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RESEARCH ARTICLE

Effect of soil amendments and nano and conventional nitrogen on potato yield and tuber quality

Wissam Hameed Abed[1*] & Bassam Ramadhan Sarheed[2]

[1]Department of Soil Science, College of Agriculture, University of Anbar, Karma 31013, Iraq
[2]Department of Soil Science, College of Agriculture, University of Anbar, Ramadi 31001, Iraq

*Correspondence email - wis23g2008@uoanbar.edu.iq

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Abstract

Soil amendments improve the chemical and fertility properties of soil, such as soil pH and cation exchange capacity and chelate nutrients, especially nitrogen, thereby preventing their loss through leaching or volatilisation. A field trial was conducted during the spring growing season of 2025 in soil with a silty loam texture to evaluate the effects of soil amendments, namely zeolite, perlite, palm frond residues and palm frond biochar in combination with different levels were symbolised as A1, A2, A3, A4 and A0 respectively, and forms of nitrogen (100 % conventional urea), (50 % conventional urea), (100 % nano nitrogen) and (50 % nano nitrogen) which were symbolised as N1, N2, N3, N4 and N0 respectively. The study aimed to assess several yield and quality parameters of potato using a randomised complete block design (RCBD) with 3 replicates (75 experimental units). Statistical analysis revealed that biochar produced the highest mean values for dry matter percentage, starch percentage in tubers, average weight of marketable tuber and marketable yield, with values of 18.40 %, 12.40 %, 112.98 g tuber^{-1} and 42.592 mg ha^{-1} respectively. Palm frond residues resulted in the highest protein percentage (11.43 %). The nitrogen treatment with 100 % nano nitrogen produced the highest average dry matter percentage, starch percentage and protein percentage in tubers, average weight of marketable tuber and marketable yield (19.28 %, 13.18 %, 15.40 %, 119.30 g tuber^{-1} and 47.777 mg ha^{-1} respectively). Overall, the results demonstrated the superiority of biochar and nano-nitrogen treatments.

Keywords: conventional nitrogen; nano-nitrogen; potato; soil amendments

Introduction

Soil amendments are those components added to soil that leads to physical, chemical and biological improvements in soil, thereby enhancing mineral uptake efficiency and plant growth. These materials include biochar, organic waste, zeolite and perlite. By improving soil structure, amendments enhance soil aeration and water-holding capacity; reduce compaction and promote microbial activity. They also improve soil pH, facilitate nutrient release and prolong nutrient availability plants (1). Previous studies have shown that zeolite application significantly improves soil nitrogen availability and crop performance (2).

Nitrogen is one of the most essential nutrients required by plants in large amounts. It is a fundamental component of amino acids that build proteins and is also related to chlorophyll compounds responsible for the photosynthesis process. In addition, nitrogen plays a key role in the synthesis of nucleic acids (deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)) as well generating energy compounds (adenosine triphosphate (ATP)). Nitrogen poses a vital effect on promoting vegetative growth of plants, as its adequate supply can increase plant height, leaf area, stem length and number of branches which facilitate enhanced photosynthetic output. It is also a critical factor in the synthesis of enzymes and plant hormones, which directly expresses growth promotion and yield improvement. Nitrogen deficiency results in stunted growth, chlorosis of leaves and weak plant structure.

Thus, nitrogen is a central element in all vital processes, and its balance affects both the quantitative and qualitative growth of crops. Previous research explained that the application of nitrogen from different sources and at various concentrations improved all studied traits, while the nano-nitrogen treatment (3), Nn3 at a level of 45 kg N ha^{-1}, showed superiority over other treatments by producing the highest values for several traits, including chlorophyll content, plant height, dry matter yield of above- ground organs, total tubers yield and total number of tubers. The nano-fertilisation treatment Nn3 at the rate of 45 kg N ha^{-1} achieved the greatest fertilisation efficiency for production, reaching 68.89 %, whereas the nano-fertilisation treatment Nn1 at the rate of 15 kg N ha^{-1} achieved the highest nitrogen use efficiency, reaching 82.47 %.

Potato (*Solanum tuberosum* L.) is a member of the Solanaceae family and is classified as a tuber crop. It ranks fourth in terms of economic and consumption importance after wheat, rice and maize and is considered one of the main crops in the global food system. This is mainly due to its nutritional value as a food source rich in energy, proteins, carbohydrates, starch, essential amino acids, as well as important minerals required for human nutrition (4). The aim of this study was to evaluate the effects of organic and mineral soil amendments combined with different levels of nano and conventional nitrogen fertilisers on the yield and quality of potato.

Materials and Methods

This trial was carried out at the Agriculture Research Station (No.1), College of Agriculture, Anbar University, located in the Ramadi District under the Agricultural Research Division of the Ministry of Agriculture, in Anbar Governorate. The experimental site is situated at 33.45° N latitude and 43.33° E longitude. The study was carried out during the spring season of 2025 in soil with a silty loam texture.

Soil sample collection

Soil samples were collected from the field before planting from 10 different locations at a depth of 0–0.30 m. A composite sub-sample of soil was taken and then passed through a 2 mm sieve for determination of its physical and chemical properties (Table 1).

The land was ploughed to a depth of 0.30 m using a moldboard plough followed by soil smoothing and leveling. The field was then divided into 3 similar blocks. Planting was performed on ridges 6 m long and 0.75 m wide, keeping a space of 1 m among experimental units and between blocks, to avoid overlap of fertiliser treatments.

Study factors and the experimental design used

A factorial experiment arranged in a randomised complete block design (RCBD) with 3 replicates was used for the two factors, which included:

First factor

Levels of nano and conventional nitrogen fertilisers, which included 100 % conventional urea (300 kg ha^{-1}), 50 % conventional urea (150 kg ha^{-1}), 100 % nano nitrogen (25 L ha^{-1}) and 50 % nano nitrogen (12.5 L ha^{-1}), in addition to the control treatment, which were symbolised as N1, N2, N3, N4 and N0 respectively. All nitrogen treatments were applied to the soil after the addition of the specified soil amendments (5).

Second factor

Soil amendments applied at a rate of 5 mg ha^{-1}, namely zeolite, perlite, palm frond residues and palm frond biochar, in addition to the control treatment and treatments were symbolised as A1, A2, A3, A4 and A0 respectively. Thus, there were 25 treatments and 75 experimental units. Table 2 presents selected characteristics of the applied soil amendments.

The chelated nano fertilisers used in the experiment was sourced from KHADRA (Green) company for nano fertiliser production and contained 17 % nitrogen, with the product of Iranian origin.

Method of application

After calculating the required quantities of fertilisers and amendments, the fertilisers were dissolved in water and enriched or saturated with amendments, then prepared solution was added to the soil one day before planting.

Planting

Potato tubers of the cultivar Burren potato were planted on 25/01/2025. Two weeks prior to planting, the tubers were taken out from cold storage to break the dormancy period. Tubers that appeared healthy and were free from deformities, mechanical damage injured or rot were selected for planting. The potatoes were planted in a single row per experimental unit, with each potato spaced 25 cm apart. A total of 24 potato tubers were in each experimental unit.

Monthly climatic data (maximum and minimum air temperature, rainfall and day length) were compiled for the experimental period and are presented in the climatic data table (Table 3).

Table 1. Some physical and chemical properties of the soil before planting

Property	Value	Unit	Property	Value	Unit
Electrical conductivity (EC)	3.22	dS m^{-1}	Bulk density	1.30	mg m^{-3}
Soil reaction (pH)	7.8	—	Particle density	2.54	mg m^{-3}
Organic matter	6.30	g kg^{-1}	Sand	22.5	%
Lime ($CaCO_3$)	125.0	g kg^{-1}	Silt	61.5	%
Gypsum	5.20	g kg^{-1}	Clay	16.0	%
Available nitrogen	14.0	mg kg^{-1}	Texture class	Silty loam	—
Available phosphorus	9.5	mg kg^{-1}	Cation exchange capacity (CEC)	18.0	cmolc kg^{-1} soil
Available potassium	180.0	mg kg^{-1}			

Table 2. Some properties of the added amendments

Property	Types of amendments				Unit
	Zeolite	Perlite	Date palm frond waste	Biochar of date palm fronds	
EC	0.68	1.32	10	7.5	dS m^{-1}
pH	7.60	6.5–7.5	7.4	7.3	-
CEC	74.2	24.1	21.7	43	cmol kg^{-1}
Total nitrogen	—	—	8.13	5.60	%
Available phosphorus	—	—	3.5	6.10	mg kg^{-1}
Available potassium	—	—	220.8	112.28	mg kg^{-1}

Table 3. Monthly climatic data associated with agricultural production (temperature, rainfall and day length)

Month	Max temp (°C)	Min temp (°C)	Rainfall (mm)	Day length (hr)
February	19	6	30	11.1
March	23	11	25	12
April	29	16	25	13
May	35	21	3	13.9

Crop management practices

Irrigation

Irrigation was carried out using a fixed sprinkler irrigation system to maintain soil moisture in the root zone field capacity levels, depending on the amount lost from the evaporation pan (6). The number of irrigations, applied water depth, leaching water depth, water volume and total irrigation water depth for each growth stage are shown in the irrigation table (Table 4).

Weeding

Weeding of the field was conducted whenever necessary using manual hand tools.

Disease control

Late blight caused by *Phytophthora infestans* was controlled using the fungicide meromyl M fungicide (mancozeb 64 % + metalaxyl 8 %) at a dose of 200 g/100 L of water with two preventive applications. The first application was applied 45 days after germination and the second was applied 10 days after the first application.

Quality yield traits

Dry matter percentage in tubers

Five tubers were taken randomly from plants in the middle ridge of each experimental unit. The tubers were washed with tap water followed by distilled water, sliced and then dried in an electric oven at a temperature of 70 °C until a constant weight is obtained, as mentioned previously (7). After removal from the oven, the samples were weighed and the dry matter percentage was determined using the following formula:

Dry matter (%) = (Dry weight of tubers/ total weight of tubers) × 100

Protein percentage in tubers

Protein percentage was calculated on a dry weight basis using the following equation (8):

Protein (%) based on dry weight = Percentage of nitrogen in tubers × 6.25

Starch percentage in tubers

This was calculated using the following equation (8):

Starch (%) = 17.55 + 0.89 (% dry matter–24.18)

Yield traits

Average weight of tubers (gm)

This was calculated by dividing the yield weight in the experimental unit by the number of tubers produced in the same experimental unit using the following equation:

Average tuber weight = Yield of the experimental unit /Number of tubers in the experimental unit

Marketable yield of tubers (Mg ha^{-1})

This was calculated based on the yield obtained from plants within each experimental unit, after excluding infected, deformed and small tubers with a diameter of less than 2.5 cm and was expressed per ha (9). The yield per ha was then calculated as follows:

Marketable production = Marketable yield per plant × Number of plants per ha

Statistical analysis

The results were statistically analysed using Genstat 12 program to determine the least significant difference (LSD) at a significance level of 0.05 for comparing treatments within the RCBD.

Results and Discussion

Quality traits

Percentage of dry matter in tubers (%)

The results presented in Table 5 demonstrate that various soil amendments, forms and levels of nitrogen and their interactions affected the percentage of dry matter in potato tubers. Significant differences were observed among all amendment treatments. The biochar addition treatment (A4) recorded the highest mean value of 18.40 % compared with the control treatment (A0), which recorded the least mean value of 16.01 %, representing an increase of 14.93 %. This superiority may be attributed to the role of biochar in improving soil fertility by providing nutrients and preventing their loss through leaching, enhancing the activity of beneficial microorganisms and increasing the soils' water-holding capacity. These effects improve plant nutrient uptake and consequently increase the dry matter percentage in tubers (10).

The results also showed significant differences among the different forms and levels of N applied in combination with soil amendments with respect to tuber dry matter percentage. The N3 treatment recorded the highest mean value (19.28 %) compared with the control treatment (N0), which recorded 15.00 %, representing an increase of 28.53 %. The increase in tubers dry matter may be attributed to the role of nitrogen in enhancing cell division and cell growth. In addition, nano-fertilisers provide a continuous supply of nitrogen in a manner compatible with plant growth requirements, which increases chlorophyll formation and the efficiency of photosynthesis leading to greater accumulation of dry matter (11).

The results also showed significant effects of the interaction between soil amendments and the different forms and levels of nitrogen compared with all treatments. The interaction treatment A4N3 recorded the highest mean dry matter percentage in tubers (20.76 %) compared with the controlled treatment (14.08 %), representing an increase of 47.44 %. This interaction between biochar and nano-nitrogen enhances nitrogen utilisation efficiency and improves carbon metabolism, which increases the

Table 4. Irrigation schedule and water application components across growth stages

Growth stages	Total water volume (m^3 ha^{-1})	Water volume (m^3 ha^{-1})	Leaching water depth (m)	Added water depth (m)	Number of irrigations
Pre-emergence stage	1106.7	1054	0.000527	0.01054	10
Vegetative growth stage	247.38	235.6	0.000589	0.01178	2
Tuber initiation stage	540.54	514.8	0.000858	0.01716	3
Tuber bulking stage	914.76	871.2	0.001089	0.02178	4
Maturity stage	526.68	501.6	0.001254	0.02508	2
Total	3336.06	3177.2	0.004317	0.08634	21

Table 5. Effect of some soil amendments and nitrogen forms and levels on dry matter percentage (%)

Nitrogen levels	Amendment types					Mean N
	No addition (A0)	Zeolite (A1)	Perlite (A2)	Date palm frond waste (A3)	Biochar of date palm fronds (A4)	
No addition (N0)	14.08	14.45	14.91	16.81	14.74	15.00
100 % N (urea) (N1)	17.11	18.72	18.26	18.77	19.68	18.51
50 % N (urea) (N2)	15.06	17.02	16.05	17.52	18.21	16.77
100 % N (nano) (N3)	17.59	19.49	18.33	20.23	20.76	19.28
50 % N (nano) (N4)	16.22	18.39	17.22	18.14	18.63	17.72
Mean amendments	16.01	17.61	16.95	18.29	18.40	
LSD (0.05)	N 0.328		A 0.328		N×A 0.734	

accumulation of solid compounds (starch and proteins) and thus raises the percentage of dry matter in tubers (12).

Starch percentage (%)

Based on the statistical analysis in Table 6, soil amendments, forms and levels of nitrogen and their interaction had significant effect on the starch percentage in potato tubers. Significant differences were observed among the amendment treatment. Treatment A4 recorded the highest mean starch percentage (12.40 %) compared with the control treatment A0, which recorded the lowest mean value (10.27 %), representing an increase of 20.74 %. This increase may be attributed to the role of biochar in improving soil properties, enhancing nutrient uptake efficiency and promoting photosynthesis. These effects facilitate the conversion of sugar into starch within potato tubers, thereby increasing the starch percentage in the yield (13).

The results in Table 6 also indicated significant differences among the different forms and levels of nitrogen applied in combination with soil amendments with respect to starch percentage. Treatment N3 produced the highest mean value (13.18 %) compared to the control treatment (N0), which had the lowest mean value (9.37 %), representing an increase of 40.66 %. The increase in nitrogen availability enhances photosynthesis efficiency and sugar production, which promotes their accumulation in storage organs and their conversion into starch. This effect may also be attributed to the slow-release characteristics of nano-nutrient fertilisers that have a high absorption ratio and expanded surface area for various metabolic reactions within the plant. All of this increases carbon assimilation rates, thereby stimulating the production of dry matter in the aerial parts and tubers, and consequently increases starch percentage (14). These findings are consistent with those reported in (15).

The results also showed a significant effect of the two-way interaction between soil amendments and nitrogen forms and levels. The treatment involving the addition of biochar with 100 % chelated nano nitrogen (A4N3) recorded the highest mean starch percentage (14.50 %) compared with the control treatment (A0N0), which recorded the lowest mean value (8.55 %), representing an increase of 69.59 %. The observed increase in starch content in potato tubers following the application of biochar and nano-nitrogen may be attributed to their complementary and synergistic effects. Biochar enhances soil fertility and nitrogen retention, whereas nano-nitrogen improves nitrogen uptake and its efficient assimilation within plant tissues. Consequently, these combined effects stimulate photosynthetic activity and activate key enzymes involved in starch biosynthesis, leading to greater starch accumulation in the tubers (16).

Protein percentage in tubers (%)

The results presented in Table 7 revealed that soil amendments, nitrogen forms and levels and their interaction significantly affected the protein percentage in potato tubers. Significant differences were observed among the amendment treatments. The organic residue treatment (A3) recorded the highest mean protein percentage (11.43 %) compared with the control treatment (A0), which recorded the lowest mean value (9.42 %), showing a rise of 21.34 %. This is because the organic residues decompose gradually and release mineral nitrogen in a stable manner, which ensures continuous nutrition for the plant. Since protein formation primarily depends on nitrogen-containing amino acids, the prolonged availability of nitrogen for a long period increases the plants' ability to synthesise proteins in leaves and tubers, as well as through improving the activity of nitrogen-fixing microorganisms (17). These results are consistent with those reported in previous study (18).

The results also showed significant differences among the various forms and levels of nitrogen supported by amendments with respect to tuber protein percentage. Treatment N3 recorded the highest mean protein percentage (15.40 %) compared with the control treatment (N0), which recorded 5.02 %, representing an increase of 206.77 %. This increase may be attributed to the role of nitrogen fertilisers in enhancing the nutritional content of crops, improving taste quality and increasing protein synthesis. Adequate nitrogen availability, particularly at the level of 100 % nano nitrogen,

Table 6. Effect of some soil amendments and nitrogen forms and levels on starch percentage (%)

Nitrogen levels	Amendment types					Mean N
	No addition (A0)	Zeolite (A1)	Perlite (A2)	Date palm frond waste (A3)	Biochar of date palm fronds (A4)	
No addition (N0)	8.55	8.88	9.29	10.98	9.13	9.37
100 % N (urea) (N1)	11.25	12.68	12.28	12.73	13.54	12.49
50 % N (urea) (N2)	9.42	11.17	10.30	11.61	12.23	10.95
100 % N (nano) (N3)	11.67	13.37	12.34	14.03	14.50	13.18
50 % N (nano) (N4)	10.46	12.39	11.35	12.17	12.60	11.79
Mean amendments	10.27	11.70	11.11	12.30	12.40	
LSD (0.05)	N 0.292		A 0.292		N×A 0.654	

Table 7. Effect of some soil amendments and nitrogen forms and levels on protein percentage in tubers (%)

Nitrogen levels	Amendment types					Mean N
	No addition (A0)	Zeolite (A1)	Perlite (A2)	Date palm frond waste (A3)	Biochar of date palm fronds (A4)	
No addition (N0)	4.02	6.04	5.10	5.23	4.69	5.02
100 % N (urea) (N1)	11.19	15.00	13.54	12.71	13.54	13.20
50 % N (urea) (N2)	10.31	7.71	8.75	8.75	10.94	9.29
100 % N (nano) (N3)	11.56	16.04	15.42	17.50	16.46	15.40
50 % N (nano) (N4)	10.00	10.21	11.46	12.94	11.15	11.15
Mean amendments	9.42	11.00	10.85	11.43	11.36	
LSD (0.05)	N 0.697		A 0.697		N×A 1.559	

promotes vegetative growth and increases leaf area, which raises the efficiency of nutrient uptake and vital processes within the plant. This leads to increased synthesis and translocation of nutritional compounds to the tubers, resulting in a higher protein percentage (19).

The results also indicated a significant interaction between soil amendments and nitrogen forms and levels. The treatment combining organic residues with 100 % chelated nano nitrogen (A3N3) recorded the highest mean protein percentage in tubers, reaching 17.50 %, compared with the control treatment 4.02 %, representing an increase of 335.32 %. This effect may be attributed to the synergistic interaction between the high availability of nano-nitrogen supplied by the fertiliser and the ability of organic residues to enhance water retention and nutrient uptake efficiency. The increased nitrogen availability stimulated vigorous vegetative growth, whereas the organic amendments improved soil moisture conservation and sustained nutrient accessibility. Collectively, these factors prolonged physiological activity, facilitating greater remobilisation of nitrogen from vegetative tissues (leaves and stems) to the developing fruits, where they were subsequently assimilated into proteins during the ripening stage (20).

Yield traits

Average weight of marketable tuber (g tuber^{-1})

Table 8 shows the effects of various soil amendments, nitrogen formulations and levels, and their interactions on the average weight of marketable tubers in potato plants. Significant differences were observed among amendment treatments. The biochar treatment A4 recorded the highest mean value (112.98 g tuber^{-1}) compared with the control treatment (A0), which recorded the lowest mean value (96.32 g tuber^{-1}), with a rise of 17.30 %.

The results also indicated significant differences among the different forms and levels of nitrogen applied in combination with soil amendments with respect to the average weight of marketable tubers. N3 treatment outperformed with the highest mean of 119.30 g tuber^{-1} compared to N0, which achieved the lowest mean value of 91.68 g tuber^{-1}, with an increase of 30.13 %.

The results also indicated a significant interaction between soil amendments and nitrogen forms and levels was also observed. The treatment combining biochar with 100 % chelated nano nitrogen (A4N3) recorded the highest mean marketable tuber weight, reaching 139.10 g tuber^{-1} compared with the control treatment 86.40 g tuber^{-1}, with an increase of 60.99 %.

Marketable yield (mg ha^{-1})

Statistical analysis in Table 9 revealed that soil amendments, nitrogen forms and levels and their interactions significantly affected the marketable yield of potato. A major difference between all amendments was observed. The biochar treatment A4 recorded the highest mean yield (42.592 mg ha^{-1}) compared with the control treatment (A0), which recorded the lowest mean yield (33.511 mg ha^{-1}), with an increase of 27.10 %.

The results also revealed significant differences among the

Table 8. Effect of some soil amendments and nitrogen forms and levels on average weight of marketable tuber (g tuber^{-1})

Nitrogen levels	Amendment types					Mean N
	No addition (A0)	Zeolite (A1)	Perlite (A2)	Date palm frond waste (A3)	Biochar of date palm fronds (A4)	
No addition (N0)	86.40	92.80	97.40	87.50	94.30	91.68
100 % N (urea) (N1)	97.70	116.80	102.50	118.50	114.50	110.00
50 % N (urea) (N2)	94.50	102.90	94.50	93.70	106.60	98.44
100 % N (nano) (N3)	102.90	116.40	105.50	132.60	139.10	119.30
50 % N (nano) (N4)	100.10	102.40	103.10	104.50	110.40	104.10
Mean amendments	96.32	106.26	100.60	107.36	112.98	
LSD (0.05)	N 6.770		A 6.770		N×A 15.13	

Table 9. Effect of some soil amendments and nitrogen forms and levels on marketable yield (Mg ha^{-1})

Nitrogen levels	Amendment types					Mean N
	No addition (A0)	Zeolite (A1)	Perlite (A2)	Date palm frond waste (A3)	Biochar of date palm fronds (A4)	
No addition (N0)	28.667	30.370	28.889	33.333	31.111	30.474
100 % N (urea) (N1)	33.333	45.185	31.111	40.370	50.741	40.148
50 % N (urea) (N2)	32.592	37.037	32.222	38.148	34.074	34.814
100 % N (nano) (N3)	37.037	52.593	40.370	48.889	60.000	47.777
50 % N (nano) (N4)	35.926	40.000	38.148	41.852	37.037	38.592
Mean amendments	33.511	41.037	34.148	40.518	42.592	
LSD (0.05)	N 2.663		A 2.663		N×A 5.955	

different forms and levels of nitrogen applied with soil amendments. Treatment N3 recorded the highest mean marketable yield (47.777 mg ha^{-1}) compared to N0, which recorded the lowest mean yield (30.474 mg ha^{-1}), with an increase of 56.78 %.

The results also indicate a significant two-way interaction between soil amendments and nitrogen forms and levels. The treatment combining biochar with 100 % chelated nano nitrogen (A4N3) recorded the highest mean marketable yield (60.000 mg ha^{-1}) compared to A0N0, which recorded the lowest mean value (28.667 mg ha^{-1}), with an increase of 109.30 %.

The results presented in Tables 8 and 9 showed the superiority of biochar in improving both average marketable tuber weight and marketable yield. This superiority may be attributed to the ability of biochar to improve the root environment, enhance soil nutrition and water retention and enhance microbial activity, which collectively contributes to the formation of larger and higher-quality tubers (21).

The increase in production with increasing nitrogen levels may also be attributed to the greater availability of nitrogen in the soil and its enhanced uptake and utilisation within the plant. These effects improve vegetative growth indicators, which subsequently lead to improved yield components (22). The superiority of the 100 % chelated nano nitrogen treatment (N3) may be attributed to the advantages of nano fertilisers, which release nutrients more slowly than conventional fertilisers. This slow release delays the nitrification process and the conversion of ammonium into nitrite and subsequently to nitrate. In addition, nano-fertilisers have unique chemical and physical properties that enhance nutrient efficiency. The higher concentration applied in treatment N3 gave a higher yield compared with treatment N4 (23).

This effect can be attributed to the interaction between the two factors examined in the study. Biochar reduces nitrogen loss through leaching and volatilisation, thereby enhancing nitrogen use efficiency. The sustained availability of nitrogen, combined with the improved root environment provided by biochar, promotes better vegetable growth and ultimately leads to increased yield (24).

Conclusion

The results indicated that the type of soil amendment and the form and level of nitrogen significantly influenced the quality and marketable yield of potato tubers. Overall, the palm frond biochar amendment produced the most favourable response, recording significantly higher tuber dry matter and starch content, as well as greater average weight of marketable tubers and marketable yield compared with other treatments. In contrast, the highest tuber protein content was observed with palm frond residues. The application of 100 % nano nitrogen was superior to all conventional nitrogen treatments for all the studied traits. The combined treatment A4N3 (biochar + 100 % nano nitrogen) proved to be the most effective for enhancing productivity and most quality traits, whereas A3N3 (palm frond residues + 100 % nano nitrogen) resulted in the highest protein percentage. Therefore, it is recommended that farmers utilise soil amendments to preserve nutrient retention and availability. Furthermore, additional studies are suggested to investigate the effect of soil amendments, particularly biochar, on various crops and supplement them with other essential nutrients besides nitrogen.

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Authors' contributions

WHA participated in design and conduction of the field experiment, collection analysis of the data and drafted the original manuscript. BRS provided the supervision, reviewed the experimental design, conducted the data interpretation and carried out manuscript revision. Both authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflicts of interest to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

Generative AI and AI-assisted tools were used to support language editing and improve clarity and grammar. The authors confirm that these tools were not used to generate or manipulate research data, conduct statistical analyses, or alter the scientific interpretation of results. After using this tool/ service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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