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ORIGINAL ARTICLE

Effects of Irrigation Management and Humic Acid on Yield and Yield Components of Peanut (*Arachis hypogaea* L.)

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A R T I C L E I N F O

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A B S T R A C T

Peanut is an oilseed plant, which is rich in seed oil and protein content. The effects of different irrigation methods and humic acid dosages were explored on yield and yield components of peanuts in Astaneh-ye Ashrafiyeh County in Guilan province, Iran, in 2018 and 2019 cropping years. The experiment was laid upon a split-plot design based on a randomized complete block design with three replications in which the main plot was assigned to irrigation treatments including rainfed treatment and irrigation to meet 60%, 80%, and 100% of water requirement, and the sub-plot was assigned to humic acid (HA) at four rates of 0, 3, 6, and 9 L ha^{-1}. The results showed that the highest biological yield (9750 kg ha^{-1}) was obtained from the plants irrigated to meet 80% of their water requirement and applied with 9 L ha^{-1} HA and the lowest (2453 kg ha^{-1}) was produced under rainfed conditions with no HA applied. Seed yield was 1863 kg ha^{-1} at the 80% water requirement level and 2067 kg ha^{-1} at the HA level of 9 L ha^{-1}. Based on the results, it can be recommended to apply 9 L ha^{-1} HA and supply 80% of the plants' water requirement as appropriate conditions for the studied region.

Introduction

After soybean, the peanut is one of the most important and economic oilseeds in hot and semi-hot regions, which is cultivated for oil (43-55%) and protein (25-28%) production (Banavath *et al*., 2018; Maleki *et al*., 2016; Krishna *et al*., 2015). About two-thirds of global peanut is produced for oil extraction, which shows the significance of this species as an oilseed plant (Janila *et al*. 2013). High oil quantity and quality, the supply of high-quality protein, the possibility of its intercropping with maize, its impact on enhancing soil organic matter and fertility, the prevention of erosion, and above all, proper cash return are the major advantages of this plant species (Ahmadi, 2008). The acreage of peanuts amounts to about 3000 ha in Iran, of which 2800 ha is located in Guilan province (Agriculture Iran Statistics, 2020).

A key factor limiting crop production throughout the world is water scarcity and the lack of proper access to modern irrigation methods (Chaves *et al*., 2003). Today, competition on water supply has been intensified among farmers. Water is a key factor in crop production, which its deficiency reduces crop yields (Costa *et al*., 2007). Water deficit is critical environmental stress that affects peanut growth and yield. Furthermore, a decline in water uptake by plants results in the reduction of transpiration, stomatal conductance, and photosynthesis, and the disruption of hormonal balance (Janila *et al*., 2013). Water deficit at the vegetation phase is most influential on peanut yields, water productivity, and dry matter production. This plant species is much more sensitive to irrigation time and amount during the growing season and

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critical stages, e.g., flowering and pod filling, than during the vegetative stage at the beginning of planting or during physiological maturity (Abou Kheira Abdrabbo, 2009; Haro *et al*., 2008). Water stress at flowering limits root growth rate and reduces canopy growth rate, resulting in a decline in biological yield and in seed yield of peanuts (Songsri *et al*., 2009; Banavath *et al*., 2018). Long-term stress affects all metabolic processes of peanut and mostly reduces its pod production (El-Boraie *et al*., 2009). Water deficit reduces peanut leaf size and duration by reducing water potential (Haro *et al*., 2008). The critical stages of peanut include pollination, milk formation, and dough formation; so, it is economical to irrigate the plants at these stages promptly and adequately (Wang *et al*., 2015). To ensure high yields, the peanut water requirement should be supplied during the growing season and irrigation should be performed regularly and adequately during the flowering stage (Krishna *et al*., 2015). It is of high importance to determine the peanut water requirement precisely as it will improve water use management at peanut farms. Moisture plays a significant role in peanut pod growth and development (Abdzad-Gohari *et al*., 2018).

Presently, the application of chemical fertilizers is decreasing due to their detrimental effects and environmental hazards, and the application of various types of organic acids, including humic acid (HA), to improve the quantity and quality of agricultural and horticultural crops has recently been increased (Barzegar *et al*., 2018). In most European countries, although soils have relatively high organic content, HA has been welcomed increasingly (Oveyssi and Ghorchi, 2012). The presence of wide varieties of mineral and hormone compounds in organic acids greatly contributes to improving the physical, chemical, and biological characteristics of the soil, increasing production and enhancing crop quality (Abdipour *et al.*, 2019; Zaferanchi *et al.*, 2019; Beheshti *et al*., 2016).

To enhance the organic content of agricultural soils, it is first necessary to specify the importance of organic matter in soils. This is possible only when we have a full understanding of organic matter's role and functions in soils (Janila *et al*., 2013). HA plays a key role in improving plants’ potential for nutrient uptake from the soil (Fallahi *et al.*, 2016). Indeed, the shoot and root growth of plants are stimulated by HA, but its impact is more evident on roots so that it increases the effectiveness of root systems (Celik *et al*., 2010). The present study aims to determine a proper irrigation regime for the peanut along with the application of HA to increase economic yield-based water use efficiency in Guilan province, Iran.

Materials and Methods

The research was conducted at an experimental farm in Astaneh-ye Ashrafiyeh (27°14' N., 49°56' E.) in Guilan province, Iran. The main plot was assigned to irrigation treatments including rainfed treatment and irrigation to provide 60%, 80%, and 100% of water requirement, and the sub-plot was assigned to HA at four rates of 0, 3, 6, and 9 L ha^{-1}. Table 1 presents the meteorological data for the studied region during the experiment (Guilan Meteorological Quarterly 2019). Rainfall during the growing season in 2018 and 2019 was 133.4 and 85.8 mm, respectively. The soil of the study site at the Islamic Azad University of Lahijan was tested for physical and chemical characteristics before the trials. The results are shown in Table 2. The soil had a loam texture. The study was carried out as a split-plot experiment based on a randomized complete block design with three replications.

Table 1. Meteorological data of the study area (2018 and 2019).

Data/Month	Jun		Jul		Aug		Sep	
	2018	2019	2018	2019	2018	2019	2018	2019
Average relative humidity (%)	60.2	58.9	58.8	62	61.3	57.2	62.8	64.5
Wind speed (m s^{-1})	2.4	2.6	2.9	3.3	2.3	2.7	2.1	2.5
Maximum temperature (°C)	27.9	28.1	32.3	29	31.1	30.8	30.4	28.6
Minimum temperature (°C)	18.2	19.3	22.7	21	22.6	22	19.7	19.4

Table 2. Physicochemical properties of the field soil.

Soil depths (cm)	N (%)	K (mg kg^{-1})	P (mg kg^{-1})	pH	Organic carbon (%)	EC (dS m^{-1})	Soil texture (g kg^{-1})
0-30	0.03	181	3.17	6.9	0.65	0.646	Sandy loam
30-60	0.03	150	2.33	6.9	0.66	0.632	

To prepare the seedbed, the farm was subjected to relatively deep plowing in the early spring and then, it was disked. At the next step, the experimental units were created at the dimensions of 4 × 3 m^2. The peanut seeds were sown on May 5 in both years. The seeds of peanut cv. 'Guil' was procured from local farmers and was sown at a depth of 4 cm in a 50 × 20 arrangement (Esmaeilpour *et al*., 2013). Before sowing, the seeds were disinfected with the fungicide Thiram (2:1000). The weeds were managed by hand for which the experimental farm was weeded twice. The soil addition was performed only once at the peg formation stage.

HA was sprayed at two steps, first at the 4-8-leaf stage and second at the flowering stage. The irrigation in this study was performed by the surface method. To determine the irrigation treatments, soil moisture discharge was used and water requirement of plant was considered as 100% irrigation treatment, and other irrigation treatments were considered as a percentage of this value (Najafi Mode, 2006). The duration and value of irrigation at each stage were determined with the depth of the root and measuring the soil moisture using a weight method in the relevant layer at any stage of irrigation. Soil moisture in the root depth using Equation (1) was calculated for soil moisture to reach the capacity limit of the farm. The duration of irrigation was also calculated after reaching the water to moisture front in the plant root depth.

$$dn = (\theta fc - \theta i).\rho b.Dr \qquad (1)$$

where: θfc: moisture at field capacity (%), θi: moisture content in the soil (%), ρb: bulk density (g cm^{-3}), and Dr: root depth (cm). Measuring the amount of water delivered to every plot was performed by flow meters. The amounts of water during growing were obtained through irrigation and rainfall (Table 3). The water delivered to each experimental unit was recorded with a contour, and the amount of water used during the plant growth period was supplied by irrigation water and effective precipitation.

Table 3. Amount of water use in each treatment in 2018 and 2019.

Year	2018	2019	2018	2019
Water requirements	Amount of irrigation (mm)		Amount of water use (mm)	
60%	372	525	505	611
80%	443	612	576	698
100%	507	678	640	773

After crop maturity, data were collected on biological yield, pod yield, seed yield, harvest index, pod number per plant, seed number per plant, and 100-seed weight. In each plot, after eliminating two marginal rows, 10 plants were randomly selected. Then, their pods, leaves, and stems were separated, oven-dried at 70°C for 48 hours, and weighed. The total weight of the dried (seed-containing) pods, dried stems, and dried leaves were recorded as the biological yield in kg ha^{-1}. To determine seed yield, mature pods were collected and husked. The harvest index in each plot was calculated as total seed dry weight divided by biological yield. To find out pod number per plant, 10 plants were randomly selected, their intact pods were collected, and they were counted. Similarly, seed number per plant was calculated on 10 randomly selected plants whose intact pods were separated and their seed content was counted. To determine 100-seed weight, 200g of dry pods were taken as a sample. Then, their seeds were oven-dried at 60°C until they reached a constant dry weight after which 100 seeds were weighed. Statistical analysis was performed using MSTATC software and mean comparisons were also performed using Tukey's multiple range tests at P≤0.05.

Results

Biological yield

The results showed that the interactive effect of irrigation and HA was significant ($p < 0.01$) on biological yield (Table 4). According to the comparison of the means, the highest biological yield of 9750 kg ha^{-1} was obtained from the plants irrigated with 80% of water requirement and treated with 9 L ha^{-1} HA, and the lowest one of 2453 kg ha^{-1} was obtained from the unirrigated and untreated plants (Table 5).

Table 4. Combined ANOVA for the effects irrigation and humic acid

Source	df	MS						
		Biological yield	Pod yield	Seed yield	Harvest index	Pod number in plant	Seed number in plant	100-weight seed
Year (Y)	1	689268	56619	35654.8	0.0025	29.37	64.8	110.3
Replication	2	8887264.3	3760299.5	1947506.9	0.0212	1504.3	5276.8	169.49
Irrigation (I)	3	68968265.3**	10348842**	5755370.9**	0.0098*	3815.9**	11200.6**	3699.1**
Y× I	3	570011.7	72238.822	48784.3	0.0023	30.61	82.78	68.8
Error	14	2954155.3	35503.4	282739.5	0.0061	100.87	327.4	157.4
Humic acid (HA)	3	49449160**	6912523.2**	3782162.9**	0.0059	2153.6**	8290.3**	209.8**
Y×HA	3	3616.6	1624.36	636.4	0.0001	0.321	0.547	0.304
I×HA	9	4687459.3**	396817.5	171122.9	0.0062*	158.9	525.4	116.4*
Y×HA×I	9	31884.3	4796.7	3223.602	0.00003	1.52	5.04	0.304
Error	48	1389822.7	367452.3	208997.8	0.0023	126.4	424.9	46.4
CV (%)		21.36	31.1	30.56	18.1	27.3	30.4	12.2

*, ** are respectively significant at levels of 5%, 1%

Table 5. Mean comparison of interaction effects for investigated traits under different treatments of irrigation and humic acid in peanut

Irrigation regime	Humic acid	Biomass yield (kg ha^{-1})	Harvest index	100-weight seed (g)
No irrigation	0	2453g	0.22ef	34.8c
	3 (lit ha^{-1})	2941fg	0.25b-f	35.7c
	6 (lit ha^{-1})	3090efg	0.19f	35.6c
	9 (lit ha^{-1})	4114def	0.29a-d	42.8c
60%	0	4512de	0.29a-d	67.7a
	3 (lit ha^{-1})	5256cd	0.25b-f	57.6b
	6 (lit ha^{-1})	5668bcd	0.24c-f	56.9b
	9 (lit ha^{-1})	6318bc	0.30abc	56.4b
80%	0	4670d	0.30abc	62.9ab
	3 (lit ha^{-1})	5341cd	0.32a	68.9a
	6 (lit ha^{-1})	7097b	0.26a-e	55.8b
	9 (lit ha^{-1})	9750a	0.27a-e	61.5ab
100%	0	4489de	0.31ab	69.2a
	3 (lit ha^{-1})	6416bc	0.23def	64.7ab
	6 (lit ha^{-1})	6622bc	0.29a-d	58.3b
	9 (lit ha^{-1})	9563a	0.26a-e	62.2ab

*Dissimilar letters indicate significant differences

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Pod yield

The results of the combined analysis of variance revealed the significant effect of irrigation and HA on pod yield at the $p < 0.01$ level (Table 4). Pod yield was 2426 and 2435 kg ha^{-1} at irrigation treatments of 80% and 100% of crop requirement, respectively, so they were categorized in the same statistical group. Among different levels of HA, the lowest and highest pod yields of 1453 and 2705.9 kg ha^{-1} were obtained from the HA rates of 0 and 9 L ha^{-1}, respectively (Table 6). By supplying nutrients for the plants and improving the physical, chemical, and biological characteristics of the soil, HA improves pod growth in peanuts. Pod yield of peanuts will decrease proportionally if they are exposed to drought during flowering.

Seed yield

The analysis of variance indicated that seed yield was significantly ($p < 0.01$) affected by irrigation and HA (Table 4). As it is evident in Table 5, the highest seed yield was observed in the plants irrigated with 80% of water requirement (1862 kg ha^{-1}) and those treated with 9 L ha^{-1} HA (2066.6 kg ha^{-1}). Water constraint and drought stress decrease leaf development, thereby reducing seed yield. Drought stress lessens yield severely depending on the cultivar (Wang *et al*., 2015).

Table 6. Mean comparison of investigated traits in peanut

Treatment	Pod yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Pod number per plant (pods)	Seed number per plant (seeds)
Irrigation regims				
No irrigation	1040c	804 b	22.8b	36.8b
60 %	1882b	1492a	42.8a	69.5a
80 %	2426a	1862a	49.4a	83.3a
100 %	2435a	1823a	49.6a	81.7a
Humic acid				
0	1453.1b	1152.4b	31.3c	49.1c
3 lit ha^{-1}	1748.3b	1342.4b	36.9bc	59.7bc
6 lit ha^{-1}	1877.8b	1421b	42.9b	69.9b
9 lit ha^{-1}	2705.9a	2066.6a	53.4a	92.6a

*Dissimilar letters indicate significant differences.

Harevest index

Based on the combined analysis of variance, the interactive effect of irrigation and HA was significant ($p < 0.05$) on the harvest index (Table 4). As is observed in Table 5, the highest harvest index of 0.32 was related to the plants irrigated with 80% of water requirement and treated by 3 L ha^{-1}. Lamb *et al.* (2017) state that the maximum harvest index is produced under full irrigation conditions. The vegetative and reproductive processes of plants vary with moisture management practices. The harvest index is not stable at different moisture levels, and the total biomass and seed yield of the plants are more sensitive to water stress than the harvest index.

Pod number per plant

According to the results of the combined analysis of variance, the effects of irrigation and HA were significant ($p < 0.01$) on the number of pods per plant (Table 4). The plants irrigated with 80% and 100% of water requirement produced the highest number of pods per plant, i.e., 49 and 50 pods, respectively (Table 6). Among the HA levels, the maximum number of pods per plant (53 pods) was obtained from the HA rate of 9 L ha^{-1}.

Seed number per plant

The results revealed that the effects of irrigation and HA were significant ($p < 0.01$) on seed number per plant (Table 4). The plants irrigated with 80% and 100% of water requirement produced 83 and 82 seeds per plant, respectively. Among the plants treated with HA, those treated with 9 L ha^{-1} HA produced the maximum number of seeds (93 seeds) per plant (Table 6).

100-seed weight

It was found by the combined analysis of variance that the interactive affects of irrigation and HA were significant ($p < 0.05$) on 100-seed weight (Table 4).

Hundred-seed weight was higher in irrigated conditions than in non-irrigated conditions. Among the interactions, the plants irrigated with 80% of water requirement and treated with 3 L ha^{-1} exhibited the highest 100-seed weight of 69 g (Table 5).

Discussion

Groundnut (Arachis hypogea), which is considered to be the 'King of Oilseeds', is an annual plant herb (legume) comes from the pea family of Fabaceae. The results showed that the effects of irrigation management and HA on many peanut traits were significant. Vorasoot *et al*., (2004) studied different irrigation conditions for peanuts and reported that biological yield was higher at full irrigation conditions than at water stress conditions. Peanut cultivars were studied under stress and irrigation conditions and it was found that biological yield was 34% lower at the stressful conditions than at the full irrigation conditions (Songsri *et al*., 2009). Water deficit at different peanut growth stages reduced photosynthesis and consequently limited leaf and stem number, resulting in a decline in biomass yield (Meena *et al*., 2012). It was reported that the application of HA enhanced biological yield, and the treatment of stress-exposed plants with HA inhibited their yield decline (Celik *et al*., 2010). HA enhances biological yield by increasing soil cation exchange capacity and improving water and nutrient uptake (Barzegar *et al.*, 2016; Davoodifard *et al*., 2010). In addition, HA reduces uptake of toxic elements form soil (Abootalebi Jahromi *et al.*, 2016) The seed filling period is the most critical period of peanut growth in terms of the water requirement (Songsri *et al*., 2009).

Since moisture is the key factor for the development of peanut pegs, moisture deficiency reduces peanut yield and decreases pod and seed weight if it happens during kernel and seed development. Drought impairs pod yield by prolonging the pod development period (Janila *et al*., 2013). The penetration of pegs into the soil and the formation of pods are influenced by soil dryness at the root zone, and this, in turn, reduces nutrient uptake by pods (Meena *et al*., 2012). Moisture deficiency decreased pod yield by 25% in peanuts (Vorasoot *et al*., 2004).

The maximum seed yield was obtained from the full irrigation conditions and the greatest decrease in peanut yield was associated with drought stress (Songsri *et al*., 2009). Research has shown that water stress reduces leaf area and subsequently yields (Lamb *et al*. 2017). A study on irrigation intervals of 1, 2, and 3 days indicated that the peanut yield was increased to the greatest extent at the irrigation interval of 1 day (El-Boraie *et al*., 2009). When HA is applied at a higher rate, increases happen in seed yield, which is a function of total dry matter yield. The application of HA ameliorates nutrient uptake and stress resistance (Abdzad Gohari and Sadeghipour, 2019). It can, therefore, be concluded that the application of HA can improve peanut growth under water stress conditions.

Vorasoot *et al*. (2004) investigated different peanut cultivars in water stress and no-stress conditions and reported that all cultivars experienced declines in harvest index upon exposure to water stress. Similarly, Songsri *et al*., (2009) reported that drought stress reduced the harvest index of different peanut cultivars. Mace *et al*., (2006) concluded that drought stress resulted in the loss of harvest index.

Vorasoot *et al*., (2004) studied peanut cultivars in water stress and no-stress conditions and concluded that pod number per plant at the physiological maturity stage was higher in all cultivars under no-stress conditions than under water stress conditions. Among the growth stages of peanuts, the availability of adequate moisture at the pod growth and development zone is necessary, and even the availability of moisture in the root zone cannot offset moisture deficiency in the pod development zone. When the soil is dry, peanut pegs cannot efficiently penetrate the soil; especially, four days after irrigation, the soil surface is very dry for peg penetration (Banavath *et al*., 2018). Thus, soil moisture at the pod development stage is a key factor for yield. HA binds to water molecules and largely hinders water evaporation. HA molecules that penetrate plant tissues bind to water molecules, thereby reducing transpiration and contributing to water retention inside the plant (Barzegar *et al*., 2018).

HA positively influences seed number per plant and crop quality by improving the synthesis of sugar, protein, and vitamins in plants (Barzegar *et al*., 2018). HA can reinforce photosynthesis, thereby improving growth and development, so it considerably influences the increase in seed number per plant, especially if it is applied before stress intensification (Banavath *et al*., 2018). Vorasoot *et al*., (2003) investigated peanut cultivars under both water stress and no-stress.

Conclusions

It can be inferred from the results that increasing the intensity of water stress reduces the studied traits. Water limitation and water stress reduce growth and consequently, yield. Peanut plants take up a lot of water to fill their seeds with water and nutrients, so the treatment of 80% of water requirement sufficed to meet the water demand of the peanuts due to increasing surface water and saturating soil pores with water, but the decline was greater in the plants irrigated with 60% of water requirement due to water deficiency. On the other hand, the plants irrigated with 100% of water requirement suffered from the decay of pods and seeds due to the increase in surface water and the saturation of soil pores with water, resulting in the loss of seed and pod yield. So, supplying 80% of the water requirement will increase peanut yield. Although drought stress reduced some studied traits, the foliar application of HA mitigated the negative impacts of water stress. HA increased flower number by improving nutrient uptake and developing vegetative and reproductive parts, which had a significant positive impact on biomass yield, seed yield, pod number per plant, and seed number per plant. The application of HA was effective in alleviating the negative impacts of water stress so that by increasing its dosage to 9 L ha^{-1}, the decline in yield and yield components can be inhibited. So, it is recommended to use this organic matter in drought and water stress conditions to cope with the stress, which would be consistent with the goals of sustainable agriculture. So, farmers are suggested to irrigate peanut plants with 80% of their water requirement and apply 9 L ha^{-1} HA.

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Conflict of interests

The authors declare that they do not have any conflict of interest.

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