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Influence of Auxin Application and Row Spacing on Growth Performance and Industrial Yield of Soybean

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ABSTRACT

To investigate the effect of spraying with indole acetic acid and the row spacing, a field experiment was carried out during the summer 2024 at the Field Crops Research Station, Tikrit University. Four concentrations of Indole Acetic Acid (IAA) (zero, 150, 300, and 450 ppm) were applied when the plants reached 35 days after planting and four row spacing (30-30, 30-60, 60-60, and 75-75 cm) were used. The experiment was applied according to RCBD design and average were tested according to Duncan test. The results showed that the 300 ppm of IAA increased the branches number per plant (9.02 branches plant^{-1}), the 100 seeds weight (16.04 g), yield (1.50 tons ha^{-1}), and the yield oil (329.59 kg ha^{-1}). The row spacing 75-75 cm recorded the highest averages in the branch number per plant (9.73 branch plant^{-1}), and the 100 seeds weight (16.89 g) while 60-60 cm was the highest in nodes number (11.79 node plant^{-1}). The interaction between IAA and row spacing affected significantly most of soybean traits. The interaction 300×75-75 was significantly higher 100 seeds weight (18.38 g) while the interaction 150×60-60 was significantly higher in nodes number (13.13 nod plant^{-1}), and the interaction 450×30-30 was the highest in the yield oil (416.64 kg ha^{-1}). The result outcomes will be benefitting the industrial and agronomic soybean community.

KEYWORDS: Soybean; Growth; Row Spacing; Auxin; IAA.

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تأثير تطبيق الأوكسين والمسافة بين الصفوف في الأداء النموي والحاصل الصناعي لفول الصويا

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الملخص

لتحقيق دراسة تأثير الرش بحامض الأندول أسيتيك **(IAA)** والمسافة بين الصفوف، أُجريت تجربة حقلية خلال صيف عام 2024 في محطة أبحاث المحاصيل الحقلية، جامعة تكريت. استُخدمت أربعة تراكيز من حامض الأندول أسيتيك (0، 150، 300، و450 جزء في المليون) عند عمر 35 يومًا من الزراعة، مع أربع مسافات بين الصفوف (30-30، 30-60، 60-60، و75-75 سم). نُفذت التجربة وفق تصميم القطاعات العشوائية الكاملة**(RCBD)** ، وقورنت المتوسطات باستخدام اختبار دنكن.
أظهرت النتائج أن تركيز 300 جزء في المليون من حامض الأندول أسيتيك أدى إلى زيادة عدد الأفرع في النبات (9.02 فرع نبات$^{-1}$)، ووزن 100 بذرة (16.04 غم)، وحاصل البذور (1.50 طن هكتار$^{-1}$)، وحاصل الزيت (329.59 كغم هكتار$^{-1}$). كما سجلت المسافة بين الصفوف 75-75 سم أعلى المتوسطات في عدد الأفرع للنبات (9.73 فرع نبات$^{-1}$) ووزن 100 بذرة (16.89 غم)، بينما كانت المسافة 60-60 سم الأعلى في عدد العقد للنبات (11.79 عقدة نبات$^{-1}$).
أثر التداخل بين حامض الأندول أسيتيك والمسافة بين الصفوف معنوياً في معظم صفات فول الصويا، إذ سجل التداخل 300×75-75 أعلى قيمة لوزن 100 بذرة (18.38 غم)، بينما سجل التداخل 150×60-60 أعلى عدد للعقد (13.13 عقدة نبات$^{-1}$)، وسجل التداخل 450×30-30 أعلى حاصل زيت (416.64 كغم هكتار$^{-1}$). تشير نتائج الدراسة إلى إمكانية الاستفادة من هذه النتائج في تحسين الإنتاج الصناعي والزراعي لفول الصويا.
الكلمات المفتاحية: فول الصويا، النمو؛ المسافة بين الصفوف؛ الأوكسين؛ حامض الأندول أسيتيك**(IAA)** .

INTRODUCTION

The soybean crop is *Glycine max* L. One of the industrial economic crops with high nutritional value. Its seeds contain a high protein content ranging from 30 to 50% and 14 to 24% oil. In addition, it contains essential amino acids and unsaturated acids, as well as some important vitamin (Vahedi, 2011). The protein percentage is one of the important qualitative qualities that determine the reason for which the crop is grown and used in industrial. Moreover, it improves soil properties and increases its fertility due to its ability to stabilize atmospheric nitrogen, which makes it an important crop in the agricultural cycle in conjunction with soil-stressed crops, thus benefiting the main crop of Nigella (Mirriam et al.,2022), and the economic importance of this crop has expanded its cultivation areas globally, as the global production of soybeans reached 378.16 million tons m², where three countries take over 81% of the world production of soybeans, including Brazil at 39%, then the United States at 29%, then Argentina at 12% (USDA, 2024). As for growth regulators, they are natural or artificial substances that play important roles in the development of plant growth, have significant have significant effects on physiological processes even when used in low concentrations, and whose importance is to improve and inhibit growth based on the plant's need (Negi et al., 2024).

Auxins improve physiological functions through their direct effect on the plant (Davies, 2010; Rademacher, 2015). Among the auxins, indoleacetic acid is a hormone characterized by the simplicity of its chemical structure, so it is considered the most available and has great physiological functions (Grossmann, 2010). It controls most of the processes of plant growth and development, including metabolism, transport, and biosynthesis. In addition, it plays a role in the emergence of axillary buds, the growth of stems, ground and photosynthetic alignments, root growth, and other processes (Rozov et al., 2013; Zhao et al., 2013). While the row spacing is important in regulating the geometric shape and biomass of the crop and increasing yield, besides reducing production costs with low seed densities (Ribeiro et al., 2017), Therefore, this study was aimed to find out the impact of the application of auxin (IAA) and row spacing on the growth and industrials productivity of soybeans.

MATERIALS AND METHODS

The experiment was carried out at the Field Crops Research Station, Tikrit university, located at a longitude of 43.679° East and latitude of 34.616° North. Random samples were taken from the soil of the field before planting and at a depth of 0.3 m to analysis soil physical and chemical qualities (table 1). The experiment was applied according to RCB Design with three replications. Auxin (IAA) was sprying on soybean leaves 35 days after planting (0, 150, 300, and 450 ppm) and four row spacing included 30-30, 30-60, 60-60, and 75-75 cm on the growth and productivity of soybeans. The area of each experimental unit was 3×3 m, and 48 experimental units were used. The experiment was prepared by plowing it with a comb plow. And then divided according to the design used into 3 sectors, and each sector contains 16 experimental units. In each experimental unit, there are a number of lines. The experiment irrigated as need by dripping irrigation system.

Table 1. Chemical and physical properties of the experimental soil

Properties*	Value
Clay	235 g kg^{-1}
Sand	475 g kg^{-1}
Silt	290 g kg^{-1}
PH	7.52 g kg^{-1}
EC	3.20 ds m
Soil Texture	Sandy loam
Lamest	224 g kg^{-1}
Gypsum	57.7 g kg^{-1}
Phosphorus	6.92 mg kg^{-1}
Nitrogen	20.6ml kg^{-1}
Potassium	107.33 mg kg^{-1}
Organic Matter	0.54 mg kg^{-1}

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The seeds were sown on June 11, 2024 by placing 3 to 4 soybean seeds at a depth of 3 cm and cover with soil. Then the field was lightly irrigated immediately after planting according to the plant's need for the all the growth and development period, and then phosphate fertilizer was added (triple superphosphate (P2O5) by 200 kg ha^{-1}) before the planting date where half of the nitrogen fertilizers (urea 46% N) was added before planting and the other half added when the plants reached 4 true leaves (V4) on the main stem. The thinning process was carried out to one plant per round in the third stage of vegetative growth, and insect control was applied regularly throughout the growing season .

Two factors were used in this experiment, First, row spacing, which included four treatment that illustrated in table 2 .

Table 2. Row spacing and the plant densities accordingly.

Row Spacing treatments	Number of rows in each experiment unit	distance between rows	Number of plants per ha
D1	9	30-30	450000
D2	7	60-30	350000
D3	5	60-60	250000
D4	4	75-75	166666

The second factor was spraying soybean plants with auxin (IAA). Using four concentrations of auxin in the experiment, (compare (distilled water), 150, 300 and 450 ppm of growth regulator were used, dissolving 0.75, 1.5 and 2.25 mg, respectively, in 5 ml of alcohol (ethanol) to facilitate dissolution, then dilute the solutions with distilled water by adding half a liter of water, after that, a 5-liter manual sprayer is used to spray the plants until the stage of complete wetting, spraying was carried out 35 days after planting. The number of nodes on the main stem (nodes plant^{-1}) was calculated from the first node on the main stem and close to the soil surface to the last node in the plant for five plants from each experimental unit and selected randomly. The branch number (branch plant^{-1}) was calculated at the harvest time from random plants. The100 seeds weight (g) was calculated by taken 100 seeds randomly from the experiment unit yield and measured. Soybean yield (ton ha^{-1}) was calculated by taken the average of plant yield and multiplied by the number of plants per hectare. Oil yield (kg ha^{-1}) was obtained by multiplying the seed yield by the percentage of oil. The experiment data was analyzed using SAS program (SAS Institute Inc.) and the averages were compared using Duncan test.

RESULTS AND DISCUSSION

Nodes Number:

Spraying using the auxin growth regulator IAA significantly affected the nodes number on the main stem, as table 3 showed that the use of a concentration of 150 ppm contributed to a significant increase in the nodes number on the main stem to reach 12.10 nod plant^{-1} while the control (0 ppm) treatment was less significant in the nodes number trait and reach 10.77 nod plant^{-1} (table 3). Auxin, such as IAA, plays an important role in stimulating the formation of nodes, as it is associated with the different hormone that regulates cell growth and tissue differentiation, especially in the peripheral growth zones and the market, as well, auxin promotes cell elongation and helps in the formation of buds and nodes by stimulating cell division and differentiation, which leads to an increase in the number of nodes on the stem (Khan et al., 2021). Auxin also regulates the balance of other phytohormones that affect branching and ganglion formation (Amoanimaa-Dede et al., 2022).

The effect of the row spacing significant impact on the quality of the number of nodes on the main leg, as between table3, the distance exceeded 60-60 cm (11.79 node plant^{-1}), 75-75 cm (11.55 node plant^{-1}), and 30-30 cm (11.60 node plant^{-1}) significantly compared to the row spacing 30-60 cm, which decreased significantly compared to the rest of the treatments (63.10 node plant^{-1}). This decrease in the treatment of 30-60 cm may be due to the fact that the distribution may be unbalanced for the distances between plants within rows compared to between rows, which leads to a disparity in plant crowding and negatively affects the regularity of longitudinal growth, and this disparity in distribution may impair the efficiency of absorption of light and nutrients, which is reflected in the structural activity of the growing top and reduces the number of nodes formed, similar results obtained by Basso et al. (2021). The overlap between IAA and the distance between the lines affected the number of nodes on the main stem, as the overlap was 60-60×150, the highest was significant, with a number of nodes amounting to 13.13 node plant^{-1} while the interaction 60-30×300 was the lowest number of nodes on the main stem, and it reached 9.30 node plant^{-1}, due to the fact that IAA has a property that during its control, vascular tissue growth, cell elongation, increased grain growth, and then increased crop production (Wang et al., 2025).

Table 3. The effect of sprying IAA, row spacing, and their interaction on nodes number (nod plant^{-1})

Row spacing (cm)	**Auxin concentrations (ppm)**				**Row spacing average**
	0	**150**	**300**	**450**	
30-30	10.66 def	12.00 b-f	11.00 a-e	12.76 abc	11.60 a
30-60	10.83 c-f	10.43 e f	9. 30 f	11.96 a-e	10.63 b
60-60	10.50 ef	13.1 3 a	12.5 3 a-d	11.00 b-f	11.79 a
75-75	11.10 b-f	12.86ab	10.76 def	11.50 a-e	11.55 a
Auxin average	10.77 c	12.10a	10.90 bc	11.80 ab	

Number of branches in the plant

The spraying treatment with IAA at a concentration of 300 ppm excelled in giving the highest rate of branches in the plant, reaching 9.02 branch plant^{-1}, and did not differ significantly from spraying at a concentration of 450 ppm (8.55 branch plant^{-1}), while the spraying treatments with IAA at concentrations of 0 and 150 ppm (8.07 and 8.09, branch plant^{-1} respectively) were the least significant (table 4), which indicates that the average concentration of IAA was the most effective in stimulation of branching, possibly by encouraging the growth of lateral shoots and increasing the rate of cell division (Nourin et al., 2024, and Negi et al., 2023). Table 4 showed the effect of spraying with IAA acid and the distances between the lines in the number of branches per plant in the soybean crop. The results indicate that there are significant differences between the coefficients in terms of the effect of distances and IAA concentrations, as well as the averages of interaction between them.

The results showed that the distance between the lines of 75-75 cm surpassed the highest average number of branches of 9.73 branch plant^{-1}, with a significant difference from the rest of the distances, reflecting the effect of large spacing in reducing crowding between plants and improving growing conditions in terms of lighting, ventilation, and nutrition, thus stimulating branching. While the row spacing 60-60 cm recorded the lowest average number of branches, amounting to 7.77 branch plant^{-1}, this decreased may be attributed to an increase in plant density that led to mutual shading and higher competition for resources, which negatively affected the adventitious growth of plants (Chavhan et al., 2024, and al-Jubouri, 2024). The interactions between IAA and row spacing did not record a significant effect on the number of branches on the main leg, as the differences were below the level of significance.

Table 4. The effect of sprying IAA, row spacing, and their interaction on number of branch (branch plant^{-1})

Row spacing (cm)	**Auxin concentrations (ppm)**				**Row spacing average**
	0	**150**	**300**	**450**	
30-30	7.66 a	7.33 a	8.66 a	8.20 a	7.96 b
30-60	7.66 a	8.06 a	9.26 a	8.06 a	8.26 b
60-60	7.10 a	7.43 a	8.16 a	8.40 a	7.77 c
75-75	9.86 a	9.53 a	10.00 a	9.53 a	9.73 a
Auxin average	7.66 a	7.33 a	8.66 a	8.20 a	7.96 b

The 100 Seeds Weight

The results of table 5 showed that both spraying with indole-acetic acid (IAA) and the row spacing had a significant effect on the weight of 100 seeds. Spraying with a concentration of 300 ppm recorded the highest average weight of 100 seeds of 16.04 g and was significantly superior to the concentrations of 0 and 150 ppm, while the treatment with a concentration of 450 ppm did not differ significantly from the concentration of 300 ppm. This suggests that spraying with IAA at a concentration of 300 ppm stimulates the accumulation of nutrients in the seeds and increases the efficiency of transfer from leaves to grains during the fullness phase, but the increase in concentration to 450 ppm did not lead to additional improvement, which may indicate an optimal limit of auxin concentration that should not be exceeded to avoid negative or inhibitory effects (Kikon et al., 2024). In terms of the effect of the row spacing, the widest distance (75-75 cm) recorded the highest average weight of 100 seeds of 16.89 g and morally outperformed the rest of the distances, while the narrowest distance (30-30 cm) recorded the lowest average of 13.37g. This difference is due to the fact that the increased spacing between the lines reduced competition between plants, which led to improved photo distribution, aeration, increased efficiency of photosynthesis, and accumulation of carbohydrate substances, which is positively reflected in the fullness and weight gain of cereals (Sodangi, 2024, and Jańczak-Pieniążek et al., 2021). As for the interactions of factors, the 75-75× 300 interference was significantly superior to all other interferences; the highest value was recorded for the weight of 100 seeds, amounting to 18.38 g, followed by the 75-75× 450 interference, weighing 17.83 g, and then the interactions 60-60×0, weighing 16.24 g. While the lowest values were recorded at the interaction of 30-30 ×0 with a weight of 11.56 g. This clearly demonstrates the positive cumulative effect of expanding the distance between the lines and using an appropriate concentration of IAA in improving the growth of grains and the accumulation of dry matter in them.

Table 5. The effect of sprying IAA, row spacing, and their interaction on 100 seed weight (g).

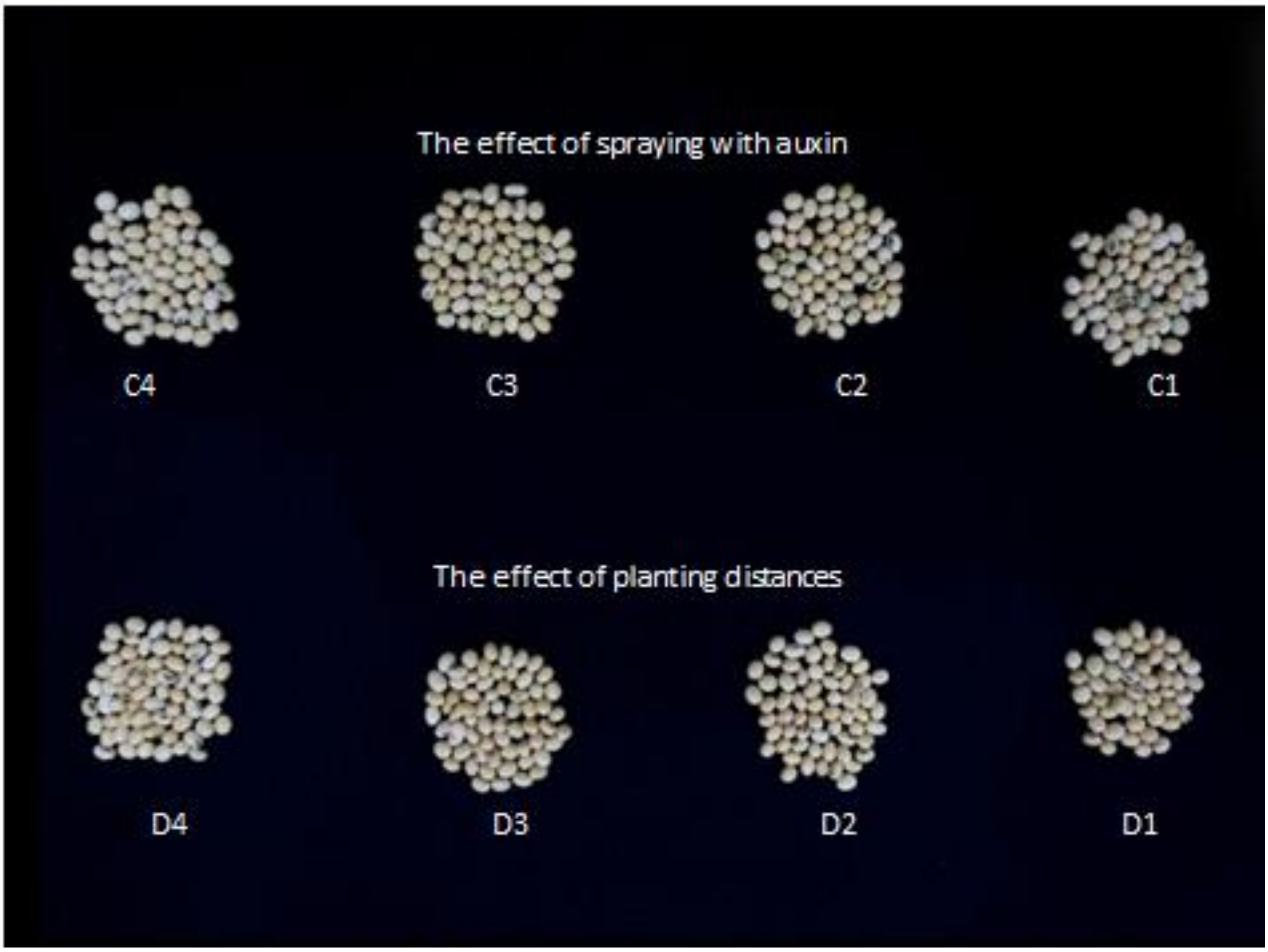
Row spacing (cm)	**Auxin concentrations (ppm)**				**Row spacing average**
	0	**150**	**300**	**450**	
30-30	11.56 g	13.17 f	14.53e	14.23 e	13.37 d
30-60	14.98 cde	14.86 ed	15.43 bcd	15.11 cde	15.09 c
60-60	16.24 b	14.89 ed	15.84 bc	15.81 cb	15.69 b
75-75	15.57 bcd	15.80 cb	18.38 a	17.83 a	16.89 a
Auxin average	14.59 b	14.68 b	16.04 a	15.74 a	

Plant Yield

The results presented in table 6 showed that both the row spacing and the concentration of spraying with auxin had a significant impact on the yield of soybeans to varying degrees. Spraying plants with IAA at concentrations of 300 and 450 ppm showed the best results (1.50 and 1.49 tons ha^{-1}, respectively) compared to lower concentrations or no spraying, which was the least significant with a yield of 1.33 tons ha^{-1}, indicating the role of auxin in improving plant growth and promoting photosynthesis and the development pods and seeds, which positively affects the overall yield (Kikon et al., 2024). The IAA effected may also be related to improving the distribution of plant resources and increasing the efficiency of their utilization, which increases crop productivity at leaf area (Nader et al., 2024, and Nahid et al., 2024). Table 6 showed the effect of row spacing on the yield of the crop by the presence of significant differences between different distances. Narrow distances such as 30-30 cm were the most productive and significant compared to other distances, with a total yield of 1.83 tons ha^{-1} while the row spacing 75-75 cm was the lowest in productivity per unit area, with a total yield of 0.89 tons ha^{-1}. This was due to the increase in the number of plants per area with a decrease in the distance between the lines, which increases the total number of plants and thus the total quotient, although the weight of an individual plant may be less when narrow row spacing. This was consistent with the concept of plant density, where planting density directly affects the total yield of the crop (Bortoli et al., 2021, and Chețan et al., 2021). The results in table 6 also showed a positive interaction between the row spacing and the concentration of IAA, as the interactions exceeded 30-30×300 significantly with the highest yield per area of 1.88 tons ha^{-1} and did not differ significantly from the interactions of 30-30×150 (1.81 tons ha^{-1}), 30-30×450 (1.87 tons ha^{-1}), 30-60×150 (1.82 tons ha^{-1}), 30-60×300 (1.81 tons ha^{-1}), and 30-60×450 (1.78 tons ha^{-1}), while the 75-75×0 and 75-75×150 interaction were the least significant with a yield of 0.73 and 0.81 ton ha^{-1}, respectively.

Table 6. The effect of sprying IAA, row spacing, and their interaction on yield (ton ha^{-1})

Row spacing (cm)	**Auxin concentrations (ppm)**				**Row spacing average**
	0	**150**	**300**	**450**	
30-30	1.74 b	1.81 ab	1.88 a	1.87 a	1.83 a
30-60	1.62 c	1.82 ab	1.81 ab	1.78 ab	1.75 b
60-60	1.24 d	1.33 d	1.27 d	1.32 d	1.29 c
75-75	0.73 f	0.81 f	1.06 e	0.98 e	0.89 d
Auxin average	1.33 c	1.44 b	1.50 a	1.49 ab	



An image showing 10% of plant yield that affected by IAA concentrations and row spacing

Oil yield

Spraying with a concentration of 300 ppm of IAA showed the highest average oil yield and amounted to 329.59 kg ha^{-1}, and did not differ significantly from the concentration of 450 ppm (324.50 kg ha^{-1}), which confirms that both concentrations were more effective in enhancing the total oil content in the crop compared to the concentration of 0 ppm (286.99 kg ha^{-1}), which was the least significant (table7), reflecting the positive effect of IAA in enhancing nutritional factors associated with the synthesis of oils in seeds, especially at medium to high concentrations (Kumar et al., 2021). As for the distances between the lines, the row spacing 30-30 cm (390.85 kg ha^{-1}) was significantly superior to the rest of the row spacing while the row spacing 75-75 cm recorded the lowest oil yield (196.21 kg ha^{-1}), which clearly indicates the importance of high plant density in enhancing oil production in soybeans (Jarecki and Bobrecka-Jamro, 2021). The results in table 7 showed that the effect of interactions was significant between spraying with IAA and the distance between row spacing, as the interactions exceeded 30-30×450 significantly with the highest oil yield of 416.64 kg ha^{-1} and did not differ significantly from the interaction 30-30×300, which gave 400.17 kg ha^{-1} while the interaction 75-75×0 decreased significantly with the lowest oil yield, reaching 155.98 kg ha^{-1}.

Table 7. The effect of sprying IAA, row spacing, and their interaction on oil yield (kg ha^{-1})

Row spacing (cm)	**Auxin concentrations (ppm)**				**Row spacing average**
	0	**150**	**300**	**450**	
30-30	364.82 cd	381.76 bc	400.17 ab	416.64 a	390.85 a
30-60	352.02 d	395.43 ab	381.63 bc	375.99 bcd	376.27 b
60-60	275.15 e	295.80e	296.07 e	290.93 e	289.49 c
75-75	155.98 h	173.94 h	240.49 f	214.43 g	196.21 d
Auxin average	286.99 c	311.73 b	329.59 a	324.50 a	

CONCLUSIONS

Spraying with auxin growth regulator (IAA) at a concentration of 300 ppm showed a clear superiority in a number of physiological and morphological qualities of the soybean crop, including: number of nodes, number of branches, weight of 100 seeds, oil yield, and yield. The row spacing had a significant effect on most of the studied traits, indicating the importance of plant distribution in improving growth and production. While the interactions between the row spacing of 75-75 cm and the concentration of 300 ppm showed superiority in many quantitative and qualitative qualities.

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