Kurdistan Journal of Applied Research (KJAR)
Print-ISSN: 2411-7684 | Electronic-ISSN: 2411-7706

Original Article

Soybean (Glycine max L.) Yield and Yield component under different Planting Time and Foliar Application of Humic Acid

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Submitted: June 16, 2023
Revised: July 25, 2023
Accepted: August 5, 2023

10.24017/science.2023.2.1

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Keywords: Soybean, Cultivation Period, Foliar Application, Humic acid.

Abstract: The layout of the current research study was RCBD with three replications conducted at Bakrajo, Sulaimani, Kurdistan, with silty clay soil texture. The main objective of this research study was to demonstrate the effect of different rates of foliar humic acid (HAR) application and different planting times (PT) on soybean yield and yield components. Five different rates of foliar humic acid were applied once, including: (0 (as control), 2 g/L, 4 g/L, 6 g/L, and 8 g/L), along with two different planting times, PT 1 on May 15th, 2022, and PT 2 on June 1st, 2022. The foliar applications of HAR had a highly significant impact on the following parameters: Pod No. Plant-1, Empty Pod Plant-1, Grain Weight Plant-1(g), and Yield (kg ha-1), and a significant impact on the Thousand Grain Weight (g). However, the effect of planting time was highly significant only for Pod No. Plant-1 and had no significant effect on the other parameters, including Empty Pod Plant-1, Grain No. Pod-1, Thousand Grain Weight (g), Grain Weight Plant-1 (g), and Yield (kg ha-1). The highest values for Pod No Plant-1, Empty Pod Plant-1, Grain Weight Plant-1 (g), and Yield (kg ha-1), and significant values for the Thousand Grain Weight (g), were observed under the foliar application of 6 g/L HAR. Additionally, the best planting time for sowing soybeans was PT 1 on the 15th of May.

1. Introduction

The soybean legume grain [Glycine max (L.)] crop contains approximately 42 percent protein and 20 % oil. It is classified under the category of an oil grain crop in agronomy [1]. Soybean is known as a crop that is highly dependent by humans due to its rich nutrient content [2]. Soybean has been grown worldwide, with a large sowing area in India. The cultivated area with soybeans covers about 11.67 million hectares, producing 8.5 million tons (737 kg per hectare) [3]. Large-scale soybean production has seen a significant increase in interest over the past ten to twelve years. However, due to low-grade management techniques in general, and specifically the nutrition of the crop, soybean production and quality have been extremely low when compared to developed nations [4]. The frequent use of inorganic fertilizers, assuming they would increase plant growth without the addition of organic substances such as humic acid (HA) to the soil, has resulted in many significant ecological and socioeconomic problems [5]. One of the biggest environmental and social issues today, especially in developing nations, is the indiscriminate usage of pesticides and fertilizers, which has led to the contamination of food, soil, air, and water [6]. In addition to improving soil quality, soil organic matter also enhances crop productivity and improves the quality of food [7].

Furthermore, organic matter can gradually reduce the dependency on chemical fertilizers. Therefore, it is essential to reconsider our fertilization methods, giving priority to organic manure and amendments [8]. Although the use of bulky organic manures may require significant labor for transportation and application, their benefits are substantial [9].

In the long run, organic matter may reduce the demand for chemical fertilizers [10]. Therefore, the approach to fertilizing techniques needs to be rethought, placing greater emphasis on organic manure and amendments. While farmers have criticized the use of heavy organic manures and demands. While farmers have criticized the use of heavy organic manures due to labor demands, it is crucial to recognize their effectiveness as complex for adsorbing and retaining inorganic plant nutrients. This, in turn, enhances plant aeration, water permeability, and water-holding capacity, thereby improving the uptake, transportation, and availability of micronutrients [11].

Humic acid is one of the organic matters that affect a variety of systems, including enzyme activity, photosynthesis, protein synthesis, water and nutrient intake, membrane permeability, and cell respiration, thereby promoting plant growth, yield, and quality [12, 13]. Humic acid can improve the photosynthesis rate by enhancing gas exchange and electron transport flux in plants, even under stress conditions [14]. Organic fertilizers containing humic acid are widely used and can be applied to crops and soil to achieve the highest crop yield; it is important to maintain adequate soil humate content [15].

The application of humic acid in agricultural systems has generated debate due to its diverse effects on crop productivity and quality [16, 17]. As humic acid significantly influences plant growth and yield, the optimal time for planting soybeans varies depending on the region and its responsiveness to day length variations [18, 19]. Additionally, the impact of planting time on the yield of soybeans and other crops varies according to the cultivation region [20]. Late planting-related environmental factors have an impact on crop characteristics related to radiation absorption and resource allocation [21]. These factors lead to reduced vegetative growth, lower reproductive capacity, and shortened reproductive phases [22].

In the case of spring-sown single harvests of soybean, grain quantity becomes the primary yield factor affected by delayed planting. Consequently, production is particularly susceptible to nutrient and water shortages during late flowering and grain filling [23]. Reproductive growth is typically constrained under limited conditions, characterized by fewer days available for growth, reduced radiation, and colder temperatures, which occur when planting is delayed [24]. Previous research studies have indicated that soybean grain production is correlated with the timing of flowering, pod setting, and grain filling stages, with earlier sowing dates resulting in an extended vegetative growth period and higher productive [24, 25]. Furthermore, it has been observed that soybean grain yield decreases with later sowing dates after May 1st [26].

In a study conducted by Ort, et al. [27], it was discovered that a delayed sowing date had a negative impact on the development and growth of soybeans, particularly under unfavorable humidity conditions. In addition to cultivar earliness, water deficiency significantly affects soybean yields in Europe and other nations. A water deficit can substantially shorten both the vegetative and generative stages, thereby limiting the overall yield [28, 29].

To optimize yields, it is recommended to plant soybeans in Poland around the beginning of April or the beginning of May when the soil temperature is above 8°C [19, 30]. According to the results of a study, soybean grain production is strongly correlated with the timing of flowering, pod setting, and grain filling stages. An earlier sowing date results in an extended vegetative growth period and improved productivity [24, 25]. After May 1st, the soybean grain yield drops with a later sowing date [26].

In a study by Ort, et al. [27], it was discovered that a delayed sowing date had a negative impact on the development and growth of soybeans, particularly under unfavorable humidity circumstances. Additionally, the water deficit significantly affects soybean yields in Europe and other nations. A water deficit can substantially shorten both the vegetative and generative stages, thereby limiting overall yield [28, 29]. Therefore, it is recommended to plant soybeans in Poland around the beginning of April or the beginning of May when the soil temperature is above 8°C [19, 30].

Soybean production in the Iraq/Kurdistan region is declining, and there is a high demand for improved productivity of this essential crop through organic practices and optimal planting time. Planting time plays a crucial role in crop productivity, and in this area, there has been limited research on soybean. Therefore, this study was conducted to evaluate the impact of planting time and foliar application of humic acid (HA) on the yield and yield components of [Glycine max (L.)].

2. Materials and Methods

2.1. *Study location*

The location of this study was Bakrajo, Sulaimani, in the Kurdistan area of Iraq, situated at coordinates 35°32'52.8"N and 45°21'16.6"E, with silty clay soil. The study materials consisted of Soybean seeds of the variety Lee-74 and organic fertilizer (Humic Acid).

2.2. *Experimental Design and Treatments*

The experimental design used in the current study was a 3-replication factorial experiment designed in a Randomized Complete Block Design (RCBD). The size of each plot was (2.0m x 3.0m). The soybean seeds were not treated with Rhizobium bacteria inoculation since the soil's acidity (pH) at sowing was greater than 6. Before sowing, the seeds were immersed in water for eight hours. Two soybean seeds were planted in each hole, spaced 25 cm apart, at a depth of 5 cm. Irrigation was performed weekly from the start of sowing until harvesting, once a week. Pesticide HG-93179 Neem oil extract concentrate was used to manage pests and diseases. Spraying to protect the plants from pest assault began one week after planting and continued weekly for 60 days. Harvesting was accomplished by gently removing the plant's roots from the soil. The chemical properties and some elements concentration of Bakrajo Soil texture are demonstrated in table (1).

The treatments used in this study included one dose of foliar application of Humic Acid at five different rates: 0 g/L, 2 g/L, 4 g/L, 6 g/L, and 8 g/L). The second factor was the planting time (PT), with (PT 1) planted on May 15th, 2022, and (PT 2) planted on June 1st, 2022.The parameters observed in this study were Pod No. Plant-1, Empty Pod Plant-1, Grain No. Pod-1, Thousand Grain Weight (g), Grain Weight Plant-1 (g), and Yield (kg/ha-1). For the statistical analysis, the Statistical Analysis System (SAS) tool was used, and the treatment mean comparison was conducted using Fisher's Least Significant Differences (LSD) when the values of (F) were under ($P \leq 0.05$).

Table 1: Chemical Properties and Some Elements concentration of Bakrajo Soil texture.

Parameters	Amount
Acidity (pH)	7.2
Electrical conductivity (EC)	1.25 (mmhos/cm)
Nitrogen	0.27 (%)
Phosphor	2.99 (mgkg^{-}1)
Potassium (K)	233.29 (mgkg^{-}1)
Calcium(Ca)	4777.6 (mgkg^{-}1)
Magnesium (Mg)	218.3 (mgkg^{-}1)
Sodium (Na)	44.9 (mgkg^{-}1)
Iron (Fe)	7.9 (mgkg^{-}1)
Zinc (Zn)	1.5 (mgkg^{-}1)
Cupper (Cu)	1.6 (mgkg^{-}1)
Manganese (Mn)	31.9 (mgkg^{-}1)
Organic Matter	1.8 (%)

3. Results and Discussion

As shown in the ANOVA table 2, it is evident that the foliar use of HAR had a highly significant impact on pod number plant-1 (No. plant-1), empty pod number plant-1, grain weight plant-1 (g), and yield (kg ha-1). Additionally, it showed a significant impact on the thousand-grain weight (g). On the other hand, the PT had a highly significant effect only on Pod No. Plant-1 did not significantly affect other parameters, including empty pod number plant-1, grain number per pod, thousand-grain weight (g), grain weight plant-1 (g), and yield (kg ha-1). The interaction effects of HAR and PT were highly significant for pod number plant-1 (No. plant-1) and significant for yield (kg ha-1). However, they did not significantly affect other yield component parameters.

Table 2: The Analysis of variance (ANOVA) of Soybean *(Glycine max L.)* yield and yield component as influenced by HAR, PT and their interaction.

S.O.V.	MS						
	DF	Pod No. Plant^{-1}	Empty Pod Plant^{-1}	Grain No. Pod^{-1}	Thousand Grain Weight (g)	Grain Weight Plant^{-1} (g)	yield (kg ha^{-1})
Block	2	1050.7ns	21.127ns	0.700ns	570.519ns	38.249ns	115.057ns
HAR	4	23935.866**	139.223**	0617ns	1082.005*	1395.127**	5104.597**
PT	1	20176.133**	0.0853ns	0.833ns	987.280ns	72.075ns	344.763ns
HAR* PT	4	8365.1333**	5.051ns	0.083ns	570.519ns	11.173ns	633.569*
Error CV	18	17.29	30.16	27.63	14.96	29.89	5.62

*, ** and ns is significances at level P ≤ 0.05 as well as P ≤ 0.01 and non-significant respectively, S.O.V. stands for Source of Variance, DF stands for the Degree of Freedom, MS stands for the Mean Square and CV stands for coefficient of variation.

Table 3 displays the number of pods plant^{-1} (Pods Plant^{-1}). The data analysis revealed that HAR foliar application had a highly significant impact on the number of pods plant^{-1}. The highest number of pods plant^{-1} was observed with a foliar spray of HA at a rate of 6 g/L, followed by sprays of HA at rates of 8 g/L and 4 g/L, which showed equally effective results. Conversely, the lowest number of pods plant^{-1} was recorded in the control group.

The use of humic acid (HA) can be connected with its inherent potential to exert a remarkable positive influence, both directly and indirectly, on the growth of plants. This may explain the larger number of pods observed under HA treatment at a concentration of 6 g/L [31] [32]. Additionally, HA treatments promote microbial activity, which, in turn, accelerates the mineralization and solubilization of organic waste. This increase in nutrient content (both macro and micro) enhances their availability, thereby facilitating the rapid growth process in crops, as desired. The hormonal activity of HA also regulates the mechanism of endogenous hormones in plants, promoting, controlling, and fostering plant growth from embryo to reproductive development [32].

Similarly, in a study, it has been recorded that spraying of humic acid significantly enhanced the number of pods per mungbean [33]. The findings of this study are consistent with those of Shuixiu and Ruizhen [34], who showed that spring soybean plants produced considerably more pods when sprayed with organic fertilizer containing humic acid. Additionally, the results of this study align with an experiment conducted on barley, which reported that HA application increased soil moisture content, leading to a higher number of tillers in barley plants. Data analysis clearly illustrates that the number of empty pods in plant^{-1} was significantly impacted by the foliar application HAR (Table 2). As shown in table 3, the highest number of empty pods plant^{-1} was recorded in the control group (0 HA), while the lowest number of pods plant^{-1} was observed with a foliar application of 6 g/L HA. The occurrence of empty pods or grain abortion in plants could be attributed to various external factors [35].

Environmental conditions that restrict a plant's ability to meet its basic nutritional, water, and photosynthesis requirements may result in pod abortion during early pod development and early grain development stages, subsequently leading to an inhibition of grain fill beyond that [35]. Foliar application of HA enhanced grain production compared to the control where HA was not applied. The maximum number of grains per pod (No. of grains pod^{-1}) resulted from the application of 6 g/L HAR, followed by 8 g/L and 4 g/L HA treatments. However, the minimum number of grains per pod (1.8333) was recorded for the control group as shown in table 3. The increase in grain production per pod could be attributed to HA's indirect beneficial influence on chlorophyll concentration. An increase in chlorophyll concentration promotes photosynthetic activity, directing more photo-assimilates toward the grain sinks [32]. This effect has been observed in the majority of crop species, including Brassica raya, mustard, aerobic rice, and wheat [36].

Whether used alone or in conjunction with the recommended macronutrient full dose, the application of HA positively impacts grain quantity. Similar results were reported in a study conducted by Vanitha and Mohandass [37] on rice grain filling under aerobic conditions. The highest percentage of grain filling was achieved when HA was applied with the recommended complete nutrient dosage for subsurface irrigation. Furthermore, the results of the current study are consistent with a study conducted by Atak and Kaya [38] which reported an increase in the number of grains/ears in maize and wheat after applying HA, compared to the control group. Similarly, the increase in grain per pod in soybean aligns with the findings of a study by Ashraf, et al. [33], where Humate solution spraying was shown to enhance grain weight. Data from tables 2 and 3 present the thousand-grain weights and their respective mean comparisons. The foliar application of humic acid demonstrated highly significant effects on thousand-grain weights. Specifically, a foliar application of 6 g/L HA resulted in the highest thousand-grain weight, followed by an application rate of g/L HAR. The lowest thousand-grain weights were observed in the control group where no HA was applied. Several studies have demonstrated that the application of HA enhances root growth and establishment of crops [37, 39, 40].

This increase in root length, in response to HA application, enhances the uptake of macro and micronutrients. HA plays a role in increasing the permeability of cell membranes, which in turn improves the intake and storage of nutrients, especially nitrogen [39, 40]. Similar findings were reported by Solaiman, et al. [41], where nitrogen application significantly increased the thousand weights of grains and other plant development indicators in chickpeas. Furthermore, HA has been found to enhance the absorption of various macro- and micronutrients such as P, K, Ca, Mg, Fe, and Zn [39, 40]. Thenmozhi, et al. [42] also reported similar results, showing that the application of humic acid led to the maximum hundred kernel weight in groundnut.

As shown in table 2, there was a highly significant impact of HA on the grain weight of Plant-1. Foliar application of HA had a highly significant impact on the yield (kg ha-1). The highest yield was achieved with a foliar application of HAR at 6 g/L, followed by 8 g/L, while the lowest grain yield was recorded in the control group (table 3). The increase in yield observed in this study was consistent with the findings of Khan and Mir [36]; and Thenmozhi, et al. [42], who suggested using HA to enhance grain yield in various crop species, including barley, wheat, peanuts, aerobic rice, mustered, and Brassica raya. Moreover, higher yield components within the same plots may have contributed to the higher grain yield in the plots treated with humic acid. The results of this study also align with previous research outcomes, indicating that HA alone enhances grain output [43, 44]. The increase in soybean yield with an optimum rate of HA is in accordance with the findings of a study conducted by Odeleye, et al. [45], where foliar application of HA led to an enhanced yield of soybean. According to the results of the current study, it is evident that the optimum foliar usage rate of HA is 6 g/L, further increases in HA application led to a decline in soybean yield and yield components.

Table 3: Soybean **(*Glycine max L.*)** Yield and yield component as affected by HAR.

HAR (g/L)	**Parameters**					
	Pod No. Plant^{-1}	**Empty Pod Plant^{-1}**	**Grain No. Pod^{-1}**	**Thousand Grain Weight (g)**	**Grain Weight Plant^{-1} (g)**	**yield (kg ha^{-1})**
HAR (0 as control)	77.1667	13.015	1.8333	102.59	25.3833	143.87
HAR (2 g/L)	103.17	8.1517	2.1667	117.53	28.45	173.37
HAR (4 g/L)	134.5	4.1217	2.5	112.64	34.8	169.7
HAR (6 g/L)	224.83	1.3933	2.6667	136.79	63.8667	222.8
HAR (8 g/L)	201.33	2.195	2.3333	106.01	37.3833	164.12
L.S.D. 5%	31.09	2.11	0.77	20.89	13.77	11.92

On the other side, the impact of PT was significant for pod No. plant-1, while it did not significantly affect other parameters, including empty pod plant-1, grain No. pod-1, thousand-grain weight (g), grain weight plant^{-1} (g), and yield (kg ha^{-1}) (table 2). As observed in table 4, the highest pod No. plant^{-1} was recorded in PT 1, and the lowest was in PT 2. The maximum empty pod plant^{-1}, grain No. pod-1, thousand-grain weight (g), grain weight plant^{-1} (g), and yield (kg ha^{-1}) were 5.8287, 2.4667, 120.85, 39.5267, and 178.16, respectively. Planting time (PT) affects soybean growth and yield, and the optimal planting time varies depending on the region and day length [18, 19]. The flowering period, pod setting, and grain-filling stages are positively correlated with yield, and an earlier planting date results in a longer growth period (vegetative and generative) [24, 25]. Delaying the sowing date after the 1st of May has been reported to increase soybean grain yield [26]. Ort, et al. [27] found that a delayed sowing date adversely affected soybean growth and development, particularly under unfavorable humidity circumstances. Water deficit, in addition to cultivar earliness, also significantly impacts soybean yields in Europe, as in other regions. Water deficit shortens both the vegetative and productive stages, leading to lower yields [28, 29]. Considering the country's climate circumstances, it is recommended to plant soybeans at the beginning of April or the beginning of May when the soil temperature is higher than 8 °C [19, 30].

Table 4: Soybean **(*Glycine max*)** Yield and yield component as effected by PT.

PT	Parameters					
	Pod No. Plant^{-1}	**Empty Pod Plant^{-1}**	**Grain No. Pod^{-1}**	**Thousand Grain Weight (g)**	**Grain Weight Plant^{-1} (g)**	**yield (kg ha^{-1})**
PT 1	174.13	5.8287	2.4667	120.85	39.5267	178.16
PT 2	122.27	5.722	2.1333	109.37	36.4267	171.38
L.S.D. 5%	19.67	1.34	0.48	13.21	8.71	7.54

4. Conclusions

The use of HA in agricultural systems has generated debate, partly due to the diverse effects it has on crop productivity and quality. According to the results of the current study, it is evident that the optimum rate of HA foliar application is 6 g/L. Raising the humic acid rate beyond this level led to a decrease in the yield and yield component of soybean. Determining the best planting time is crucial, as it significantly impacts plant growth and yield, and varies according to climatic changes and the response of different varieties to the length of the day. Based on the findings, the best period for cultivating soybean with humic acid was on 15 May, which resulted in the maximum yield and yield components compared to planting soybean at a later period. However, it's essential to note that the best planting time may differ depending on the specific needs and conditions of each agricultural system.

Data availability: Data will be made available on request.

Conflicts of interest: The authors declare that they have no known Competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding: The authors did not receive support from any organization for the submitted work.

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