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Effects of Water Stress Conditions and Plant Growth Regulators on Growth, Yield and Yield Components in Durum Wheats (*Triticum turgidum* L. var. Durum) under the Jordan Conditions

[1]Al-Tabbal Jalal Ahmed and [2]Y. Ayad Jama
[1]Al-huson College, Al-balqa, Applied University, Irbid, Jordan
[2]Faculty of Agriculture, University of Jordan, Jordan

Abstract: Greenhouse and field studies were conducted at the University of Jordan Research Station during 2000/2001 growing season to examine the influence of Mepiquat Chloride (1,1-dimethyl piperidinium Chloride) and Ethephon (2-chloroethyl-phosphonic acid) on growth, yield and water use efficiency of two selected wheat cultivars (Namely, Hourani 27 and Petra, *Triticum turgidum* L. var. Durum). In greenhouse pot experiments, seeds of wheat cultivars were soaked in Mepiquat Chloride solution at a rate of 0, 250, 500 and 750 mg kg^{-1} in one experiment. Ethephon was sprayed independently at a rate of 0, 150, 300 g ha^{-1} at the Zadoks 10 and 20, respectively in a second experiment. Plants in both experiments were subjected to two moisture levels: No stress and water stress for the entire growth period of the two cultivars. In field experiments, Ethephon solutions was sprayed independently at a rate of 0, 150, 300 and 450 g ha^{-1} at the Zadoks 10, 20 and 30, respectively in the first experiment. Seeds of both cultivars were soaked in Mepiquat Chloride solution at a rate of 0, 250, 500, 750 and 1000 mg kg^{-1} in a second experiment. Mepiquat Chloride and Ethephon treatment had no influence on shoot: root ratio of cultivars. Grain yield of cultivars grown either under well water or water stress conditions increased with Mepiquat Chloride treatment. Ethephon treatment only increased grain yield and harvest index of Hourani cultivar under well-watered conditions in both greenhouse and field experiments. This might be attributed to the increase in the number of fertile tillers per plant.

Key words: Mepiquat Chloride, Ethephon, wheat, water deficit, grain yield, yield component, water use efficiency

INTRODUCTION

Wheat is cultivated for human nutrition in Jordan as well as in different parts of the world. The average wheat productivity in Jordan (1300 kg ha^{-1}) is far below its yield potential (FAO, 1992, 1994, 1996 and 1998). This is due to lack of adequate soil moisture for the entire growth cycle of the crop (Jaradat, 1988). In Jordan about 61 thousand hectares is being cultivated with wheat (FAO, 1998) annually. Most of which is unirrigated and crops encounter drought stress of varying degrees at different growth stages. Water deficit or drought has profound effects on wheat production in Jordan and worldwide. Water stress at the Zadoks 20, 30 and entire growth stages of wheat significantly reduce grain and straw yield (Ismail, 1996). Plant growth regulators have been used over the past decades for several purposes. Exogenous applications of Indole Acetic Acid (IAA) or 2, 4-dichlorophenoxyacetic acid (2,4-D) was found to overcome drought induced growth inhibition of wheat plants when drought coincides with seed head formation and flowering stages (Hale and Orcutt, 1987). On the other hand, Ethephon reduced the size of corn plants and induced a reduction in water consumption in the post spraying period, when treatment was applied at an early vegetative stage (Kasele *et al*., 1994). Several other reports pointed-out the effects of plant growth regulators such as Mepiquat Chloride, Ethephon and others, on improving stress tolerance (Fernandez *et al*., 1992; Xu and Taylor, 1992; Kasele *et al*., 1994; D'Andria *et al*., 1997). Mepiquat Chloride and Ethephon have been traditionally used with crops like cotton and cereals to control lodging, but their effect on wheat under water deficit conditions wasn't given enough attention. So, it is hypothesized that both Mepiquat Chloride and Ethephon reduce plant size when applied at early stages and induce a reduction in water consumption in the post-spraying period. This might extend water availability to later stages essential for yield formation and therefore increase water use efficiency.

The main objective of this study was examine the ability of Mepiquat Chloride and Ethephon to improve

Corresponding Author: Al-Tabbal Jalal Ahmed, Al-huson College, Al-balqa, Applied University, Irbid, Jordan

water stress tolerance of the cultivars, more specifically to determine the effects of Mepiquat Chloride and Ethephon application on yield, yield components and shoot to root ratio.

MATERIALS AND METHODS

Seeds of two durum wheat cultivars (Namely, Hourani 27 and Petra (Hourani nawawi x Jori) *Triticum turgidum* L. var. Durum) were obtained from the National Center for Agricultural Research and Technology Transfer (NCARTT), Amman, Jordan. Two plant growth regulators; Mepiquat Chloride (1,1-dimethyl piperidinium Chloride) and Ethephon (2-chloroethyl-phosphonic acid) were used. These chemicals were obtained from Anhui Com., Anhui, China. Experiments were carried out both at greenhouse and fields.

The first experiment of the greenhouse was done as follows: Seeds of the two cultivars were soaked in Mepiquate Chloride solution at a rate of 0, 250, 500 and 750 mg kg^{-1}, stirred and covered by a cloth wetted with the same treatment and kept for 12 h at room temperature. Then, moisted seeds were spread out in thin layers and air-dried. At the same time, Pots were filled with soil composed of 58% clay, 34% silt and 8% sand. They brought to field capacity prior to sowing the seeds by tap water. The field capacity and the permanent wilting point of this soil were 28.4 and 14.7% from weight. In addition, pots weights' were measured and the amount of water equal to the weight loss was added. One week from planting, the seedlings were thinned to four plants per pot. Diammonium phosphate fertilizer was added at a rate of 0.4 g per pot (equivalent to 100 kg ha^{-1}) at the Zadoks 6. Pots were kept under well watered (= between field capacity and 30% available water depletion) and water stressed conditions (around 70% available water depletion) from emergence until maturity. Two sets of pots were used, one for determination of the yield and yield components at maturity and the other for the shoot:root measurements. For these calculations, sample plants were pulled out from the soil at the Zadoks 10, 20 and 30. Shoots were separated from roots and dried in oven at 70±5°C. The weight of the shoot and root was used for the calculation of shoot:root ratio. The second experiment of the greenhouse was done as follows: Seeds of the cultivars were grown in pots similar to that used in the first experiment and maintained under the same two water levels. Water solutions of Ethephon plus surfactant [Tween 20^{R} (Polyoxyethylene Sorbitan Monolaurate), 10 mL L^{-1})] was prepared and sprayed independently at a rate of 0, 150 and 300 g ha^{-1} at the Zadoks 10 and 20, respectively using hand sprayer. Each pot was surrounded by a portable wood barrier to prevent Ethephon's drift into adjacent pots (Dahnous *et al*., 1982). Plants were sampled at two stages for each Ethephon treatment; first at the Zadoks 18 and 23 for plants treated at the Zadoks 10 and second at the Zadoks 28 and 34 for plants treated at the Zadoks 20. Then, shoots were separated from roots and dried in an oven at 70±5°C before weighing.

Two field experiments were also conducted at the University of Jordan Campus during the year 2000/2001 to evaluate the effect of growth regulators on yield under rainfed conditions. University Campus field is located in Amman (32°01' N latitude and 35°52' E longitude with an elevation of 980 m). This location has a Mediterranean climate, mild rainy winter and hot dry summers. For these experiments, Soil composed of 55% clay, 38% silt and 7% sand. Furthermore, the total seasonal precipitation was 377 mm during the growing season which is lower than long term average (493 mm). The first experiment of the field was done as follows: Seeds of the cultivars were sown in plots consisting of eight rows 2.4 m long and 0.25 m apart on December 10, 2000. Seeding rate was adjusted to 250 plants per square meter. The Ethephon solutions were sprayed independently at a rate of 0, 150, 300 and 450 g ha^{-1} at the Zadoks 10, 20 and 30, respectively. Treatments consisted of two cultivars, four different Ethephon concentrations and three application stages in a Randomized Complete Block Design (RCBD) with three replications. The second experiment of the field was done as follows: Seeds of the two cultivars were soaked in Mepiquat Chloride solution of five different concentrations (0, 250, 500, 750 and 1000 mg kg^{-1}) before sowing as described by (Bhat *et al*., 1990). Treated seeds were sown in similar plots described in the first experiment of the field with similar design. Treatments consisted of two cultivars and five Mepiquat Chloride concentrations arranged in a Randomized Complete Block Design (RCBD) with three replications.

Observations and statistical measurements: The measured variables included grain yields, biological yield, plant height, number of fertile tillers and number of kernels per spike. Water use efficiency was calculated for greenhouse pot experiments (Ehdaie and Waines, 1994). Data for each trait were analyzed in a Randomized Complete Block Design (RCBD) with factorial arrangements using SAS program (SAS, 1996). Mean values were compared using the Least Significant Difference test (LSD) at the 0.05 probability level (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Shoot: root ratio: The mean shoot:root of the treated plants tended to be lower than control by up to 7% for the Ethephon and 13% for the Mepiquat Chloride (Table 1).

Table 1: Effect of foliar applications of Ethephon at two growth stages and seed treatments with Mepiquat Chloride on shoot:root of the used cultivars

Treatments	Concentration ($g\ ha^{-1}$)	Treatment at Zadoks 10	Treatment at Zadoks 20
Ethephon	0	1.75	2.78
	150	1.71	2.66
	300	1.71	2.61
LSD ($p \leq 0.05$)		0.19	
	Concentration $mg\ kg^{-1}$	Sampling at Zadoks 10	Sampling at Zadoks 20
Mepiquat Chloride	0	0.90	3.25
	250	1.40	2.82
	500	0.82	3.00
	750	0.78	3.64
LSD ($p \leq 0.05$)		0.58	

Table 2: Effect of cultivars, water regimes and stage of Ethephon application on shoot to root ratio sampled at two dates

		Treated at Zadoks 10		Treated at Zadoks 20	
Cultivars	Water regimes	Sampled at Zadoks 18	Sampled at Zadoks 23	Sampled at Zadoks 28	Sampled at Zadoks 34
Hourani	Well water	1.41	3.20	2.65	2.78
	Water stress	1.41	1.75	1.66	1.77
Petra	Well water	0.92	2.95	2.19	2.99
	Water stress	0.83	3.04	2.64	2.96
	LSD ($p \leq 0.05$)	0.31		0.33	

These are desirable attributes by which plants optimize productivity under limited water supply and make plants more water conservative (Fernandez *et al*., 1991). Under well-watered conditions, Hourani showed higher but not statisticaly significant shoot:root ratio than Petra up to Zadoks 23 (Table 2). No differences between cultivars on shoot:root were observed at Zadoks 28 and Zadoks 34. Also, shoot:root of Hourani was significantly ($p<0.05$) higher than Petra, grown under water stressed conditions, at Zadoks 18 and less than Petra at Zadoks 23 or at Zadoks 28 and Zadoks 34 (Table 2). Such variation could be due to different response of shoot and root growth of these cultivars to water stress. Shoot dry weights for the cultivars were reduced by up to 70 and 42%, respectively. The reduction in root dry weight was 52 and 42%, respectively under water stressed conditions (data not shown). The effects of Mepiquat Chloride and Ethephon on shoot and root growth did not match with previous studies that reported the impact of plant growth retardant on shoot suppression and root enhancement. Early applications of Ethephon and other plant growth retardents (Ma and Smith, 1991; Rajala and Peltonen-Sainion, 2001) reduced shoot growth in barley. However, 21% of the shoot:root ratio was reduced after late application of Cycoel (Rajala and Peltonen-Sainio, 2001). Foliar application of Ethephon at stem extension resulted in a significant reduction in total biomass of wheat by 8% at earlier stages with no effect on total phytomass at harvest (Cox and Otis, 1989).

Under well-watered conditions, Hourani cultivar had more shoot to root ratio than Petra cultivar up to Zadoks 23 (Table 2). On the other hand, shoot to root ratio of Hourani cultivar sampled at the Zadoks 18 was more than Petra cultivar grown under water stressed conditions and less than Petra cultivar sampled at Zadoks 23 or for plants sampled at Zadoks 28 and 34. Such variation could be due to the response difference of shoot and root growth of these cultivars to water stress. Shoot dry weight for Hourani and Petra cultivar was reduced by up to 70 and 42%, respectively, while the reduction in root dry weight was 52 and 42%, respectively under water stressed conditions (data not shown).

Foliar applications of other plant growth retardants have been found to reduce shoot to root ratio of wheat through reduction in the phytomass partitioned to shoot (De *et al*., 1982; Cox and Otis, 1989). Early applications of Ethephon and Cycosel (Ma and Smith, 1991; Rajala and Peltonen-Sainion, 2001) reduced shoot growth in barley. However, 21% of the shoot to root ratio was reduced after late application of CCC (Rajala and Peltonen-Sainio, 2001). Foliar application of Ethephon at stem extension resulted in a significant reduction in total biomass of wheat by 8% at earlier stages whereas it had no effect on total phytomass at harvest (Cox and Otis, 1989).

Yield and yield components: Seed treatment with 750 $mg\ kg^{-1}$ of Mepiquat Chloride significantly improved grain yield of Hourani and Petra cultivars grown under well water treatment (Table 3). However, under water stress, this increase was not statistically significant. Grain yield of Hourani increased by 19-29% after treatment with 150, 300 $g\ ha^{-1}$ of Ethephon, while grain yield of Petra was not affected (Table 4). Grain yield of Petra and Hourani grown under water stress did not change with Ethephon treatments. Under field conditions, the grain yield of the Hourani increased by up to 12% after treatment with 450 $g\ ha^{-1}$ of Ethephon. This effect was not observed at Petra (Table 5). Early application of Ethephon, at the Zadoks 10 and 20, improved grain yield of Hourani than applied at the Zadoks 30 by up to 11% (Table 6). There are previous indications that when applied at earlier growth stages, plant growth regulators may have more versatile effects on plant growth (Rajala and Peltonen-Sainion, 2001). Cereal grain is the product of some main components such as number of spikelets per spike, number of kernels per spike and kernel mass (Mitchell, 1985). The net effect of growth regulators on grain yield depends on the balance of positive, null, or negative responses of individual yield components to these growth regulators (Moes and Stobbe, 1991). The increase in grain yield after treatment with various concentrations

Table 3: Effect of Mepiquat chloride concentration and water level on grain yield (g pot^{-1}), harvest index, number of fertile tillers per plant and number of kernels per main spike of the cultivars grown in the greenhouse

Cultivar	Concentration ($mg\ kg^{-1}$)	Grain yield		Harvest index		Number of fertile tillers per plant		Number of kernels per main spike	
		Well water	Water stress	Well water	Water stress	Well water	Water stress	Well water	Water stress
Hourani	0	10.8	2.4	0.23	0.21	2.2	1.1	33.9	14.8
	250	11.2	3.4	0.24	0.21	2.2	1.3	37.4	18.9
	500	12.1	3.4	0.23	0.22	2.7	1.2	36.4	18.8
	750	14.4	3.4	0.25	0.21	2.9	1.3	39.7	18.8
Petra	0	15.7	6.9	0.39	0.41	3.0	1.3	40.0	20.2
	250	15.6	6.7	0.37	0.36	3.1	1.3	39.9	24.7
	500	21.5	7.3	0.39	0.37	3.6	1.4	43.3	26.4
	750	21.6	7.3	0.39	0.37	3.7	1.4	43.1	26.3
LSD ($p \leq 0.05$)		1.5		0.09		0.4		5.5	

Table 4: Effect of Ethephon concentration and water level on grain yield (g pot^{-1}), harvest index, number of fertile tillers per plant, plant height (cm) and number of kernels per main spike of two wheat cultivars grown in the greenhouse

Cultivar	Concentration ($g\ ha^{-1}$)	Grain yield		Harvest index		Number of fertile tillers per plant		Plant height (cm)	
		Well water	Water stress	Well water	Water stress	Well water	Water stress	Well water	Waterstress
Hourani	0	10.8	2.4	0.24	0.21	2.2	1.1	98.6	63.5
	150	12.9	2.4	0.29	0.21	2.2	1.1	89.7	63.4
	300	13.9	2.4	0.31	0.21	2.3	1.1	82.8	62.9
Petra	0	15.5	6.8	0.39	0.37	3.0	1.4	73.3	60.7
	150	15.5	6.8	0.39	0.37	3.0	1.4	73.2	60.7
	300	15.6	6.8	0.39	0.37	3.0	1.4	73.2	60.7
LSD ($p \leq 0.05$)		1.0		0.03		0.2		3.9	

Table 5: Effect of cultivar and ethephon concentration on grain yield ($g\ ha^{-1}$), harvest index, number of fertile tillers per plant and plant height (cm) for wheat plants grown in the field

Cultivar	Concentration ($g\ ha^{-1}$)	Grain yield ($g\ ha^{-1}$)	Harvest index	Number of fertile tillers per plant	Plant height (cm)
Hourani	0	3258	0.24	1.6	60.0
	150	3522	0.27	1.8	55.7
	300	3606	0.29	1.8	54.4
	450	3651	0.32	1.8	50.9
Petra	0	3912	0.31	1.9	46.5
	150	3900	0.33	1.9	45.2
	300	3922	0.34	1.9	45.9
	450	3972	0.34	1.9	45.5
LSD ($p \leq 0.05$)		189	0.03	0.1	1.9

Table 6: Effect of cultivar and stage of ethephon application on grain yield ($g\ ha^{-1}$), harvest index, number of fertile tillers per plant and plant height (cm) for wheat plants grown in the field

Cultivar	Stage of application	Grain yield ($g\ ha^{-1}$)	Harvest index	Number of fertile tillers per plant	Plant height (cm)
Hourani	Zadoks 10	3648	0.30	1.80	52.2
	Zadoks 20	3581	0.30	1.80	54.4
	Zadoks 30	3298	0.24	1.60	59.3
Petra	Zadoks 10	3965	0.34	1.90	45.5
	Zadoks 20	3920	0.34	1.90	45.7
	Zadoks 30	3895	0.32	1.90	46.2
LSD ($p \leq 0.05$)		157	0.02	0.03	1.6

of Mepiquat Chloride and Ethephon might be attributed to the increase in number of fertile tillers per plant and number of kernels per main spike (Table 3 and 4). Under well water conditions, Greenhouse studies indicated that number of fertile tillers per plant for plants treated with 750 g kg^{-1} of Mepiquat Chloride increased by up to 23 and 32% for Petra and Hourani cultivars, respectively (Table 3). No significant effects were observed for Ethephon application. On the other hand, no significant effects of Mepiquat Chloride were observed under field conditions. Hourani responded to Ethephon application by up to 12% increase after treatment with 450 g $ha^{-1}$of Ethephon (Table 5).

Stage of Ethephon application was only significant under field conditions. Treatment at the Zadoks 10 and 20 produced more fertile tillers than treatment at the Zadoks 30 (Table 6) while no responses were observed for Petra. Earlier application of Ethephon has been tested previously as a method of decreasing the dominance of the main spike of barley in order to get better synchronization of tiller formation and to increase tiller survival, spike number per unit area and to grain yield (Waddington and Cartwright, 1986, cited by Ma and Smith, 1991, 1992). Also, number of kernels per spike increased by up to 18% after treatment with Mepiquat Chloride in the greenhouse (Table 3). Moes and Stobbe (1991) had shown a decrease in number of kernels per spike of barley cultivars after treatment with 240 g ha^{-1} of Ethephon. This indicates that growth retardants influences cereals yield by having a positve or negative effect on individual yield components.

Harvest index is a factor that cultivar was increased after treatment with Ethephon under well water conditions by up to 29% in the greenhouse and up to 33% in the field of Hourani (Table 4 and 5). For Petra, this component, was increased by up to 10% in the field. Plant height was only affected by Ethephon. Similarly, Hourani values were

Table 7: Interaction effect of cultivar with water regimes on water use efficiency (g grain yield kg^{-1} water) of wheat plants grown in the greenhouse

Cultivar	Water regimes: Well water	Water stress
Hourani	0.84	0.70
Petra	1.52	0.83
LSD ($p \leq 0.05$)	0.06	

reduced by up to16% with Ethephon treatment under well water conditions and field in pot experiment (Table 4 and 5). Responses of Hourani cultivar to Ethephon was obvious at earlier growth stages. Plant height was shorter by 4-12% when Ethephon was sprayed at Zadoks 10 than at 20 and 30 (Table 6). These results agree with previous reports concerning Ethephon applications on maize (Cox and Andrade, 1988) barley (Foster and Taylor, 1993) and wheat (Van Sanford *et al*., 1989).

Water use efficiency: Water use efficiency was not affected from Ethephon and Mepiquat Chloride treatments. Petra cultivar had greater water use efficiency than Hourani under well water and water stressed conditions (Table 7). Petra cultivar had shorter canopy and greater water use efficiency, which may be due to a remobilization of carbon from stem to grain during the grain filling period and this was indicated by the 40% greater grain yield (Table 3). These results are in agreement with Siddique *et al*. (1990) who reported that modern wheat cultivars had higher water use efficiency than the olders ones.

CONCLUSIONS

There were no observed significant influences of Mepiquat Chloride and Ethephon on shoot:root ratio. Mepiquat Chloride treatment increased grain yield under favorable soil water status and the treatment with 750 mg kg^{-1} gave highest yield. Ethephon treatment increased Hourani's grain yield under well-watered conditions. Nevertheless, no such effect was noticed under water stressed conditions. Although, Petra had shorter plants and out yielded Hourani. Petra cultivar had higher water use efficiency than Hourani cultivar both under well water and water stress conditions. Similarly, differences between yield components of the used cultivars caused different levels of the grain yield. Yield increases after treatment with growth regulator may be due to an increase in the number of fertile tillers per plant and number of kernels per main spike.

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