INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 3, No. 2, p. 122-131, 2013

RESEARCH PAPER OPEN ACCESS

Soybean growth under drought stress and foliar manganese

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Key words: drought stress, dry weight, LAI, manganese, soybean.

doi: http://dx.doi.org/10.12692/ijb/3.2.122-131 Article published on February 25, 2013

Abstract

The objective of the present study was to investigate effect of manganese foliar application on soybean growth under drought stress condition. Therefore, a field experiment was conducted as a split split plot based on randomized complete block design with three replicates in Kermanshah province, Iran, 2010. Treatments includes: two irrigation regimes, two foliar treatments, and eight soybean cultivars. At the V4 growth stage, the plants were sprayed twice with 0.5% manganese liquid or distilled water. During the reproductive growth stages, five plants were selected from each plot randomly and leaf area index, stem, leaf, pod, and seed dry weight were measured. The results shown that in stressed plants leaf, stem, pod and seed dry weight was reduced. Total dry weight decreased with irrigation withholding by 12.5%. In addition, soybean plants have lower leaves at the end of growing season under water deficit conditions. Furthermore, in well water condition, Clark, Williams, and DPX cultivars had the highest response to Mn foliar application. Also, Mn application at water deficit condition had significant effect on pod and grain dry weight in all of evaluated cultivars. Total dry weight of M7 cultivar had the lowest response to manganese application in both condition compared the other cultivars.

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Introduction

Soybean growth is measured by the amount of total dry matter accumulating in the plant. Soybean growth and yield are sensitive to drought stress (Boyer, 1983; Westgate and Peterson, 1993). In particular, late maturity groups of soybean cultivars are more susceptible to drought stress. Superiority of soybean dry weight in MGIII (maturity group III) compared MGIV (maturity group IV) at water deficit conditions were observed in our previous study (Kobraee and Shamsi, 2012). In the other word, late maturity group of soybean are the most sensitive to water stress as compared to early maturity groups. Also, a particular stage of plant growth stage may be more sensitive to drought stress than the others. For example, water deficit at flowering stage, further reduced of soybean growth and yield. Abayomi (2008) emphasized that flowering stages in early maturity group of soybean is most sensitive to drought stress. In the other side, resistance of plants to biotic and abiotic stress related to the micronutrients status of plants (Peleg *et al.,* 2008; El-Fouly *et al.*, 2011). Ghasemian *et al.*, (2010) stated that resistance to environmental stress increased by foliar application of micronutrients. In drought stress conditions, crop roots cannot absorb some important nutrients such as micronutrients (Heidarian *et al.*, 2011) and foliar spraying of elements more influential as compared to soil application (Narimani *et al.*, 2010). It is necessary to evaluate the application of manganese fertilizer on stressed plants in climatic condition of Kermanshah province, Iran. Therefore, the aim of this study was to investigation the effect of manganese foliar application on growth and dry matter accumulation in different organs of soybean plant.

Materials and methods

A field experiment was conducted as a split split plot based on Randomized Complete Block design with three replicates in 96 plots at Agricultural Research field of Islamic Azad University of Kermanshah in 2010. Soil samples were collected from experimental area at 0-30 cm depth. The texture of the soil based on silty clay with (silt 49.1%, clay 42.4%, and sand 8.5%), pH 7.3, organic matter 2.6, total nitrogen 0.11%, available phosphorus, potassium, zinc, iron and manganese 8.2, 531, 0.81, 2.76, and 4.49, respectively. Treatments includes: two irrigation regimes: (I1) Irrigation at all of growth stages, (I2) Irrigation Withholding at flowering stage. There were two foliar treatments which consisted: (Mn0) spray with distilled water, (Mn1) manganese spray, and eight soybean cultivars includes: Clark (V1), Williams (V2), Sahar or Pershing (V3), Hobbit (V4), Gorgan 3 (V5), M7 (V6), M9 (V7), and DPX (V8). The quantity of irrigation water in each plot was calculated according to Karam *et al.*, (2005), controlled by counter and exercise irrigation treatment at flowering stage. At the V4 growth stage (based on Fehr and Caviness, 1977), the plants were sprayed twice (with one week interval) with 0.5% manganese liquid or distilled water until the leaves were wet. During the reproductive growth stages and at 20, 50 and 80 days after flowering, five plants were selected from each plot randomly and leaf area index and dry matter accumulation in different organs of plant were measured, separately. Leaf area index was determined by leaf area meter and for measure of stem (SDW), leaf (LDW), pod (PDW), grain (GDW) and total dry weight (TDW) samples were dried at 70^{oc} and 48 hours and weighed accurately. Sampling continued until the soybean maturity stage and/or harvested time. Finally, excel software was used to draw figures.

Results and discussion

Growth of plant communities has been studied by a technique called “Growth Analysis” whereby certain calculations are made relative to the total dry matter (TDM) present and the LAI during the growing season. The term partitioning describes the distribution of the new assimilate to growth of various plant parts. The effect of irrigation regimes on leaf area index, stem and leaf dry weight of soybean cultivars at 20, 50, and 80 days after flowering were shown in Table 1. These results indicated that the highest LAI in soybean was achieved in $50_{(daf)}$. In beginning of flowering stage up to 50 days after flowering, leaf area index increased and from this stage onwards up to maturity stage ($80_{(daf)}$), LAI is decreased.

Table 1. The effect of irrigation regimes on leaf area index, stem and leaf dry weight of soybean cultivars .

Cultivar	Irrigation treatment	LAI			SDW (g)			LDW (g)		
		Sampling date			Sampling date			Sampling date		
		20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)
V_1	I_c	2.52	5.92	1.98	3.60	4.64	4.48	5.18	6.49	3.26
	I_w	2.13	4.31	1.35	2.93	3.81	3.56	4.47	5.51	2.58
V_2	I_c	2.67	6.15	2.04	3.63	4.76	4.54	5.31	6.64	3.41
	I_w	2.21	4.31	1.33	2.88	3.98	3.52	4.58	5.78	2.77
V_3	I_c	2.51	5.95	1.97	3.54	4.78	4.61	5.20	6.38	3.27
	I_w	2.10	4.21	1.29	2.87	3.82	3.48	4.53	5.63	2.52
V_4	I_c	2.58	5.95	1.98	3.56	4.73	4.45	5.19	6.41	3.32
	I_w	2.11	4.19	1.30	2.88	3.88	3.44	4.53	5.58	2.57
V_5	I_c	2.61	5.97	1.91	3.59	4.61	4.46	5.26	6.54	3.17
	I_w	2.13	4.29	1.26	2.79	3.85	3.36	4.47	5.75	2.57
V_6	I_c	2.55	5.95	1.95	3.60	4.77	4.55	5.20	6.54	3.37
	I_w	2.14	4.27	1.29	2.84	3.86	3.40	4.58	5.71	2.59
V_7	I_c	2.50	5.99	1.99	3.65	4.71	4.42	5.16	6.39	3.32
	I_w	2.13	4.25	1.33	2.86	3.85	3.40	4.52	5.73	2.61
V_8	I_c	2.58	5.99	2.01	3.55	4.65	4.25	5.19	6.42	3.30
	I_w	2.16	4.27	1.27	2.84	4.00	3.43	4.50	5.78	2.58

LAI: leaf area index, SDW: stem dry weight, LDW: leaf dry weight.

V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.

I_c: irrigation at all of growth stages, and I_w: withholding irrigation at flowering growth stage

Sampling date: 20(daf), 50(daf), and 80(daf): 20, 50, and 80 days after flowering, respectively.

Also, irrigation withholding at flowering stage reduces LAI in all of soybean cultivars. Yuncai, *et al.*, (2008) study showed that leaf growth significantly decreased by drought stress and this reduces occurred in length and weight of leaves. Comparison of leaf area index in different cultivars at 20(daf) showed that leaf area index ranged between 2.50 to 2.67 in complete irrigation (I_c) and 2.10 to 2.21 in water deficit conditions (I_w). Whereas, these values in 50(daf) were recorded 5.95 to 6.15 in I_c and 4.19 to 4.31 in I_w. Difference between leaf area index at I_c and I_w at 80(daf) is greater, as in I_c 1.26 to 1.35 and in I_w 1.91 to 2.04 were recorded. Soybean plants have lower leaves at the end of growing season under water deficit conditions. (Table1). The highest LAI at 20, 50, and 80 days after flowering in well water condition belonged to Williams cultivar. With regard to irrigation cutting at flowering stage, the greatest decrease in LAI was seen in the Gorgan3 cultivar (18.39%). Schmidhalter *et al.*, (1998) emphasized that leaf growth is highly sensitive to drought stress. Water deficit inhibited biomass accumulation in stem, and this effect was the most in 80 day after flowering (Table 1). Stressed plants have lower stem dry weight at maturity stage and similar results were obtained for leaf dry weight. Comparison of cultivar in stress condition at 20(daf) and 80(daf) was showed that Clark had high dry weight in stem and leaf, while, at 50(daf) the Williams is better than the others. In both conditions, soybean stem and leaf dry weight dropped from 50(daf) to 80(daf), that this reduction in dry weight of leaf was more than the stem dry weight. Soybean growth is measured by the amount of total dry matter accumulation in the plant. Reduction in cell division and plant dry weight, resulting water deficit has been emphasized by previous studies (Kozlowski, 1986; Maiti *et al.*, 2000; Robertson *et al.*, 2004; Thalooth *et al.*, 2006). In both conditions (well

water and water deficit) up to 80 days after flowering, pod and seed dry weight increased. In water deficit condition, the highest pod dry weight per plant belonged to Clark cultivar (2.22 g plant^{-1}), but in complete irrigation, Williams with 2.84 g plant^{-1} had the highest pod dry weight per plant.

Table 2. The effect of irrigation regimes on pod, grain and total dry weight of soybean cultivars.

Cultivar	Irrigation treatment	PDW (g)			GDW (g)		TDW (g)		
		Sampling date			Sampling date		Sampling date		
		$20_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$	$20_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$
V_1	I_c	0.17	1.64	2.76	1.74	4.32	6.21	13.19	11.19
	I_w	0.10	1.18	2.22	1.51	3.19	4.44	11.54	9.96
V_2	I_c	0.18	1.77	2.84	1.75	4.63	6.41	13.41	11.40
	I_w	0.13	1.35	2.17	1.59	3.39	4.67	11.73	10.16
V_3	I_c	0.17	1.68	2.64	1.72	4.42	6.24	13.26	11.22
	I_w	0.11	1.23	2.13	1.52	3.24	4.45	11.60	10.00
V_4	I_c	0.15	1.61	2.78	1.77	4.53	6.24	13.27	11.23
	I_w	0.12	1.23	2.08	1.51	3.21	4.54	11.57	9.99
V_5	I_c	0.18	1.61	2.75	1.71	4.43	6.34	13.24	11.19
	I_w	0.12	1.16	2.05	1.53	3.28	4.40	11.56	9.97
V_6	I_c	0.17	1.70	2.72	1.70	4.48	6.34	13.31	11.27
	I_w	0.12	1.21	1.91	1.49	3.25	4.55	11.68	10.03
V_7	I_c	0.17	1.73	2.66	1.72	4.50	6.31	13.28	11.31
	I_w	0.12	1.25	1.86	1.53	3.20	4.55	11.55	10.01
V_8	I_c	0.18	1.70	2.79	1.75	4.41	6.33	13.23	11.17
	I_w	0.12	1.26	1.95	1.55	3.32	4.55	11.58	10.03

PDW: pod dry weight, GDW: grain dry weight, and TDW: total dry weight.

V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.

I_c: irrigation at all of growth stages, and I_w: withholding irrigation at flowering growth stage

Sampling date: $20_{(daf)}$, $50_{(daf)}$, and $80_{(daf)}$: 20, 50, and 80 days after flowering, respectively.

Grain samples taken on 50 and 80 days after flowering showed that trend of grain growth in well water ranged between 147 to 164 per cent. Also, these changes for water deficit conditions were recorded about 88 to 118 per cent (data not shown). Maximum and minimum changes belonged to Williams (164%) and Clark cultivars (147%), respectively. Furthermore, water deficit decreased grain weight per plant in both sampling date $50_{(daf)}$ and $80_{(daf)}$ about 9%-13% and 25%-29%, respectively (data not shown). In addition, Hobbit and M9 had the Most of the response to water stress. The greatest total dry weight in soybean was obtained at 50 days after flowering stage. Generally, in this experiment as a result of drought stress, total dry weight decreased by 12.5%, and similar response was observed in all of evaluated cultivars (Table 2). Lobato *et al.*, (2008) found that dry matter accumulation in soybean plant decreased when that drought occurred. All of evaluated traits in this experiment were affected by manganese foliar application. Manganese increases Leaf area index and stem, leaf, pod and grain dry weight per plant (Tables 3 and 4). Heitholt *et al.*, (2002) reported that manganese application increases soybean growth and production. In both conditions (complete irrigation and irrigation withholding at flowering stage), Mn application led to that more leaves remain on the soybean plants at $80_{(daf)}$. As an important result, the highest values in growth index were observed in 50 days after flowering stage. Interaction effects of irrigation treatments and manganese foliar application on LAI and dry matter accumulation in

different parts of soybean plant at 20, 50, and 50 days after flowering stage were shown in Table 5 and 6. The results were showed that, in both irrigation treatments and all of soybean cultivars, LAI increased by manganese foliar application.

Table 3. The effect of manganese foliar application on leaf area index, stem and leaf dry weight of soybean cultivars.

Cultivar	Foliar treatment	LAI			SDW (g)			LDW (g)		
		Sampling date			Sampling date			Sampling date		
		20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)
V_1	Mn_0	2.17	4.89	1.44	3.12	4.07	3.88	5.14	5.87	2.76
	Mn_1	2.47	5.34	1.83	3.41	4.38	4.15	4.98	6.13	3.08
V_2	Mn_0	2.27	4.92	1.48	3.19	4.20	3.95	5.30	6.07	2.95
	Mn_1	2.61	5.55	1.96	3.32	4.55	4.11	5.09	6.35	3.23
V_3	Mn_0	2.19	4.89	1.45	3.03	4.11	3.91	5.16	5.92	2.77
	Mn_1	2.42	5.28	1.79	3.39	4.50	4.18	5.03	6.10	3.02
V_4	Mn_0	2.23	4.92	1.50	3.07	4.12	3.85	5.22	5.90	2.76
	Mn_1	2.46	5.22	1.81	3.37	4.48	4.04	4.99	6.09	3.09
V_5	Mn_0	2.23	4.92	1.41	3.11	4.05	3.86	5.26	5.98	2.79
	Mn_1	2.51	5.34	1.76	3.27	4.43	3.96	5.00	6.31	2.98
V_6	Mn_0	2.20	4.87	1.47	3.07	4.21	3.89	5.21	5.97	2.76
	Mn_1	2.49	5.36	1.80	3.37	4.42	4.06	5.00	6.27	3.14
V_7	Mn_0	2.19	4.91	1.51	3.10	4.09	3.85	5.17	5.84	2.80
	Mn_1	2.44	5.33	1.81	3.41	4.48	3.97	4.97	6.28	3.13
V_8	Mn_0	2.21	4.86	1.47	3.07	4.11	3.85	5.18	5.89	2.80
	Mn_1	2.53	5.37	1.81	3.32	4.49	3.83	5.04	6.31	3.08

LAI: leaf area index, SDW: stem dry weight, LDW: leaf dry weight.
V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.
Mn_0: spray with distilled water, and Mn_1: manganese spray
Sampling date: 20(daf), 50(daf), and 80(daf): 20, 50, and 80 days after flowering, respectively.

Drought stress affects the mineral nutrient in soil and plant organs (Yuncai, *et al.*, 2008), therefore, in these conditions, plants growth enhances by Adequate nutrient supply (Studer, 1993; Bagayoko *et al.*, 2000; Bruck *et al.*, 2000). Yuncai *et al.*, (2008) reported that, under Short-term drought stress, foliar nutrient application is more efficient than the soil application. On the other side, in well water condition, Clark, Williams, and DPX cultivars had the highest response to Mn application. Under water deficit condition with manganese foliar application, leaf area index in Williams cultivar increased by 20.3% at 80(daf). While, in stress condition and with manganese used, Pershing and Hobbit cultivars had the highest stem dry weight. It is important to note that, passage of 50 days after flowering and approaching the maturity stage of soybean, stem and leaf, and total dry weight in all of cultivars were reduced. At the end of growing season, leaves are falling; therefore total dry weight per plant loss is the cause. Mn application at water deficit condition had significant effect on pod and grain dry weight in all of evaluated cultivars. However, the impressionable of grain dry weight of soybean cultivars from the Mn foliar application was very different. So that, Mn foliar application increased grain weight of cultivars by 10.9 to 18.9 per cent in well water condition and 10.7 to 16.1 per cent in water deficit condition. Finally, under drought stress, grain dry weight in Clark, Williams, and M7 had a greater response to manganese foliar application than the

other cultivars, whereas, the minimum responses were belonged to Pershing, Hobbit, Gorgan3, M9, and DPX. Also, the similar results were observed in total dry weight. In both irrigation treatments, dry weight per plant in M7 cultivar had the lowest response to manganese foliar application.

Table 4. The effect of manganese foliar application on pod, grain and total dry weight of soybean cultivars.

Cultivar	Foliar treatment	PDW (g)			GDW (g)		TDW (g)		
		Sampling date			Sampling date		Sampling date		
		20(daf)	50(daf)	80(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)
V_1	Mn_0	0.11	1.31	2.36	1.57	3.51	5.14	11.97	10.28
	Mn_1	0.15	1.52	2.62	1.66	4.00	5.56	12.75	10.86
V_2	Mn_0	0.14	1.43	2.29	1.64	3.71	5.28	12.18	10.49
	Mn_1	0.17	1.69	2.72	1.71	4.31	5.80	12.96	11.07
V_3	Mn_0	0.12	1.33	2.11	1.60	3.63	5.16	12.06	10.35
	Mn_1	0.16	1.58	2.66	1.64	4.03	5.53	12.80	10.86
V_4	Mn_0	0.12	1.33	2.13	1.61	3.56	5.16	12.04	10.38
	Mn_1	0.15	1.58	2.73	1.67	4.18	5.66	12.81	11.35
V_5	Mn_0	0.14	1.29	1.92	1.58	3.57	5.20	12.00	10.36
	Mn_1	0.16	1.47	2.88	1.65	4.14	5.45	12.80	10.80
V_6	Mn_0	0.14	1.35	2.09	1.56	3.60	5.26	12.16	10.38
	Mn_1	0.15	1.56	2.71	1.63	4.13	5.63	12.83	10.91
V_7	Mn_0	0.13	1.39	1.83	1.61	3.60	5.22	12.14	10.32
	Mn_1	0.16	1.62	2.70	1.64	4.10	5.64	12.69	10.99
V_8	Mn_0	0.14	1.39	1.94	1.61	3.61	5.22	12.11	10.24
	Mn_1	0.15	1.55	2.80	1.68	4.12	5.66	12.70	10.95

PDW: pod dry weight, GDW: grain dry weight, and TDW: total dry weight.
V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.
Mn_0: spray with distilled water, and Mn_1: manganese spray
Sampling date: 20(daf), 50(daf), and 80(daf): 20, 50, and 80 days after flowering, respectively.

Table 5. Interaction effects of irrigation regimes and manganese foliar application on leaf area index, stem and leaf dry weight of soybean cultivars.

			LAI			SDW (g)			LDW (g)		
			Sampling date			Sampling date			Sampling date		
			20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)	20(daf)	50(daf)	80(daf)
V_1	I_c	Mn_0	2.28	5.68	1.70	3.36	4.41	4.25	5.00	6.35	3.15
		Mn_1	2.76	6.17	2.27	3.85	4.87	4.71	5.37	6.63	3.38
	I_w	Mn_0	2.07	4.10	1.19	2.89	3.73	3.52	4.35	5.40	2.38
		Mn_1	2.19	4.52	1.39	2.97	3.90	3.60	4.59	5.63	2.78
V_2	I_c	Mn_0	2.39	5.82	1.69	3.57	4.53	4.38	5.12	6.47	3.31
		Mn_1	2.95	6.49	2.39	3.69	5.00	4.70	5.51	6.82	3.52
	I_w	Mn_0	2.15	4.02	1.28	2.81	3.87	3.52	4.49	5.68	2.59
		Mn_1	2.27	4.61	1.54	2.96	4.10	3.52	4.68	5.89	2.95
V_3	I_c	Mn_0	2.30	5.70	1.73	3.38	4.57	4.41	4.98	6.32	3.19

		Mn_1	2.71	6.21	2.21	3.71	5.00	4.81	5.42	6.45	3.35
	I_w	Mn_0	2.08	4.08	1.17	2.68	3.65	3.41	4.41	5.52	2.35
		Mn_1	2.13	4.35	1.38	3.07	4.00	3.55	4.65	5.79	2.69
V_4	I_c	Mn_0	2.35	5.73	1.75	3.44	4.50	4.30	5.07	6.23	3.18
		Mn_1	2.82	6.18	2.21	3.68	4.96	4.60	5.31	6.59	3.46
	I_w	Mn_0	2.11	4.12	1.25	2.71	3.75	3.40	4.38	5.57	2.41
		Mn_1	2.11	4.27	1.41	3.06	4.01	3.48	4.68	5.59	2.73
V_5	I_c	Mn_0	2.37	5.75	1.65	3.47	4.36	4.21	5.10	6.35	3.06
		Mn_1	2.85	6.25	2.17	3.71	4.87	4.73	5.42	6.73	3.29
	I_w	Mn_0	2.10	4.10	1.17	2.75	3.70	3.51	4.35	5.61	2.47
		Mn_1	2.17	4.49	1.35	2.83	4.00	3.21	4.59	5.89	2.68
V_6	I_c	Mn_0	2.31	5.70	1.71	3.45	4.61	4.50	5.00	6.35	3.25
		Mn_1	2.79	6.21	2.19	2.69	4.93	4.61	5.41	6.73	3.49
	I_w	Mn_0	2.09	4.05	1.23	2.69	3.81	3.29	4.48	5.60	2.40
		Mn_1	2.19	4.52	1.41	2.99	3.91	3.52	4.69	5.82	2.79
V_7	I_c	Mn_0	2.29	5.73	1.75	3.48	4.53	4.32	4.96	6.20	3.21
		Mn_1	2.72	6.25	2.23	3.82	4.90	4.52	5.37	6.59	3.44
	I_w	Mn_0	2.10	4.10	1.27	2.73	3.65	3.38	4.46	5.49	2.39
		Mn_1	2.17	4.41	1.39	3.00	4.06	3.42	4.58	5.97	2.83
V_8	I_c	Mn_0	2.31	5.71	1.77	3.41	4.41	4.10	4.90	6.25	3.19
		Mn_1	2.85	6.27	2.26	3.70	4.90	4.40	5.48	6.59	3.41
	I_w	Mn_0	2.12	4.01	1.18	2.74	3.91	3.60	4.40	5.53	2.41
		Mn_1	2.21	4.47	1.36	2.95	4.09	3.27	4.61	6.03	2.75

LAI: leaf area index, SDW: stem dry weight, LDW: leaf dry weight.
V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.
I_c: irrigation at all of growth stages, and I_w: withholding irrigation at flowering growth stage.
Mn_0: spray with distilled water, and Mn_1: manganese spray
Sampling date: $20_{(daf)}$, $50_{(daf)}$, and $80_{(daf)}$: 20, 50, and 80 days after flowering, respectively.

Table 6. Interaction effects of irrigation regimes and manganese foliar application on pod, grain and total dry weight of soybean cultivars.

			PDW (g)			**GDW (g)**		**TDW (g)**		
			Sampling date			Sampling date		Sampling date		
			$20_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$	$20_{(daf)}$	$50_{(daf)}$	$80_{(daf)}$
V_1	I_c	Mn_0	0.15	1.53	2.52	1.69	3.97	6.00	12.97	10.96
		Mn_1	0.19	1.76	3.00	1.76	4.67	6.43	13.41	11.42
	I_w	Mn_0	0.08	1.09	2.20	1.46	3.05	4.28	10.98	9.61
		Mn_1	0.12	1.28	2.25	1.57	3.44	4.69	12.10	10.31
V_2	I_c	Mn_0	0.16	1.61	2.61	1.73	4.23	6.15	13.15	11.13
		Mn_1	0.21	1.93	3.07	1.79	5.03	6.67	13.67	11.67
	I_w	Mn_0	0.12	1.25	1.97	1.55	3.19	4.42	11.21	9.85
		Mn_1	0.14	1.46	2.37	1.63	3.59	4.93	12.25	10.48
V_3	I_c	Mn_0	0.15	1.54	2.47	1.68	4.19	6.03	13.06	10.99

		Mn_1	0.20	1.82	2.82	1.77	4.65	6.45	13.46	11.45
	I_w	Mn_0	0.10	1.12	1.76	1.52	3.08	4.30	11.06	9.72
		Mn_1	0.12	1.35	2.51	1.52	3.41	4.61	12.15	10.28
V_4	I_c	Mn_0	0.14	1.57	2.45	1.75	4.15	5.98	13.00	11.07
		Mn_1	0.17	1.79	3.11	1.79	4.91	6.51	13.55	11.40
	I_w	Mn_0	0.11	1.10	1.82	1.47	2.97	4.35	11.09	9.69
		Mn_1	0.13	1.37	2.35	1.55	3.45	4.83	12.06	10.30
V_5	I_c	Mn_0	0.17	1.49	2.35	1.68	4.10	6.12	13.0	11.00
		Mn_1	0.19	1.73	3.16	1.74	4.76	6.39	13.49	11.39
	I_w	Mn_0	0.11	1.10	1.49	1.47	3.05	4.28	11.00	9.73
		Mn_1	0.13	1.22	2.61	1.55	3.52	4.52	12.12	10.21
V_6	I_c	Mn_0	0.16	1.57	2.37	1.65	4.11	6.17	13.16	11.06
		Mn_1	0.18	1.83	3.07	1.75	4.85	6.51	13.47	11.48
	I_w	Mn_0	0.12	1.13	1.48	1.48	3.09	4.36	11.17	9.71
		Mn_1	0.12	1.29	2.35	1.51	3.42	4.75	12.19	10.35
V_7	I_c	Mn_0	0.15	1.62	2.35	1.71	4.19	6.13	13.18	11.09
		Mn_1	0.20	1.89	2.98	1.73	4.82	6.49	13.39	11.53
	I_w	Mn_0	0.11	1.16	1.31	1.52	3.02	4.31	11.11	9.56
		Mn_1	0.13	1.35	2.42	1.55	3.39	4.79	12.00	10.46
V_8	I_c	Mn_0	0.17	1.60	2.41	1.73	4.12	6.15	13.09	10.84
		Mn_1	0.19	1.78	3.17	1.77	4.71	6.52	13.37	11.50
	I_w	Mn_0	0.12	1.19	1.48	1.50	3.10	4.30	11.14	9.65
		Mn_1	0.12	1.33	2.43	1.61	3.54	4.81	12.03	10.31

PDW: pod dry weight, GDW: grain dry weight, and TDW: total dry weight.
V_1: Clark, V_2: Williams, V_3: Pershing, V_4: Hobbit, V_5: Gorgan3, V_6: M7, V_7: M9, V_8: DPX.
I_c: irrigation at all of growth stages, and I_w: withholding irrigation at flowering growth stage.
Mn_0: spray with distilled water, and Mn_1: manganese spray
Sampling date: $20_{(daf)}$, $50_{(daf)}$, and $80_{(daf)}$: 20, 50, and 80 days after flowering, respectively.

Acknowledgment

Thanks from The Islamic Azad University for supporting projects. This research was supported by Islamic Azad University, Kermanshah Branch, Kermanshah, Iran.

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