Arab Univ. J. Agric. Sci., Ain Shams Univ., Cairo, Egypt
27(2), 1405-1422, 2019
Website: http://ajs.journals.ekb.eg

RESPONSE OF SOYBEAN GROWTH TO NANO-MINERAL FERTILIZERS UNDER TWO IRRIGATION INTERVALS

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Received 4 April, 2019 Accepted 30 April, 2019

ABSTRACT

During summer seasons of 2015 and 2017, a field experiment was conducted at the Research and Experimental Station (30°19′ N, 31°16′ E), Faculty of Agriculture, Ain Shams University at Shalakan, Kalubia Governorate, Egypt, to investigate the effects of combinations between hydroxyl apatite nanoparticles (0, 3, and 6 kg/fad) and calcium carbonate nanoparticles (0, 500g/fad) as nano-fertilizers under irrigaton intervals, (irrigation every 2 or 3 weeks whereas irrigation every 2 weeks as a recommended practice) on growth of soybean plants. Irrigation intervals had statistically significant effect on plant height (cm), number of branches per plant, number of leaves per plant, leaf area index, number of pods per plant, number of root nodules per plant, root dry weight per plant, stem dry weight per plant, leaves dry weight per plant and pods dry weight per plant. These results were fairly true in the two studied seasons 2015, 2017 and combined result. plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of nodules per plant and number of pods per plant of soybean plants which treated with 500 g/fed surpassed untreated plants in the two studied seasons 2015, 2017 and combined. Soybean plants treated with 6 kg hydroxyl apatite nanoparticles per feddan out-numbered other plants in its numbers of leaves per plant, leaf area index, number of root nodules per plant and number of pods per plant in the two growing seasons 2015, 2017 and combined data. Results showed that normal irrigation x 500g/fed calcium carbonate nanoparticles x 6kg/fed hydroxyl apatite nanoparticles was the effective combination for producing the highest values of plant height (cm), number of branches per plant, number of leaves per plant, leaf area index, number of pods per plant, number of root nodules per plant, root dry weight per plant (g), stem dry weight per plant (g), leaves dry weight per plant (g) and pods dry weight per plant (g). There weren't significant results between plants treated with nano-mineral fertilizers under irrigation every 3 week and plants untreated but irrigated every 2 week in all growth traits, which reflect appositive result of this chemical substance in mitigation harmful effect of water shortage in season 2015, 2017 and combined data.

Keywords: Soybean, Nano fertilizers, Calcium Carbonate Nanoparticles, Hydroxyl apatite nanoparticles, irrigation intervals.

INTRODUCTION

Soybean is a vital source of vegetable protein for food and animal feed world-wide. It is predicted to become a major crop in Africa **(Sinclair et al 2014)**. Soybean occupies a unique position in science and agriculture, in addition of being a crop with enormous uses. Soybean is grown in almost all parts of the world for human consumption, industry and animal feed **(Boydak et al 2002).** Soybean plays an important role in supplying oil and protein needed by humans **(Agarwal, 2007; Shi et al 2010)**. Its protein has great potential as a major source of dietary protein. The oil produced from soybean seeds is highly digestible and contains no cholesterol **(Essa et al 2001)**.

Irrigation is one of the important factors affecting soybean growth, yield and its related components. Exposing soybean plants to soil moisture stress at any phase of its life cycle might lead to detrimental effect on growth, yield and its components. The most important stages for soybean plants to have adequate water are during pod development and seed fill **(Kranz et al 1998)**. During the last few years, water has become a limited resource in Egypt. Consequently, the search for technologies/ measures to save/ conserve water in irrigated agriculture has intensified. Therefore, decreasing plant water consumption by longer irrigation intervals will save irrigation through reducing number of irrigation but still attain similar economic yield **(Mahmoud, Gamalat et al 2013)**. **Ibrahim and Kandil Hala (2007)** in clay loam soil in Egypt found that irrigation intervals significantly affected the growth and yield parameter. The highest values of plant height, plant dry weight, no. of seeds/plant and yields/fed were obtained by irrigation every 14 days as compared with irrigation every 7 and 21 days.

The emergence of nanotechnology and the development of new nanodevices and nanomaterials open up potential novel applications in agriculture and biotechnology **(Scott and Chen, 2003 and Joseph and Morrison, 2006).** It considers the greatest solution can we choose now to develop our agriculture practices. Consequently, our information's about that technology must be growing up. Nanotechnology concentrated on the application of modern strategies for management of water and pesticides **(Ram et al 2014)**. Promising nanotechnology applications address low use efficiency of agricultural production inputs and stress of drought and high soil temperature. Nanoscale agrichemical formulations can increase efficiency use and decrease environmental losses. Nanoporous materials capable of storing water and slowly releasing it during times of water scarcity could also increase yields and save water **(Bouwmeester et al 2009).**

Mined phosphate rock is increasingly considered a strategic resource whose supply could become severely limited in the future and there are no substitutes for phosphorus in agriculture. Utilization of phosphorus from the applied commercial phosphorus (p) fertilizers by plants is very low due to its complex chemical reactions in soils. The efficiency of applied P fertilizer is assumed as low as about 20% depending on soil properties. This has led to a search for more efficient strategies for improving crop production in low P soils **(Shenoy and Kalgudi 2005)**. Phosphorus use efficiency can be improved by optimizing land use, preventing erosion, maintaining soil quality, improving fertilizer recommendations and fertilizer placement methods, improving crop genotypes, promoting mycorrhizas **(Schr€oder et al 2011)** and using manures and biochar **(Gunes et al 2014)**. In addition to these, using synthetic nano-hydroxyapatite [Ca_{10} $(PO_4)_6(OH)_2$; NHA] can be promising strategy to increase P fertilizer use efficiency. The current literature on NHA is mainly focused on its biomedical applications while potential agricultural applications have not been adequately addressed **(Kottegoda et al 2011)**. **Kottegoda et al (2011)** used urea modified hydroxyapatite as slow release fertilizer. **Liu and Lal (2014)** considered NHA as alternative P fertilizer and they suggested that NHA can potentially enhance soybean grown in peat-perlite mixture.

Calcium is an alkaline material widely distributed in the earth. It is the fifth most abundant element (by mass), usually found in sedimentary rocks in the mineral forms of calcite, dolomite and gypsum. Plants need calcium for growth and development it activates number of enzyme activities, metabolisms, nitrate uptake (a useable form of nitrogen), biomass ratio **(Savithramma, 2002)** and photosynthetic rate **(Savithramma, 2004; Savithramma et al 2007)**. Calcium carbonate is a primary component of garden lime, also known as agricultural lime, which is used to enhance the soil quality by increasing pH and water holding capacity of acidic soils. Calcium carbonate sources such as limestone and chalk, along with other chemical compounds are used in the preparation of agricultural lime, when added to the soil acts as a calcium source for plants **(Sabriye et al 2012)**. Recently, **Kara and Sabir (2010)** tested a 100% natural product made of Ca, Mg, Fe and Si elements and found beneficial in production of robust plants by accelerating vegetative growth in nursery. Sprayed onto the leaves the activated micronized particles penetrate through the stomata into the leaves. In the leaves the particles are split into CO_2 and CaO and MgO which are immediately available for plant. This process is triggered by chlorophyll absorbing light resulting in CO_2 plus H_2O being converted to carbohydrates and O_2. The nano-particles can enter directly through the stoma into the leaf **(Karaand Sabir, 2010)**. The calcite particles are then split into CaO and CO_2 which, as demonstrated by **Chen et al (2004)**, is the driving force of the photosynthesis. The aim of this study to evaluate response of soybean plants growth to hydroxyl apatite nanoparticles and calcium carbonate nanoparticles under two irrigation intervals.

MATERIALS AND METHODS

Experimental site

During summer seasons of 2015, 2016 and 2017, a field experiment was conducted at the Research and Experimental Station (30°19′ N, 31°16′ E), Faculty of Agriculture, Ain Shams University at Shalakan, Kalubia Governorate, Egypt, to study the effects of combinations between hydroxyl apatite nanoparticles and calcium carbonate nanoparticles as nano-fertilizers under two irrigation intervals, on growth of soybean plants (*Glycine max*, Merrill c.v. Giza 111). In 2016 season, experiment was canceled owing to weed competition. The soil was clay loam and its properties are shown in **Table (1)**. The preceding crop was wheat in both seasons.

Table 1. Soil properties of the Research and Experimental Station at Shalakan

Soil depth (cm)	Mechanical analysis %			Chemical properties				
	Clay	Silt	Sand	Organic matter %	pH	EC dSm^{-1}	$CaCo_3$ (%)	
0–30	40	43	17	1.65	7.72	1.5	2.1	
	Available macronutrients (mg kg^{-1} soil)							
		N		P	K			
		1189		2.2	327			
	Soluble cations and anions (mg 100g $soil^{-1}$)							
	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
	0.0	11.5	26.2	19.4	7.8	2.7	15.3	0.9

Experimental treatments

The experiment included 12 treatments which were the combinations of:

1- Hydroxyl apatite nanoparticles (HA): foliar application of three concentrations, i.e. zero kg fed^{-1} (control), 3 kg fed^{-1}, 6 kg fed^{-1}. A Hydroxyl apatite nanoparticle was sprayed three times after 25, 45, and 65 days from sowing. A Hydroxyl apatite nanoparticle was purchased from Bio-Nano fertilizer company and was characterized by x – ray diffraction, average crystal size 16.9 Nano-meters.

2- Calcium carbonate nanoparticles (CC): foliar application of two concentrations, i.e. zero g fed^{-1} (control), 500 g fed^{-1} calcium carbonate nanoparticle was sprayed three times after 25, 45, and 65 days from sowing. Calcium carbonate nanoparticles was purchased from Bio-Nano fertilizer company and was characterized by x – ray diffraction, average crystal size 93.3 Nano-meters.

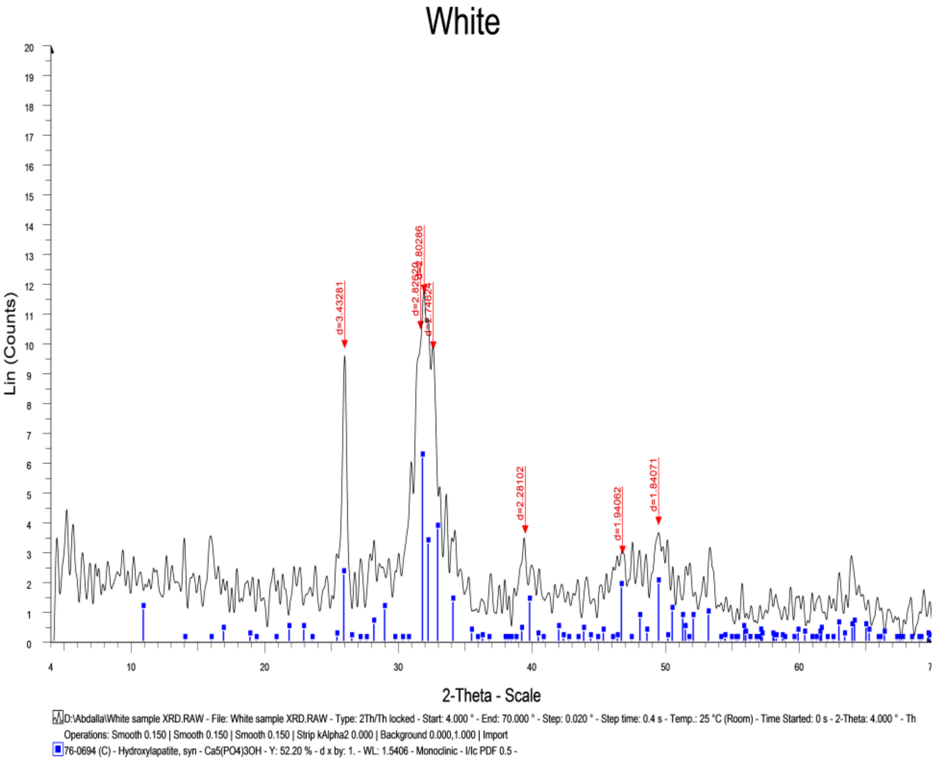


Fig. 1. X-ray diffraction patterns of hydroxyapatite nanoparticles

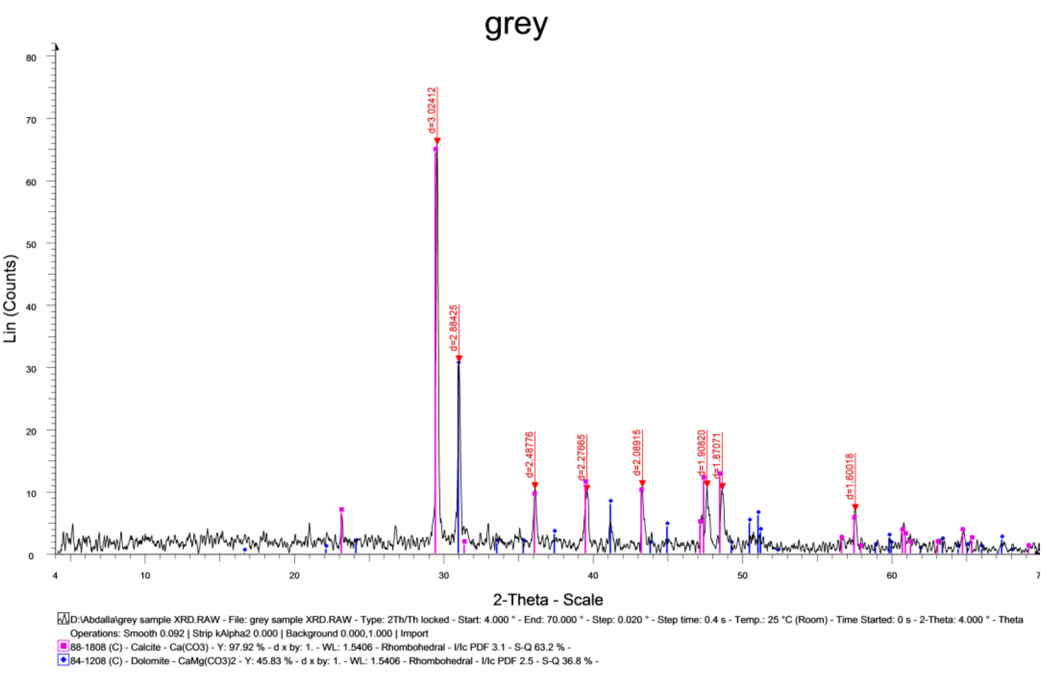


Fig. 2. X-ray diffraction patterns of calcium carbonate nanoparticles)

3- Irrigation intervals: irrigation treatments, (irrigation at 2 and 3 weeks whereas irrigation every 2 weeks as a recommended practice). Irrigation treatments were followed after El-Mohaya irrigation (25 days after planting).

Experimental practices and design

Treatments were arranged in the strip split plot design in 4 replicates. Plot area was 10.8 m^2 (6 ridges 3 m as long 0.60 m apart). Soybean seeds were sown in hills (20 cm between hills) on 25 th May and 28 th May in 2015 and 2017, respectively. Two plants were left in every hill while plant cultivation in the two sides of hill. Seeds were inoculated with *Bradyrhizopium Jabonicum* before sowing directly and nitrogen fertilizer (urea 46% N) was applied at the rate of 15 kg nitrogen as an active dose after 25 days from sowing.

Soybean (C.V. Giza 111) seeds (gained from, Field Crops Research Institute, ARC) were broadcasted at a rate of 30 kg fad^{-1}, after irrigation. All other recommended cultural practices were adopted throughout the two seasons according to (Research Department, Field Crops Research Institute, ARC).

Sampling and assessments

Five plants were taken at random after 80 days from sowing of each plot to study the following growth characters:-

1. Plant height (cm),
2. Number of branches/plant,
3. Number of leaves/plant,
4. Leaf area index (LAI),
5. Number of root nodules/plant,
6. Number of pods/plant,
7. Root dry weight/plant (g),
8. Stem dry weight/plant (g),
9. Leaves dry weight/plant (g),
10. Pods dry weight/plant (g).

Leaf area index (LAI) was estimated according to **Watson (1947).**

Statistical analysis

Data were subjected to analysis of variance (ANOVA) according to **Gomez and Gomez (1984)**, using COSTATC software. The combined analysis of variance for the data of the two seasons was performed after testing the error homogeneity. The differences among means were tested using the least significant difference (LSD) test at 0.05% probability level.

RESULTS AND DISCUSSION

A- Effect of irrigation intervals

Data presented in **Table (2)** show that plant height and numbers of leaves per plant were significantly influenced by irrigation intervals in the two studied seasons 2015, 2017 and combined result while numbers of branches per plant as well as leaf area index were significantly affected by the irrigation intervals in the second season (2017) only. In respect, plants irrigated every three weeks scored the superiority in its number of nodules per plant and/or number of pods per plant in the two growing seasons under study. The previous measure characters scored the highest values in the second season than the first one. These results may be due to the effect of water abundance in increasing growth characters of soybean.

Results in **Table (3)** indicated that irrigation intervals had statistically significant effect on root dry weight per plant, stem dry weight per plant, leaves dry weight per plant and pods dry weight per plant. These results were fairly true in the two studied seasons 2015, 2017 and combined result. Plants irrigated every three weeks surpassed others of two weeks in all measure characters. The increments were 0.86, 4.62, 4.97 and 2.45 g/plant for root, stem, leaves and pods in combined results. These results may be regarded to the effect of sufficient water in pushing growth of soybean through cell numbers, cell elongation and cell division which in term of dry matter accumulation of root, stem, leaves and pods. **Erkan et al (2004), Chafi et al (2012) and Mahmoud, Gamalat et al (2013)** resulted similar results.

B- Effect of calcium carbonate nanoparticles rates

Data presented in **Table (4)** show that plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of nodules per plant and number of pods per plant of soybean plants which treated with 500 g/fed surpassed untreated plants in the two studied seasons 2015, 2017 and combined. The increments in the measure characters were so great and enough to reach the 5% level of significance. These results may be owing to calcium carbonate nanoparticles can enter directly through the stoma into the leaf and then split into (CaO) which important on growth it activates (number of enzyme activities, metabolisms, nitrate uptake, biomass ratio and photosynthetic rate) and (CO_2) which is the driving force of the photosynthesis.

Dry matter accumulation of soybean plants sprayed with 500g/fed of calcium carbonate nanoparticles out-weight other untreated plants in root, stem and leaves in the first season and combined results while pods weight influenced significantly in the second season and combined results (**Table 5)**. Same workers came to the same trends**, P. Yugandhar and N. Savithramma (2013), Sabir et al (2014) and Natalia et al (2017).**

C- Effect of hydroxyl apatite nanoparticles rates

Plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of root nodules per plant and number of pods per plant of soybean plants statistically significant influenced by treating with hydroxyl apatite nanoparticles rates in the two studied seasons 2015, 2017 and combined result **(Table 6)**. Soybean plants treated with 6 kg hydroxyl apatite nanoparticles per feddan out-numbered other plants in its numbers of leaves per plant, leaf area index, number of root nodules per plant and number of pods per plant in the two growing seasons 2015, 2017 and combined data. These trends may be due to the more great permeability and high speed of hydroxyl apatite nanoparticles which mean more easily to penetrate into soybean leaves and release P and Ca which play an important role in pushing plant growth of soybean plants.

Results tabulated in **Table (7)** indicate that dry matter accumulation of soybean plant organs root, stem, leaves and pods significantly increased by treating with hydroxyl apatite nanoparticles as shown in combined results. **Liu and Zhao (2013), Liu and Lal (2014), Liu and Lal (2015) and Mehmet et al (2018)** came to the same trends.

D- Effect of interaction between irrigation intervals and calcium carbonate nanoparticles

Results in **Table (8)** show that vegetative measurements, plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of nodules per plant, number of pods per plant, root dry weight per plant, stem dry weight per plant, leaves dry weight per plant and pods dry weight per plant statistically influenced by interaction between irrigation intervals and calcium carbonate nanoparticles in the two growing seasons 2015 and 2017. Soybean plants irrigated every two weeks and sprayed by 500 g/fed calcium carbonate nanoparticles had the highest value of plant height (70.0 cm and 78.56 cm), numbers of branches per plant (3.31 and 3.50), numbers of leaves per plant (31.85 and 48.63), number of root nodules per plant (51.50 and 76.38), number of pods per plant (70.04 and 71.71) , root dry weight per plant (3.03 and 2.47), stem dry weight per plant (8.64 and 15.14), leaves dry weight per plant (15.87 and 20.71) and pods dry weight per plant (10.56 and 20.11) in the two growing seasons 2015 and 2017, respectively. These results may be due to the role of calcium carbonate in building plant organs and its metabolism in the abundance of water irrigation. Same workers came to similar trends as **Erkan et al (2004), Chafi et al (2012) and Sabir et al (2014).**

E- Effect of interaction between irrigation intervals and hydroxyl apatite nanoparticles

Data in **Table (9)** revealed that irrigation intervals X hydroxyl apatite nanoparticles interaction had significant effects on growth attributes, plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of nodules per plant, number of pods per plant, root dry weight per plant, stem dry weight per plant, leaves dry weight per plant and pods dry weight per plant. These results were fairly true under 5% level of significance in the two studied seasons 2015 and 2017. Soybean plants treated with 6 kg/fed hydroxyl apatite nanoparticles and irrigated every 2 weeks scored the highest values for the previous mentioned characters. These results may be explaining the effect of hydroxyl apatite nanoparticles with more irrigation in pushing metabolism accumulation in plant organs. **Mahmoud, Gamalat et al (2013), Liu and Lal (2015) and Mehmet et al (2018)** came to the same trends.

F- Effect of interaction between calcium carbonate nanoparticles and hydroxyl apatite nanoparticles

Results tabulated in **Table (10)** indicated that interaction between calcium carbonate nanoparticles and hydroxyl apatite nanoparticles had statistically significant effects on soybean plant growth

Table 2. Effect of irrigation intervals on growth attributes of soybean during the two growing seasons 2015, 2017 and combine

irrigation intervals (week)	Plant height (cm)			Number of branches per plant			Number of leaves per plant			Leaf area index			Number of root nodules per plant			Number of pods per plant		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
2	73.10	74.90	74.00	2.73	3.34	3.04	28.67	38.16	33.41	7.19	5.99	6.59	60.21	62.90	61.55	47.18	63.79	55.48
3	56.54	61.31	58.92	2.85	2.95	2.90	23.00	28.84	25.92	7.57	4.98	6.27	38.50	39.15	38.32	30.33	48.61	39.47
LSD at 5%	**2.51**	**4.72**	**2.25**	**n.s**	**0.38**	**n.s**	**1.75**	**3.03**	**1.92**	**n.s**	**0.53**	**n.s**	**2.49**	**3.28**	**1.10**	**0.96**	**4.93**	**2.76**

Table 3. Effect of soybean irrigation intervals on dry weight accumulation of root, stem, leaves and pods in the two growing seasons 2015, 2017 and combine

irrigation intervals (week)	Root (g/plant)			Stem (g/plant)			Leaves (g/plant)			Pods (g/plant)		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
2	2.56	2.49	2.53	7.50	13.45	10.48	14.24	20.03	17.13	9.96	19.24	14.95
3	1.43	1.91	1.67	4.34	7.38	5.86	8.37	15.96	12.16	7.74	17.26	12.50
LSD at 5%	**0.13**	**0.33**	**0.20**	**0.57**	**2.99**	**1.38**	**1.38**	**2.01**	**0.26**	**2.11**	**1.51**	**1.56**

Table 4. Effect of calcium carbonate nanoparticles rates on growth characters of soybean during the two growing seasons 2015, 2017 and combine

Calcium carbonate g/fed	Plant height			Number of branches per plant			Number of leaves per Plant			Leaf area index			Number of root nodules per plant			Number of pods per plant		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
zero	60.96	67.04	64.00	2.45	2.95	2.70	32.92	26.52	24.22	5.63	5.07	5.35	40.65	40.25	40.45	33.11	51.69	42.40
500	68.68	69.17	68.92	3.14	3.34	3.24	29.75	40.48	35.11	9.13	5.90	7.51	57.06	61.79	59.43	44.40	60.72	52.56
LSD at 5%	**0.25**	**n.s**	**4.26**	**0.50**	**0.33**	**0.36**	**1.28**	**4.78**	**2.24**	**0.52**	**0.43**	**0.38**	**6.35**	**3.63**	**3.86**	**0.88**	**4.23**	**2.31**

Table 5. Effect of calcium carbonate nanoparticles rates on dry weight accumulation of root, stem, leaves and pods in the two soybean growing seasons 2015, 2017 and combine

Calcium carbonate g/fed	Root (g/plant)			Stem (g/plant)			Leaves (g/plant)			Pods (g/plant)		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
zero	1.38	2.25	1.92	5.03	9.57	1.30	9.47	17.35	13.41	7.91	17.67	12.79
500	2.40	2.15	2.27	6.82	11.26	9.04	13.14	18.64	15.89	9.79	19.53	14.66
LSD at 5%	**0.35**	**n.s**	**0.29**	**0.63**	**n.s**	**0.90**	**0.95**	**n.s**	**1.17**	**n.s**	**0.27**	**1.19**

Table 6. Effect of hydroxyl apatite nanoparticles (kg/fed) on growth characters of soybean during the two growing seasons 2015, 2017 and combine

Hydroxyl apatite kg/fed	Plant height			Number of branches per plant			Number of leaves per plant			Leaf area index			Number of root nodules per plant			Number of pods per plant		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
zero	58.19	62.38	60.28	2.55	2.52	2.53	22.77	24.51	23.64	6.22	4.72	5.47	37.81	37.69	37.75	32.31	45.27	38.79
3	67.60	73.06	70.33	2.94	3.45	3.20	26.00	37.07	31.54	6.78	5.81	6.28	49.88	57.50	53.69	37.91	56.45	47.18
6	68.67	68.88	68.77	2.89	3.47	3.18	28.73	38.92	33.83	9.14	5.93	7.53	58.88	57.88	58.38	46.05	66.89	56.47
LSD at 5%	**2.23**	**5.11**	**3.45**	**0.30**	**0.32**	**0.22**	**1.33**	**2.84**	**1.68**	**0.81**	**0.42**	**0.48**	**4.78**	**2.72**	**2.74**	**1.52**	**4.53**	**2.14**

Table 7. Effect of hydroxyl apatite nanoparticles (kg/fed) on dry weight accumulation of root, stem, leaves and pods in the two soybean growing seasons 2015, 2017 and combine

Hydroxyl apatite kg/fed	Root (g/plant)			Stem (g/plant)			Leaves (g/plant)			Pods (g/plant)		
	2015	2017	combien	2015	2017	combien	2015	2017	combien	2015	2017	combien
zero	1.73	1.80	1.77	4.82	8.01	6.42	10.01	15.21	12.61	7.08	16.41	11.75
3	2.01	2.41	2.21	6.21	10.67	8.44	12.12	18.54	15.33	8.98	18.43	13.70
6	2.24	2.38	2.31	6.73	12.56	9.65	11.79	20.23	16.01	10.49	20.96	15.73
LSD at 5%	**0.28**	**0.26**	**0.18**	**0.83**	**2.41**	**1.06**	**1.42**	**1.14**	**0.70**	**1.07**	**1.68**	**1.17**

Table 8. Effect of interaction between irrigation intervals and calcium carbonate nanoparticles on growth characters of soybean during the two growing seasons 2015 and 2017

	Calcium carbonate nanoparticles (g/fed)			
Date	**2015**		**2017**	
Irrigation intervals (weeks)	**Zero**	**500**	**Zero**	**500**
Trait	**Plant height (cm)**			
2	70.10	70.10	71.23	78.56
3	51.82	61.25	62.85	59.77
LSD at 5%	**4.11**		**7.26**	
Trait	**Number of branches / plant**			
2	2.50	3.31	3.19	3.50
3	2.40	2.96	2.71	3.19
LSD at 5%	**0.36**		**0.32**	
Trait	**Number of leaves / plant**			
2	25.48	31.85	27.69	48.63
3	18.35	27.65	25.35	32.33
LSD at 5%	**1.41**		**3.04**	
Trait	**Leaf area index**			
2	6.51	10.38	5.71	6.27
3	4.75	7.88	4.43	5.53
LSD at 5%	**1.52**		**0.63**	
Trait	**Number of root nodules / plant**			
2	42.85	51.50	49.42	76.38
3	23.38	37.29	31.08	47.21
LSD at 5%	**1.93**		**4.89**	
Trait	**Number of pods / plant**			
2	50.38	70.04	55.88	71.71
3	30.92	44.08	47.50	49.73
LSD at 5%	**4.45**		**6.96**	
Trait	**Roots dry weight (g/plant)**			
2	2.09	3.02	2.51	2.47
3	1.07	1.77	1.99	1.82
LSD at 5%	**0.14**		**0.49**	
Trait	**Stem dry weight (g/plant)**			
2	6.36	8.64	11.75	15.14
3	3.68	4.99	7.39	7.37
LSD at 5%	**0.74**		**2.53**	
Trait	**Leaves dry weight (g/plant)**			
2	12.60	15.86	19.35	20.70
3	6.33	10.40	15.34	16.57
LSD at 5%	**1.64**		**2.11**	
Trait	**Pods dry weight (g/plant)**			
2	9.36	10.55	19.77	20.10
3	6.45	9.02	15.56	18.95
LSD at 5%	**1.16**		**1.32**	

Table 9. Effect of interaction between irrigation intervals and hydroxyl apatite nanoparticles on growth characters of soybean during the two growing seasons 2015 and 2017

	Hydroxyl apatite nanoparticles (kg/fed)					
Date	**2015**			**2017**		
Irrigation intervals (weeks)	**Zero**	**3**	**6**	**Zero**	**3**	**6**
Trait	**Plant height (cm)**					
2	66.69	78.31	76.31	66.78	79.44	78.47
3	49.69	58.89	61.03	57.98	66.68	59.28
LSD at 5%	**2.91**			**6.80**		
Trait	**Number of branches / plant**					
2	2.59	3.03	3.13	2.84	3.50	3.69
3	2.50	2.84	2.66	2.19	3.41	3.25
LSD at 5%	**0.51**			**0.42**		
Trait	**Number of leaves / plant**					
2	25.03	28.91	32.06	26.97	42.09	45.41
3	20.50	23.09	25.41	22.04	32.05	32.44
LSD at 5%	**2.08**			**2.98**		
Trait	**Leaf area index**					
2	6.24	7.60	9.38	5.50	5.96	6.50
3	6.20	5.96	8.90	3.93	5.65	5.63
LSD at 5%	**1.39**			**0.62**		
Trait	**Number of root nodules / plant**					
2	39.81	44.94	56.78	46.25	66.31	76.13
3	24.81	30.88	35.31	29.13	39.63	48.69
LSD at 5%	**2.47**			**3.29**		
Trait	**Number of pods / plant**					
2	45.69	54.38	80.56	54.06	63.41	73.91
3	29.94	37.19	45.38	36.47	49.50	59.88
LSD at 5%	**3.73**			**5.56**		
Trait	**Roots dry weight (g/plant)**					
2	2.23	2.70	2.75	2.13	2.63	2.72
3	1.24	1.31	1.73	1.48	2.19	2.05
LSD at 5%	**0.31**			**0.41**		
Trait	**Stem dry weight (g/plant)**					
2	5.68	7.88	8.96	10.34	13.73	16.28
3	3.96	4.55	4.50	5.69	7.61	8.85
LSD at 5%	**1.31**			**3.46**		
Trait	**Leaves dry weight (g/plant)**					
2	12.34	14.94	15.44	17.94	19.43	22.73
3	7.68	8.80	8.64	12.49	17.66	17.73
LSD at 5%	**2.39**			**1.91**		
Trait	**Pods dry weight (g/plant)**					
2	8.38	10.64	10.38	19.20	18.84	21.79
3	5.79	7.33	10.11	13.63	18.01	20.14
LSD at 5%	**2.09**			**2.03**		

Table 10. Effect of interaction between hydroxyl apatite and calcium carbonate nanoparticles on growth characters of soybean during the two growing seasons 2015 and 2017

	Hydroxyl apatite nanoparticles (kg/fed)					
Date	**2015**			**2017**		
Calcium carbonate (g/fed)	**Zero**	**3**	**6**	**Zero**	**3**	**6**
Trait	**Plant height (cm)**					
0	54.00	64.36	64.53	63.73	68.11	69.28
500	62.38	70.84	72.81	61.03	78.00	68.47
LSD at 5%	**2.45**			**5.46**		
Trait	**Number of branches / plant**					
0	1.97	2.56	2.89	2.34	3.03	3.47
500	2.97	3.13	3.31	2.69	3.47	3.88
LSD at 5%	**0.55**			**0.42**		
Trait	**Number of leaves / plant**					
0	19.22	21.44	25.09	18.95	29.46	31.16
500	26.31	30.56	32.38	30.06	44.69	46.69
LSD at 5%	**2.31**			**3.24**		
Trait	**Leaf area index**					
0	4.25	5.71	6.93	3.99	5.73	5.49
500	8.18	7.85	11.35	5.43	5.89	6.38
LSD at 5%	**2.07**			**0.89**		
Trait	**Number of root nodules / plant**					
0	24.91	31.88	42.56	29.19	50.56	41.00
500	39.72	43.94	49.53	46.19	64.44	74.75
LSD at 5%	**4.31**			**6.55**		
Trait	**Number of pods / plant**					
0	29.94	49.96	41.94	39.88	53.41	61.78
500	45.69	50.06	75.81	50.66	59.50	72.00
LSD at 5%	**7.45**			**8.05**		
Trait	**Roots dry weight (g/plant)**					
0	1.43	1.58	1.75	1.93	2.41	2.35
500	2.04	2.44	2.73	1.68	2.41	2.35
LSD at 5%	**0.51**			**0.41**		
Trait	**Stem dry weight (g/plant)**					
0	3.91	4.95	6.16	6.31	10.08	12.33
500	5.68	7.30	7.48	9.71	11.26	12.80
LSD at 5%	**0.93**			**4.62**		
Trait	**Leaves dry weight (g/plant)**					
0	8.34	10.20	9.88	14.86	18.31	18.40
500	14.36	11.68	13.38	15.56	18.78	22.05
LSD at 5%	**1.96**			**2.16**		
Trait	**Pods dry weight (g/plant)**					
0	5.96	7.99	9.79	14.43	16.44	19.78
500	8.20	9.98	11.20	18.40	20.41	22.15
LSD at 5%	**1.84**			**1.65**		

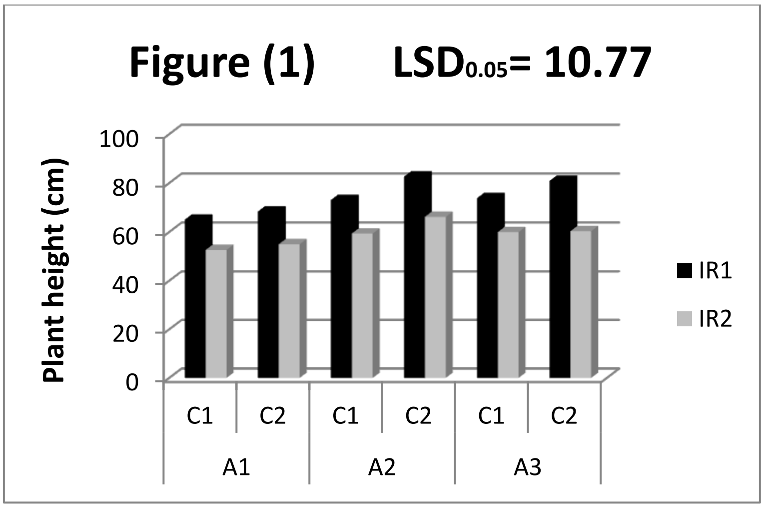


Figure (1) LSD0.05= 10.77
Plant height (cm)
100
80
60
40
20
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2

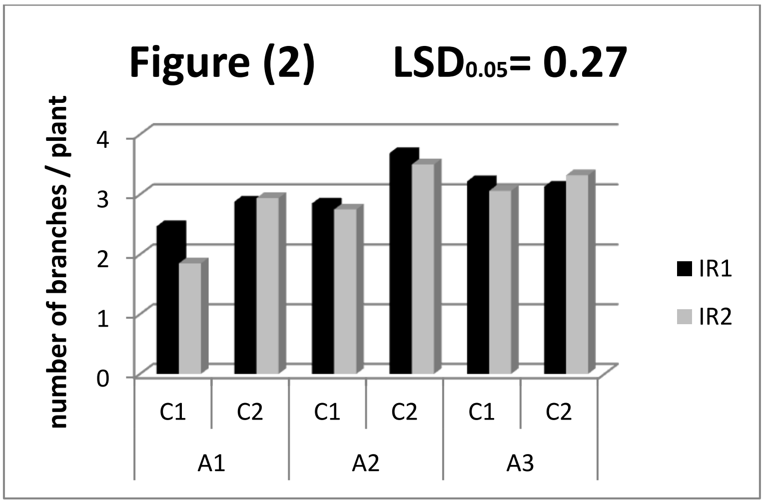


Figure (2) LSD0.05= 0.27
number of branches / plant
4
3
2
1
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2

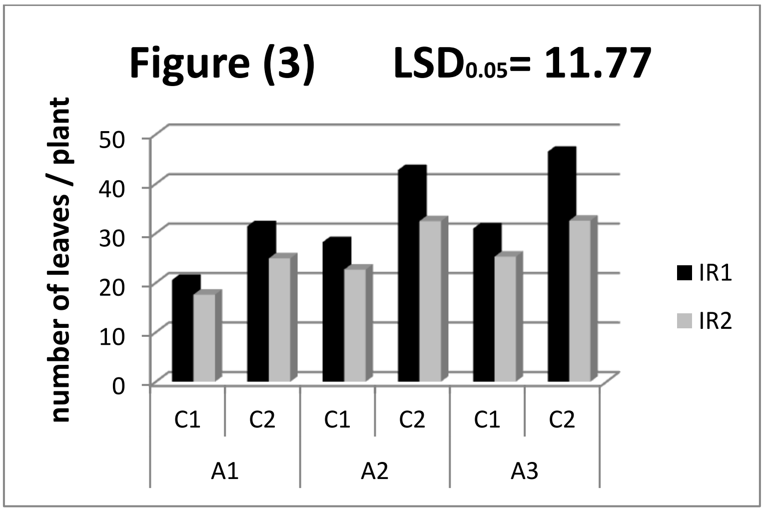


Figure (3) LSD0.05= 11.77
number of leaves / plant
50
40
30
20
10
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2

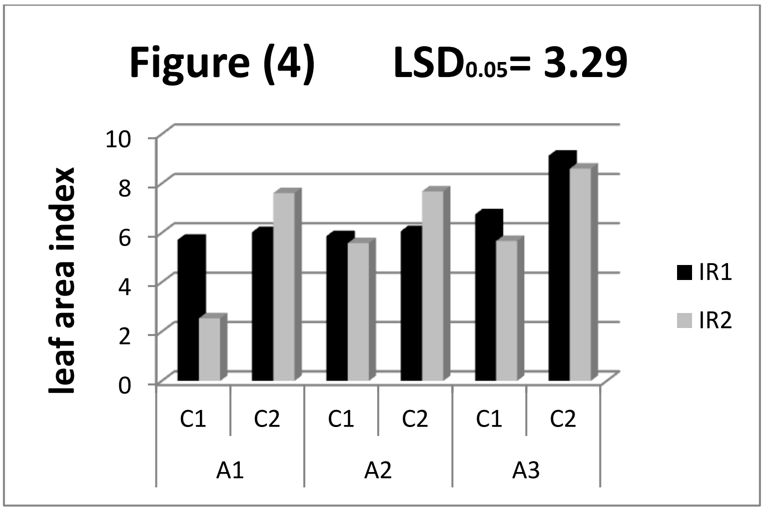


Figure (4) LSD0.05= 3.29
leaf area index
10
8
6
4
2
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2

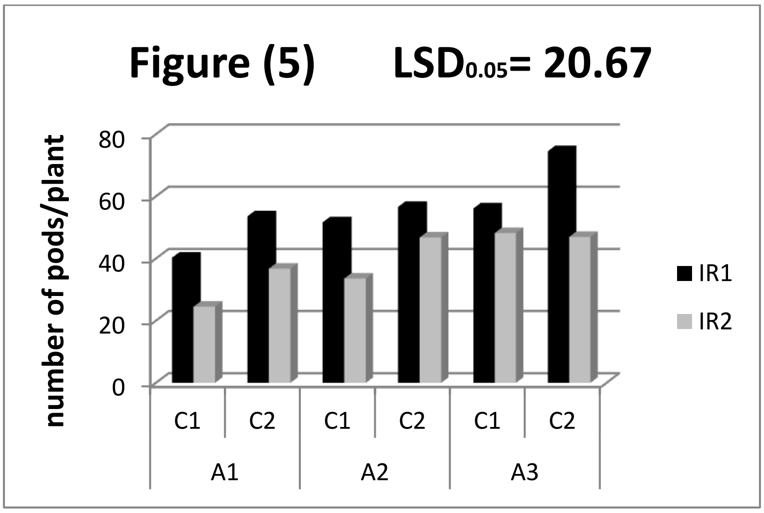


Figure (5) LSD0.05= 20.67
number of pods/plant
80
60
40
20
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2

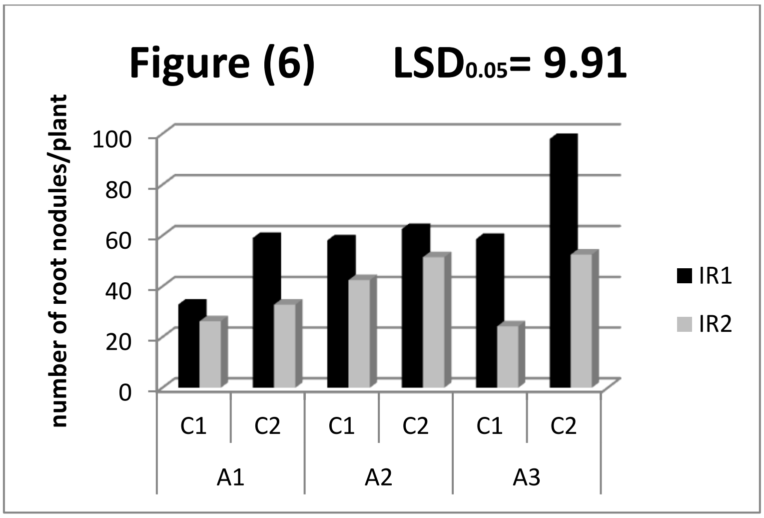
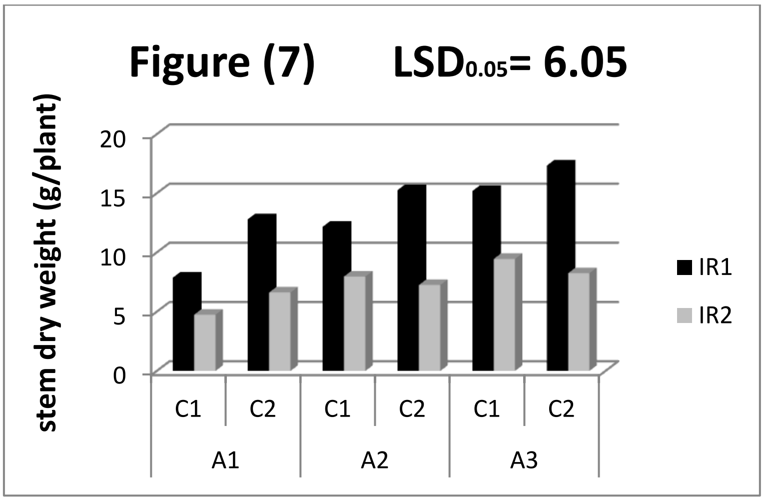


Figure (6) LSD0.05= 9.91
number of root nodules/plant
100
80
60
40
20
0
C1
C2
C1
C2
C1
C2
A1
A2
A3
IR1
IR2



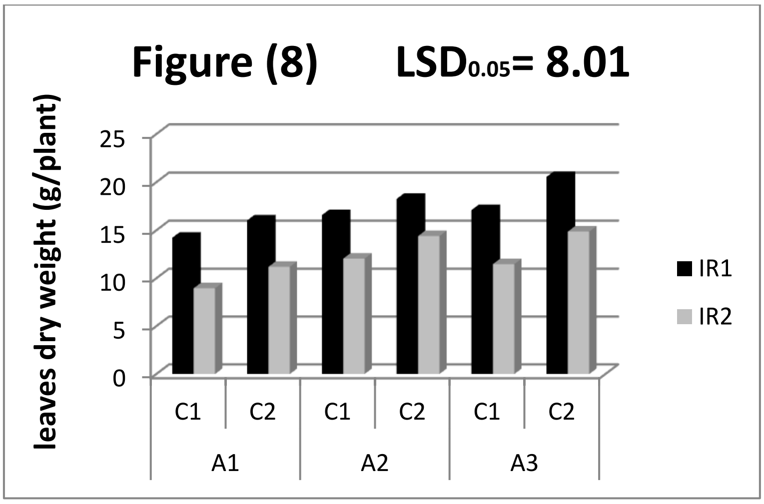


Fig. 3 (1-8). Plant height (cm); Number of branches/plant; Number of leaves/plant; Leaf area index; Number of pods/plant; Number of root nodules/plant; Stem dry weight (g/plant); Leaves dry weight (g/plant) respectively**.** The significant interaction along with irrigation intervals (**IR1** every 2 weeks and **IR2** every 3 weeks), calcium carbonate nanoparticles (**C1** zero g/fed and **C2** 500 g/fed) and hydroxyl apatite nanoparticles (**A1** zero kg/fed, **A2** 3 kg/fed and **A3** 6kg/fed) of soybean growth characters.

as plant height, numbers of branches per plant, numbers of leaves per plant, leaf area index, number of nodules per plant, number of pods per plant, root dry weight per plant, stem dry weight per plant, leaves dry weight per plant and pods dry weight per plant in the two studied seasons 2015 and 2017. Soybean plants treated with 500 g/fed calcium carbonate nanoparticles and 6 kg/fed hydroxyl apatite nanoparticles had the maximum values for the previous mentioned characters. These effects were so great and enough to reach the 5% level of significance (table 10). These results drew attention of some investigators as **P. Yugandhar and N. Savithramma (2013), Sabir et al (2014) and Mehmet et al (2018).**

G- Irrigation intervals X calcium carbonate nanoparticles X hydroxyl apatite nanoparticles interaction

Fig. from 1 to 8 show the effect of the interaction between calcium carbonate, hydroxyl apatite levels and irrigation intervals treatments on soybean growth parameters. Results revealed clearly that the interaction effect was significant. This significant effect of the above interaction means that the tested calcium carbonates and hydroxyl apatite levels do not take the same behavior under the different treatments of irrigation intervals. Results also showed that soybean plants were treated with 3 kg/fed hydroxyl apatite nanoparticles (A_2), 500 g/fed calcium carbonate nanoparticles (C2) and irrigation every two weeks (IR 1) gave the highest means values of plant height (82.66cm) and number of branches /plant (3.69) but interaction between 6 kg/fed hydroxyl apatite nanoparticles (A_3) and 500 g/fed calcium carbonate nanoparticles (C2) under irrigation every 2 week (IR 1) scored the maximum values of numbers of leaves (46.50) per plant, leaf area index (9.13), number of nodules per plant (98.01), number of pods per plant (74.57), stem dry weight per plant (17.35 g) and leaves dry weight per plant (20.55 g). On the other hand the lowest means values were recorded at combination between zero kg/fed hydroxyl apatite nanoparticles (A_1) and zero g/fed calcium carbonate nanoparticles (C1) under irrigation every 3 week (IR 2) on all growth attributes. As shown from **Fig. (1 to 8)** there weren't significant results between plants treated with nano-mineral fertilizers under irrigation every 3 week and plants untreated but irrigated every 2 week in all growth traits, which reflect appositive result of these chemical substances in mitigation harmful effect of water shortage. **Liu and Zhao (2013), Mahmoud Gamalat et al (2013) Liu and Lal (2014), Liu and Lal (2015), Erkan et al (2004) and Mehmet et al (2018)** came to the same trends.

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مجلة اتحاد الجامعات العربية للعلوم الزراعية ، جامعة عين شمس ، القاهرة ، مصر
مجلد(27)، عدد(2)، 1405-1422، 2019
Website: http://ajs.journals.ekb.eg

أستجابة نمو فول الصويا للأسمدة المعدنية النانومترية تحت فترتين للرى

[116]

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Received 4 April, 2019 Accepted 30 April, 2019

الموجـــــــز

أقيمت تجربتان حقليتان فى محطة تجارب وبحوث كلية الزراعة جامعة عين شمس بشلقان، محافظة القليوبية، جمهورية مصر العربية، أثناء صيف 2015، 2017 لدراسة تأثير التفاعل بين جزيئات الهيدروكسى أباتيت النانومترية ثلاث مستويات (صفر كجم/فدان، 3 كجم/فدان، 6 كجم/فدان) و جزيئات كربونات الكالسيوم النانومترية مستويان (صفر جرام/فدان، 500 جرام/فدان) تحت فترتى رى (الرى كل أسبوعين كمعاملة موصى بها، الرى كل ثلاث أسابيع) على نمو نباتات فول الصويا. أحدثت فترات الرى تأثيرا معنويا على ارتفاع النبات بالسنتيمتر، عدد الأفرع/نبات، عدد الأوراق/نبات، دليل مساحة الأوراق، عدد العقد الجذرية/نبات، عدد القرون/نبات، الوزن الجاف للجذور/نبات، الوزن الجاف للسيقان/نبات، الوزن الجاف للأوراق/نبات، الوزن الجاف للقرون/نبات. وكانت تلك النتائج تفوقت تقريبا فى كلا الموسمين والتحليل المشترك بينهم. صفات أرتفاع النبات بالسنتيمتر، عدد الأفرع/نبات، عدد الأوراق/نبات، دليل مساحة الأوراق، عدد العقد الجذرية/نبات، عدد القرون/نبات، الوزن الجاف للجذور/نبات، الوزن الجاف للسيقان/نبات، الوزن الجاف للأوراق/نبات، الوزن الجاف للقرون/نبات لنباتات فول الصويا المعاملة ب500 جرام كربونات كالسيوم نانومترية للفدان تفوقت على تلك غير المعاملة فى كلا الموسمين والتحليل المشترك بينهم. نباتات فول الصويا المعاملة ب 6 كجم هيدروكسى أباتيت نانومترى تفوقت على غير المعاملة فى صفات عدد الأفرع/نبات، عدد الأوراق/نبات، دليل مساحة الأوراق، عدد العقد الجذرية/نبات، عدد القرون/نبات، الوزن الجاف للجذور/نبات، الوزن الجاف للسيقان/نبات، الوزن الجاف للأوراق/نبات، الوزن الجاف للقرون/نبات فى كلا الموسمين والتحليل المشترك بينهم. التفاعل بين مستوى الرى كل أسبوعين (الموصى به) ومستوى 500 جرام/فدان كربونات كالسيوم نانومترية ومستوى 6 كجم/فدان هيدروكسى أباتيت نانومترى أعطى أفضل توليفة رفعت من قيم أرتفاع النبات بالسنتيمتر، عدد الأفرع/نبات، عدد الأوراق/نبات، دليل مساحة الأوراق، عدد العقد الجذرية/نبات، عدد القرون/نبات، الوزن الجاف للجذور/نبات، الوزن الجاف للسيقان/نبات، الوزن الجاف للأوراق/نبات، الوزن الجاف للقرون/نبات. لم يوجد فرق معنوى بين النباتات المعاملة بالأسمدة النانومترية تحت مستوى الرى كل ثلاث أسابيع والنباتات غير المعاملة بتلك الأسمدة ولكن رويت كل أسبوعين فى جميع صفات النمو مما يعكس تاثير ايجابى لتلك المواد فى تخفيف حدة الأثر الضار لنقص المياه على النباتات وذلك فى كلا الموسمين والتحليل المشترك بينهم.

الكلمات الدالة: فول الصويا، الأسمدة النانومترية، كربونات الكالسيوم النانومترية، الهيدروكسى أباتيت النانومترى، فترات الرى

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