Research Article

Effect of Planting Density and Rhizospheric Administration of Humic Acid on Growth and Yield Parameters of Potato (*Solanum tuberosum* L.)

Ali Amer Dahham[1] , Aws Jawad Kadhim[2] , Ali Ibadi Manea[2],and Sarmad Salim Ali[2]

[1]*Department of Horticulture, College of Agriculture, University of Al-Qadisiyah, Diwanyah - Iraq;* [2]*Department of Horticulture, College of Agriculture, University of Karbala, Iraq.*

Abstract | Optimization of planting geometry and supplementation with biostimulants can significantly enhance the growth and yield of the potato crop. This *in-situ* experiment aimed to investigate the effect of planting distance and humic acid application on the growth and yield of the potato crop. Treatments included two planting distances, *i.e.,* 25 and 35 cm, and three humic acid concentrations, *i.e.,* 0, 5, and 10 g L^{-1}. The results demonstrated a significant effect of both factors (planting distance and humic acid) on most of the vegetative and quantitative traits of the potato plants. The distance of 35 cm resulted in the highest values for average number of leaves and tubers per plant and total per plant yield and total marketable yield, which were 33.4 leaves $plant^{-1}$, 5.31 tubers $plant^{-1}$, 416 kg $plant^{-1}$, 363 kg $plant^{-1}$, 16.64 tons ha^{-1}, and 14.51 tons ha^{-1}, respectively. The humic acid administration @ 5 g L^{-1} resulted in the highest values of the number of branches and leaves per plant, *i.e.,* 2.53 and 32.1 leaves $plant^{-1}$, respectively, as compared to the control. Similarly, the concentration of 10 g L^{-1} significantly increased the average number of tubers per plant, 5.27 tubers $plant^{-1}$. Moreover, the interaction of both factors, particularly of 35 cm planting distance and humic acid application @ 5 and 10 g L^{-1}), exhibited a significant increase in most vegetative and quantitative traits of the potato plants. These results, in general, suggest that maintaining plants at wider distances along with the rhizospheric administration of humic acid can be considered to enhance the vegetative and yield parameters of the potato crop.

Received | April 27, 2025; **Accepted** | May 20, 2025; **Published** | July 24, 2025
***Correspondence** | Ali Amer Dahham, College of Agriculture, University of Al-Qadisiyah, Diwanyah - Iraq; **Email:** ali76@agre.uoqasim.edu.iq
Citation | Dahham, A.A., A.J. Kadhim, A.I. Manea and S.S. Ali. 2025. Effect of Planting density and rhizospheric administration of humic acid on growth and yield parameters of potato (*Solanum tuberosum* L.). *Sarhad Journal of Agriculture,* 41(3): 1206-1213.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.3.1206.1213
Keywords | Potato production, Planting distance, Biostimulant, Humic acid, Plant growth traits, Potato yield parameters

Introduction

Potato, *Solanum tuberosum* L., belongs to the family *Solanaceae* and is one of the main perennial herbaceous vegetables serving as the staple food for billions of people worldwide, including Iraq (Al-Sharifi *et al.*, 2020; Mishra *et al.*, 2024). Potatoes constitute the daily food for more than 80% of the world population and are a key source of carbohydrates, proteins, and other nutrients. It is a rich source of vitamins and minerals (Navarre *et al.*, 2009). Potato is an important economic crop worldwide, and ranks at fourth after wheat, rice, and maize. Its global production exceeds 300 million tons per annum, while its production and area under potato cultivation in Iraq is about 300 thousand tons and 18780 hectares, respectively (Abed and Ahmed, 2023; FAO, 2024).

The cultivation and productivity of any agricultural crop including potato are affected by the mechanical treatments such as planting method, planting depth, and planting distance. Planting distance have a significant impact on all crop growth traits. According to the literature, the potato yield was obtained with greater plant to plant distance as it provides ample space for root spread, vegetative growth and tubers development of potatoes (Chehaibi *et al*., 2013; Al-Sharifi *et al*., 2021; van Dijk *et al*., 2022). Plant to plant and row to row distances play a vital role in the production of tuber crops. Narrowing these distances to get higher plant density results into increased competition (for water, light, and nutrients) between the crop plants, leading to the poor growth and development and the accumulation of dry matter, which leads to poor crop production (Pandey *et al*., 2015). Planting distance has a significant impact on the economically important traits such as tuber size, tuber quality, and total yield. It significantly affects the growth, plant height, tuber size, and yield of potatoes (Nxumalo *et al*., 2020; Regasa *et al*., 2022; Abewoy, 2024).

Moreover, the productivity of crops and their vegetative and productive traits are greatly influenced by the physical characteristics of the field soils (Vaičys and Mažvila, 2009; Khalouf *et al*., 2019; Sainju *et al*., 2022). Improving the soil chemical and physical characteristics exert a positive impact on the growth traits of potato crop (Setiyo *et al*., 2016; Al-Sharifi *et al*., 2021; Wang *et al*., 2022). One of way to improve the soil physico-chemical properties is the amendments and supplementation of soil profiles with biofertilizers and bio-stimulants (Mahapatra *et al*., 2022; Chaudhari *et al*., 2023; El-Shaieny *et al*., 2023; Rajesaheb *et al*., 2025). A variety of biofertilizers and bio-stimulants have been shown to enhance potato growth traits, and tuber yield both in terms of quantity and quality (Jardin, 2015; Mohaseb *et al*., 2018; Gleń-Karolczyk *et al*., 2022; Karak *et al*., 2023; Zarzecka and Gugał, 2024).

Humic acid is one of the organic bio-stimulants used to stimulate plant growth and improve crop production (Baligah *et al*., 2022). Humic acid administration instead of chemical fertilizers has many advantages for agricultural crops such as it increases the nutrient supply, tolerance to abiotic stress, and high-quality yield (Qin and Leskovar, 2020; Liu *et al*., 2024; Shahrajabian and Sun, 2024). It improves the crop growth and increases yield and quality (Zhou *et al*., 2019; Omar *et al*., 2022). The use of humic acid via soil amendments improves the soil physical and chemical properties and the absorption of essential nutrients by plants including potatoes (Man-hong *et al*., 2020; Bayat *et al*., 2021). Humic acid may increase the starch content of tubers, dry matter accumulation, tuber production, and increase soil nutrients and nutrient uptake by plants, which increases the nutrient content of tubers, including tuber size (Suh *et al*., 2014; Al-Bayati *et al*., 2019; Şanlı *et al*., 2024).

In light of the aforementioned importance of planting distance and soil amendments by biostimulants, this study aimed to determine the effect of different planting (plant to plant) distance and the application of different concentrations of humic acid on some vegetative and growth traits and yield components of potato crop under field conditions.

Materials and Methods

This field experiment was performed to assess the effect of planting distance and humic acid on the growth and yield parameters of the potato crop. The experiment was carried out under the Tomato and Potato Development Project in one of the fields of the Agricultural Department located 25 km north of Hillah City, Babylon, Iraq, during the autumn season of 2023-2024. The experiment was conducted following the Complete Randomized Block Design (RCBD), and each treatment was replicated thrice. Treatments included two planting distances *i.e.* A1= 25 cm, and A2= 35 cm, and three humic acid concentrations *i.e.* B1= 0 g L^{-1}, B2= 5 g L^{-1}, and B3= 10 g L^{-1}.

Soil samples were taken randomly from the field before planting and were pooled to make a composite soil sample to analyze the soil characteristics (Table 1). The chemical and physical characteristics of soil under trial were analyzed in the Muradiyah Research Station of the Babylon Agriculture Directorate following protocols described previously by Chapman (1965), and Page *et al*. (1982).

The field soil was plowed perpendicularly and was divided into three blocks (replicates). Each replicate included 6 experimental units, and each experimental unit included 3 rows with a length of 3.5 m and a width of 0.75 m. The potato variety Borin was sown in this experiment. Tubers were planted at a distance of 25 cm with 42 tubers, and at a distance of 35 cm with 30 tubers in one experimental unit. Humic acid concentrations were made by dissolving pure humic acid in water and applying it under the tubers, @ 100 ml per tuber. The application was repeated three times during the first growing season at 10 days after the tubers emerged, the second at the tuber formation stage, and the third at the tuber size enlargement stage. The processes of weeding, irrigation, and control were made when needed.

Table 1: *Physico-chemical properties of the soil under trial determined at the time of seedbed preparation.*

Soil characteristics	Values	Units
pH	7.9	-
Electrical conductivity (EC)	3.5	m3/ds
Soil organic matter	11.3	g kg^{-1}
Available Nitrogen	13.4	mg kg^{-1}
Available phosphorus	5.6	mg kg^{-1}
Available potassium	192.0	mg kg^{-1}
Bulk density	1.13	g cm^{3}
Sand	155	g kg^{-1}
Silt	600	g kg^{-1}
Clay	245	g kg^{-1}
Soil texture	Silt loam	

After the tubers were fully matured, they were harvested, and the following traits were measured, *i.e.,* number of leaves, number of main branches, number of buds per plant, plant height, chlorophyll content, total and marketable yield per plant, and total and marketable yield per hectare. Data was analyzed by the R program (version 4.1.2, R, Vienna, Austria) using analysis of variance (ANOVA), and the Least Significant Difference (LSD) post-hoc was used to compare the treatment means at a standard probability level (α = 0.05).

Results and Discussion

Effect of planting distance and humic acid application on potato plant characteristics

Plant height (cm): There was no significant effect of the planting distances on the average plant height (Table 2). However, the application of humic acid significantly impacted the plant height, as the treatment B3 (10 g L^{-1}) resulted in the highest average value (49.7 cm) of plant height as compared to the control treatment, which resulted in the lowest value (43.2 cm). Similarly, a significant effect on the average height of potato plants was shown by the binary interaction between the planting distances and the application of humic acid (Table 2). The interaction treatment A1×B3 resulted in the highest average value (52.5 cm) compared to A1×B1, which resulted in the lowest value (Table 2).

Table 2: *Impact of planting distance and humic acid application and their interactions on the vegetative growth traits of potato (Solanum tuberosum L.) crop.*

Treatments	Plant height (cm)	Number of branches (n)	Number of leaves per plant	Chlorophyll content in leaves (SPAD)
A1 (25 cm)	45.1	2.04	26.6	48.1
A2 (35 cm)	45.0	2.22	33.4	44.8
LSD (at α = 0.05)	N.S.	N.S.	6.30	N.S.
B1 (0 g L^{-1})	43.2	1.80	28.1	44.2
B2 (5 g L^{-1})	42.3	2.53	32.1	47.4
B3 (10 g L^{-1})	49.7	2.07	29.8	47.7
LSD (at α = 0.05)	5.96	0.64	N.S.	N.S.
A × B Interaction				
A1×B1	40.6	1.63	25.5	39.3
A1×B2	42.2	2.67	27.3	45.5
A1×B3	52.5	1.83	26.9	49.7
A2×B1	45.7	1.97	30.6	49.1
A2×B2	42.5	2.40	37.0	49.4
A2×B3	46.9	2.30	32.7	45.7
LSD (at α = 0.05)	8.56	0.90	10.91	9.36

A = plant to plant distance, B = humic acid concentration, NS = non-significant ($P \geq 0.05$).

Number of main branches per plant: There was no significant effect of the planting distance on the number of main branches (Table 2). The application of humic acid B2 (5 g L^{-1}) resulted in a significantly higher branching number per plant (2.53 branches $plant^{-1}$), while the control resulted in the lowest branching value of 1.80 branches $plant^{-1}$. The two-way interaction between the planting distances and humic acid applications increased the branching number, as treatment A1×B2 produced the highest and significant value of 2.67 branches $plant^{-1}$ as compared to the control A1×B1, which had the lowest value for 1.63 branches $plant^{-1}$ (Table 2).

Number of leaves per plant: In this case, the planting distance of 35 cm resulted in a significantly higher value for the number of leaves per plant (33.4 leaves plant^{-1}). No significant difference was observed between the treatments of humic acid application on the number of leaves per plant. The two-way interaction between planting distances and the application of humic acid A2×B2 resulted in the highest value (37.0 leaf plant^{-1}), as compared to the lowest value exhibited by the control treatment.

Chlorophyll content in leaves (SPAD): Data regarding the soil plant analysis development (SPAD) value as a non-destructive measure of leaf chlorophyll content showed that there was no significant impact of both factors, *i.e.,* planting distances and the application of humic acid, on the chlorophyll content of potato leaves (Table 2). However, the interaction between them significantly affected the chlorophyll content of leaves, as A1×B3 resulted in the highest value (49.7 SPAD), as compared to the control, for which the lowest value was recorded for this trait.

Effect of planting distance and humic acid application on potato yield parameters

Number of tubers per plant: There was a significant effect of the planting distances on the average number of tubers per plant (Table 3). Treatment A2 (35 cm) showed a significant increase in the number of tubers (5.31 tuber plant^{-1}), and the application of humic acid also exhibited significant differences, as the humic acid treatment B3 (10 g L^{-1}) showed the highest significant value (5.27 tuber plant^{-1}), as compared to the lowest value (4.19) of the number of tubers showed by the control treatment. Treatment A2×B1 resulted in the highest significant value of 5.80 tuber plant$^{-1,}$ which differed significantly from most treatments.

Total potato yield (g plant^{-1} and ton ha^{-1}): There was a significant impact of the planting distance factor on the total yield of potato, either per plant or per hectare (Table 3). The planting distance of 35 cm (treatment A2) resulted in the highest yield rate of 416 g plant^{-1} and 16.64 tons ha^{-1}. However, no significant difference was seen regarding the humic acid application treatments on the total potato yield values. The interaction treatment A2×B1 resulted in the highest total plant yield (433 g plant^{-1}) and yield per hectare (17.31 ton ha^{-1}), and it was statistically at par with the rest of the treatments (Table 3).

Marketable potato yield (g plant^{-1} and ton ha^{-1}): Regarding the marketable potato yield either on per plant basis or on a hectare basis, the treatment A2 (planting distance of 35 cm) resulted in the highest and significant value for the marketable potato yield of 363 g plant^{-1} and 14.51 tons ha^{-1} (Table 3). However, there were humic acid treatments did not show any statistical difference for their impact on marketable plant yield. The interactions of A2×B1 and A2×B3 resulted in the highest values of 368 and 361 g plant^{-1} and 14.73 and 13.85 tons ha^{-1} with significant differences from the rest of the treatments (Table 3).

Table 3: *Impact of planting distance and humic acid application, and their interactions on the yield of potato (Solanum tuberosum L.) crop.*

Treatments	Number of tubers (plant^{-1})	Total plant yield (g plant^{-1})	Marketable plant yield (g plant^{-1})	Total yield (ton ha^{-1})	Marketable yield (ton ha^{-1})
A1 (25 cm)	4.47	294	245	11.60	9.60
A2 (35 cm)	5.31	416	363	16.64	14.51
LSD (at α = 0.05)	0.78	71.5	71.3	3.021	2.820
B1 (0 g L^{-1})	4.19	353	296	14.11	11.82
B2 (5 g L^{-1})	4.97	346	289	13.93	11.57
B3 (10 g L^{-1})	5.27	366	328	14.31	12.77
LSD (at α = 0.05)	0.965	N.S.	N.S.	N.S.	N.S.
A × B Interaction					
A1×B1	4.73	273	223	10.92	8.92
A1×B2	4.00	291	220	11.81	8.78
A1×B3	4.67	319	294	12.07	11.08
A2×B1	5.80	433	368	17.31	14.73
A2×B2	4.87	401	359	16.05	14.36
A2×B3	46.9	2.30	32.7	45.7	13.85
LSD (at α = 0.05)	8.56	0.901	10.91	9.36	8.27

A = plant to plant distance, B = humic acid concentration, NS = non-significant (P ≥ 0.05).

This *in-situ* study was done to assess how planting distance and supplementation of humic acid can enhance or impact the yield parameters and plant growth traits of the potato crop. Results of the study exhibited a significant effect of both factors on most of the plant traits and yield parameters. It was observed that the number of branches of the potato plant was less at the short distance (25 cm), and the number of leaves per plant increased significantly at the wider distance (35 cm). It would be due to the reason that shorter planting distances increased the density of plants, which enhanced the competition of plants for soil nutrients and sunlight, and thus the growth of fewer stems and branches. It means short planting distance of 25 cm enhanced the competition of plants for sunlight and thus, led to long potato plant stems and fewer branches compared to other potato plants maintained at 35 cm planting distance (Nxumalo *et al*., 2020; Abewoy, 2024). Competition for sunlight in potato and other plants resulted in taller and more branched plants than usual as a result of phototropism (Vinterhalter and Vinterhalter, 2015). Conversely, Mvumi *et al*. (2018) reported that plants planted at wider distances had lower heights and more branches than plants planted at narrow distances. This is due to the better or sufficient availability of nutrients, water, and sunlight, as the plants at wider distances have less competition and grow more buds and leaves (Craine and Dybzinski, 2013).

The increase in plant vegetative characteristics may also be attributed to the effect of direct administration of humic acid affecting various vital processes and its important role in improving cell division and elongation (Nardi *et al*., 2021). These processes include respiration, photosynthesis, protein synthesis, increased enzymatic reactions, and vital activities such as respiration and photosynthesis, thus stimulating and increasing the number of main branches (Canellas and Olivares, 2014). This is consistent with what was found by Al-Jumaili *et al*. (2010), Suh *et al*. (2014), and Lazzarini *et al*. (2022) that the humic acid application led to an increase in the main stem numbers per plant.

In addition, the planting distance of 35 cm also significantly affected all yield parameters of the potato plants, *i.e.,* number of tubers per plant, per plant total and marketable yield, and total and marketable yield. The reason is that the better availability of sunlight in plants led to an increase in the photosynthesis process on one hand, and an increase in the root area on the other hand, which led to an increase in biological processes and cell division, and thus the accumulation of dry matter and starch (Haverkort, 2007; Schulz *et al*., 2019). This is consistent with what was narrated by Mvumi *et al*. (2018) and Derebe and Kola (2024). The interaction between planting distances and humic acid application also affected the crop. The interaction of 35 cm planting distance and 5 g L^{-1} humic acid application significantly increased the values for all crop traits. These results corroborate the findings of Alenazi *et al*. (2016) and Man-hong *et al*. (2020), which reported that the potato growth was improved by the treatment or application of humic acid, because it improved the photosynthesis system and improved the productivity of fresh tubers in insufficient irrigation conditions. Haider *et al*. (2015) and Andrejiová *et al*. (2023) found that humic acid treatment increased the yield of potato tubers compared to untreated plants. The results of Mahmoud and Hafez (2010) and Keskin and Akınerdem (2021) demonstrated that humic acid causes an increase in fresh weight, size, and quality of tubers by increasing the concentration of humic acid used. This is consistent with the results that indicated that humic acid treatment increases the activity of antioxidants to avoid oxidative stress caused by disease infection and thus a significant increase in the total and marketable potato yields as recorded in treatments A2×B1 and A2×B3 (Lazzarini *et al*., 2022; Şanlı *et al*., 2024).

Conclusions and Recommendations

Overall results of this field study demonstrated that potato plants planted at shorter planting distances would result in plants with fewer branches and leaves, while the wider planting distances exhibited better plant growth traits and yield components. Moreover, the rhizospheric administration of water-soluble humic acid either alone or in combination with wider planting distance increased the vegetative growth traits of the potato plants, and exerted a significant and positive effect on the quantitative yield components of the potato crop as well.

Novelty Statement

This field experiment was performed to assess the effect of planting distance and humic acid on the growth and yield parameters of the potato crop.

Author's Contribution

Ali Amer Dahham, Aws Jawad Kadhim, Ali Ibadi Manea and Sarmad Salim Ali: Conceptualization, methodology, formal analysis, investigation, resources, data curation, project administration.
Aws Jawad Kadhim: Writing—original draft preparation.

Conflict of interest
The authors have declared no conflict of interest.

References

Abed, M.N. and A.A. Al-Razaq. 2023. Efficiency of production resource utilization for sustainable potato crop production in Baghdad governorate. Int. Conf. Environ. Sustain., Cham: Springer Nature Switzerland. pp. 295-309. https://doi.org/10.1007/978-3-031-57054-4_21

Abewoy, D., 2024. Plant spacing and nitrogen fertilizer effect on potato (*Solanum tuberosum*) growth, yield and quality. J. Glob. Acad. Agric. Biosci., 6(1): 8-14. https://doi.org/10.36348/gajab.2024.v06i01.002

Al-Bayati, H.J.M., N.S. Mutar and A.I. Manea. 2019. Type of application dry yeast extract and poultry manure on growth and yield of potato. Plant Arch., 19(2): 3648-3652.

Alenazi, M., M.A. Wahb-Allah., H.S. Abdel-Razzak., A.A. Ibrahim and A. Alsadon. 2016. Water regimes and humic acid application influences potato growth, yield, tuber quality and water use efficiency. J. Am. Potato Res., 93: 463-473. https://doi.org/10.1007/s12230-016-9523-7

Al-Jumaili, A.W.A. Zarq and M. Saloum. 2010. The effect of spraying with humic acid and potassium fertilizer on the growth and yield of potatoes under a drip irrigation system. Diyala Agric. J., 4(1): 205-219.

Al-Sharifi, M.Y.S., S.K. Al-Sharifi and A. Maryam. 2020. A study of some rice growth properties under impact practical speed and tillage depth. J. Euphrates Agric. Sci., 12(1): 110-121.

Al-Sharifi, S.K.A., S.A. ALaamer and I. Hamzah. 2021. Effect of some mechanical planting methods on potato tuber characteristics. AgricEngInt: CIGR J. Open Access., 23(4): 91-102.

Andrejiová, A., S. Adamec, A. Hegedűsová, O. Hegedűs and R. Rosa. 2023. Verification of the humic substances and PGPB biostimulants beneficial effects on the potato yield and bioactive substances content. Slovak J. Food Sci., 17. https://doi.org/10.5219/1805

Baligah, H.U., M.H. Chesti, Z.A. Baba and S.A. Mir. 2022. Humic acids as bio-stimulants. In: Second. Agricult. Sustain. Livelihood in India. Cham: Springer International Publishing. pp. 201-211. https://doi.org/10.1007/978-3-031-09218-3_15

Bayat, H., F. Shafie., M.H. Aminifard and S. Daghighi. 2021. Comparative effects of humic and fulvic acids as biostimulants on growth, antioxidant activity and nutrient content of yarrow (*Achillea millefolium* L.). Sci. Hortic., 279: 109912. https://doi.org/10.1016/j.scienta.2021.109912

Canellas, L.P. and F.L. Olivares. 2014. Physiological responses to humic substances as plant growth promoter. Chem. Biol. Technol. Agricult., 1: 1-11. https://doi.org/10.1186/2196-5641-1-3

Chapman, H.D., 1965. Cation- exchange capacity. Methods of soil analysis: Part 2. Chem. Microbiol. Prop., 9: 891-901. https://doi.org/10.2134/agronmonogr9.2.c6

Chaudhari, V.M., N.K. Patel., D.C. Barot and N. Nadoda. 2023. Role of bio-stimulants in solanaceous vegetable crops: A review. Int. J. Adv. Biochem. Res., 7(2S): 178-183. https://doi.org/10.33545/26174693.2023.v7.i2Sc.205

Chehaibi, S., B. Douh., E.B.M. Dridi and M.H. Bechir. 2013. Impact of mechanical planting depth and density on agronomic parameters of organic potato *Solanum tuberosum* L. J. Appl. Hortic., 15(2): 147-149. https://doi.org/10.37855/jah.2013.v15i02.29

Craine, J.M. and R. Dybzinski. 2013. Mechanisms of plant competition for nutrients, water and light. Funct. Ecol., 27(4): 833-840. https://doi.org/10.1111/1365-2435.12081

Derebe, A.D. and A.W. Kola. 2024. Effect of planting density on growth, light interception and tuber yields of potato varieties (*Solanum tuberosum* L.) at Guji highland of southeastern Ethiopia. Ethiop. J. Appl. Sci. Technol., 14(2): 16-27.

El-Shaieny, A.A.H., H.M. Farrag and G.A. Zayed. 2023. Assessing the effects of some bio-stimulants on soil properties, physiological, and biochemical responses of cowpea plants under water deficit conditions. SVU Int. J. Agric. Sci., 5(4): 38-59. https://doi.org/10.21608/svuijas.2023.249207.1319

FAOSTAT, 2024. Food and agricultural organization statistical database, Crop production.

Gleń-Karolczyk, K., E. Boligłowa and L. Luty. 2022. Health parameters of potato tubers under the influence of soil applied bio-preparations and bio-stimulants. Appl. Sci., 12(22): 11593. https://doi.org/10.3390/app122211593

Haider, G., H.W. Koyro., F. Azam., D. Steffens., C. Müller and C. Kammann. 2015. Biochar but not humic acid product amendment affected maize yields via improving plant-soil moisture relations. Plant Soil, 395: 141-157. https://doi.org/10.1007/s11104-014-2294-3

Haverkort, A.J., 2007. Potato crop responses to radiation and day length. In: Potato. Biol. Biotechnol., 353-365. Elsevier Science BV. https://doi.org/10.1016/B978-044451018-1/50059-2

Jardin, P., 2015. Plant biostimulants: Definition, concept, main categories and regulation. Sci. Hortic., 196: 3-14. https://doi.org/10.1016/j.scienta.2015.09.021

Karak, S., U. Thapa and N.N. Hansda. 2023. Impact of biostimulant on growth, yield and quality of potato (*Solanum tuberosum* L.). Biol. Forum., 15: 297-302.

Keskin, N.Ç. and F. Akınerdem. 2021. The effect of humic acid applications on growth and quality properties of potato (*Solanum tuberosum* L.). J. Inst. Sci. Technol., 11(2): 1559-1567. https://doi.org/10.21597/jist.840082

Khallouf, A., J. Aree., K. Amera., K. Nabela and W. Salwa. 2019. Effect of biofertilizers on some fertility soil properties and some qualitative and production traits of potato. Syrian J. Agricult. Res., 6(1): 276-287

Lazzarini, R., M.M. Müller., P.R.C. Lazzarini., C. Tamanini., C.K.D. Matos and J. Kawakami. 2022. Humic substances: Effects on potato growth and yield. Hortic. Brasil., 40(1): 33-38. https://doi.org/10.1590/s0102-0536-20220104

Liu, Y., X. Lan., H. Hou., J. Ji., X. Liu and Z. Lv. 2024. Multifaceted ability of organic fertilizers to improve crop productivity and abiotic stress tolerance: Review and perspectives. Agronomy, 14(6): 1141. https://doi.org/10.3390/agronomy14061141

Mahapatra, D.M., K.C. Satapathy and B. Panda. 2022. Biofertilizers and nanofertilizers for sustainable agriculture: Phycoprospects and challenges. Sci. Total Environ., 803: 149990. https://doi.org/10.1016/j.scitotenv.2021.149990

Mahmoud, A.R. and M.M. Hafez. 2010. Increasing productivity of potato plants (*Solanum tubersoum* L.) by using potassium fertilizer and humic acid application. Int. J. Acad. Res., 2: 83-88.

Man-hong, Y., Z. Lei., X. Sheng-tao., B. Neil., McLaughlin and L. Jing-hui. 2020. Effect of water-soluble humic acid applied to potato foliage on plant growth, photosynthesis characteristics and fresh tuber yield under different water deficits. Sci. Rep., 10: 7854. https://doi.org/10.1038/s41598-020-63925-5

Mishra, P., A.A. Alhussan, D.S. Khafaga, P. Lal, S. Ray, M. Abotaleb and E.S.M. El-Kenawy. 2024. Forecasting production of potato for a sustainable future: Global market analysis. Potato Res., 67(4): 1671-1690. https://doi.org/10.1007/s11540-024-09717-0

Mohaseb, M.I., H. Khafagy, M. Mahrous and S.M. Abdel-azeem. 2018. Effect of humic substances addition and foliar spraying with biostimulants on growth, yield and quality of potato (*Solanum tuberosum*). Ann. Agric. Sci. Moshtohor., 56(4).

Mvumi, C., A. Mawoko, A. Muropa and A. Tsindi. 2018. Effects of in-row spacing on growth and yield of Irish potato (*Solanum tuberosum* L.) varieties in eastern highlands of Zimbabwe. Int. J. Agro. Agric. Res., 12(5): 19-26.

Nardi, S., M. Schiavon and O. Francioso. 2021. Chemical structure and biological activity of humic substances define their role as plant growth promoters. Molecules, 26(8): 2256. https://doi.org/10.3390/molecules26082256

Navarre, D.A., A. Goyer and R. Shakya. 2009. Nutritional value of potatoes: Vitamin, phytonutrient, and mineral content. Adv. Potato Chem. Technol., Acad. Press. pp. 395-424. https://doi.org/10.1016/B978-0-12-374349-7.00014-3

Nxumalo, K.A., F. Hlanze, M.T. Masarirambi and P.K. Wahome. 2020. Effect of intra-row spacing on growth and yield of irish potato (*Solanum tuberosum* L. cv. Mondial) grown in a sub-tropical environment of eswatini. J. Agric. Sustain., (13).

Omar S., R. Abd-Ghani, H. Khaeim, A.H. Sghaier and M. Jolánkai. 2022. The effect of nitrogen fertilisation on yield and quality of maize (*Zea mays* L.). Acta Alimentaria, 51(2): 249-258. https://doi.org/10.1556/066.2022.00022

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of soil analysis. 2nd edn. Am. Soc. Agron. Madison, WI., USA.

Pandey, N., S. Kumar and G. Singh. 2015. Effect of planting geometry on growth and yield of mustard varieties. Int. J. Farm Sci., 5(2): 47-52.

Qin, K. and D.I. Leskovar. 2020. Humic substances improve vegetable seedling quality and post-transplant yield performance under stress conditions. Agriculture, 10(7): 254. https://doi.org/10.3390/agriculture10070254

Rajesaheb, K.S., S. Subramanian, P. Boominathan, S. Thenmozhi and M. Gnanachitra. 2025. Bio-stimulant in improving crop yield and soil health. Commun. Soil Sci. Plant Anal., 56(3): 458-493. https://doi.org/10.1080/00103624.2024.2416925

Regasa, M., W. Garedew and A. Olika. 2022. Effect of tuber size and intra- row spacing on the yield and quality of potato (*Solanum tuberosum* L.) varieties. Adv. Agric., 2022(1): 5619201. https://doi.org/10.1155/2022/5619201

Sainju, U.M., D. Liptzin and J.D. Jabro. 2022. Relating soil physical properties to other soil properties and crop yields. Sci. Rep., 12(1): 22025. https://doi.org/10.1038/s41598-022-26619-8

Şanlı, A., G. Cansever and F.Z. Ok. 2024. Effects of humic acid applications along with reduced nitrogen fertilization on potato tuber yield and quality. Turk. J. Agric. Food Sci. Technol., 12(s4): 2895-2900. https://doi.org/10.24925/turjaf.v12is4.2895-2900.7367

Schulz, V.S., S. Munz, K. Stolzenburg, J. Hartung, S. Weisenburger and S. Graeff-Hönninger. 2019. Impact of different shading levels on growth, yield and quality of potato (*Solanum tuberosum* L.). Agronomy, 9(6): 330. https://doi.org/10.3390/agronomy9060330

Setiyo, Y., I.B.P. Gunadnya, I.B.W. Gunam, I.D.G.M. Permana, I.K.B. Susrusa and I.L. Triani. 2016. Improving physical and chemical soil characteristics on potatoes (*Solanum tuberosum* L.) cultivation by implementation of Leisa system. Agric. Agric. Sci. Proc., 9: 525-531. https://doi.org/10.1016/j.aaspro.2016.02.172

Shahrajabian, M.H. and W. Sun. 2024. The importance of salicylic acid, humic acid and fulvic acid on crop production. Lett. Drug Design Discov., 21(9): 1465-1480. https://doi.org/10.2174/1570180820666230411102209

Suh, H.Y., K.S. Yoo and S.G. Suh. 2014. Tuber growth and quality of potato (*Solanum tuberosum* L.) as affected by foliar or soil application of fulvic and humic acids. Hortic. Environ. Biotechnol., 55: 183-189. https://doi.org/10.1007/s13580-014-0005-x

Vaičys, M. and J. Mažvila. 2009. The influence of soil characteristics on plant productivity and ecological stability. Ekologija, 55(2): 99-106. https://doi.org/10.2478/v10055-009-0012-x

van Dijk, L.C., M.E. de Vries, W.J. Lommen and P.C. Struik. 2022. Transplanting hybrid potato seedlings at increased densities enhances tuber yield and shifts tuber-size distributions. Potato Res., 65(2): 307-331. https://doi.org/10.1007/s11540-021-09522-z

Vinterhalter, D. and B. Vinterhalter. 2015. Phototropic responses of potato under conditions of continuous light and subsequent darkness. Plant Growth Reg., 75: 725-732. https://doi.org/10.1007/s10725-014-9974-0

Wang, X., Y. Duan, J. Zhang, I.A. Ciampitti, J. Cui, S. Qiu and P. He. 2022. Response of potato yield, soil chemical and microbial properties to different rotation sequences of green manure-potato cropping in North China. Soil Till. Res., 217: 105273. https://doi.org/10.1016/j.still.2021.105273

Zarzecka, K. and M. Gugała. 2024. Biostimulants and herbicides shape the structure of potato tuber yield. Plant Soil Environ., 70(7). https://doi.org/10.17221/103/2024-PSE

Zhao, Y., M. Zhou, K. Xu, J.H. Li, S.S. Li, S.H. Zhang and X.Y. Yang. 2019. Integrated transcriptomics and metabolomics analyses provide insights into cold stress response in wheat. Crop J., 7: 857-866. https://doi.org/10.1016/j.cj.2019.09.002