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Effect of Anoxia on Root Growth and Grain Yield of Wheat Cultivars

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Abstract**—**Waterlogging reduces shoot and root growth and final yield of wheat. Waterlogged sites have a combination of low slope, high rainfall, heavy texture and low permeability. This study was aimed the importance of waterlogging on root growth and wheat yield. In order to study the effects of different waterlogging duration (0, 10, 20 and 30 days) at growth stages (1-leaf stage, tillering stage and stem elongation stage) on root growth of wheat cultivars (Chamran, Vee/Nac and Yavaroos), one pot experiment was carried out. The experiment was a factorial according to a RCBD with three replications. Results showed that root dry weight and total root length in the anthesis and grain ripening stages and biological and grain yields were significantly different between cultivars, growth stages and waterlogging durations. Vee/Nac was found superior with respect to other cultivars. Susceptibility to waterlogging at different growth stages for cultivars was 1-leaf stage > tillering stage > stem elongation stage. Under waterlogging treatments, grain and biological yields, were decreased 44.5 and 39.8%, respectively. Root length and root dry weight were reduced 55.1 and 45.2%, respectively, too. In this experiment, decrease at root growth because of waterlogging reduced grain and biological yields. Based on the results, even short period (10 days) of waterlogging had unrecoverable effects on the root growth and grain yield of wheat.

Keywords**—**Wheat, waterlogging, root length, root dry weight, grain yield.

I. INTRODUCTION

ABOUT 10% of the global land areas and one million hectare of the sown areas in Iran are under condition waterlogging [7]. Waterlogging reduces shoot and root growth and final yield, in crop plants. In these regions, there are high rainfall, heavy texture (clay) soil, low slopes and poorly drained soils [8]. During waterlogging, the gas exchange between soil and air decreases, as gas diffusion in water is decreased 10000- fold. O_2 in the soil is depleted rapidly, and the soil may become hypoxic or anoxic within a few hours. Soil oxygen deficits can restrict plant performance directly through root metabolism or indirectly by changed plant nutrient availability. Oxygen is needed to produce energy for growth during the breakdown of organic compounds. When the oxygen is depleted from soil, the roots and aerobic microorganisms lose almost all capacity to produce energy; hence, they stop growing and may die [15]. Waterlogging can affect on several physiological processes, such as absorption of water [10], root and shoot hormone relations [4], and decrease the uptake and transport of ions through roots causing nutrient deficits [5]. The severity of the effects of waterlogging depend on the plant, the genotype [14], [9], [13], the growth stage of the plant [17], [14], the depth of the water level [3], and the duration of the waterlogging event [1].

Some evidence of genotypic differences in tolerance to waterlogging exists in wheat. Van Ginkel et al. [13] identified 14 waterlogging-tolerant spring wheat lines. Using a 5-week waterlogging treatment, Sayre *et al.* [9] identified six tolerant genotypes in terms of number of tillers, leaf chlorosis, senescence, fertility, grain yield and kernel weight.

In wheat, waterlogging can reduce grain yield of winter wheat [1]-[12]. Even short-term transient waterlogging can have considerable effects on growth and yield of dryland crops. Ultimately, both root and shoot dry mass production reduced [3]-[4]. Waterlogging reduces leaf elongation, photosynthesis, kernel number, and final yield [2]-[11]-[12]-[16]. Yield reduction is due to waterlogging, disease and loss of nitrogen by leaching and denitrification.

To date, with few exceptions [2], [4], most experiments investigating the effects of waterlogging duration on final yield were considered. The objectives of this study was to determine the form of response to different levels of waterlogging of several quantitative traits of wheat, including root length, root dry weight (at the anthesis and grain ripening stages), grain and biological yields in a pot experiment, to estimate losses from waterlogging, and to evaluate tolerance to waterlogging stress of spring wheat genotypes.

II. MATERIALS AND METHODS

A pot experiment was carried out in order to study the effects of different waterlogging durations (0, 10, 20 and 30 days) at growth stages 1-leaf stage, tillering stage and stem elongation stage on root growth of wheat cultivars (Chamran, Vee/Nac and Yavaroos). The experiment was a factorial according to a RCBD with three replications.

Seed of the three wheat cultivars were planted at 10 mm depth in each of 208 plastic (PVC) pots (height 60 cm, diameter 15 cm) on 5 January. After emergence, the seedlings were thinned to eight plants per pot. The pots were holed in side 1 cm above the bottom. The soil of pots containing of the soft river sand and the farm soil from depth 0-30 cm (sieved

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and then fine mixed in proportion 1:4) taken from the Research Field in Ramin Agriculture and Natural Resources University. The pots were fertilized pre-plant with 300 kg ha^{-1} (N-P-K), and later top-dressed N as urea applied in tillering and stem elongation to equal 100 kg ha^{-1} for each time. The pots, at the start of waterlogging treatment were moved to the small pool to maintain to desired water level with depth 60 cm. In this condition, soil in the pots saturated from water. At the anthesis and grain ripening stages (Vee/Nac on 30 April, chamran and yavaroos on 5 May) for take out of roots from pot, about 12 h immersed in water and then the soil attached to roots was removed by sieving to pass a 0.5 mm opening. Samples of roots were conserved in glycerin and water solution (1:1). Method used for the measurement of root length is given by line intersect method [6]. A 0.8 grid was used. Different root sections were dried for 48 h at 65 °C and dry weight was determined. The biological yield (shoot dry weight) was determined after drying at 75 °C for 48 h. Data of this experiment were analyzed with using the MSTATC statistical software. In addition, means comparison were carried out with 5% probability levels (DMRT).

III. Results and Discussion

A. Length and Root Dry Weight at the Anthesis Stage

The mean of root length and root dry weight was significant different between cultivars, start of waterlogging stages (growth stages) and waterlogging durations (p=0.01). Vee/Nac had the highest root length and root dry weight (5515 cm $plant^{-1}$ and 0.501 g $plant^{-1}$), and yavaroos was the lowest (4886 cm $plant^{-1}$, and 0.458 g $plant^{-1}$), respectively. Start of waterlogging treatment at the stem elongation stage was found superior compared to other stages. Root length and root dry weight were decreased with waterlogging duration for wheat cultivars (Table 1).

Results of our study indicated that, root dry weight and root length, with increase of waterlogging duration were significantly reduced so that in 10, 20 and 30 d waterlogging treatment, root dry weight 37.7, 44.3 and 54.0%, and for root length 25.8, 47.0 and 58.8% reduced compared to the control, respectively. Significant interaction of cultivar×waterlogging duration for root dry weight indicated that the average root dry weight of cultivars changed at different durations differently for the four levels of waterlogging (p=0.01). The three cultivars responding to the levels of waterlogging were not parallel at different durations. A significant interaction was between Start of waterlogging stage×waterlogging duration for root length, but not significant the other interaction effects (Tables 2 and 3).

B. Length and Root Dry Weight at the Grain Ripening Stage

Analyses of variance and means comparisons showed that between cultivars, start of waterlogging stages and different waterlogging durations observed significant different in terms of length and root dry weight (p=0.01). Based on results, Vee/Nac had the highest root dry weight (0.316 g $plant^{-1}$) and root length (3387 cm $plant^{-1}$) and yavaroos an amount the lowest. Between the start of waterlogging stages, 1-leaf stage and stem elongation stage were the lowest and the highest amount of length (cm $plant^{-1}$) and root dry weight (g $plant^{-1}$), respectively. Different of waterlogging durations were significant, so that root dry weight in 10, 20 and 30 d decreased 26.5, 35.4 and 45.1% compared to the control, respectively. Amount of root length also decreased 27.6, 43.6 and 55.1% compared to the control, respectively (Table 1). For wheat grown in waterlogging soil for 14 d, Malik *et al.* [3] observed a decrease in maximum length of the seminal roots, which indicates death and decay of seminal root apices under these conditions. Means comparisons of interactions showed, in the tables 2 and 3.

C. Biological Yield

Biological yield was significant between all the treatments (p=0.01). Means comparisons showed that chamran produced the highest of biological yield with 2.88 g $pant^{-1}$. Between start of waterlogging stages, 1-leaf stage and stem elongation stage with production 2.26 and 3.05 g $plant^{-1}$ were the lowest and the highest of the biological yield, respectively. 10, 20 and 30 d waterlogging durations reduced 32.2, 35.6 and 39.7% biological yield compared to the control, respectively. A significant interaction were between cultivar×start of waterlogging stage (p=0.01) and start of waterlogging stage×waterlogging duration (p=0.01), but not significant the other interaction effects (Tables 1, 2 and 3).

D. Grain Yield

The mean of grain yield was significant different between cultivars, start of waterlogging stages and waterlogging durations (p=0.01). Grain yield obtained in the Vee/Nac with 1.218 g $plant^{-1}$ compared to chamran and yavaroos cultivars with 1.123 and 1.113 g $plant^{-1}$, respectively. Between start of waterlogging stage, stem elongation stage and 1-leaf stage had the highest and the lowest grain yield, respectively. Waterlogging at early vegetative stages effected growth and yield more than waterlogging during the late vegetative or reproductive phase. Bao [17] reported, based on an experiment on wheat cultivars that the most susceptibility to waterlogging at different stages was obtained at early growth stages. Grain yield decreased by waterlogging duration as at durations 10, 20 and 30 d reduced 26.6, 34.3 and 44.4% compared to the control, respectively (Tables 1). Musgrave and Ding [12] observed a 45% reduction, and Collaku and Harrison [1] found a 44% decrease in wheat yield from waterlogging. A significant interaction were between cltivar×start of waterlogging stage and start of waterlogging stage×waterlogging duration (p=0.01), but not significant the other interaction effects (Tables 2 and 3).

TABLE I
MEAN COMPARISON OF DIFFERENT TREATMENTS ON ROOT DRY WEIGHT (RDW), ROOT LENGTH (RL), BIOLOGICAL (BY) AND GRAIN YIELDS (GY) PER PLANT

Treatments		Anthesis Stage		Grain Ripening Stage			
		RDW(g)	RL(cm)	RDW (g)	RL(cm)	BY(g)	GY(g)
Cultivar	Chamran	0.472^{ab}	5445^{a}	0.295^{ab}	3028^{b}	2.881^{a}	1.123^{b}
	Vee/Nac	0.501^{a}	5515^{a}	0.316^{a}	3387^{a}	2.607^{b}	1.218^{a}
	Yavaroos	0.458^{b}	4886^{b}	0.283^{b}	2773^{c}	2.492^{b}	1.113^{b}
Growth Stage	1-leaf	0.432^{c}	4710^{c}	0.270^{c}	2876^{c}	2.267^{c}	1.008^{c}
	Tillering	0.478^{b}	5362^{b}	0.301^{b}	3059^{b}	2.661^{b}	1.192^{b}
	Stem Elongation	0.512^{a}	5774^{a}	0.322^{a}	3254^{a}	3.052^{a}	1.255^{a}
Waterlogging Duration	0 d	0.725^{a}	7876^{a}	0.407^{a}	4545^{a}	3.640^{a}	1.558^{a}
	10 d	0.451^{b}	5840^{b}	0.300^{b}	3107^{b}	2.466^{b}	1.158^{b}
	20 d	0.403^{c}	4173^{c}	0.263^{c}	2559^{c}	2.343^{c}	1.023^{c}
	30 d	0.332^{d}	3239^{d}	0.223^{d}	2040^{d}	2.192^{d}	0.866^{d}

Means with similar letter(s) in a column (between two horizontal lines) are not significantly different at P=0.05, according to Duncan's Multiple Range Test.

TABLE II
EFFECTS OF WATERLOGGING AT DIFFERENT GROWTH STAGES AND WHEAT ON ROOT DRY WEIGHT (RDW), ROOT LENGTH (RL), BIOLOGICAL (BY) AND GRAIN YIELDS (GY) PER PLANT

Treatments		Anthesis Stage		Grain Ripening Stage			
Cultivar	Growth Stage	RDW(g)	RL(cm)	RDW(g)	RL(cm)	BY(g)	GY(g)
Chamran	1-Leaf	0.413^{d}	5029^{cde}	0.256^{cd}	2899^{cd}	2.395^{d}	0.920^{e}
	Tillering	0.457^{cd}	5508^{abc}	0.307^{ab}	3110^{bc}	2.977^{b}	1.252^{ab}
	Stem Elongation	0.546^{a}	5800^{ab}	0.321^{ab}	3074^{bc}	3.272^{a}	1.196^{bc}
Vee/Nac	1-Leaf	0.472^{bcd}	4694^{e}	0.305^{ab}	3014^{c}	2.328^{d}	1.095^{cd}
	Tillering	0.498^{abc}	5743^{ab}	0.307^{ab}	3312^{b}	2.566^{c}	1.227^{ab}
	Stem Elongation	0.532^{ab}	6109^{a}	0.333^{a}	3835^{a}	2.927^{b}	1.333^{a}
Yavaroos	1-Leaf	0.411^{d}	4409^{e}	0.248^{cd}	2714^{d}	2.078^{e}	1.007^{de}
	Tillering	0.480^{bc}	4834de	0.290^{bc}	2754^{d}	2.442^{cd}	1.097^{cd}
	Stem Elongation	0.486^{abc}	5414^{bcd}	0.310^{ab}	2853^{cd}	2.957^{b}	1.233^{ab}

Means with similar letter(s) in a column are not significantly different at P=0.05, according to Duncan's Multiple Range Test.

TABLE III
EFFECTS OF DIFFERENT WATERLOGGING DURATIONS (WD) AND DIFFERENT GROWTH STAGES OF WHEAT ON ROOT DRY WEIGHT (RDW), ROOT LENGTH (RL), BIOLOGICAL (BY) AND GRAIN YIELDS (GY) PER PLANT

Treatments		Anthesis Stage		Grain Ripening Stage			
Growth Stage	WD(d)	RDW(g)	RL(cm)	RDW(g)	RL(cm)	BY(g)	GY(g)
1-Leaf	0	0.712^{a}	7902^{a}	0.404^{a}	4572^{a}	3.640^{a}	1.572^{a}
	10	0.401^{cd}	4775^{c}	0.260^{cde}	2756^{c}	1.931^{f}	0.942^{ef}
	20	0.340^{d}	3303^{ef}	0.223^{ef}	2377^{d}	1.826^{fg}	0.848^{f}
	30	0.265^{e}	2888^{f}	0.192^{f}	1811^{e}	1.672^{g}	0.668^{g}
Tillering	0	0.723^{a}	7975^{a}	0.408^{a}	4502^{a}	3.677^{a}	1.545^{a}
	10	0.456^{bc}	6136^{b}	0.293^{c}	3236^{b}	2.516^{d}	1.221^{bc}
	20	0.395^{cd}	4436^{cd}	0.273^{cd}	2433^{d}	2.315^{e}	1.060^{de}
	30	0.341^{d}	2998^{f}	0.231^{def}	2008^{e}	2.176^{e}	0.942^{ef}
Stem Elongation	0	0.736^{a}	8001^{a}	0.412^{a}	4613^{a}	3.656^{a}	1.558^{a}
	10	0.493^{b}	6611^{b}	0.342^{b}	3329^{b}	2.952^{b}	1.311^{b}
	20	0.475^{b}	4780^{c}	0.292^{c}	2869^{c}	2.890^{b}	1.163^{cd}
	30	0.392^{cd}	3831de	0.246^{de}	2300^{d}	2.727^{c}	0.983^{e}

Means with similar letter(s) in a column are not significantly different at P=0.05, according to Duncan's Multiple Range Test.

IV. CONCLUSION

The present study clearly demonstrated the negative effects of waterlogging on growth and survival of root system, balances of root and shoots growth. The cessations of root growth, reduced shoot growth of wheat under 10-30 d waterlogging stress. Susceptibility to waterlogging at different stages was 1-leaf stage > tillering stage > stem elongation stage. Vee/Nac, because of rapid development was the most tolerant cultivar to waterlogging stress.

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