Evaluation of uptake rate and distribution of nutrient ions in wheat (*Triticum aestivum* L.) under waterlogging condition

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Abstract

Waterlogging is an important factor which is influence on nutrient uptake. Therefore, in this study, the uptake and distribution of nutrients ions in different parts of plant were investigted in wheat cultivars. This study was conducted at the Agricultural Research Station, Islamic Azad University- Ahvaz Branch. Experimental design was a factorial according to randomized complete block design (RCBD) with three replications. In this experiment three wheat cultivars namely “Chamran”, “Dez” and “Verry/nac” were used. These were grown under no-waterlogging (control), 7 days and 14 days of waterlogging. Meanwhile, waterlogging treatments for each cultivar were given separately at three different growth stages namely at the beginning of tillering stage, at the beginning of stem elongation stage and at the commencement of booting stage. The results showed that the concentration of N, K, Fe, Mn, Cu and Zn in root, stem and seed did not affect when waterlogging was applied at different growth stages, significantly. Duration of waterlogging significantly decreased concentration of N, K, Cu and Zn in all parts of plant. The concentration of Fe and Mn in the root increased significantly after duration of waterlogging, but decreased in stem and seed. Results also showed a significant difference between tested wheat cultivars for concentration of N, K, Fe, Mn, Cu and Zn in all parts of plant.

Keywords: potassium; nitrogen; root; shoot; wheat

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Introduction

Wheat (*Triticum aestivum* L.) is the first cereal grain consumed by humans around the globe. (Anonymous, 2010). Wheat production suffers from many kinds of abiotic stresses including temperature, air pollution, drought, waterlogging etc. (Afzal Sunbal et al., 2015). Waterlogging is the state of land in which the soil surface becomes saturated with water especially due to excessive rainfall or irrigation, particularly in areas with poor drainage or level (Sharma et al., 2009). Approximately 10% of the global land area experiences waterlogging stress every year (Volkov, 2012). In Iran about 5.7% of total arable lands suffer from waterlogging stress (Ghobadi, 2006). Since the speed of oxygen movement in waterlogged soils is about 10,000 times less than normal aerobic soil (Sarmadnia and Kochaki, 2012), plants and microorganisms experience oxygen deficiency. In waterlogged condition, root growth decreases and gets restricted to small

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Table 1
Soil composition of the experimental field

Depth (cm)	pH	EC	Total N%	P(Av.) ppm	K(Av.) ppm	Soil components			Soil Texture
						Clay %	Silt %	Sand %	
0-30	7.6	3.1	0.054	5.9	145	38	45	17	Silty clay loam
30-60	8.4	2.9	0.050	5.5	138	38	48	14	Silty clay loam

EC= Electrical conductivity, N= Nitrogen, P= Phosphorus, K= Potassium, ppm= parts per million, Av.= Available

region near the soil surface. Behavior and perceptible variations of roots under waterlogging appeares after approximately 48 h (Akhtar and Nazir, 2013). In the absence of oxygen, root growth and functional relationship between root and shoot is disturbed due to insufficient energy generated by the root respiration (Lahouti et al., 2014). It is observed that decrease in concentrations of nitrogen, phosphorous, potassium, calcium, and magnesium in the shoot of wheat seedlings soon after the start of waterlogging are mainly due to the inhibition of ion uptake and their transport. Premature senescence of older leaves under waterlogging stress was because of reallocation of elements (N, P, and K) to younger leaves (Akhtar and Nazir, 2013; Najeeb et al., 2015; Aldana et al., 2014). Under waterlogging conditions and oxygen depletion, anaerobic soil microorganisms derive their energy from the reduction of soil nitrate (NO_3^-) to nitrite (NO_2^-), nitrous oxide (N_2O) and molecular nitrogen (N_2). These gases (N_2O and N_2) are lost to the atmosphere in a process called denitrification (Lahouti et al., 2014). In waterlogged soils, due to depletion of redox potential and electron excess, Fe^{+3} and Mn^{+4} are changed to Fe^{+2} and Mn^{+2}, respectively. Thus, solubility of iron and manganese rises to toxic levels (Aldana et al., 2014; Lahouti et al., 2014). Investigation of soil pH in alkaline and acid soils after several weeks waterlogging demonstrated a decrease of pH in alkaline soils and increase of pH in acid soils toward neutrality (Najafi, 2013). According to Setter et al. (2009) changes in Mn concentration in shoot of wheat is related to seasonal condition. The maximum concentration of Mn in shoot of wheat occurs under long period of waterlogging, high temperature of environment, and drought period of environment. However, in some cases, concentration of Mn was the same as in the case of absence of waterlogged conditions. Jimenez et al. (2015) reported that uptake and transport of N, P, K, Ca, Mn, Cu, and Zn in shoots decreased under oxygen deficiency, significantly, but concentration of Fe and Ca were not affected by waterlogging. Also, nutrient deficiency was the main cause for poor plant growth in waterlogged soil rather than toxicity factor. Sharma et al. (2018) noted that in waterlogged alkaline soils absorption of N, P, K, Ca, and Mg reduced, but absorption of Na, Fe, and Mn increased in wheat. It is also demonstrated that in waterlogged acidic soils the concentration of Al, Mn, and Fe in shoots of wheat increased (Khabaz-Saberi and Rengel, 2010) while in neutral soils these elements decreased or remained the same as in the control plants (Khabaz–Saberi et al. 2006).

Therefore, in the present work the problems of nutrients uptake was investigated in wheats under waterlogging conditions as it is of an immense importance for wheat production.

Materials and Methods

This experiment was conducted at the Agricultural Research Station of Islamic Azad University, Ahvaz Branch during 2009-2010 crop seasons. Ahvaz is located in South-west of Khuzestan province. The longitude, latitude, height above sea level of the study area are 48°, 40′, 31°, 20′, and 18 m, respectively. To evaluate the effect of waterlogging condition, three wheat cultivars namely “Chamran”, “Dez” and “Verry/nac” were used. The three wheat cultivars are spring wheats with different plant heights. Verry/nac cultivar is early maturing compared with the other cultivars (Anonymous, 2006). The cultivars were grown under no-waterlogging (control), 7 days, and 14 days of waterlogging. Waterlogging treatments for each cultivar were given separately at three different growth stages namely at the beginning of tillering stage (ZG[1]21), at the beginning of stem elongation stage (ZG31), and at the commencement of booting stage (ZG45). Experimental design was factorial according to randomized complete block design (RCBD) with three replications. For the measurement of soil compositions in experimental field, we took ten soil samples randomly from different sites of the field before the tillage. Soil samples were collected from two different depths (0-30 and 30-60 cm). The soils of each depth were mixed and analyzed separately in the Agricultural Research Center Laboratory. The results of soil analysis are shown in Table 1.

On the basis of soil compositions (Table 1) and recommendation of Agricultural Research Center, 150 Kg/ha N (75 kg/h at sowing stage and 75 kg/h at tillering stage), 100 Kg/ha P_2O_5, and 100 Kg/ha K_20 (at sowing) were applied. Urea (46% N), Tripe super phosphate (48% P_2O_5), and potassium sulfate (50% K_2O) were used as fertilizer. For preparation and sowing, the experimental field was irrigated. When the soil moisture changed to field capacity (FC), the field was plowed 25 cm deep. Disk harrow and Leveler machines were used for clod breaking and balancing of field surface. Meanwhile, one time disk harrow was applied after pre-plant fertilization. Thereafter, on the basis of research plan, the levees (30 to 40 cm in height) were constructed for each plot. In order to prevent penetration of water from one plot to the other plots, two meter distance between plots was maintained. Each plot included seven rows. Each row was six meter long. The rows were 20 cm apart. Distances between plots were two meters. Total numbers of plots were 81. Sowing of seed was done on 21st November. Seed density for each cultivar was according to the ideal seed density in location (400 seeds per square meter). The field was irrigated immediately after sowing. Waterlogging was accomplished by using water channel which was near the field. Soil was kept saturated with water by continuous irrigation for duration of waterlogging. Harvest of wheat cultivars was done when the moisture content of seeds ranged from 13 to 14 percent. For determination of nutrient ions in plant, a sample from different parts of plant (root, stem, and seed) was taken at ripening stage of plant. The samples were dried to constant weight in an oven. Percentage of nitrogen was analyzed by Kjeldhal method. For determination of nutrient ions, namely Mn, Cu, Zn, and Fe, samples were dry-ashed at 550°C for 2 h and the ash was solubilized in 10 ml HCl. Volume of the solution was adjusted to 100 ml with distilled water. Atomic absorption machine (AA 680 model, Varian Co. Australia) was used to estimate the nutrient ions. Total K was measured by a flame photometer (Flame Photometer, 115 VAC).

The data collected was analyzed statistically by using computer software “MSTATC”. Duncan's multiple range tests at alpha level 5% was computed to compare the significant differences among means.

Results

Nitrogen

Results of analysis of variance for nitrogen percentage in different parts of plant are shown in Table 2. In our study, the maximum nitrogen percentage in the three cultivars was observed in seeds and the minimum was obtained from stems (Table 4). Effects of waterlogging at different growth stages were not significant. But the results of mean comparison showed that the nitrogen percentage in shoot (stem and seed) decreased due to damage to root system as compared to the control; but after waterlogging condition, the absorption of nitrogen increased by roots. In light of this, nitrogen percentage under waterlogging at early growth stages (ZG21 and ZG31) increased in the roots, but nitrogen percentage of shoots (stem and seeds) was not affected (Table 2). Results also showed that increasing of waterlogging duration inhibited uptake and translocation of nitrogen, significantly (Table 2). In our study reductions in nitrogen percentage under W_7 and W_{14} were 18.6% and 26.5% in roots, 6.2% and 9.4% in stem,

1. Zadoks scale (ZG) is a decimal code for the growth stage of cereals (Zadoks et al., 1974).

Table 2
Results of analysis of variance for ion concentrations in different parts of plant under waterlogging condition

Treatments		Nitrogen			Potassium			Iron		
Cultivars	df	Root	Stem	Seed	Root	Stem	Seed	Root	Stem	Seed
Replication	2	0.051	0.012	0.035	1207.1	68.8	0.6	14.8	102.2	17.9
Cultivars (C)	2	1.333**	0.141**	0.197**	5849.9**	3622.1**	71.6 ns	3049.0**	80920.5**	628.7**
Stage of waterlogging (S)	2	0.013 ns	0.004 ns	0.040 ns	106.1 ns	43.1 ns	45.4 ns	253.4 ns	220.1ns	3.3 ns
C * S	4	0.005 ns	0.000 ns	0.000 ns	80.0 ns	14.8 ns	14.3 ns	16.6 ns	110.8 ns	19.7 ns
Duration of waterlogging (D)	2	0.526**	0.007**	0.047 *	1705.1*	6086.9**	591.7**	1499.9*	117.5 ns	340.6*
C * D	4	0.004 ns	0.000 ns	0.001 ns	7.1 ns	245.5 ns	65.1 ns	80.6 ns	120.4 ns	9.1 ns
S * D	4	0.020 ns	0.001 ns	0.015 ns	16.4 ns	14.6 ns	46.2 ns	109.0 ns	36.0 ns	0.4 ns
C * S* D	8	0.007 ns	0.000 ns	0.000 ns	47.1 ns	7.2 ns	0.4 ns	31.5 ns	34.4 ns	4.6 ns
Error	52	0.026	0.002	0.021	525.4	525.9	93.3	373.4	395.6	84.7
Coefficient of variation %		18.4	14.4	9.3	12.2	11.8	13.0	7.6	9.3	13.2

ns, * and ** not significant, significant at the P value of 0.05 and 0.01, respectively

Table 3
Results of analysis variance for ion concentrations in different parts of plant under waterlogging condition

Treatments		Manganese			Zinc			Copper		
Cultivars	df	Root	Stem	Seed	Root	Stem	Seed	Root	Stem	Seed
Replication	2	30.2	3.1	1.8	126.9	0.3	8.1	10.3	0.53	0.2
Cultivars (C)	2	31.0 ns	27.2**	81.2**	2245.5**	155.2**	64.6**	2311.3**	11.04**	0.1 ns
Stage of waterlogging (S)	2	223.3*	3.4 ns	9.1*	6.5 ns	0.6 ns	15.8*	28.3 ns	0.01 ns	0.1 ns
C * S	4	12.9 ns	17.6**	2.6 *	16.2 ns	0.3 ns	3.0 ns	0.5 ns	0.02 ns	0.2 ns
Duration of waterlogging (D)	2	351.4*	19.2*	135.7**	3968.8**	12.1**	312.8**	1413.4**	1.9*	3.6**
C * D	4	1155.8**	56.8**	15.2**	835.6**	1.2 ns	37.8**	132.7**	0.5 ns	0.2 ns
S * D	4	69.7 ns	1.3 ns	3.7 ns	1.5 ns	0.05 ns	4.7 ns	15.7 ns	0.0 1 ns	0.1 ns
C * S* D	8	9.0 ns	3.3 ns	0.6 ns	2.3 ns	0.04 ns	1.0 ns	1.5 ns	0.008 ns	0.1 ns
Error	52	87.0	4.1	2.9	59.5	2.1	3.9	13.1	0.4	0.2
Coefficient of variation %		8.0	10.6	12.1	10.4	18.1	11.6	16.2	11.5	11.5

ns, * and ** not significant, significant at the P value of 0.05 and 0.01, respectively

and 2.5% and 5.1% in seeds as compared with control, respectively.

Potassium

Findings showed that potassium concentrations in different parts of plant (except seed) were significantly varied in three wheat cultivars (Table 2). Maximum potassium in wheat cultivars was observed in roots and the minimum was recorded in seeds (Table 4). There were not significant differences for the effect of waterlogging at different growth stages on potassium concentration (Table 2). However, investigation of mean data for roots, stems, and seeds showed that the concentration of potassium in different parts of the plants declined by waterlogging especially at earlier Zadoks growth stages (Table 4). Duration of waterlogging significantly affected storage of potassium in different parts of the plants (Table 2). In our experiment increasing waterlogging duration from 0 to 14 days caused a decline in potassium concentration in different parts of plants (Table 4). Maximum and minimum potassium losses were observed in stems and roots by 1.02 % and 0.56%, respectively.

Iron

Results showed that iron concentrations differed in wheat cultivars and different parts of plants, significantly (Table 2). Maximum iron in the three wheat cultivars was obtained in roots and the minimum was found in seeds (Table 4). Results of analysis of variance also showed that iron concentrations were not significantly different under waterlogging at different growth stages (Table 2). Investigation of mean data under waterlogging at early growth stages (ZG21 and ZG31) indicated a slight decrease in iron

Table 4

Mean comparison for ion concentrations in different parts of the plants under waterlogging condition

Treatments / Cultivars	Nitrogen (%)			Potassium(mg/kg)			Iron(mg/kg)		
	Root	Stem	Seed	Root	Stem	Seed	Root	Stem	Seed
Chamran	0.91±0.11 b	0.24±0.03c	1.636±0.14a	196.0±19.32a	189.7 ±23.3b	75.3±12.60 a	255.5 ±9.28a	165.8±4.034 c	66.68 ±9.55b
Dez	0.62 ±0.25c	0.27±0.02b	1.51±0.12 b	197.7± 29.67a	184.7 ±17.8b	75.5 ±7.80a	241.2 ±27.5b	273.6± 6.71a	75.27 ±10.04a
Verry/nac	1.06 ±0.15a	0.38±0.06a	1.47±0.12b	171.4± 7.75b	206.8±26.7 a	72.6 ±6.44a	262.0 ±8.84a	203.3 ±28.55b	67.18 ±3.32b
Stage at which waterlogging started									
ZG21	0.20± 0.20a	0.29± 0.06a	1.57±0.18b	186.2 ± 29.89a	192.4 ±23.8a	73.0 ±10.15a	250.2±17.97 a	211.7 ±45.61a	69.40 ±8.75a
ZG31	0.29 ±0.29a	0.30 ±0.06a	1.54±0.14ab	188.7 ±24.65 a	193.9 ±25.5a	74.8±7.84 a	252.4 ±24.33a	213.6±47.55 a	69.63 ±10.14a
ZG45	0.27±0.27a	0.31±0.08a	1.49±0.10ab	190.1 ±15.94a	194.9±25.1 a	75.6 ±9.93a	256.2 ±14.98a	217.3 ±52.36a	70.09±8.47 a
Duration of waterlogging									
Wo (control)	1.02 ±0.29a	0.32±0.08a	1.580± 0.19a	197.0 ±23.26a	209.1±24.3a	79.8±3.9a	245.1±13.24b	216.1± 46.7a	73.37±7.30a
W7	0.82 ±0.20b	0.30±0.06ab	1.54±0.13 ab	186.6 ±26.76ab	193.0± 27.2b	72.3±10.48b	253.7 ±22.38ab	214.6 ±49.74a	69.48 ±8.59ab
W14	0.75 ±0.18b	0.28±0.06b	1.49±0.09b	181.4 ±19.37b	179.1±7.4 c	71.3 ±9.80b	260.0 ±19.16a	212.0 ±49.35a	66.28 ±9.90b

Means with different letters are significantly different at P≤0.05, using Duncan's Multiple Range Test.

Table 5

Mean comparison for ion concentrations in different parts of the plants under waterlogging condition

Treatments / Cultivars	Manganese(mg/kg)			Zinc(mg/kg)			Copper(mg/kg)		
	Root	Stem	Seed	Root	Stem	Seed	Root	Stem	Seed
Chamran	116.0 ±7.73a	18.1 ±3.31b	14.3 ±3.29b	68.58 ±6.607b	5.84 ±0.43c	15.39 ±3.80b	32.66 ±10.74a	5.02 ±0.98b	4.28 ±0.60a
Dez	116.9 ±11.95a	20.0 ±2.93a	15.7 ±2.66a	68.75 ±21.09b	7.76 ±0.55b	17.57 ±2.66a	14.87 ±3.28c	6.21 ±0.18a	4.40 ±0.51a
Verry/nac	118.1 ±14.53a	19.4 ±1.82a	12.2 ±1.64c	84.46 ±8.83a	10.61 ±2.24a	18.39 ±1.64a	19.35 ±5.92b	6.00 ±0.39a	4.33 ±0.51a
Stage at which waterlogging started									
ZG21	114.0 ±9.25a	18.8 ±1.50a	13.6 ±2.92b	74.42 ±15.90a	8.24 ±2.13a	17.74 ±3.40a	23.36 ±10.59a	5.77 ±0.74a	4.41 ±0.52a
ZG31	117.3 ±11.72a	19.2 ±3.07a	13.9 ±2.87ab	73.93 ±16.60a	8.04 ±2.52a	17.34 ±3.94ab	22.19 ±10.44a	5.75 ±0.68a	4.33 ±0.59a
ZG45	119.7 ±13.26a	19.5 ±3.59a	14.7 ±3.06a	73.44 ±14.49a	7.94 ±2.54a	16.26 ±4.20b	21.32 ±10.75a	5.72 ±5.72a	4.27 ±0.50a
Duration of waterlogging									
Wo (control)	114.6 ±12.49b	20.1 ±2.68a	16.6 ±2.33a	87.71 ±12.6a	8.72 ±2.3a	20.97 ±1.93a	30.04±11.75a	6.02 ±0.79a	4.75 ±0.30a
W7	115.3 ±3.57b	19.0 ±2.72b	13.2 ±2.00b	69.20 ±9.96b	8.11 ±2.80ab	15.87 ±2.80b	21.12 ±8.13b	5.72±0.80ab	4.20 ±0.64b
W14	121.1 ±14.84a	18.5 ±2.63b	12.4 ±2.64b	64.89 ±13.25c	7.38 ±1.78b	14.51 ±3.21c	15.71 ±5.10c	5.50 ±0.75b	4.06 ±0.32b

Means with different letters are significantly different at P≤0.05, using Duncan's Multiple Range Test.

concentration in roots as compared to late growth stages (Table 4). Extending of waterlogging duration from 7 to 14 days significantly increased concentration of iron in root system. In opposite manner, concentration of iron in shoots (stems and seeds) decreased with prolonging waterlogging duration (Table 2).

Manganese

Results showed that manganese concentration in different parts of plant were significantly different for tested wheat cultivars, except roots (Table 3). The maximum and minimum of manganese concentration in wheat cultivars obtained in roots and seeds, respectively (Table 5). There was a significant effect of waterlogging at different growth stages on manganese concentration in roots and seeds (Table 3). Inspection of mean values (Table 5) indicated that the manganese concentration in roots was less under waterlogging at early growth stages (ZG21 and ZG31) as compared to late growth stage (ZG45). Results also showed that the minimum of manganese concentration in shoot (stem and seeds) obtained under waterlogging at early growth stages. Manganese concentration in all parts of plant was significantly different under duration of waterlogging (Table 3). Extending of waterlogging duration was reduced manganese concentration in shoot (stem and seeds) (Table 5). Investigation of interaction between wheat cultivars and duration of waterlogging demonstrated that reaction of wheat cultivars to increasing of waterlogging duration was significantly different in roots, stem and seeds (Table 3) and (Table 6). Also, reactions of wheat cultivars to waterlogging at different growth stages were different for manganese concentration in stem and seed (Table 3) and (Table 7).

Table 6
Mean comparison for the interactions between wheat cultivars and duration of waterlogging for manganese concentration (mg/kg) in different parts of the plants

Cultivars	Duration of waterlogging	Root	Stem	Seed
Chamran	Wo(control)	108.2 ±0.98c	21.91 ±2.35a	18.49 ±0.30a
	W7	115.2 ±2.64bc	16.71 ± 1.25de	12.44 ±1.35c
	W14	124.5 ±6.01ab	15.63 ±1.76e	11.86 ±1.68cd
Dez	Wo (control)	127.5 ±14.85a	20.66 ±2.76ab	17.22 ±2.46a
	W7	114.9 ±3.78bc	19.13 ±3.08 bc	15.04 ± 2.10b
	W14	108.3 ±3.67c	20.34 ±3.04ab	14.80 ±2.92 b
Verry/nac	Wo(control)	108.0 ±1.27c	17.78 ±0.33 cd	14.13 ±0.42b
	W7	115.6 ±4.46c	21.16 ±1.35ab	12.00 ±0.81cd
	W14	130.7 ±19.09a	19.40 ±1.57bc	10.58 ±0.83d

Means with different letters are significantly different at P≤0.05, using Duncan's Multiple Range Test.

Table 7
Mean comparison for the interactions between wheat cultivars and stages of waterlogging for manganese concentration (mg/kg) in different parts of plant

Cultivars	Stage at which waterlogging started	Root	Stem	Seed
Chamran	ZG21	112.8 ±3.92a	19.28 ±2.05b	13.29 ±3.96 bc
	ZG31	116.2 ±7.58a	18.09 ±3.35bc	13.96 ±3.39bc
	ZG45	118.9 ±10.02a	16.89 ±4.11c	15.54 ±2.22ab
Dez	ZG21	115.2 ±9.45a	18.86 ±1.27bc	15.61 ±1.33ab
	ZG31	117.2 ±9.05a	19.74 ±3.76ab	15.67 ±2.40ab
	ZG45	118.3 ±8.18a	21.53 ±2.82a	15.79 ±3.93a
Verry/nac	ZG21	114.0 ±7.75a	18.30 ±1.00bc	11.83 ±2.21d
	ZG31	118.5 ±9.36a	19.91 ±1.78ab	12.09 ±1.50d
	ZG45	121.9 ±13.44a	20.12 ±2.10ab	12.79 ±1.02cd

Means with different letters are significantly different at P=0.05 , using Duncan's Multiple Range Test

Zinc

Results of this study indicated a significant difference in zinc concentrations of the wheat cultivars under study (Table 3). Maximum zinc concentration in all parts of the studied wheat was observed in roots while the minimum level was obtained in stems (Table 5). Effects of waterlogging at different growth stages were not significant in different parts of wheat, except seeds (Table 5). Screening of mean values showed that zinc concentrations in different parts of plants were slightly less at later growth stages (ZG45) as compared to earlier growth stages (ZG21 and ZG31).

It was found that after waterlogging condition at the beginning of tillering stage, plants absorbed more zinc ions as compared to the later growth stages. Waterlogging duration significantly decreased zinc concentrations in all parts of the plants (Table 3). Percentages of reduction of zinc in roots, stems, and seeds were 1.9%, 1.1%, and 2.2 % for each day waterlogging condition. Meanwhile, percentages of reduction of zinc in all parts of plants for the first week of waterlogging was more than the second week. Interactions between wheat cultivars and duration of waterlogging for zinc concentrations in roots and seeds were significantly different at 1% statistical level (Table 3). There were reductions of zinc concentration in all wheat cultivars under increasing waterlogging stress. But their response to stress were not parallel (Table 8).

Copper

Results for copper concentration in different parts of plants showed significant differences in wheat cultivars, except seed (Table 3). Maximum copper concentration in three tested cultivars was observed in roots and the minimum was recorded in seeds (Table 5). Waterlogging at different growth stages did not affect copper concentration in different parts of the plant (Table 3). But, the copper availability in different parts of the plants under waterlogging at early growth stages (ZG21 and ZG31) was more than the later growth stages (ZG45). Duration of waterlogging induced a strong reduction of copper concentrations in different parts of the plants (Table 3). Percentages of reduction of copper concentrations in roots, stems, and seeds were 3.41%, 0.62%, and 1.03% for each day of waterlogging, respectively. Interactions between wheat cultivars and duration of waterlogging were significantly different in roots (Table 3). Percentages of reductions of copper concentration for each day waterlogging were 3.71% in Verry/nac cultivar, 3.54% in Chamran cultivar and 2.65% in Dez cultivar (Table 9).

Discussion

Waterlogging for 7 and 14 days inhibited uptake and translocation of nitrogen to roots, stems, and seeds. This was due to the reduction in root system, leaching, and denitrification of nitrogen in the soil. Ren (2017) and Betancourt-osorio and sanchez-canro (2016) also reported a reduction in nitrogen uptake by root after waterlogging condition as a result of reduction in nitrogen concentration in the soil through increasing of leaching and denitrification. Waterlogging applied at ZG21 and ZG31 decreased nitrogen percentage in stems and seeds due to more reduction in root system as compared to waterlogging applied at ZG45. Percentage of nitrogen after waterlogging applied at ZG21 and ZG31 increased in the root as compared to waterlogging applied at ZG45. This was because of long duration after waterlogging applied at ZG21 and ZG31 till ripening stage of plant for absorption of nitrogen by root. But absorption of nitrogen by roots did not increase nitrogen percentage in stems and seeds.

Results showed that waterlogging for 7 and 14 days caused a decline in the concentration of potassium in roots, stems and seeds. Akhtar and Nazir (2013), Najeeb et al. (2015), and Steffens et al. (2005) reported that potassium reduction in the shoot after waterlogging is due to the reduction in uptake and transport of potassium from roots to shoots. Results showed that concentration of potassium declined after waterlogging applied at ZG21 and ZG31 as compared to the waterlogging applied at ZG45. This was because of more reduction in root system after waterlogging applied at ZG21 and ZG31 as compared to waterlogging applied at ZG45 and consequently more inhibition in the uptake of potassium by roots.

Manganese and iron concentrations in different parts of the plants were significantly different for studied wheat cultivars. This was mainly due to the genetic differences of cultivars in for storage of manganese in different parts of plant. Meanwhile, the concentration of iron and manganese in roots increased after waterlogging duration for 7 and 14 days. It is suggested that in waterlogged soils, Mn^{+3} and Fe^{+3} altered to Mn^{+2} and Fe^{+2} and became more soluble in the soil. Thus, iron uptake increased by the root and could rise to toxic levels (Aldana et al., 2014; Scholz, 2016). Khabaz-Saberi (2010) observed more absorption of iron in waterlogged alkaline soils. In the present study, the concentration of iron and manganese decreased in stems and seeds after increasing of waterlogging duration. This was because of the reduction in the root system after waterlogging condition and consequently reduction in translocation of iron and manganese from roots to shoots. Ma et al. (2016) reported that under oxygen deficiency uptake and transport of manganese decreased in aerial parts of wheat, but the concentration of iron was not affected by waterlogging. Khabaz–Saberi et al. (2006) indicated that in waterlogged acidic soils the concentration of Mn and Fe in shoots of wheat increased while in neutral soils these elements decreased or remained the same as in control plants. Results also showed that the concentration of iron and manganese in roots was less after waterlogging applied at ZG21 and ZG31 as compared to waterlogging applied at ZG45. This was due to a long duration after waterlogging applied at ZG21 and ZG31 till ripening stage of the plants for reduction of iron and manganese from toxic levels to sufficiency in the plant. Concentration of iron and manganese in stems and seeds was less after waterlogging applied at

ZG21 and ZG31 as compared to the waterlogging applied at ZG45. This was due to more reduction in root system and transport of iron and manganese from root to all parts of shoots.

Results showed that waterlogging for 7 and 14 days decreased copper and zinc concentration in different parts of plants. This was due to a reduction in root system and leaching of copper and zinc in soil under waterlogging condition. Herzog et al. (2016) also reported a reduction in the uptake and transport of Cu and Zn in shoots of wheat under oxygen deficiency. Result also showed that the concentration of copper and zinc in different parts of the plants under study was more after waterlogging applied at ZG21 and ZG31 as compared to waterlogging applied at ZG45. This was due to long duration after waterlogging applied at ZG21 and ZG31 till the ripening stage of the plant for the uptake and translocation of copper and zinc from roots to shoots.

Conclusion

Analysis of results for nitrogen, potassium, iron, manganese, copper, and zinc concentrations in roots, stems, and seeds indicated significant differences between the three wheat cultivars. Meanwhile, the ion concentrations differed in different parts of the plants. Effects of waterlogging at different growth stages mainly were not significantly different. But the effects of durations of waterlogging were significantly different in different parts of the plants. Variations of nutrients in roots were dependent on the availability of ions in the soil solution under waterlogging stress. In light of this, concentrations of iron and manganese increased while concentrations of other ions decreased in roots. Results also showed that the concentration of all tested ions in the shoot (stems and seeds) decreased with an increase in waterlogging duration.

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