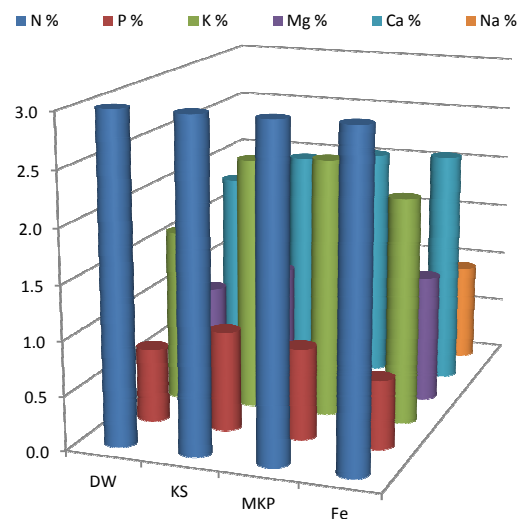


Fig 2: Effect of foliar fertilization on mineral status of Moringa plant (LSD 5% N: 0.26, P: 0.04, K: 0.17, Mg: 0.08, Ca: 0.15, Na: 0.06)

Application of K reduced the adverse effect of drought by reducing the excessive uptake of Na by the plant under

drought [33]. They added that, foliar applied K maintained the turgor pressure and internal water balance of the leaves. Alam (1994) [42]. revealed that water deficit has strong damaging effect on the plants and it reduced the uptake of P and Ca by plants. Kidambi *et al.*, (1990) [51] observed no effect of water stress on P uptake. On the other hand, higher P uptake in wheat plants was reported under water stress by Khondakar *et al.*, (1983) [52] who stated that, foliar application of K ameliorated the adverse effect of drought on plants and improved the uptake of P by 36% and Ca by

18% in plants under water deficit at grain filling stage. Potassium is essential to plants, as it increases drought tolerance, stem strength and plant growth. Potassium is made available primarily to the root by soil diffusion processes controlling K movement to the root surface. Soil water content is a key factor influencing the diffusion rate, and so drought conditions may result in limiting K uptake (Nelson *et al.*, 2012).

Table 2: Effect of soil moisture content and foliar fertilizers on some growth characters of Moringa

Table 17. Effect of soil moisture content and foliar fertilizers on some growth characters of Moringa										
IDASM	Foliar fertilizer	Plant height (cm)	Number of branches	Dry weight (g)					Top/root ratio	
				Root	Stem	Leaves	Top	Whole plant		
40	DW	113.4	4.75	11.02	11.32	3.67	14.99	26.01	1.36	
	KS	119.5	7.08	16.87	14.29	7.2	21.49	38.36	1.27	
	MKP	126.6	7.59	17.56	16	8.63	24.63	42.19	1.40	
	Fe	126.6	6.37	12.35	15.62	6.34	21.96	34.31	1.78	
	Mean	121.5	6.45	14.45	14.31	6.46	20.77	35.22	1.45	
60	DW	111.4	5.76	10.09	7.99	5.83	13.82	23.91	1.37	
	KS	112.4	5.76	15.35	13.65	6.55	20.2	35.55	1.32	
	MKP	127.3	6.78	18.72	15.34	6.88	22.22	40.94	1.19	
	Fe	101.2	6.07	13.24	14.02	3.16	17.18	30.42	1.30	
	Mean	113.1	6.09	14.35	12.75	5.61	18.36	32.71	1.29	
80	DW	101.2	5.06	12.38	9.48	4.49	13.97	26.35	1.13	
	KS	103.3	5.36	15.44	12	5.77	17.77	33.21	1.15	
	MKP	108.3	7.38	18.67	14.02	5.58	19.6	38.27	1.05	
	Fe	102.3	5.06	14.36	13.05	4.68	17.73	32.09	1.23	
	Mean	103.8	5.71	15.21	12.14	5.13	17.27	32.48	1.14	
Mean values of foliar fertilizer		DW	108.7	5.19	11.16	9.60	4.66	14.26	25.42	1.29
LSD at 5%	KS	111.7	6.07	15.89	13.31	6.51	19.82	35.71	1.25	
	MKP	120.7	7.25	18.32	15.12	7.03	22.15	40.47	1.21	
	Fe	110.0	5.83	13.32	14.23	4.73	18.96	32.27	1.44	
	irrigation	5.32	0.31	0.45	0.41	0.29	0.98	1.87	0.07	
	Foliar fert.	7.35	0.42	0.75	0.74	0.37	1.23	2.36	0.09	
	Irrig X Fol	9.88	0.65	0.98	0.88	0.55	1.78	3.89	0.13	

IDASM= Irrigation after depletion of available soil moisture percentages

DW= distilled water KS=Potassium sulfate MKP=Mono potassium phosphate Fe=Ferrous sulfate

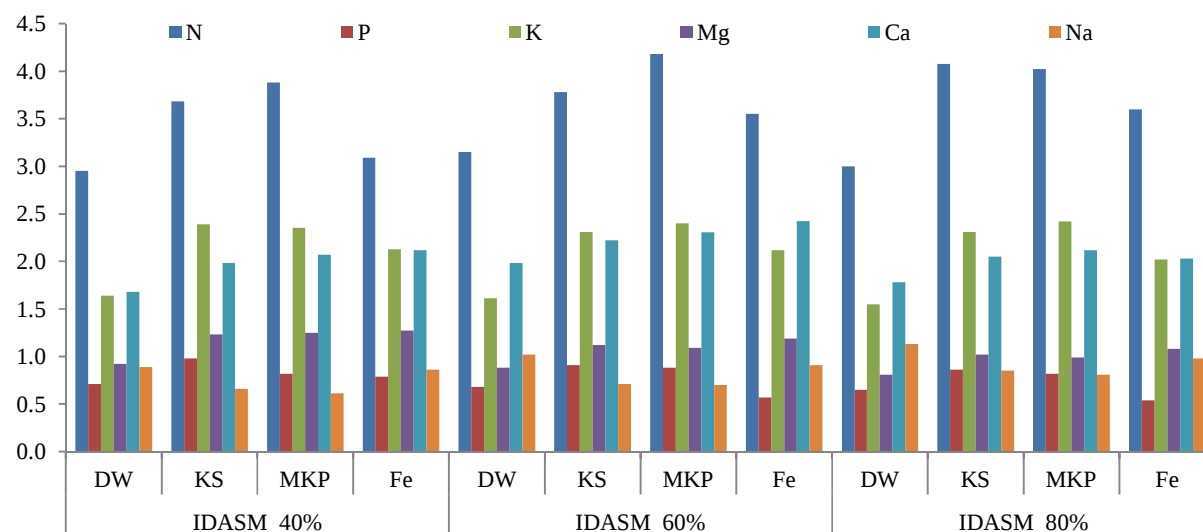


Fig 3: Effect of interaction between water stress and foliar fertilization on mineral status of Moringa plant (LSD 5% N: 0.31, P: 0.06, K: 0.22, Mg: 0.11, Ca: 0.21, Na: 0.09)

References

- 1- Fugile, L. J (1999): The Miracle tree, *Moringa oleifera*: Natural nutrition for the tropics, Dakar World service, 68p
- 2- Aiyelaagbe, I. O. O. (2011): Nigerian Horticulture: Facing the challenges of human health and agricultural productivity. Keynote address presented at the 29th Annual National Conference of Horticultural Society of Nigeria, (HORTSON): 24-29 July, 2011, Makurdi.
- 3- Fahey, J. W. (2005): *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic and prophylactic properties. *Trees for life Journal* 1:5 <http://tfljournal.org/article.php/20051201124931586>
- 4- Newman, W. , Siddique, M., Basea, S. M. ; Khan, R. A., Gull, H., Oleson, M. and Munir , H. (2012); Response of *moringa oleifera* to saline condition. *Intr. J. of Ageic. and Biol.*, 5: 757-762.
- 5- Manikavelu, A., Nadarajan, N., Ganiesh, S.K., Ganamalar , R. P. and Babu, R. C. (2006): .Drought tolerance in rice: Morphological and molecular Genetics Consideration . *Plant Growth Reg.*, 50: 121-138.
- 6- Taiz, L. and Zieger, E. (2006): *Plant Physiology*. 4th Ed. Sinauer Associates, Inc., Publishers , Massachusetts.
- 7- Farooq, M., Wahid, A., Fijuta, K., Kobayashi, D. and Basra, S. M. (2009): Plant drought stress, effects, mechanisms and management. *Agron. Sustain Dev.*, 29: 185-212.
- 8- Marschner, H. (1995): "Mineral Nutrition of Higher Plants" 2nd Ed, Acad. Press. London.
- 9- Sharma, N., P. Jha, A. B., Dubey, R. S. and Pessaraki, M. (2012): Reactive oxygen species, oxidative Damage and antioxidative defense mechanism in plants under stressful conditions. *J. of Bot.*, 1-36-43.
- 10- Agrawal, A. , Gupta, S., Gupta, N.K., Kandelwal, S.K. and Barhagava, R. (2013): Effect of sodium chloride on gas exchange , antioxidative defense mechanism and accumulation in different cultivars of Indian jojoba. *Photosynthetica*, 51:1-7.
- 11- Silva, S. L. (2004): Transpiration and ion partitioning in grafted seedling and rootstocks of different cashew genotypes exposed to salt stress. *Fortaliza*, pp.65.
- 12- Chavis, L. H., Viegas, R.A., Vasconuceles, A. C. and Viera, H. (2005): Effect of potassium on moringa plant grown in nutrients solution. *Revistaia De Biologia E.Ciencais De Terra*, 5 (2): 1-8.
- 13- Saxena, N. P. (1985): The role of potassium in drought tolerance, *Potash review*, 5 (16): 1-15.
- 14- Umar, S. and Moinuddin, (2002): Genotypic differences in yield and quality of groundnut as affected by potassium nutrition under erratic rainfall conditions. *J. Plant Nutr.*, 25: 1549-1562.
- 15- Graziano, L. and Lamattania, M. (2005): Nitric oxide and iron in plants. An emerging and converging story. *Trends Plant Sci.*, 10 (1):4-8.
- 16- Imtiaz, M. , Rashid, A., Khan, P., Memon, M. Y. and Islam, M. (2010): The role of micronutrients in cop production and human health. *Pak. J. of Bot.*, 42(4): 2565-2578.
- 17- Akhtar, S., Shahzad, A., Arshad, M. and Ul-Hassan, F. (2013): Moropho-physiological evaluation of ground nut (*Archis hypogaea* L.) genotypes for iron deficiency. *Pak. J. of Bot.*, 45(3): 893- 898.
- 18- Cottenie, A, Verloo, M., Kiekens, L., Velghe, G. and Camerlynch, R.(1982): Chemical Analysis of plants and soils. Laboratory of Analytical and Agrochemistry State University, Ghent-Belgium.
- 19- Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. John Wiley and sons, Inc. London, UK (2nd edtn) 13-175
- 20- Youssef, R. A., Hussein, M. M. and Abd El-Khadr, A. A. (2012): Growth and mineral status of barley plants as affected by drought and foliar fertilizer. *Life Science Journal*, 9 (2): 1166-1173.
- 21- Bryle, B. R., Trout, T. J., Ayer, J.E., and Johansen ,R.S. (2003): Growth and production of peach trees irrigated by

- furrow, microjet, drip or surface drip irrigation system. Hort. Sci., 38 (6): 1112-1116.
- 22- Syvertsen, J. P.(1986): Integration of water stress in fruit trees. Hort. Sci., 20: 1039- 1043.
 - 23- Campo, M. G. (2010): Physiological and Growth Responses to Irrigation of a Newly Established Hedgerow Olive Orchard. HortScience, 45 (5): 809-814.
 - 24- Baker, N. R.(2008): Chlorophyll fluorescence: a probe of photosynthesis in vivo. Ann. Rev. Plant Biol., 59:89-113.
 - 25- Zhu, J. M., Alvarez, S., Marsh, E. L., Noble, M. E., Cho, J. J., Sivaguru, M., Chen, S. X., Nguyen, H. T., Wu, Y. J. and Schachtman, D. P. (2007): Cell wall proteome in the maize primary root elongation zone. II. Region-specific changes in water soluble and lightly ionically bound proteins under water deficit. Plant Physiol., 145: 1533-1548.
 - 26- Nonami, H. (1998): Plant water relations and control of cell elongation at low water potentials, J. Plant Res., 111: 373-382.
 - 27- Jones, H. G. (1992): Plants and microclimate: A quantitative approach to environmental plant physiology. 2nd edition, Cambridge University press.
 - 28- Medrano, H., Escalona, J. M., Bota, J., Gulias, J. and Flexas, J. (2002): Regulation of photosynthesis of C₃ plants in response to progressive drought. Stomatal conductance as a reference parameter. Annals of Botany, 89: 895-905.
 - 29- Baraktuallah, A., Akthar, N., Abrar, M. Raouf, A. (2012): Effect of drought in morphological and mineral composition of *Abelmoschus esculentus* L. Middle-East J. of Medicinal plant Res., 1 (3): 59-62.
 - 30- Maser, P., M. Gierth and J. I. Schroeder. (2002): Molecular mechanisms of potassium and sodium uptake in plants. Plant Soil, 247: 43-54.
 - 31- Nelson, K. A., Motavalli, P. P., Stevens. W. P, Kinding, J. A., Dunn, D. and Nathan, N. (2012): Foliar potassium fertilizer additives affect soybean response and weed control with glyphosate. Intr. J. of Agron., 12:1-10.
 - 32- Chen, Y., Guo, Q, Lio, L., Liuo, L. and Zhu, Z. (2011): Influence of fertilization and drought stress in the growth and production of secondary metabolites on *Pronella vulgaris* L.J. medicinal Plant Res., 5(9):1749-1755.
 - 33- Raza, M. A., Saleem, M. F., Shah, G. M., Jamil, M. and Khan, H. (2013): Potassium applied under drought improves physiological and nutrient uptake performances of wheat (*Triticum Aestivum* L.). J. Soil Sci. Plant Nutr., 13 (1): Temuco mar. 2013 Epub 06-Feb-2013
 - 34- Mengel, K. and Kirkby, E. A. (2001): Principles of Plant Nutrition, 5th edn. pp. 864, Kluwer Academic Publishers Dordrecht, The Netherlands.
 - 35- Cakmak, I. (2005): The role of potassium in alleviating detrimental effects of abiotic stresses in plants. J. Plant Nutr. Soil Sci., 168: 521- 530.
 - 36- Sangakkara, U. R., Frehner, M. and Nosberger, J. (2000): Effect of soil moisture and potassium fertilizer on shoot water potential, photosynthesis and partitioning of carbon in mungbean and cowpea. J. Agron. Crop Sci., 185: 201-207.
 - 37- Damon, P. M., and Rengel, Z. (2007): Wheat genotypes differ in potassium efficiency under glasshouse and field conditions. Aust. J. Agric. Res., 58: 816-823.
 - 38- Lindhauer, M. G. (1985): Influence of K nutrition and drought on water relations and growth of sunflower (*Helianthus annuus* L.) Z. Pflanzenernaehr. Bodenk, 148: 654-669.
 - 39- Garg, B. K. (2003) Nutrient uptake and management under drought: nutrient-moisture interaction, Curr. Agric. 27: 1-8.
 - 40- Fani, E. (2013): Effect of drought stress in leaf mineral in alfalfa in climatic conditions of the south west of Iran. Intr. J. of Agric. Res. and Review., 3(3):608-609.
 - 41- Hu, Y., Burucs, Z. and Schmidhalter, U. (2008): Effect of foliar fertilization application on the growth and mineral nutrient content of maize seedlings under drought and salinity. Soil Science & Plant Nutrition, 54 (1): 133-141.
 - 42- Alam, S. M. (1994): Nutrient by plants under stress conditions. In: Pessarakli M (eds) Handbook of Plant and Crop Stress, pp. 227-246. Marcel Dekker, New York.
 - 43- Sinha, S. K. and Nicholas, D. J. D. (1981): Nitrate reductase. In: Paleg, L., Aspinall, D. (eds) The Physiology and Biochemistry of Drought Resistance in Plants, pp. 145-169. Academic Press, Sydney.
 - 44- Prasad, K. and G. Bisht (2011): Evaluation of nutritive, antioxidant and mineral composition of Pavetta indica Linn. leaves. Research J. Phytochemistry., 5: 54-59.
 - 45- Silva, I. R., Furtini Neto, A. E., Vale, F. R. and Curi, N. (1996): Eficiência nutricional para potássio em espécies florestais nativas Revista Brasileira Ciencia do Solo, :20: 257-264.
 - 46- Hallmark, W. B. and S.A. Barber. (1981): Root growth and morphology, nutrient uptake, and nutrient status of soybeans as affected by soil K and bulk density. Agron. J., 73: 779-782.
 - 47- Shabala, S. and Y. Hariadi, (2005): Membrane ion transporters and light-induced responses from broad bean leaf mesophyll. Planta, 221: 56-65.
 - 48- Ramirez, L., Griziano, M. and Lamattina, L. (2008): Decoding of plant response to iron deficiency. In nitrogen oxide a central player. Plant Signal and Behav., 3(10):795-797.
 - 49- Ramirez, L., Zabaleta, E. J. and Lamattina, L. (2010): Nitric oxide and frataxin: two players contributing to maintain cellular iron homeostasis Ann Bot., 105 (5): 801-810.
 - 50- Ashraf, M. and Foolad, M. R. (2005): Pre-sowing seed treatment-a shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions. Adv. Agron. 88, 223-271.
 - 51- Kidambi, S. P., Matches, A. G., Bolger, T. P. (1990): Mineral concentration in alfalfa and rainfallow as influenced by soil moisture level. Agron. J., 82: 229-236.
 - 52- Khondakar, Z. H., Aslam, A., Rehman, S., Khan, T. H. (1983): Influence of soil moisture stress on yield, grain quality, availability and uptake of N, P and K by wheat. Int. J. Tropical Agric., 1: 211-220.