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Effects of Humic Acid Applications along with Reduced Nitrogen Fertilization on Potato Tuber Yield and Quality

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ABSTRACT

This research was conducted in 2020 to determine the effects of leonardite-derived humic acids (Humas-15, Liquid Humus and Humico Maximix-K) with different properties, along with reduced nitrogen fertilization, on tuber yield and quality in potatoes (cv. Van Gogh). In the study, chemical fertilizer applications were made as basic fertilization (20 N 10 P 10 K), reduced fertilization I (15 N 10 P 10 K) and reduced fertilization II (10 N 10 P 10 K). Humic acids were applied twice with irrigation water, at the beginning of the flowering period and 15 days later. Humas-15 and Liquid Humus were applied at 1.0 and 2.0 lt/da doses, and Humico Maximix-K was applied at 400 and 800 g/da doses. A total of seven traits (tuber number per plant, tuber yield per plant, marketable tuber yield, total tuber yield, dry matter content, reducing sugar content and total sugar content) were measured. Reducing nitrogen applications with humic acid applications significantly affected all the traits studied. Humic acid applications combined with reduced nitrogen fertilization increased the number of tubers per plant by up to 13%, marketable tuber yield by up to 18% and total tuber yield by up to 16% compared with the control. Total and reducing sugar contents varied between 1.27-1.58% and 159-389 mg/100g fw, respectively depending on the applications. In the study, the highest tuber yield was obtained from 1.0 and 2.0 L/da Humas-15 and 2.0 L/da Liquid Humus applications applied together with reducing nitrogen applications which have close values to the recommended fertilization applications.

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Introduction

Potatoes are among the most widely consumed and nutrient-rich vegetable crops globally. Cultivated in 164 countries, their tubers serve as a daily staple for almost one billion people. Alongside their expanding range of uses, the rising global population is driving a steady increase in potato demand. One of the most crucial methods for boosting agricultural productivity is the addition of essential nutrients to the soil to support plant growth, using both chemical and organic fertilizers. Inorganic fertilizers are generally highly effective and fast-acting due to their quick-release formulations, which provide nutrients to plants. In our country, the significant lack of organic matter in soils greatly increases on artificial fertilizers; plants are often unable to fully benefit from these fertilizers (Özkan, 2007). Additionally, the long-term use of chemical fertilizers in agricultural fields has been associated with negative consequences, including soil salinization, heavy metal accumulation, nutrient imbalance, disruption of microbial activity, and nitrate buildup (Das et al., 2023).

The development of a thriving, profitable, and sustainable production system largely depends on soil health. Soil health can be achieved through multi-year crop rotations and implementation of appropriate agronomic practices, such as effective nutrient management. The use of soil enhancers, including those enriched with humic acids (HA), positively affects the biological balance and overall health of the soil.

HA functions as a biostimulants, organic substance recognized for their role in enhancing plant growth and boosting crop production. Integrating HA into chemical fertilizers presents a promising strategy to improve both crop yields and fertilizer efficiency (Liu et al., 2019). HA act as biostimulants, organic compounds known for promoting plant growth and increasing crop productivity. Incorporating HA into chemical fertilizers offers a promising approach to enhancing both crop yields and the efficiency of fertilizer use (Liu et al., 2019). The application of HA-based fertilizers not only enhances soil physicochemical properties and nutrient uptake by plants

(Bayat et al., 2021) but also promotes crop growth, yield, and quality (Akladious & Mohamed, 2018; Zhou et al., 2019). The use of HA-based fertilizers improves soil physicochemical properties and enhances nutrient uptake by plants (Bayat et al., 2021). Additionally, it fosters crop growth, increases yields, and improves overall crop quality (Akladious & Mohamed, 2018; Zhou et al., 2019).

Humic substances, which are among the most complex and biologically active organic compounds found in soil, play a crucial role in shaping soil properties and influencing microbial structure and activity, thereby ensuring an improved nutrient supply to plants (Canellas & Olivares, 2014). Studies have consistently demonstrated the effects of HA on the growth of various crops, such as potato, sugar beet, and corn (Wilczewski et al., 2018; Marenych et al., 2019). For instance, Şanlı et al. (2013) reported that applying leonardite at rates of 200–600 kg/ha increased total tuber yield by 6–25% of potato.

The application of organic fertilizers, such as HA, which benefit both plant health and soil texture, is of great agronomic importance for enhancing plant yields. In potatoes, reducing excessive and unregulated chemical fertilization in favor of using organic fertilizers like HA is seen as a key approach to protect both environmental and human health on one hand and to ensure the sustainability of agriculture on the other. Current study aims to determine the effects of different HA sources (Humat-15, Liquid Humus, and Humico Maximix-K) on yield and quality of potatoes when used alongside reduced nitrogen fertilization.

Materials and Methods

Experimental Site

The field experiment was conducted in Isparta, Türkiye (37º 50' 47'' N, 30º 32' 12'' E, 1035 m) during the 2022 crop season. The soil in the experimental area was classified as loam, with a pH of 8.2, a total salt content of 0.025%, and a cation exchange capacity of 38%. It is rich in lime (25.5%), low in organic matter (1.58%), deficient in available phosphorus (18.2 mg/kg P_2O_5), rich in potassium (188 mg/kg K_2O), and low in total nitrogen content (0.82%). During the research year, the total rainfall during the vegetation period (April–September) was 195 mm, exceeding the long-term average of 173 mm. The average temperature during the same period was 20.8°C, closely aligned with the long-term average of 20.6°C. The relative humidity during the vegetation period (54.3%) was also similar to the long-term average (50.5%).

Experimental Design

The study was established in three replications according to randomized complete block in a split plot design, reduced fertilizer applications were applied to the main plots, while humic acid applications were applied to the subplots. Seed potatoes (cv Van Gogh) were planted in plots of 6.6 m in length with a 30 × 70 cm spacing in the first week of May. Four rows of potatoes were planted in each plot. In the study, a compose fertilizer (15-15-15) was applied to all plots at a rate of 66 kg/da before planting. During the earthing-up process, Nitro Power fertilizer (33% N) was applied at a rate of 33 kg/da for the standard fertilizer (SF) applications and 16.5 kg/da for the reduced nitrogen fertilization-I (RNF-I). No top-dressing was applied in the reduced nitrogen fertilization-II (RNF-II) treatments. In this way, the amounts of nitrogen, phosphorus, and potassium per decare for the SF, RNF-I, and RNF-II applications were 20-10-10, 15-10-10, and 10-10-10, respectively.

HA (Humas-15, Liquid Humus and Humico Maximix-K) were applied to plants twice via irrigation water: once at the beginning of the flowering period (stolon initiation) and again at the end of flowering (approximately two weeks after the first application). Humas-15 and Liquid Humus were applied at doses of 1.5 and 3.0 l/da, while Humico Maximix-K was applied at 400 and 800 g/da. Plots without humic acid application were used as controls. Before planting, tubers were treated with a fungicide (Emesto® Silver FS 118, containing 100 g/l Penflufen + 18 g/l Prothioconazole at a dose of 20 ml/100 kg of seed) to protect against seed-borne infections and with an insecticide (Gaucho FS 600, containing 600 ml/L Imidacloprid) to protect against the Colorado potato beetle (*Leptinotarsa decemlineata*). Water needs of the plants were met through drip irrigation, with watering conducted once a week for 4 hours each time. For weed control, a selective herbicide registered for potatoes (Sencor WP 70, containing 70% Metribuzin) was applied at a rate of 70 g/da immediately after planting (pre-emergence). Harvesting was done when the skin formation of the tubers was complete. Tuber number and yield per plant were determined by randomly selecting 20 plants of each plot, and marketable tuber yield and total tuber yield were determined by harvesting all the plants in the plot. Tuber sample from each sub-plot was collected to measure the tuber dry matter, total soluble sugars (TSS), total sugar and reducing sugar content. Tuber dry matter content was calculated according to International Potato Centre (2006), reducing sugar and total sugar content in a potato was quantified following the Somogyi–Nelson method (Nelson, 1944) with some adjustments.

Statistical Analysis

The data obtained from the measurements and analyses were analyzed using the General Linear Model (GLM) procedure in the SAS (2009) statistical software, following the Randomized Block Design. The analysis was performed using standard analysis of variance (ANOVA), and the differences between the means were determined using the LSD test.

Table 1. Some Properties of Humic Acids Used in the Study

Content	Humas-15	Liquid Humus	Humico Maximix-K
Total Organic Matter (%)	10.0	15.0	45.0
Total Humic and Fulvic Acids (%)	15.0	12.0	80.0
Water-Soluble Potassium Oxide (%)	2.0	2.0	8.0
pH	8-10	11-13	8-12

Table 2. Effects of HA applications on the tuber number, tuber yield per plant, marketable and total tuber yield

HA Applications	Reduced Nitrogen Fertilization					
	RNF-I	RNF-II	Mean	RNF-I	RNF-II	Mean
	Tuber number per plant (number)			Tuber yield per plant (g)		
H-15 - 1.5 l/da	8.27 cd	6.83 g	7.55 E	888 de	695 h	790 D
H-15 - 3.0 l/da	8.57 c	7.13 fg	7.85 DE	915 cd	718 h	816 D
LH - 1.5 l/da	9.23 b	7.37 eg	8.30 CD	984 bc	751 gh	867 D
LH - 3.0 l/da	9.80 ab	7.57 ef	8.68 BC	1034 ab	796 fg	915 B
HM - 400 g/da	9.77 b	7.43 eg	8.60 C	1031 ab	803 fg	917 B
HM - 800 g/da	10.43 a	7.80 de	9.12 AB	1057 a	829 ef	943 B
Control	8.33 cd	6.93 fg	7.63 E	892 de	687 h	790 D
SF	9.43 b	9.33 b	9.38 A	1090 a	1079 a	1085 A
Mean	9.23 A	7.55 B		986 A	795 B	
	Marketable tuber yield (kg/da)			Total tuber yield (kg/da)		
H-15 - 1.5 l/da	3068	2551	2809 D	3657 ce	2875 h	3266 DE
H-15 - 3.0 l/da	3149	2599	2874 CD	3723 cd	2941 gh	3333 DE
LH - 1.5 l/da	3376	2800	3088 BC	3958 bc	3110 fh	3534 CD
LH - 3.0 l/da	3641	2948	3294 B	4200 ab	3277 eg	3738 BC
HM - 400 g/da	3595	2923	3259 B	4233 ab	3305 eg	3769 BC
HM - 800 g/da	3709	2975	3342 B	4382 a	3348 df	3865 B
Control	3028	2605	2816 D	3607 ce	2888 h	3248 E
SF	3596	3651	3623 A	4423 a	4465 a	4444 A
Mean	3395 A	2881 B		4023 A	3276 B	

SF: Standard fertilization, H-15: Humas-15, LH: Liquid Humus, HM: Humico Maximix-K, RNF: Reduced nitrogen fertilization

Results

In SF applications, the tuber number per plant, which was 9.43, significantly decreased to 8.33 with RNF-I applications and to 6.93 with RNF-II. In RNF-I applications, the application of HM at a dose of 800 g/da resulted in a higher tuber number compared to SF. Applications of 1.5 l/da and 3.0 l/da LH, as well as 400 g/da HM, resulted in a tuber number similar to SF. In plants treated with RNF-II, only the application of 800 g/da HM showed a tuber number-increasing effect compared to the control (Table 2). The effects of reduced nitrogen fertilizer applications on tuber yield per plant was statistically significant. The tuber yield, which was 1090 g/plant in SF, decreased to 892 g/plant in RNF-I and to 687 g/plant in RNF-II. In RNF-I applications, the addition of 3.0 L/da LH and 400 or 800 g/da HM significantly increased tuber yield per plant compared to the control (892 g/plant) and resulted in yields similar to SF. The same applications also significantly increased tuber yield per plant in RNF-II-treated plants compared to the control (687 g/plant). However, the effects of H-15 and 1.5 l/da LH applications were insignificant (Table 2).

Compared to the recommended SF, the marketable tuber yield decreased by approximately 16% with RNF-I applications and by 28% with RNF-II applications. The LH 3.0 l/da applications and HM applications at both doses, performed alongside RNF-I applications, significantly increased the marketable tuber yield compared to the control and were similar to SF. Similarly, the significantly reduced marketable tuber yield in RNF-II applications showed a substantial increase with the addition of 3.0 l/da LH and HM applications at both doses but was still determined to be lower than SF (Table 2). Compared to SF, total tuber yield decreased by approximately 23% in RNF-I applications and by 54% in RNF-II applications. In RNF-I applications, the addition of 3.0 l/da LH and 400 and 800 g/da HM compensated for the reduced nitrogen, resulting in tuber yield being equal to SF. However, in RNF-II applications, 3.0 l/da LH and HM applied at both doses increased total tuber yield by 16% compared to the control, but the total tuber yield in these treatments remained 33% lower than SF (Table 2).

Tuber dry matter content increased with the reduction in nitrogen fertilization, rising from 22.3% in SF to 22.4% in RNF-I applications and 23.2% in RNF-II applications. The effects of HA applications on dry matter content were found to be statistically significant, and all HA treatments resulted in a significant increase in dry matter content when compared to SF. The effects of HA applications on tuber TSS values were statistically significant, with all HA treatments led to a substantial increase in tuber TSS content. The highest TSS were observed with high-dose applications of each HA source. Compared to SF, RNF applications increased TSS content, with no significant differences observed between RNF-I and RNF-II. HA applications significantly affected tuber reducing sugar content, with LH applications at a dose of 3.0 l/da yielding the highest reducing sugar content, followed by the 1.5 l/da dose of LH. No significant differences in reducing sugar content were observed between SF and RNF applications. However, LH applications at both 1.5 and 3.0 l/da doses, when combined with RNF applications, led to an increase in reducing sugar content. Tuber total sugar content significantly increased in RNF applications (1.72% and 1.89%, respectively) compared to SF applications (1.58–1.61%). The effects of HA applications had a statistically significant effect on total sugar content, with the highest total sugar contents observed in LH and HM applications at both doses.

Table 2. Effects of humic acid applications on the dry matter content, TSS, reducing and total sugar content

HA Applications	Reduced Nitrogen Fertilization					
	RNF-I	RNF-II	Mean	RNF-I	RNF-II	Mean
	Dry matter content (%)			TSS (%)		
H-15 - 1.5 l/da	22.53	22.87	22.70 BC	7.33	7.70	7.52 C
H-15 - 3.0 l/da	22.87	23.41	23.14 AB	7.73	8.27	8.00 AB
LH - 1.5 l/da	22.67	23.20	22.94 AC	7.70	7.79	7.75 B
LH - 3.0 l/da	23.10	23.51	23.31 A	7.97	8.40	8.19 A
HM - 400 g/da	22.36	22.87	22.62 C	7.50	7.73	7.62 B
HM - 800 g/da	22.83	23.07	22.95 AC	7.72	7.95	7.84 AC
Control	22.42	23.18	22.80 AC	7.40	7.80	7.60 B
SF	21.23	21.30	21.27 D	6.37	6.30	6.33 D
Mean	22.50 B	22.92 A		7.47	7.74	
	Reducing sugar content (mg/100 g fw)			Total sugar content (%)		
H 15 - 1.5 l/da	157.3 d	176.3 cd	166.7 D	1.74	1.82	1.78 C
H 15 - 3.0 l/da	177.7 cd	196.3 cd	187.0 CD	1.69	1.88	1.78 C
LH - 1.5 l/da	258.0 ab	224.0 bc	241.0 B	1.77	1.92	1.84 AC
LH - 3.0 l/da	307.3 a	248.3 b	277.9 A	1.81	2.10	1.95 A
HM - 400 g/da	181.3 cd	184.0 cd	182.7 CD	1.74	2.05	1.90 AB
HM - 800 g/da	217.0 b	195.3 cd	206.1 C	1.84	1.97	1.90 AB
Control	197.0 cd	157.6 d	177.3 D	1.72	1.89	1.80 BC
SF	191.3 cd	185.0 cd	188.1 CD	1.58	1.61	1.60 D
Mean	210.9	195.9		1.71 B	1.93 A	

SF: Standard fertilization, H-15: Humas-15, LH: Liquid Humus, HM: Humico Maximix-K, RNF: Reduced nitrogen fertilization

Discussion

In the study, reducing total nitrogen fertilization to 15 kg/da prevented declines in tuber number and yield in potatoes with LH and HM applications. However, when no nitrogen was applied, HA treatments had no impact on tuber number or yield per plant. The observed increase in tuber number in response to nitrogen may be linked to enhanced stolon production via gibberellin biosynthesis in potatoes (Alemayehu et al., 2015). Nitrogen, as a key element, plays a vital role in chlorophyll synthesis and vegetative growth processes. Similarly, Jafari-Jood et al. (2013) reported significant increases in tuber number with nitrogen application. The positive effects of HA on potato plants are likely due to its role in promoting cell elongation and division, which enhance the growth under optimal conditions (Mohammad et al., 2014; Menajid et al., 2021). HA plays a crucial role in stimulating plant growth by enhancing mineral nutrition, which positively influences root and leaf development (Zandonadi et al., 2016). Additionally, humic substances improve crop yield and quality by boosting soil enzyme activity (Sellamuthu & Govindaswamy, 2003). These findings align with previous studies (Al-Dogji et al., 2016; Şanlı et al., 2013; Mohsen & Alvan, 2019), which reported significant increase in vegetative growth with the HA applications. However, the effects of HA on tuber number and yield were less pronounced when combined with 10 kg/da of nitrogen compared to 15 kg/da. This suggests that HA mainly enhance plant growth by improving nutrient uptake, but their efficacy is limited when soil nitrogen levels are insufficient. Consistent with these findings, Feleafel et al. (2019) observed no impact of HA on tuber number and yield under conditions of reduced nitrogen fertilization in potatoes.

With the reduction in nitrogen fertilization, both marketable and total tuber yield decreased. Under conditions where total nitrogen applications were 15 kg/da, LH and HM applications mitigated the yield reduction and produced results comparable to 20 kg/da nitrogen applications. Under conditions with a total of 10 kg/da nitrogen fertilization, although these applications were not as effective as standard fertilization, they increased tuber yield by more than 16% compared to the control. The stimulatory effects of nitrogen on tuber yield are likely due to its role in promoting plant growth, which enhances photosynthesis critical for tuber development. Nitrogen application supports increased growth, leading to higher photosynthetic output and improvements in tuber weight, diameter, and number. As a key element in plant biochemical and physiological processes, nitrogen fosters cell proliferation and enlargement, thereby boosting overall vegetative growth (Leghari et al., 2016). HA further enhance plant growth by increasing the absorptive surface area of roots through structured root morphology remodeling (Schmidt et al., 2007). They also interact with root organic acid exudates, affecting root area, primary root length, and lateral root number (Canellas et al., 2008). Beyond root development, HA exhibit enzyme- and hormone-like activities (Piccolo et al., 1992) and can inhibit soil-borne phytopathogenic fungi, aiding in plant disease control (Loffredo et al., 2008). Research consistently highlights the positive impact of HA on potato growth and tuber yield (Şanlı et al., 2013; Çöl Keskin & Akınerdem, 2021; Kołodziejczyk, 2021).

With the reduction of nitrogen fertilization, tuber dry matter ratio and TSS content increased. Similarly, humic acid applications combined with reduced nitrogen fertilization increased the dry matter and TSS content of tubers compared to SF. N is crucial for potato growth;

however, an excessive supply can delay maturity, potentially reducing dry matter and starch level (Koch et al., 2019). In addition, excess nitrogen fertilization redirects dry matter accumulation to other parts of the plant, leading to excessive stolon and canopy growth. This delays both leaf maturation and tuber differentiation, ultimately shortening the tuber bulking period, and reducing yield and tuber dry matter (Goffart et al., 2008). Furthermore, some researchers reported that the efficiency of agronomic nitrogen use decreases linearly with increasing nitrogen doses (Darwish et al., 2006; Kumar et al., 2007; Fontes et al., 2010). HA sources are characterized by their high potassium content. In addition, the high cation exchange capacity of HA's enhances the availability of many nutrients in the soil through a chelating effect. These nutrients play a vital role in various physiological activities, such as enzyme activation, participation in photosynthesis, and increasing the production of processed carbohydrates, which are stored in the tubers as dry matter. Moreover, the slow decomposition of HA in the soil, combined with its high uptake efficiency and large surface area for metabolic reactions within the plant, enhances photosynthesis rates. This, in turn, stimulates dry matter production in the tubers (Qureshi et al., 2018). Research also highlights the positive effects of HA on potato quality, with HA applications significantly improving tuber dry matter content (Ekin, 2019). Alenazi et al. (2016) demonstrated that the application of humic acid enhances potato tuber quality by increasing starch content.

While reduced nitrogen fertilization did not significantly affect reducing sugar content, it showed a partial increase in total sugar content. Among HA sources, only LH applications elevated reducing sugar content, but all HA treatments resulted in higher total sugar content compared to SF. Potato tubers contain substantial amounts of sucrose, glucose, and fructose which influence their suitability for processing. High levels of reducing sugars are undesirable for high-temperature processing because they act as precursors for the Maillard reaction, while sucrose serves as the main source of reducing sugars through enzyme-catalyzed hydrolysis (van Eck, 2007). Furthermore, Locascio et al. (1984) reported that an inverse relationship exists between nitrogen fertilization rates and tuber dry matter and starch levels. As nitrogen fertilization increases, tuber dry matter and starch content tend to decrease. This supports the "carbon/nitrogen balance" theory, which suggests that when nitrogen availability limits plant growth, metabolism shifts towards the production of carbon-rich compounds like starch and sugars.

Conclusion

Reducing the use of nitrogen fertilizers and replacing them with soil humic acid applications enhances both tuber yield and nutritional quality in potato plants. Specifically, the combination of reduced nitrogen fertilization (RNF-I: 15N-10P-10K) with 1.5 l/da LH and 400 g/da HM shows promise as a low-input, safe, and environmentally friendly agricultural practice for improving potato productivity and quality.

Declarations

This study was presented at the 7th International Anatolian Agriculture, Food, Environment and Biology Congress, (Kastamonu, TARGID 2024)

Author Contribution Statement

Arif ŞANLI: Project administration, supervision, formal analysis, and writing the original draft

Gamze CANSEVER: Data collection, conceptualization, methodology

Fatma Zehra OK: Data collection, investigation, review and editing

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Conflict of Interest

The authors declare no conflict of interest.

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