

The Interaction Effect of Nitrogen and Potassium Fertilization on Potato (*Solanum tuberosum* L.) Yield

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ARTICLE HISTORY

Received 11 August 2026
Revised 24 September 2026
Accepted 01 October 2026
Online 07 October 2026

KEYWORDS

Potato yield;
Nitrogen fertilization;
Potassium fertilization;
Nutrient interaction;
Libya.

ABSTRACT

Potato (*Solanum tuberosum* L.) is a globally important food crop, requiring balanced nutrient management to achieve high yield and quality. Nitrogen (N) and potassium (K) are two essential macronutrients where interaction plays a critical role in tuber development. This study was conducted at the Agricultural Research Station, University of Tripoli, Libya, to evaluate the effects of different nitrogen and potassium application rates and their interaction on potato yield. A split plot design with three replications was used, testing four nitrogen levels (0, 150, 225, and 300 kg N/ha) and three potassium levels (0, 150, and 300 kg K₂O/ha). Results showed that yield increased progressively with higher nitrogen rates, while potassium application further improved this response. The highest yield (36.8 t/ha) was obtained at the combined application of 300 kg N/ha⁻¹ and 300 kg K₂O/ha. Nitrogen application under zero potassium conditions produced comparatively lower yields, confirming that potassium enhances nitrogen use efficiency. Overall, the findings highlight that potato yield is maximized not through isolated nutrient application but through balanced N-K management. This study provides evidence for precision fertilization strategies that improve productivity, tuber quality, and sustainability under Libyan agro ecological conditions.

تأثير التفاعل بين التسميد النيتروجيني والبوتاسي على محصول البطاطس (*Solanum tuberosum* L.)

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المخلص	الكلمات المفتاحية
تعد البطاطس (<i>Solanum tuberosum</i> L.) من أهم المحاصيل الغذائية في العالم، ويعتمد تحقيق إنتاجية عالية وجودة جيدة على الإدارة المتوازنة للعناصر الغذائية. يُعتبر النيتروجين (N) والبوتاسيوم (K) من أهم المغذيات الكبرى، ويؤدي تداخلهما دوراً أساسياً في نمو وتطور الدرنات. أُجريت هذه الدراسة في محطة البحوث الزراعية بجامعة طرابلس - ليبيا، بهدف تقييم تأثير معدلات مختلفة من التسميد بالنيتروجين والبوتاسيوم وتداخلهما على إنتاجية البطاطس. استُخدم تصميم القطاعات المنشقة بثلاث مكررات، حيث تمت دراسة أربع مستويات من النيتروجين (0، 150، 225، 300 كجم N/هـ) وثلاث مستويات من البوتاسيوم (0، 150، 300 كجم K ₂ O/هـ). أظهرت النتائج أن زيادة معدلات النيتروجين أدت إلى ارتفاع تدريجي في الغلة، بينما عزز التسميد بالبوتاسيوم هذا التأثير بشكل ملحوظ. وسُجلت أعلى إنتاجية (36.8 طن/هـ) عند التداخل بين 300 كجم N/هـ و 300 كجم K ₂ O/هـ. كما أن التسميد بالنيتروجين في غياب البوتاسيوم أعطى إنتاجية أقل، مما يؤكد دور البوتاسيوم في تحسين كفاءة استخدام النيتروجين. تؤكد هذه النتائج أن تحقيق أعلى إنتاجية للبطاطس لا يتم عبر التسميد المنفرد، بل من خلال الإدارة المتوازنة للنيتروجين والبوتاسيوم. وتوفر هذه الدراسة دليلاً عملياً لاستراتيجيات التسميد الدقيق التي تعزز الإنتاجية وجودة الدرنات واستدامة الزراعة في الظروف البيئية الليبية.	محصول البطاطس التسميد النيتروجيني التسميد البوتاسي التفاعل بين العناصر الغذائية ليبيا

Introduction

Potato (*Solanum tuberosum* L.) is one of the world's most important food crops, ranking fourth after maize, rice, and wheat in terms of production and consumption. Its global significance extends beyond food security, as potato cultivation contributes substantially to rural incomes, industrial processing, and nutritional diversity [1-3]. With increasing demand for both fresh and processed products, the global potato processing market was valued at USD 40.97

billion in 2023 and is projected to grow substantially [4,5,6], underscoring the need to optimize yield and quality in sustainable agricultural systems.

Nitrogen (N) and potassium (K) are among the most critical macronutrients required for potato production [7-9]. Nitrogen plays a central role in vegetative growth, tuber initiation, and yield formation, but excessive application can reduce tuber dry matter and quality [10]. Potassium regulates water balance, carbohydrate translocation, and stress tolerance,

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https://doi.org/10.63318/waujpasv4i2_57

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while also influencing tuber quality traits such as specific gravity and starch content [11,12]. Although both nutrients are individually essential, their interaction is particularly important: adequate potassium supply enhances nitrogen use efficiency, while imbalances can lead to reduced productivity, poor tuber quality, and environmental losses [13].

Despite decades of research, the interaction between N and K fertilization in potato remains incompletely understood, especially under diverse agroecological conditions. Earlier studies often general potassium's effect on tuber dry matter [14], but recent findings suggest that outcomes depend strongly on fertilizer source, application rate, and soil characteristics [15]. Similarly, while nitrogen requirements are well established, defining economically optimum rates that maximize yield without affecting quality continues to be a challenge [16]. This difficulty highlights the need for context-specific studies that integrate both nutrients to refine fertilization strategies.

The aim of this study was to evaluate the effect of nitrogen and potassium fertilization, and their interaction, on potato yield. By quantifying yield responses and identifying optimal nutrient combinations.

Materials and methods

Study site selection

The experiment was conducted at the Agricultural Research Station of the Faculty of Agriculture, University of Tripoli, located at longitude 13°13'17" and latitude 32°50'17". The soil at the site is characterized by a light to medium texture, low organic matter content, and high pH levels due to the presence of calcium carbonate, as confirmed by pre-fertilization soil analysis Table (1).

Table 1: Some physical and chemical soil properties of soil before the starting the experiment

Parameter	Unit	Value	Reference
Sand	% (w\w)	78.0	Hydrometer method by [17], the soil texture was Sandy loamy
Silt	% (w\w)	12.0	
Clay	% (w\w)	10.0	
Bulk Density	g\cm ³	1.47	[17]
Organic matter	% (w\ w)	0.1	[18]
Total Nitrogen	% (w\w)	0.049	[19]
Mineral - N	ppm (mg\kg)	24.0	[20]
Available P	ppm (mg\kg)	11.0	[21]
Available K	ppm (mg\ kg)	40.8	[22]
Eq. CaCO ₃	% (w\w)	13.0	[23]
Soil pH (1:1)	--	7.54	[22]
Soil EC (1:1)	dS\cm	0.34	[22]
Cation Exchange Capacity	meq\100 g soil	7.0	[24]

Experiment design and field setup

The experiment was laid out in a field measuring 28 meters in length and 13 meters in width. Each experimental plot measured 2 × 2 m². Prior to planting, the soil was prepared through standard agricultural practices including plowing, leveling, and weed removal. These operations, along with irrigation, were maintained until harvest.

Soil sampling and preparation

Given the small size of the field and its status as uncultivated land, nine random soil samples were collected from depth of 0–25 cm. These were combined into three composite samples (each composed of three random subsamples) and sent to the laboratory for physical and chemical analysis.

Potato planting

Following soil preparation and plot division, certified seed tubers of the cultivar 'Taurus' were planted. Based on the supplier's recommendations and supervisor guidance, planting was done in rows spaced 75 cm apart, with 35 cm between plants within each row.

Irrigation and phosphorus fertilization

Sprinkler irrigation was used, with water application rates based on volumetric soil moisture content. Irrigation was scheduled every other day, adjusted for rainfall. To ensure optimal growth conditions, phosphorus fertilization was applied at a rate of 132 kg P₂O₅ ha⁻¹ using concentrated super-phosphate (46% P₂O₅), based on soil analysis and in accordance with [25]. The application was made in a single dose at planting.

Fertilizer Treatments

Commonly used fertilizers in Libya were used in this experiment:

Nitrogen fertilizer

Nitrogen was applied as urea (46% N) in a single dose after seedling emergence and the development of the fourth leaf. Four nitrogen levels were tested: 0, 150, 225, and 300 kg N ha⁻¹.

Potassium fertilizer

Potassium was applied as potassium sulfate (50% K₂O) in two doses: the first at planting and the second before flowering. Three potassium levels were tested: 0, 150, and 300 kg K₂O ha⁻¹.

Potato yield

Following 118 days of growth, which concluded the experimental period, the entire plot corresponding to each replicated nitrogen and potassium treatment combination was harvested to determine the total yield. The above-ground plant material (haulms) was removed, and potato tubers from the entire harvest area of each plot were carefully dug out, ensuring all marketable and non-marketable tubers were collected. These tubers were then cleaned of soil debris, weighed using a calibrated scale to obtain the total fresh weight in kilograms (kg) per plot, and this measurement was subsequently converted to a standard yield unit, typically tons per hectare (t ha⁻¹), to provide a consistent and scalable metric for statistical analysis of the interaction effects between the two applied nutrients.

Statistical analysis

A split-plot design within a completely randomized design (CRD) was used to ensure uniformity across experimental units, with three replications. Nitrogen treatments were assigned to main plots due to their primary importance, while potassium treatments were assigned to subplots. Data were analyzed using SPSS version 23 to determine treatment differences, and the Least Significant Difference (LSD) test was used to compare means for yield and other variables [26].

Results and Discussion

Effect of Nitrogen Fertilization on Potato Yield

Figure 1 shows the relationship between the nitrogen (N) application rate and potato yield. The data demonstrate a consistent, linear increase in yield with rising nitrogen levels across the entire treatments range (0 to 300 kgN ha). Yield values increased from a minimum of 26.0 ton\ha in the control treatment (0 kg N\ha) to a maximum of 35.3-ton ha⁻¹ at the highest application rate of 300 kg N\ha.

Linear regression analysis revealed a remarkably strong positive correlation between the nitrogen rate and crop yield.

The high coefficient of determination ($R^2 = 0.9778$) indicates that 97.78% of the variation in potato yield can be explained by the nitrogen application rate, suggesting a highly predictable and consistent crop response under the experimental conditions.

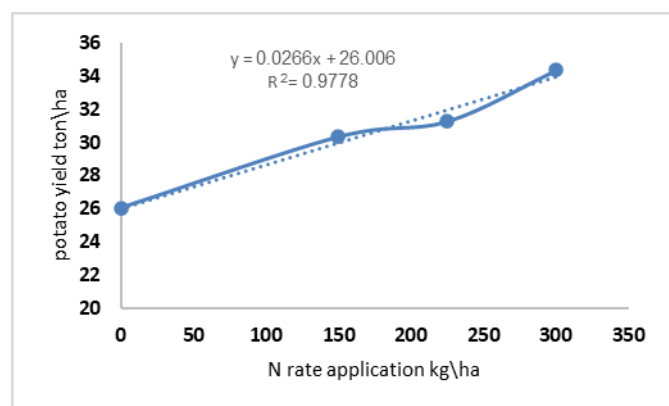


Figure 1: The effect of nitrogen application fertilizers on potato yield

This clear trend aligns with established agronomic principles establishing nitrogen as a primary limiting nutrient in potato production, directly governing vegetative growth, canopy development, tuber initiation, and overall sink capacity [10, 27]. Because the yield continued to climb linearly up to 300 kg N/ha, the crop remained highly responsive within this range without reaching a distinct plateau or exhibiting signs of excessive vegetative consumption or toxicity. While [16] reported an economically optimal nitrogen fertilizer rate (EONFR) range of 157–216 kg N/ha, the findings of this study suggest that specific local agroecological conditions and soil profiles can extend productivity benefits to higher application rates. This strong linear response likely reflects favourable soil health, high cultivar responsiveness, and optimized nutrient uptake.

Although high nitrogen rates maximize yield, potential trade-offs regarding tuber quality must be considered. As noted by [28] and [29] excessive nitrogen can delay tuber maturity and reduce dry matter content. Therefore, determining the final farmgate optimal rate must balance total volume against specific gravity requirements for processing or fresh markets. Future research should evaluate rates beyond 300 kg N/ha to locate the exact agronomic plateau.

Effect of Potassium Fertilization on Potato Yield

The relationship between the potassium (K) application rate and potato yield is presented in Figure 2. Similar to the nitrogen response, a strong positive correlation was observed as potassium application rates increased from 0 to 300 kg K₂O/ha. The plotted data points follow a highly linear trend ($R^2 = 0.9885$), confirming that potassium fertilization played a substantial role in enhancing productivity, with less than 2% of the variation left unexplained.

This prominent yield increase highlights the high potassium demand inherent to the potato crop, particularly for roles in carbohydrate translocation, stomatal regulation, and tuber bulking. The findings of this study corroborate those of [30] and [31], who reported that robust potassium nutrition enhances overall plant growth, water use efficiency, and tolerance to environmental stressors. Furthermore, recent precision fertilization research highlights that adequate

potassium stabilizes the rhizosphere microbiome, securing long-term soil productivity alongside immediate seasonal yield benefits [32].

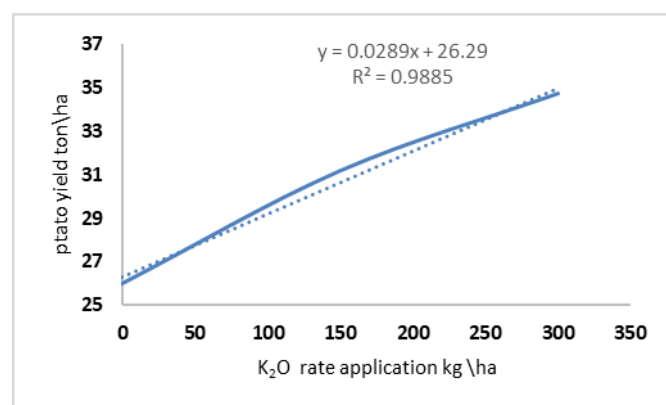


Figure 2: The effect of potassium fertilizer application on potato yield

Because potassium acts as a "quality nutrient," the positive yield response across the tested range (up to 300 kg K₂O/ha) implies concurrent improvements in tuber size distribution and starch accumulation. However, when adapting these findings into broader fertilizer recommendations, the potassium source must be factored in; potassium chloride (KCl) can sometimes depress tuber dry matter via chloride accumulation, whereas potassium sulfate (K₂SO₄) generally yields neutral or positive quality outcomes [11]. Ultimately, the steady yield climb observed here under increasing K levels cannot be viewed entirely in isolation; it heavily reflects potassium's capacity to facilitate the uptake and assimilation of other primary inputs, specifically nitrogen [13].

Interaction Between Nitrogen and Potassium Fertilization

The combined application of nitrogen and potassium revealed a clear, synergistic interaction rather than a merely additive effect. As illustrated in Figure 3, increasing nitrogen rates led to progressive yield increases at each individual potassium level. Reciprocally, higher potassium rates consistently amplified yield performance at every given nitrogen level.

The absolute highest yield was achieved at the maximum combined treatment of 300 kg N/ha and 300 kg K₂O/ha, establishing that optimal productivity is reached when both macros are comprehensively managed. Notably, the crop's yield response to increasing nitrogen was visually and statistically steeper when potassium was available at its maximum rate (300 kg K₂O/ha). Conversely, applying high nitrogen under zero-potassium conditions yielded comparatively poor results, demonstrating that a lack of available potassium severely handicaps the plant's capacity to utilize nitrogen efficiently.

Mechanistically, this synergy is driven by balanced source-sink dynamics. Nitrogen fuels the "source" accelerating vegetative canopy growth, leaf area index, and chlorophyll synthesis, while potassium drives the "sink" activating essential starch synthesizing enzymes, managing stomatal conductance, and facilitating the rapid loading and transport of those nitrogen derived photosynthates into developing tubers [11, 36]. Without adequate potassium, a high-nitrogen plant produces sugars that it cannot efficiently shift into the tubers, stalling yield potential.

The finding of this study observed synergy closely mirrors

the findings of [13], who demonstrated that elevated soil potassium statuses directly enhance nitrogen use efficiency (NUE) and overall potato productivity. Balanced N–K regimens also carry major economic weight by optimizing marketability; historical and recent trials alike show that integrated N–K applications significantly shift tuber size profiles away from small, unmarketable grades toward premium medium and large sizes [18, 37–39].

In summary, these results validate the rule that potato yield optimization cannot be achieved via isolated nutrient spikes. Maximizing agronomic output relies on integrated, site-specific N–K programs adjusted for localized soil fertility and target market criteria.

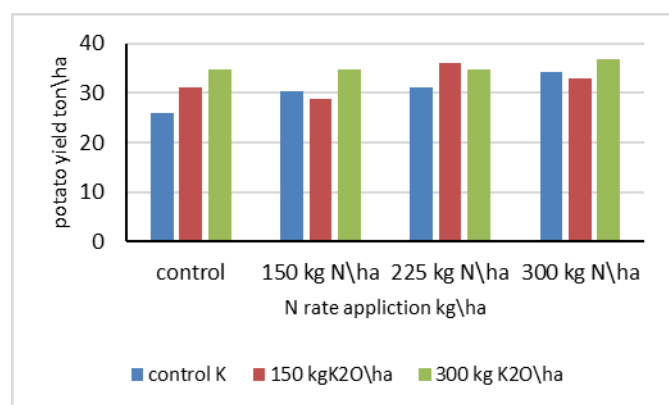


Figure 3: The effect of interaction between nitrogen and potassium rate application on potato yield

Recommendations

Based on the significant yield increases, strong linear relationships ($R^2 > 0.97$), and distinct nutrient synergies observed in this study, the following recommendations are made for potato cultivation and future research:

Practical Recommendations for Growers and Agronomists

Adopt Integrated N–K Management: Farm managers should abandon isolated nutrient applications. Because nitrogen and potassium exhibit a highly synergistic interaction, nitrogen fertilizers should always be balanced with corresponding potassium applications to maximize Nitrogen Use Efficiency (NUE) and prevent nutrient locking.

Target Balanced High-Rate Inputs: Under the specific agroecological conditions of this study, optimal productivity is achieved at the highest combined tested rates of 300 kg N/ha and 300 kg K₂O/ha. Growers targeting maximum yield volume should lean toward the upper thresholds of these ranges, provided soil moisture and health are non-limiting.

Factor in Fertilizer Sources and Target Markets: When implementing high potassium rates, practitioners must select the appropriate K source based on market requirements. For fresh consumption or industrial processing requiring high specific gravity, Potassium Sulphate (K₂SO₄) is recommended over Potassium Chloride (KCl) to safeguard tuber dry matter content from chloride-induced reductions.

Recommendations for Future Academic Research

Determine the agronomic and economic plateau: Because potato yields continued to increase linearly up to 300 kg N/ha and 300 kg K₂O/ha without reaching a plateau, future trials should expand the testing range to higher limits (e.g., up to 400 or 450 kg N/ha). This is critical to establishing the absolute agronomic maximum and calculating the Economically Optimal Rate of Nitrogen (EONFR).

Evaluate comprehensive tuber quality parameters: Future studies must deeply evaluate internal quality traits—such as dry matter percentage, specific gravity, hollow heart incidence, and starch-to-sugar ratios across these high-input ranges. This will ensure that maximizing sheer yield volume does not inadvertently degrade industrial processing quality.

Investigate multilocation and multi-seasonal variables: To validate these results for regional fertilizer frameworks, this experiment should be replicated across diverse soil textures (e.g., sandy vs. loamy soils) and varying irrigation regimes to chart how environmental stressors impact the N–K synergy.

Conclusion

This study demonstrated that both nitrogen and potassium fertilization significantly influence potato yield, with nitrogen driving vegetative growth and assimilate production, and potassium enhancing carbohydrate translocation, tuber bulking, and stress tolerance. Yield increased progressively with higher nitrogen rates, while potassium application further amplified this response, confirming its role as a “quality nutrient” essential for maximizing productivity. The highest yield was achieved at the combined application of 300 kg N/ha and 300 kg K₂O/ha, underscoring the synergistic effect of balanced N–K management.

These findings are consistent with recent research showing that adequate potassium supply improves nitrogen use efficiency and enhances tuber yield and quality [33, 35–36]. The interaction between N and K was not merely additive but synergistic, with the combined effect exceeding the sum of their individual contributions. This synergy highlights the importance of integrated nutrient management strategies that calibrate both N and K rates according to soil fertility, cultivar requirements, and market demands.

In practical terms, the results emphasize that fertilizer recommendations for potato should adopt a holistic approach, considering the interactive effects of nitrogen and potassium rather than treating them independently. Precision fertilization strategies such as split applications, fertigation, and the use of potassium sulfate for processing varieties can further optimize yield, improve tuber quality, and reduce environmental losses. Ultimately, balanced N–K management represents a cornerstone of sustainable potato production, ensuring high productivity, economic viability, and resilience in the face of growing global food demands.

Author Contributions: **Ksheem:** formulated the research objectives, developed the methodology, designed the experimental layout, interpreted the research findings, and wrote the complete manuscript. **Kara:** contributed to executing the field experiment and conducting the chemical laboratory analyses. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: “The authors declare no conflict of interest.”

Data Availability Statement: “The data are available at request OR Not applicable.”

Funding: “This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. However, Rouad Altheqa for Agricultural Development and investment provided support in the form of potato seeds and fertilizers, which contributed to the successful execution of the experimental work.”

Acknowledgement: “The authors gratefully acknowledge the financial and technical support provided by Rouad Altheqa for Agricultural Development, which supplied potato seeds

and fertilizers essential for conducting this research. The contribution of the company was instrumental in facilitating the experimental work. The corresponding author also wishes to acknowledge Mr. Suhil Kara, who carried out all field operations and laboratory analyses, ensuring the successful completion of this study. The authors declare that there are no conflicts of interest related to this support."

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