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Enhancing soybean defense mechanism against certain piercing-sucking pests and its growth parameters under water deficit stress by exposing seeds to three magnetic field exposure durations

Hala H Alakhdar[1], Mohammed M Abou-Setta[1], Zeinab E Ghareeb[2], Kh A Shaban[3]
[1] Plant Protection Research Institute, Agriculture Research Center, Egypt
[2] Central Laboratory for Design and Statistical Analysis Research, Agriculture Research Center, Egypt
[3] Soils Water and Environmental Research Institute, Agriculture Research Center, Egypt

Abstract
The efficacy of pre-sowing treatment of soybean seeds with a magnetic field for 0, 15, 30, and 60 mints were studied on the natural infestation with *Tetranychus urticae*, *Thrips tabaci*, *Phenacoccus solenopsis*, and *Bemisia tabaci.* Also, plant growth parameters and yield were considered under full and half irrigation rates over two successive summer seasons of 2020 and 2021 in Egypt. Results showed a positive enhancing plant defense effect of these treatments on soybean crops with a reduction in *T. urticae* and other piercing-sucking insects over the two seasons. The population of *T. urticae* and other piercing-sucking insect pests over the two years was in a significant negative relation with seeds magnetic exposure times as well as with irrigation amount. Reduced irrigation rate did not affect crop quality parameters (i.e. plant length, No. of branches/plant, weight of pods/plant, and seeds yield). The response to seeds' different magnetic exposure times on yield quantity (i.e. carbohydrates, protein, chlorophyll, ash, and oil contents) was determined as third degree of a polynomial model. The seeds' exposure times of 15 or 30 min. were significantly higher than 0 and 60 min.

Keywords: soybean, magnetic field, water stress, *Tetranychus urticae*, piercing-sucking insect

Introduction

Climate change is expected to produce an increase in drought and temperature procedures in the next decades, especially in Mediterranean regions where they are expected to be more common and intense (IPCC 2013). Water scarcity is one of the main tasks facing crop production; the yield of soybean was reduced by 40% due to drought stress on a worldwide scale. In Egypt, soybean acreages had declined drastically from about 42 thousand ha. in 1991 to about 7.2 thousand ha. in 2009 due to several biotic and abiotic stresses negatively affecting soybean production (Khalil *et al.* 2011) [23]. Reducing water consumption and deficit irrigation by improving technologies and new methods is very valuable for increasing the water use efficacy due to the limitation of water resources in agriculture (Abdelraouf *et al.* 2013; Zhoua *et al*. 2020) [3, 41].

Water deficit stress has been historically promoted as one key factor for herbivore outbreaks. The correlation between drought and arthropod outbreaks is dependent on the intensity, timing, and feeding behavior that the herbivore belongs to. Generally, drought stresses produce meaningful alterations in biochemistry and plant metabolism that may change the physiology of the host-plant and adapt the nutritional values, affective herbivorous, and piercing-sucking pest performance (Sivritepe *et al.* 2009) [33]. Enhancement of plant-pest resistance requires more precise knowledge of pest-plant relationships (Alakhdar and Shoala 2021; Alakhdar and Abou-Setta 2021) [7, 9].

Tetranychus urticae Koch (Acari: Tetranychidae) and other piercing-sucking insects (i.e. the whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae); invasive mealybugs *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) and Onion Thrips, *Thrips tabaci*, Linderman (Thripidae: Thysanoptera) are pests of *Glycine max* ((L.) Merr.) (Fabales: Fabaceae) (Arif *et al.* 2009; Fand and Suroshe 2015, Mesbah *et al.* 2019, Alakhdar 2020, Alakhdar and Ghareeb 2021) [11, 16, 26 8]. They can decrease plant health and yield by removing large amounts of plant photosynthetic from the leaves, heavy infestations can reduce plant growth, the number of seed size, and decrease pods set consistency, that drop-off yield quality, and quantity

The agronomic application of magnetic fields in plant protection and production has shown potential in influencing traditional systems, enhancing the average of germination rates, shoot and root growth parameters, developing high productivity, ever-increasing photosynthetic pigment content, and intensifying cell division, as well as nutrient and water uptake. Furthermore, several studies indicated that it helps to reduce the oxidative damage caused by stress situations in plants by reducing the large injuries produced by field pests on economically important plants

(Sarraf *et al.* 2020) [29]. Few studies have focused on magnetic field effects on insects. It has been shown to affect the orientation, oviposition, development, fecundity, and behavior of a wide variety of pests (Hozayn *et al.* 2016) [18].

This study aimed to evaluate the effect of deficit irrigation water and exposure time of soybean seeds to the magnetic field on the natural infestation with *T. urticae* and associated piercing-sucking insects concerning tested treatments and studying soybean plant parameters and yield.

Materials and Methods

Field experiments were performed on an experimental farm at Plant Protection Research Institute, Agriculture Research Center, Giza, Egypt, during the two successive summer seasons of 2020 and 2021, to study the effect of deficit water irrigation and exposure times to the magnetic field of soybean, *Glycine max* seeds on plant growth parameters, and yield. The population occurred as a natural infestation with the two-spotted spider mites, *Tetranychus urticae*, and other piercing-sucking insects (i.e. *Thrips tabaci*, *Phenacoccus solenopsis*, and *Bemisia tabaci*) were evaluated under the tested treatments.

Experiment design

In the two seasons, experiments were conducted in a split-plot design with three replicates. The used two levels of irrigation were (100 and 50 % F.C. as 2500 and 1250 m^3 of water, respectively over the growing season), arranged randomly as the main plot. Magnetic exposed seeds at different times (0, 15, 30, and 60 mints) were distributed randomly as a subplot. Population density of *T. urticae* and other piercing-sucking pests were counted for all treatments.

The magnetic used devise was the Delta Water System. The diameter of the magnetic device was 2 inches. The intensity of the magnetic field produced by the devise is 1.5 T. at Soil, Water and Environmental Research Institute, Agriculture Research Center, Giza, Egypt.

Soybean variety Giza 111 was obtained from Field Crops Research Institute, Agriculture Research Center, Giza, Egypt. All farming processes were carried out before sowing and all horticultural procedures were the same for all plots. Sowing was carried out on the 1st week of May 2020 and 2021. Plant samples of three replicates were taken after 75 days from sowing. Samples of each plot were prepared for some physiological characters and vegetative growth parameters were studied.

Population density of *T. urticae* and associated piercing-sucking insects

Population density of all motile stages of *T. urticae*, *T. tabaci*, *P. solenopsis*, and pupae of *B. tabaci* were monitored fortnightly in different treatment plots from the last week of May to the first week of Oct. during the two year seasons. Ten leaves were chosen from each replicate. The number of pests was counted and identified at the Acarology lab. Plant Protection Research Institute, Agricultural Research Center. The accumulated mean of pests counts per leaf was recorded over the two growing seasons and presented herein.

Plant and Yield parameters

Plant characters were recorded after 75 days of the sowing date. It presents the full vegetative growth stage before flowering. At harvesting in mid-October 2020 and 2021 the following characteristics were recorded, plant length (cm.); no. of pods/ plant; the weight of pods (gm./plant), the weight of seeds (gm./plant); the weight of 100 seeds (gm./plant) (Alakhdar *et al*. 2020) [6]. The oven-dried plant part samples were ground and digested according to the methods explained by Chapman and Pratt (1961) [13]. The plant contents of N, P, K, Fe, Mn, and Zn were determined in plant digestion using the methods described by Cottenie *et al.* (1982) [14]. Oilseeds content was decided using Soxhlet apparatus and petroleum ether as solvent according to A.O.A.C. (1990). The protein percentage of seeds was calculated by multiplying the nitrogen percentage by the factor 6.25 as described by Hymowitz *et al.* (1972) [19]. Proline content was estimated according to the methods described by Bates *et al.* (1973) [12].

Data analysis

Obtained data were analyzed using Procs REG and ANOVA in SAS Anonymous (2003) [10]. Simple regression was used for yield parameters and irrigation rates as Y= a ± b (Irrigation rate). The multiple regression was used for the effect of irrigation and exposure time on studied pests as Y= a ± b_1 (Irrigation rate) ± b_2 (Exp time). Factors affecting plant quality were analyzed as one-way ANOVA. Mean means were compared by Tukey's HSD (*P*= 0.05 level) in the same program.

Results

The population of *Tetranychus urticae* and other piercing-sucking insects

The obtained results are presented in Table (1). These data were studied for leaf samples inspected fortnightly over the two growing seasons. Statistical analysis indicated significant linear reduction as a result of different tested treatments. Both tested treatment levels indicated significant negative relations with considered pests. Probability was highly significant (P was 0.0001 to 0.0008) (Table 1). Both factors ' calculated slopes were larger for irrigation than magnetic exposure times. This means that the reduced irrigation rate was more effective in general than the magnetic exposure time.

Differences in the levels of spider mite and other piercing-sucking insect infestations were observed with the changes in nutrients in the plants with drought stress (Tables 1 and 2). The population of pests increased faster when feeding on drought-stressed than on normal-irrigated soybean plants (Fig 1). Drought treatment (50% FC) resulted in higher mean counts of all considered pests. The mean population of *T. urticae*, *T. tabaci*, *P. solenopsis*, and *B. tabaci*, was higher by 24.25, 14.74, 11.1, and 19%, respectively than normal irrigation.

Soybean seeds were exposed to three periods of magnetic field 15, 30, and 60 min before sowing. The population of all pests under study showed a significant decrease with the increase of exposure time to the magnetic field all over the two seasons. Magnetic exposure times resulted in reducing mean populations of considered pests by 39 to 76.83% for *T. urticae,* 39.04 to 57.37% for *T. tabaci,* 30.73 to 75.27 % for *P. solenopsis,* and 41.33 to 71.78% for *B. tabaci* with normal irrigation. On the other hand, the reduction in the number of *T. urticae* was 48.5 to 73.18, *T. tabaci* was 31.31 to 62.06, *P. solenopsis* was 31.1 to 50.49, and *B. tabaci* was 37.96 to 66.1 % underwater deficit irrigation, meanwhile, the reduction percentages in the pest's population were with the two types of irrigations and pre-sowing exposure to the magnetic field.

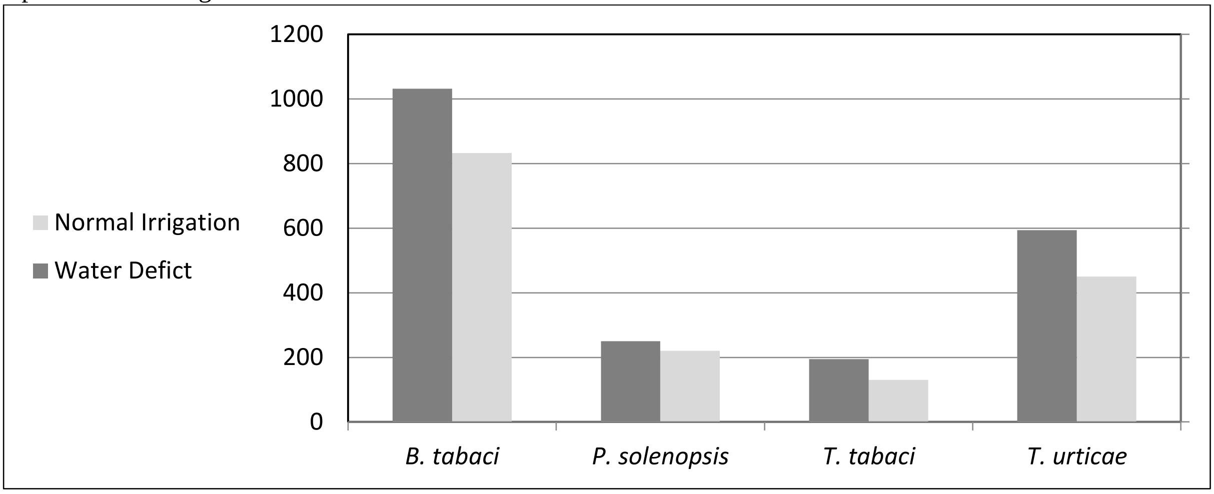

Fig 1: Mean population of *T. urticae* and associated piercing-sucking insects in relation to water deficit.

Table 1: Multiple regression for the population of *T. urticae* and associated piercing-sucking insects in relation to different treatments

Irrigation	Magnetic exp. time (min.)	*T. urticae*	*T. tabaci*	*P. solenopsis*	*B. tabaci*	
100%	0	457.50	125.50	224.50	827.50	
	15	279.00	76.50	155.50	485.50	
	30	177.50	62.50	126.00	297.50	
	60	106.00	53.50	55.50	233.50	
50%	0	604.00	170.00	252.50	1022.00	
	15	311.00	136.50	174.00	634.00	
	30	183.00	105.00	152.50	471.50	
	60	162.00	64.50	125.00	346.50	
Regression values	F2,21	35.5	10.12	79.95	46.98	
	P	0.0001	0.0008	0.0001	0.0001	
	b (Irrigation)	-112.00	-60.33	-75.00	-320.33	
	b (Exp. time)	-5.986	-1.253	-2.33	-9.874	

Polygon graph to treatment-pest comparison

Yan *et al*., 2000 [41] used bi-plot polygon graphs to study the effects of the used treatments on the traits by treatments*traits (TT). In this study, the graph concerned with showing treatments effects and presented the interaction patterns of treatments on the different pests by treatments* pests (TP). Polygon can be used to compare treatments effects on the multiple pests (*T. urticae, T. tabaci, P. solenopsis, and B. tabaci*) to identify the best treatments for plant-pest resistance under irrigation treatment in soybean breeding programs Yan and Rajcan (2002) [39]. Data of different types of treatments (magnetic and irrigation) for infestation of the four pests (populations) in soybean were labeled in Figure (2). The first two principal components explained 99.58 % (more than 60%, achieving the goodness bi-plot model) of the variation for the measured pest's infestation Yan and Kang (2003) [40].

Polygon graph in Figure (2) illustrated which magnetic under irrigation treatment combination-won- where-for pests' infestation. The polygon view of the bi-plot graph was divided into five sectors, revealing the main two sectors (right and left sides). The population on the treatments indicated that IM3 (magnetic treatment after 60 min. under 100% irrigation) was the vertex treatment for *T. tabaci* and *P. solenopsis* pests. IM3 treatment had a negative infestation and decrease pests (highest effect on the population pests). However, the vertex treatment DM0 (without magnetic treatment under 50% irrigation) had a positive effect (lowest effect and increase in the population). Meanwhile, the vertex treatment combinations of IM2, DM2, and IM1 (in the same left-side sector) had good infection effects on *T. tabaci* and *P. solenopsis* pests.

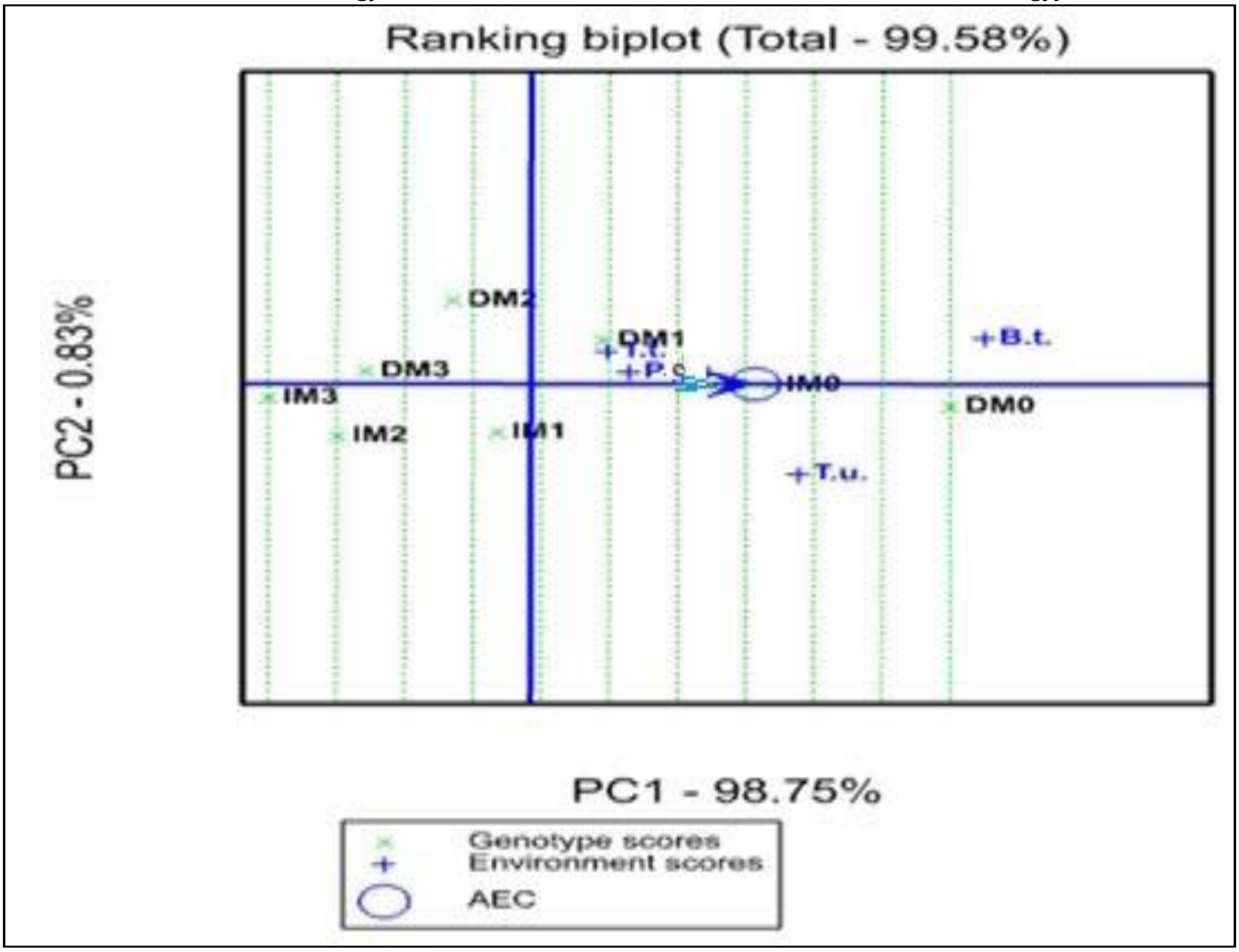

Fig 2: The polygon view of the bi-plot graph shows which magnetic under irrigation treatment combination won-where-for pests' infection.

IM0, IM1, IM2, and IM3 are pre-sowed seeds for 0, 15, 30, and 60 mins. under normal irrigation. DM0, DM1, DM2, and DM3 are pre-sowed seeds for 0, 15, 30, and 60 mins. under drought stress.

Pests were distributed on the graph according to their interaction by treatments. Hence, *T. tabaci* and *P. solenopsis* are located nearest to the affected treatments (near left side) inside the graph, indicating to *T. tabaci* and *P. solenopsis* pests were the most affected pests by negative treatments (IM3, IM2, DM3, DM2, and IM1). Meanwhile, *T. urticae* and *B. Tabaci* pests located the farthest outside the graph, registering the highest population number especially, IM0 and DM0 treatments (without magnetic treatments). Therefore, magnetic treatments were important in decreasing the pest populations under any irrigation conditions and developing resistance to the studied pests with lower infestation and population numbers.

Effect of different treatments on leaves nutrients concentrations

The obtained results are presented in Table (2). These data were obtained for leaves of soybeans after 75 days of the sowing date. Statistical analysis indicated no significant differences between tested treatments on leaves' contents of carbohydrate, total chlorophyll, ash, protein, and oil percent. Only proline indicated high significance compared with other treatments without a specific trend (Table 2). As general tested treatments did not alter leaves contents.

Table 2: Effect of different treatments on leaves nutrients concentrations

Irrigation	Magnetic exp. time (min)	Carbohydrate (mg/g f. w.)	Proline (mg/g f.w.)	Chlorophyll (mg/g f. w.)	Ash (%)	Protein (%)	Oil%
100%	0	3.75^{a}	35.1^{ab}	4.85^{a}	5.14^{a}	20.5^{a}	18.11^{a}
	15	3.89^{a}	21.85^{bc}	4.98^{a}	6.18^{a}	20.8^{a}	21.07^{a}
	30	4.02^{a}	15.3^{d}	5.06^{a}	7.1^{a}	21.38^{a}	21.53^{a}
	60	3.79^{a}	33.2^{ab}	4.92^{a}	5.77^{a}	21.00a	20.86^{a}
50%	0	3.69^{a}	41.3^{a}	4.52^{a}	4.35^{a}	20.31^{a}	17.05^{a}
	15	3.89^{a}	33.5^{ab}	4.88^{a}	5.1^{a}	21.00^{a}	19.05^{a}
	30	3.9^{a}	28.1^{bc}	4.93^{a}	5.95^{a}	21.44^{a}	19.39^{a}
	60	3.85^{a}	35.21^{ab}	4.77^{a}	4.98^{a}	21.31^{a}	19.76^{a}
F7,16		0.03	16.08	0.08	2.46	0.05	0.65
P		1.00	0.0001	0.9988	0.0642	0.9997	0.7133

Means with the same letter in the same column are not significantly different using Tukey's HSD (P = 0.05).

Effect of different treatments on seeds nutrients

The obtained results are presented in Table (3). These data were obtained for seeds at harvest. Statistical analysis indicated no significant differences between tested treatments on seeds of N, K, and Zn (Table 3). Moderate significance occurred for P and Fe but didn't present clear differences with control values. In the case of Mn significance was high (P =0.0072) but again didn't present clear differences with control values. So in general tested treatments did not alter seeds' nutrient concentrations.

Table 3: Effect of different treatments on seeds nutrients

Irrigation	Magnetic exp. time (min)	Macronutrients conc. (%)			Micronutrients conc. (mg/kg)		
		N	P	K	Fe	Mn	Zn
100%	0	4.05[a]	0.35[b]	2.75[a]	88.65[ab]	56.32[b]	30.52[a]
	15	4.17[a]	0.43[ab]	2.96[a]	93.68[ab]	64.32[ab]	36.85[a]
	30	4.26[a]	0.46[ab]	3.05[a]	98.52[a]	68.95[ab]	38.95[a]
	60	4.12[a]	0.41[ab]	2.83[a]	92.14[ab]	62.14[ab]	33.89[a]
50%	0	4.01[a]	0.33[ab]	2.71[a]	87.63[b]	55.48[b]	30.51[a]
	15	4.10[a]	0.42[ab]	2.88[a]	90.48[ab]	63.14[ab]	34.96[a]
	30	4.20[a]	0.44[a]	2.97[a]	95.87[ab]	65.34[a]	36.52[a]
	60	4.18[a]	0.40[ab]	2.80[a]	90.15[ab]	60.19[ab]	32.18[a]
F7,16		1.62	3.00	0.40	3.23	4.34	1.83
P		0.2008	0.0324	0.9999	0.0246	0.0072	0.1495

Means with the same letter in the same column are not significantly different using Tukey's HSD (P = 0.05).

Yield components as affected by different treatments

The obtained results are presented in Table (4). These data were obtained for yield parameters at harvest. Statistical analysis was conducted at two different levels. The first was the effect of the irrigation rate. There was an insignificant negative relation between irrigation rates and the most considered parameters. This means that reduced irrigation or drought did not affect yield parameters.

The response of these parameters to different magnetic exposure durations was noticed to be in the third degree of the polynomial, so they were fitted to this model. Most considered parameters indicated a very high degree of significance (Table 4). This means that median exposure duration of 15 and 30 minutes were the most effective compared with 0 and 60 minutes of magnetic exposure except for the weight of 100 seeds, where this relation was insignificant.

Table 4: Mean values of yield parameters as affected by different treatments.

Irrigation	Mag.exp. time (min)	P.L. (cm)	No. P./P.	W. P/P.(gm.)	W. S/P.(gm.)	W.100/S. (gm.)
100%	0	59.63	19.32	28.32	25.63	10.85
	15	74.32	35.62	38.85	36.85	11.85
	30	69.34	33.21	36.29	34.12	11.49
	60	65.21	28.63	32.14	28.96	11.32
50%	0	58.32	22.31	29.56	26.52	11.14
	15	72.14	36.2	38.54	35.62	12.36
	30	75.33	38.25	39.1	37.12	12.48
	60	67.32	35.21	33.46	30.14	11.85
Regression values for irrigation	F1,23	0.15	1.65	0.36	0.17	1.44
	P	0.7016	0.213	0.5567	0.6867	0.2434
	b (Irrigation)	-2.305	-7.715	-2.53	-1.92	-1.16
Regression values for exposure time	F3,23	13.35	15.63	10.58	9.58	1.06
	P	.0001	<.0001	0.0002	0.0004	0.3891
	b (Exp. time)	1.684	1.729	1.172	1.189	0.134
	b $(\text{Exp. time})^2$	-0.056	-0.056	-0.04	-0.039	-0.005
	b $(\text{Exp.time})^3$	0.0005	0.0005	0.0004	0.00034	0.00004

P.l.: Plant length (cm.);No.p./p.: No. of pods/ plant;W. P/P.(gm.): Weight of pods (gm./plant);W.S/P. (gm.): Weight of seeds (gm./plant);W.100/S.(gm.): Weight of 100 seeds (gm./plant).

Discussion

Our results were reported significant negative linear relations as a result of different tested treatments. Reduced irrigation rate was responsible for mean higher populations of *T. urticae* and other piercing-sucking insects i.e. (*B. tabaci, T. tabaci*, and *P. solenopsis*) while longer magnetic exposure time was responsible for mean populations' reduction.

Data shown that the drought-stressed plants increased the performance of *T. urticae* and piercing-sucking insects. These findings could have significant implications for pest outbreaks under future climate change scenarios when longer periods of drought and less water availability are expected for irrigated plants like soybean in semiarid environments (IPCC, 2013) [21]. The performance of *T. urticae* and the other piercing-sucking insects on soybean depends on the rate of adaptation of their populations to this particular host (Agrawal *et al*., 2002; Kant *et al*., 2008) [4, 22]. Moreover, some of the changes increased by drought stress on plant nutritional composition and plant defenses (Inbar *et al*., 2001) [20] have been identified as key factors affecting pest host preferences and performance (Wybouw *et al*., 2015) [35]. Available free sugars and essential amino acids, which are limiting nutrients for mite growth and reproduction, seemed to improve the nutritional value of drought-stressed tomato plants for *T. urticae* (Ximénez-Emb ό n 2016) [37]. Plants under drought stress mobilize existing proteins and complex carbohydrates into amino acids and simple sugars, respectively, for osmotic adjustments and the transference of available plant nitrogen and carbon. The amino acids can be used by arthropods as a direct energy substrate for glycolysis and the production of ATP (Scaraffia and Wells, 2003; Ximénez-Embún *et al*., 2017) [34].

An improved understanding of the interactions between the magnetic field and the plant responses could revolutionize crop protection through increased resistance to pests and drought stress conditions, as well as the superiority of nutrient and water utilization, resulting in the improvement of crop yield. Researchers are trying to find other techniques which must be proficient, clean and affordable, and free from pesticides. Treating seeds with a magnetic field before sowing can decrease the use of synthetic inputs such as fertilizers, pesticides, therefore, crop protection can be improved and crop production and its quality can also be enhanced (Mahajan and Pandey 2014) [24]. Our findings indicated that seeds' longer magnetic exposure time mediated the negative effect of water stress in pests' higher levels of infestation. Other few studies tested the effect of exposure to the magnetic field in integrated pest management programs as an alternative treatment for pest control in the field. The effect of magnetic force and magnetic water on the population of *Tetranychus urticae* on soybean was investigated by Abd El-Rahman (2017) [2], who observed a decrease in the population density of *T. urticae* motile stages after one week of application. On cotton, the mean number of *T. urticae* and *Amblyseius gossipi* individuals were reduced by magnetic force and magnetic water concentrations with different degrees of effectiveness between them. On the other hand, feeding and morphology of treated soybean plants affected with *T. urticae* were differed in the effectiveness between all concentrations and control**.**

Horticultural-wise, soybeans shoot after 75 days of growth was not significantly affected by tested treatments including N, K, Mn, and Zn. Both P and Fe were significant without a specific trend. Similar was reported to carbohydrate, chlorophyll, ash, protein, and oil percentages. In general, tested treatments did not alter shots and leaves contents. As regarding proline contents, data also reveal that the increase in water deficit increased proline contents. Application of all interactions between the water deficit level and magnetic treatments used counteracted the adverse effect of water deficit, where it increased proline contents as compared to FC levels. The possibility of proline affecting turgidity of the plant under severe stress conditions by increasing membrane permeability to water and acting as an osmo-regulator. Moreover, proline promotes the production of cytokinins which improved plant growth (Shetty, 1992) [32]. By scavenging reactive oxygen species, proline can protect plant cells from oxidative damage (Shao, *et al*., 2008). Ca^{++} was revealed to reduce the damaging effects of stress in wheat by increasing the content of proline, thus improving the water status and growth of seedlings and reducing membrane injury (Nayyar, 2003) [27].

The application of magnetized seeds, with different water deficit levels, increased the most growth parameters if compared with controls. The highest values of Plant length (cm), No. of pods/ plant, Weight of pods (gm/plant), Weight of seeds (gm/plant), Weight of 100 seeds (gm/plant), and Weight of seeds (ton/fed) were achieved by seeds exposed to 30 min. magnetic field. The beneficial effects of magnetic treatment of seeds under various water deficit levels may be due to the influence of the magnetic field on ion uptake, which improves the nutritional process, water absorption, and biochemical processes, (Dhawi, 2009) [15] and causes an increase in proliferation, gene expression, and protein biosynthesis and alternations in cell membrane properties on tissue, cellular and subcellular levels (Phillips, *et al*., 1992). Ions or free radicals exert electric charges on living cells, acting as endogenous magnets. Exogenous magnetic fields can affect these endogenous magnets, causing unpaired electrons to orient (Goodman, 2002; Maheshwari and Grewal 2009; Selim and El-Nady 2011) [17, 25, 30].

Conclusion The results of the current study demonstrate some beneficial effects of magnetically treated seeds on soybean and play an important role in the protection of soybean plants against pest infestations. Results showed a significant decrease in *T. urticae* populations and the associated insects, *T. tabaci*, *P. solenopsis,* and *B. tabaci*, with the increase of exposure time to the magnetic field all over the two seasons by the two rates of irrigations. On the other hand, the adverse effects of drought stress, improve crop productivity, which would lead to significant water savings for the irrigation sector.

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