PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.2706

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RESEARCH ARTICLE

Biochar-based organic amendments on soil health, nutrient status and quality of potato (*Solanum tuberosum*)

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OPEN ACCESS

ARTICLE HISTORY

Received: 05 June 2023
Accepted: 23 August 2023

Available online
Version 1.0 : 14 October 2023

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE

Singh J, Kumar P, Siddique A. Biochar-based organic amendments on soil health, nutrient status and quality of potato (*Solanum tuberosum*). Plant Science Today (Early Access). https://doi.org/10.14719/pst.2706

Abstract

Cultivation of quality potatoes ensures a good earning compared to low quality, especially in terms of tuber weight and starch content. Therefore, an experiment was laid out to find out the impact of an organic amendment based on the combinations of biochar, vermicompost, poultry manure, and bone meal for the enrichment of soil health and quality of potato crops at the research farm of Lovely Professional University, Punjab. The parameters of pH, EC, organic carbon, soil microbial biomass, nitrogen, phosphorus, potassium, labile carbon, and particulate organic carbon (POC) were used to understand the soil health improvement, while starch content and grading systems ranging from A to C were used for the quality of the potato. Among the treatments, most of the parameters were recorded as statistically significant at $p>0.05$. The highest improvement in terms of pH, EC, organic carbon, soil microbial biomass, nitrogen content, labile carbon, and particulate organic carbon (POC) was recorded in T_3 (7.58, 0.39 dSm^{-1}, 0.53 %, 333.3 µg g^{-1}, 198.3 kg ha^{-1}, 3.71 and 7.0 g kg^{-1} of soil) compared to T_0 (7.38, 0.32 dSm^{-1}, 0.44 %, 325.33 µg g^{-1}, 171.5 kg ha^{-1}, 2.33 and 3.0 g kg^{-1} g kg^{-1}), while the phosphorus and potassium contents were estimated highest in T_2 (17.4 and 255 kg ha^{-1}). The quality parameters like starch content and grading quality of potato tubers were also influenced positively and estimated significantly highest in T_3 (53.60 % and 153.7 q ha^{-1} of A grade potato). This study has shown the potential to improve the quality of potato tuber by providing a desirable soil environment to coordinate with potato plants.

Keywords

Biochar; labile carbon; organic carbon; particulate organic carbon; potato; starch

Introduction

Crop production enhancement and soil health are equally important in agriculture, providing additional benefits to the soil for a good harvest, because healthy soil is the backbone of a healthy harvest (1). Organic amendments based on biochar have been considered for a long time to have a positive impact on soil health and crop growth, which is a carbon-rich material produced by heating organic biomass in anoxic conditions (2, 3). It has a porous structure that can help to retain moisture in the soil, which is especially useful in dry regions. It also improves soil structure and consistency by increasing the amount of stable organic matter, soil aeration, and reclaiming soil by reducing soil erosion in the soil (4, 5). It acts as a sponge for nutrients, holding onto them until they are needed by plants, while in turn, it reduces nutrient runoff and leaching, leading to better nutrient availability for plant growth (6).

Moreover, it provides a safe habitat for soil microbes that promote soil health and nutrient cycling (7). Hence, the influence of biochar-based organic amendment is not limited to the improvement in soil physical, biochemical, and biological factors but also improves the yield and quality of potato crops (3). Additionally, the amendment upgrades the quality of potato tubers and enhances the amount of starch in tubers while reducing some harmful compounds (8).

Vermicompost, poultry manure, and bone meal are excellent sources of major and micronutrients wherein vermicompost is beneficial to increase the porosity, bulk density, aeration, and water retention, while bone meal may increase the availability of calcium, which increases the length as well as strength of the roots (9).

Overall, the use of such a type of amendment may be a promising strategy for improving soil health, nutrient release efficiency, and the quality of potato crops. However, the effects may vary depending on factors such as the type of biochar used, application rate, and soil conditions. Therefore, consistent research is needed to fully understand the potential benefits and limitations of this approach.

Materials and Methods

Execution of research work

A field-based experiment was laid out over the research farm of Lovely Professional University during the *Rabi* season to evaluate the impact of organic amendments based on biochar on soil health improvement, nutrient release efficiency, and quality of potato tubers. Kufri Pukhraj, a popular variety of potatoes, was used along with a total of thirteen combinations of treatments, including 25% RDF, vermicompost, bone meal, poultry manure, and biochar, which were randomized in RBD. The organic-based resources were placed in the soil before the 15 days of sowing, while a 100% RDF was used as a control.

Soil sample analysis

Soil was collected from each plot through a tool called "soil sampling auger" before and after the planting of potato tubers to analyze the status of soil health in terms of pH and EC (dSm^{-1}) by using the instrument pH and EC meter (Model No LT-49 and Conductivity meter 306). To know the status of organic carbon, a standard protocol proposed by (10) was used, wherein 2 g of soil sample was placed in 500 ml of volumetric flask, and subsequently, 10 ml $K_2Cr_2O_7$, 20 ml H_2SO_4, 20 DW, 20 ml H_3PO_4 and 7-8 ml of diphenylamine indicator were added into them. The sample was titrated against the 0.2 N ferrous ammonium sulphate, while the amount of OC% was calculated as per the given formula:

$$\text{Organic carbon (\%)} = \frac{(\text{Blank reading - Final reading}) \times 0.003 \times 100}{2} \quad \text{.............(Eqn. 1)}$$

Soil microbial biomass carbon and nutrient status

Soil microbial biomass carbon ($\mu g\ g^{-1}$) was carried out as per (11), wherein 10 g of sample was fumigated with ethanol-free chloroform and extracted with 0.5 M K_2SO_4 by shaking them on a shaker for ½ an hour. The oxidized carbon in extracts was measured and expressed as per the DW basis (105^0 C for 24 h), while the amount of N, P, and K was estimated as per (12-14).

Labile carbon and particulate organic carbon

Labile carbon from the soil sample was estimated according to (15), which is based on permanganate oxidizable carbon, where 2 g of soil was centrifuged and oxidized with 25 ml of 0.33 M $KMnO_4$ by placing it on a shaker for 60 minutes. The change in concentration of $KMnO_4$ was used to estimate the amount of carbon oxidized by using the following formula. At the same time, the particulate organic carbon was analyzed as per (16).

$$\text{POXC (mg kg-1)} = \frac{(\text{B-S}) \times 50 \times \text{Volume of } KMnO_4 \times 1000 \times 9}{2 \times 1000 \times \text{Weight of soil}} \quad \text{.....................(Eqn. 2)}$$

Estimation of starch (%)

Starch content was analyzed as per (17), wherein 80% alcohol and perchloric acid were used to extract starch from potato tubers, and anthrone was used as an indicator. The amount of starch present in samples was determined by using a colorimeter, while the final value was presented in percent.

Determination of potato quality

The quality of potato tubers was analyzed by grading harvested potatoes, while the grades were based on the weight of the tuber A (>75 g), B (75-50 g), and C (<50 g).

Statistical analysis

The data received from the experiment units were subjected to statistical analysis to scrutinize the relevance of treatment combinations applied over the experimental unit. It is done by adopting the statistical design known as Randomized Block Design (RBD) through SPSS 21st version, while the significant difference exists among the treatments were extracted by employing the critical difference ($p<0.05\%$).

Results and discussion

Soil pH and electrical conductivity (dSm^{-1})

In the present piece of research work, we attempted to analyze the efficiency of biochar-based organic amendments on soil pH and electrical conductivity (dSm^{-1}). As per the results, it was depicted in Fig. 1 that both the parameters were noticed to be highly significant at $P<0.05$. Out of all the treatments, T_3 had the greatest improvement in soil pH (7.58) and EC (0.39 dSm^{-1}), followed by T6 (7.56 and 0.38 dSm^{-1}) compared to T_0 (7.38 and 0.32 dSm^{-1}). The data presented in parenthesis (Table 1), revealed the % increase (+) in soil pH and % increase/decrease (+/-) over

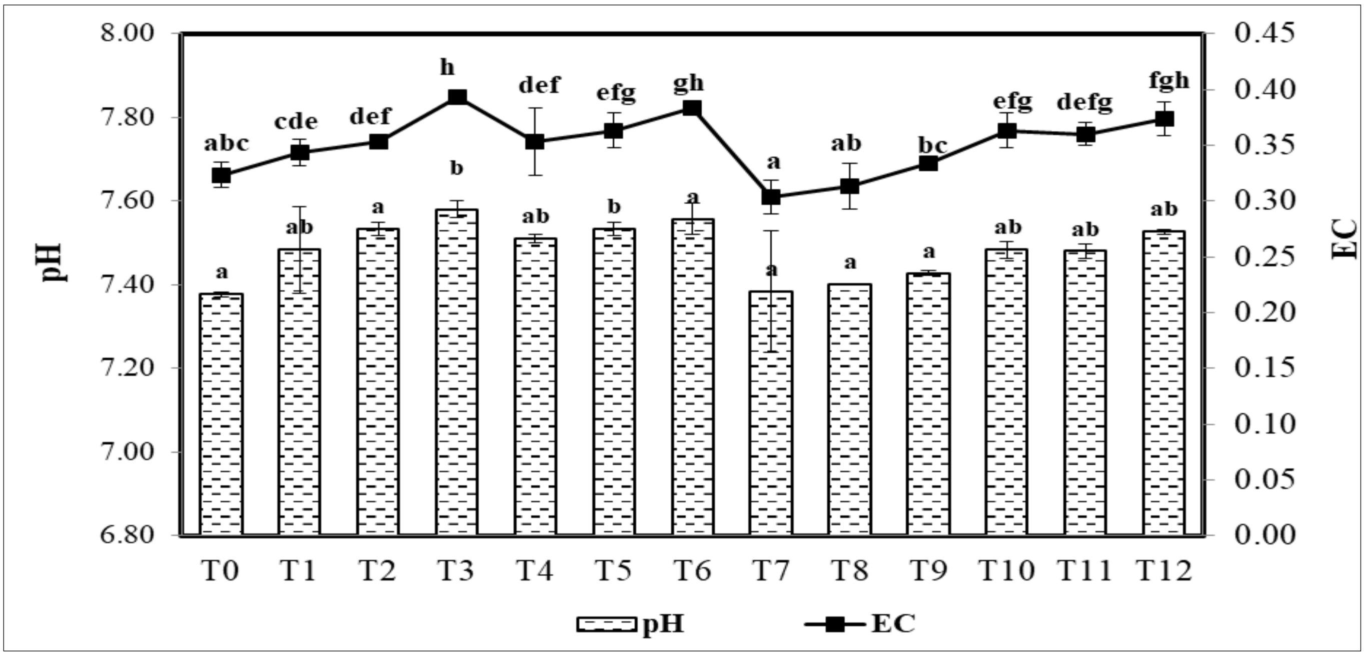

Fig. 1. Effect of organic amendments on pH and EC (dSm^{-1}) of the experimental unit.

control of EC due to the amendment of treatments, wherein the highest increase was in T_3 (2.68%), T_6 (2.38%), and T_2 (2.08%), respectively. The % increase in EC was recorded in T_3, T_6, and T_{12} at 17.80, 15.65 and 13.39% compared to the control, while the data in parenthesis also reveals the % decrease over the control in T_7 and T_8 at 6.59 and 3.19 % (Table 1).

highest gain in soil microbial biomass carbon (µg g^{-1}) was recorded in T_3 (333.3 µg g^{-1}), followed by T_2 (330.3 µg g-1) as compared to the rest of the treatments including control (0.44 and 325.3 µg g^{-1}). The difference in gain of OC and soil microbial biomass carbon in terms of % increase (+) over control was recorded highest in T_2 (16.33%) and T_3 (30.30%), while the least gain in both the parameters was recorded in T_6 and T_5 (Table 1).

Table 1. Effect of organic amendments on pH and EC, OC, Soil microbial biomass carbon, Nitrogen, P_2O_5 and K_2O in terms of % increase over control.

Treatments details	pH	EC	OC	Soil microbial biomass carbon	Nitrogen	P_2O_5	K_2O
T_0	7.38	0.32	0.44	232.33	171.50	12.0	232.7
T_1	[+1.43]	[+5.83]	[+13.16]	[+28.59]	[+9.26]	[+20.53]	[+5.14]
T_2	[+2.08]	[+8.49]	[+16.46]	[+29.67]	[+10.60]	[+31.07]	[+8.76]
T_3	[+2.68]	[+17.80]	[+16.46]	[+30.30]	[+13.53]	[+27.27]	[+4.63]
T_4	[+1.78]	[+8.49]	[+7.69]	[+16.23]	[+3.83]	[+11.76]	[+2.65]
T_5	[+2.08]	[+11.01]	[+7.04]	[+14.37]	[+4.19]	[+8.40]	[+2.79]
T_6	[+2.38]	[+15.65]	[+5.71]	[+15.31]	[+3.76]	[+10.45]	[+0.85]
T_7	[+0.0]	[-6.59]	[+9.59]	[+19.98]	[+6.28]	[+14.29]	[+2.79]
T_8	[+0.32]	[-3.19]	[+7.69]	[+19.14]	[+6.11]	[+13.04]	[+2.28]
T_9	[+0.67]	[+3.0]	[+9.59]	[+19.70]	[+4.58]	[+14.29]	[+1.87]
T_{10}	[+1.43]	[+11.01]	[+13.73]	[+21.86]	[+8.24]	[+16.08]	[+3.72]
T_{11}	[+1.38]	[+10.19]	[+9.59]	[+20.80]	[+8.29]	[+20.0]	[+4.16]
T_{12}	[+1.99]	[+13.39]	[+11.41]	[+21.06]	[+7.13]	[+17.81]	[+3.46]

RDF = Recommended dose of fertilizer, $\mathbf{T_0}$= 100 % N, P and K, $\mathbf{T_1}$= 25% RDF +75% (BM+VC+PM) +20 % bio-char, $\mathbf{T_2}$=25% RDF + 75% (BM+VC+PM) + 30% bio-char, $\mathbf{T_3}$= 25% RDF + 75 % (BM+VC+PM) + 40 % Biochar, $\mathbf{T_4}$= 25% RDF +75% BM +20% bio-char, $\mathbf{T_5}$ = 25% RDF + 75% VC + 20% bio-char, $\mathbf{T_6}$ = 25% RDF + 75% PM + 20% bio-char, $\mathbf{T_7}$= 25% RDF +75% BM + 30% bio-char, $\mathbf{T_8}$= 25% RDF + 75% VC + 30% bio-char, T_9 = 25% RDF + 75% PM + 30% bio-char, $\mathbf{T_{10}}$= 25% RDF + 75% BM + 40% bio-char, $\mathbf{T_{11}}$= 25% RDF +75% VC + 40% biochar, $\mathbf{T_{12}}$= 25% RDF+75% PM + 40% bio-char

Organic carbon and soil microbial biomass carbon

The data depicted in Fig. 2 revealed the improvement in organic carbon (OC) and soil microbial biomass carbon due to the use of organic-based treatments, while both the parameters were detected as highly significant at $P<0.05$. Out of all the combinations of the treatments, T_3 and T_2 had the highest gain in organic carbon (0.53%), while the

Release of nutrient content (nitrogen, P2O5, and K2O kg ha-1)

The impact of the applied treatments was also assessed regarding the release of nitrogen, P_2O_5, and K_2O in the soil (Fig. 3), wherein all the parameters were found statistically significant at ($p<0.05$). Out of all the treatments, T_3 was recorded statistically superior for the nitrogen (198.33 kg ha^{-1}),

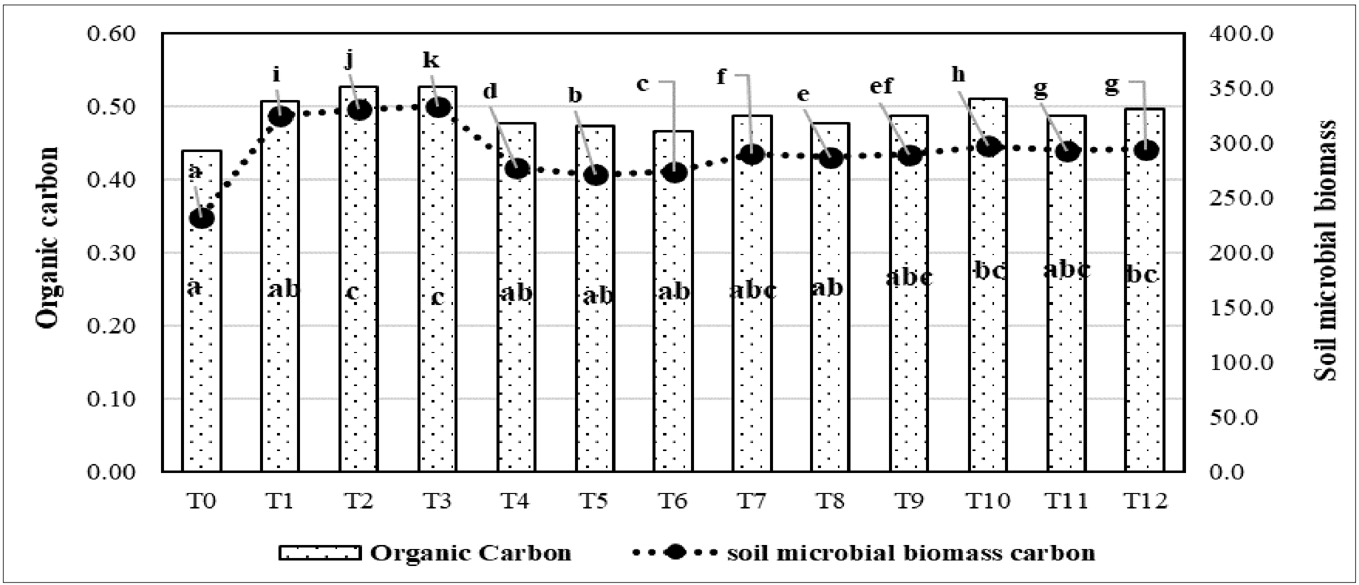

Fig. 2. Effect of organic amendments on OC (%) and Soil microbial biomass carbon (μg g^{-1} of the soil) of the experimental unit.

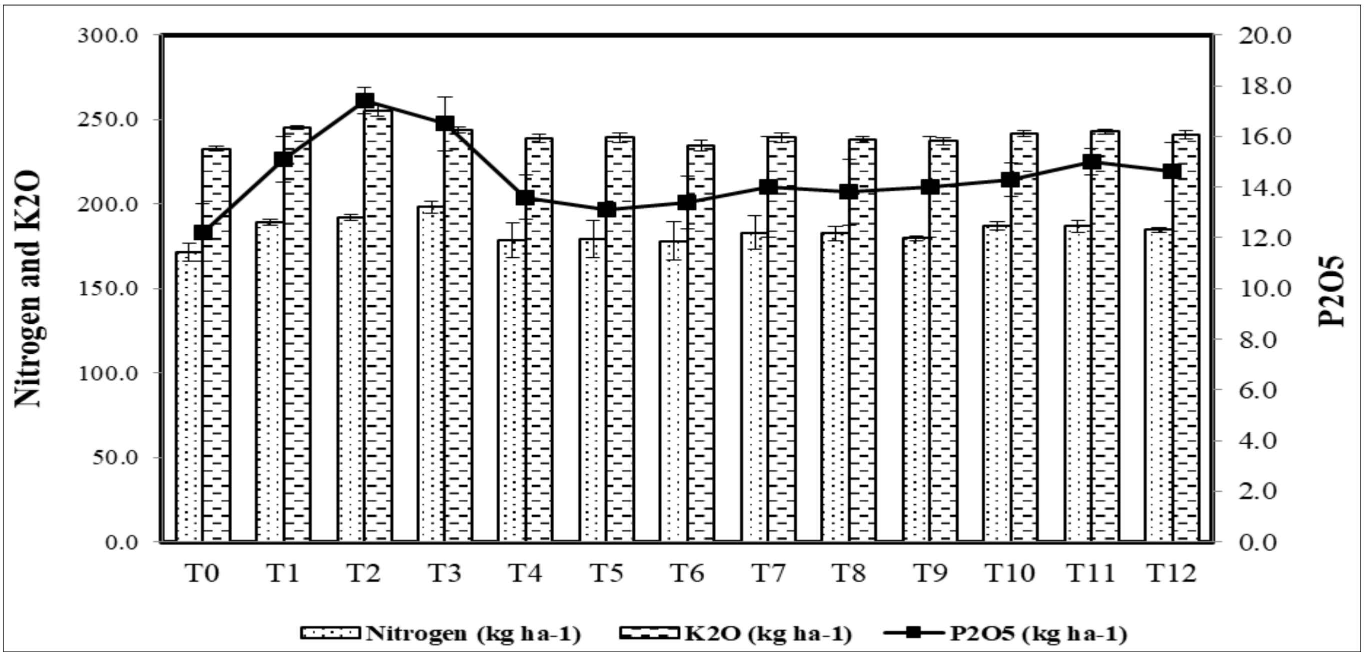

Fig. 3. Effect organic amendments on nitrogen, P_2O_5 and K_2O (kg ha^{-1}) of the experimental unit.

while T_2 was most effective for the P_2O_5 (17.4 kg ha^{-1}), and K_2O (255 kg ha^{-1}) as compared to T_0 (171.50, 12.0 and 232.7 kg ha^{-1}). The beneficial impact of the treatments was also given in parenthesis (Table 1), where the highest % increase over control for the nitrogen was in T_3 (13.53%), while for the P_2O_5 and K_2O, it was 31.03 and 8.76%, respectively.

Labile carbon and particulate organic carbon

In continuation of the assessment of soil health parameters, labile carbon and particulate organic carbon (POC) were analyzed under the influence of biochar-based organic amendments, and both the parameters were found to be highly statistically significant ($P<0.05$). Among the treatments, the highest increase in both biochemical parameters was noticed in T_3 (3.71 and 7.0 g kg^{-1} of soil) compared to control (2.33 and 3.0 g kg^{-1} of soil). The second most effective treatment for labile carbon was T_2 (3.28 g kg^{-1}), reflecting a nonsignificant difference with T_3, while for the POC, T_2 showed a significant difference with T_3 along with the substantial difference of 6.6 g kg^{-1} of soil (Fig. 4 and 5).

Potato quality as per the grading (A, B and C)

The impact of applied treatment was studied in relation to the quality of potato on the basis of grade, wherein G-A (>75 g), G-B (50-75 g), and G-C (<50 g). Data depicted in Fig. 6 reveals that, out of all the treatments, G-A quality was recorded maximum in T_3 (153.7 q ha^{-1}) followed by T2 and T1 (151.8 and 150.5 q ha^{-1}), which marginally differ from each other. The performance of the treatments for G-B was recorded the same as G-A, wherein T_3, T_2, and T_1 were recorded at 147.5, 146.4, and 145.1 q ha^{-1}. However, the G-C quality of potato was highest in T_5 at 97.1 q ha^{-1}, followed by T_6 and T_4 at 94.2 and 93.1 q ha^{-1} (Fig. 6).

Potato quality as per the starch content (%)

In continuation of quality parameters, starch content was estimated from the potato tubers and found that the parameter was statistically significant ($P<0.05$). Out of all the

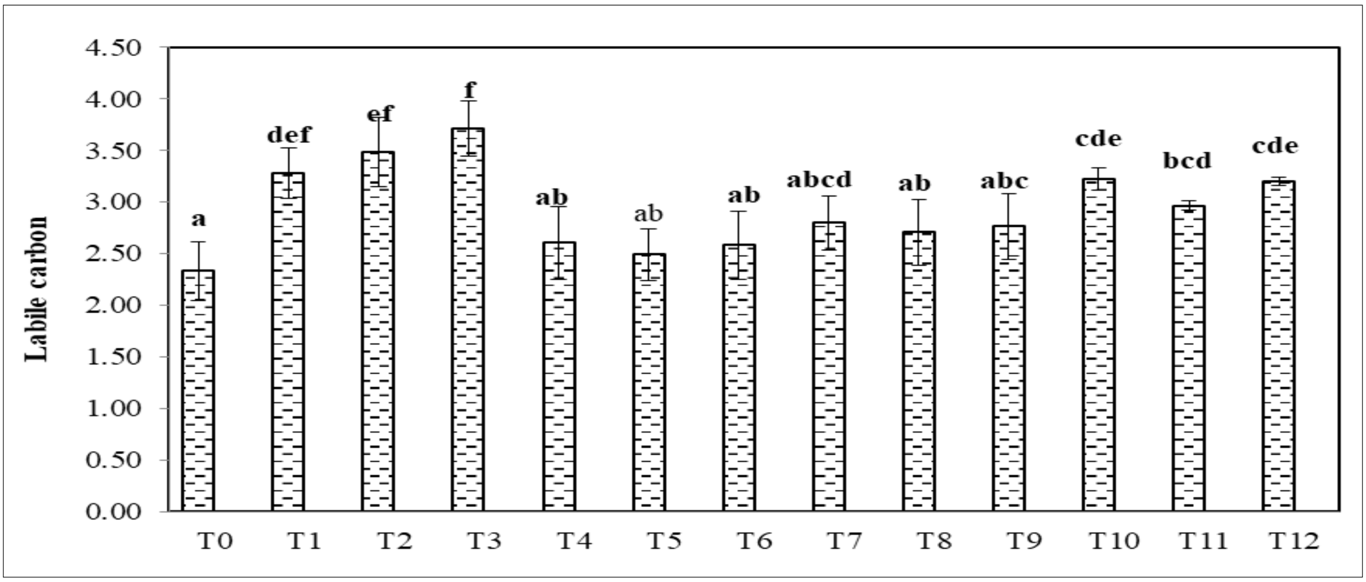

Fig. 4. Effect of organic amendments on the labile carbon (g kg^{-1} soil) of the experimental unit.

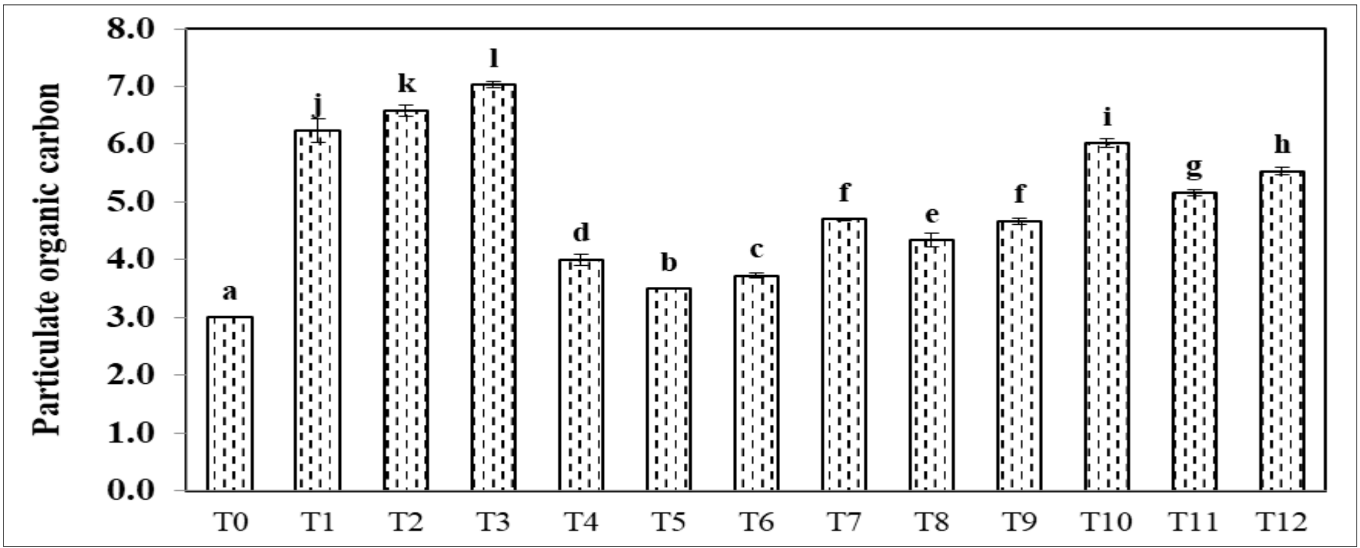

Fig. 5. Effect of organic amendments on the particulate organic carbon (g kg^{-1} soil) of the experimental unit.

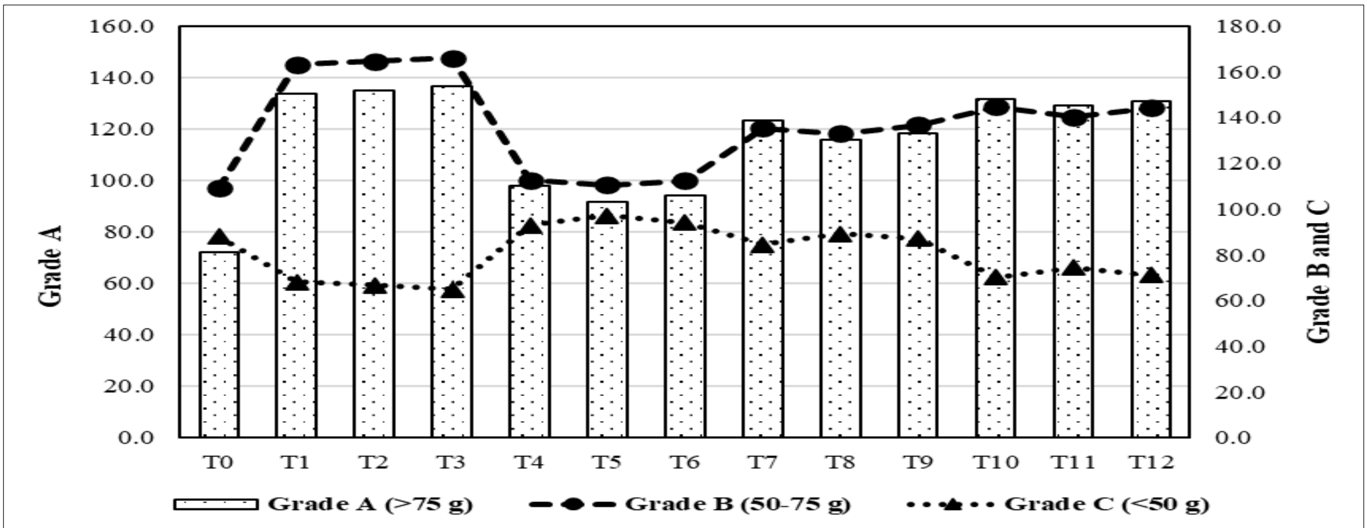

Fig. 6. Effect of organic amendments on potato quality on the basis of grade.

combinations of treatment, the highest improvement in starch content in % was detected in T_3 (53.60%), while the second most was recorded in T_2 and T_1 (53.23 and 53.0%) compared to T_0 (47.0%), while these three were recorded nonsignificant differences among them (Fig. 7).

Soil pH and EC are often used to define the quality of soil, whether it is acidic, alkaline, or saline. Data received from Fig. 1 revealed that out of all the treatments, T_3 was recorded as the highest value of pH and EC (dSm^{-1}), while the same treatment was also noticed as one of the best treatments for organic carbon (%), soil microbial biomass

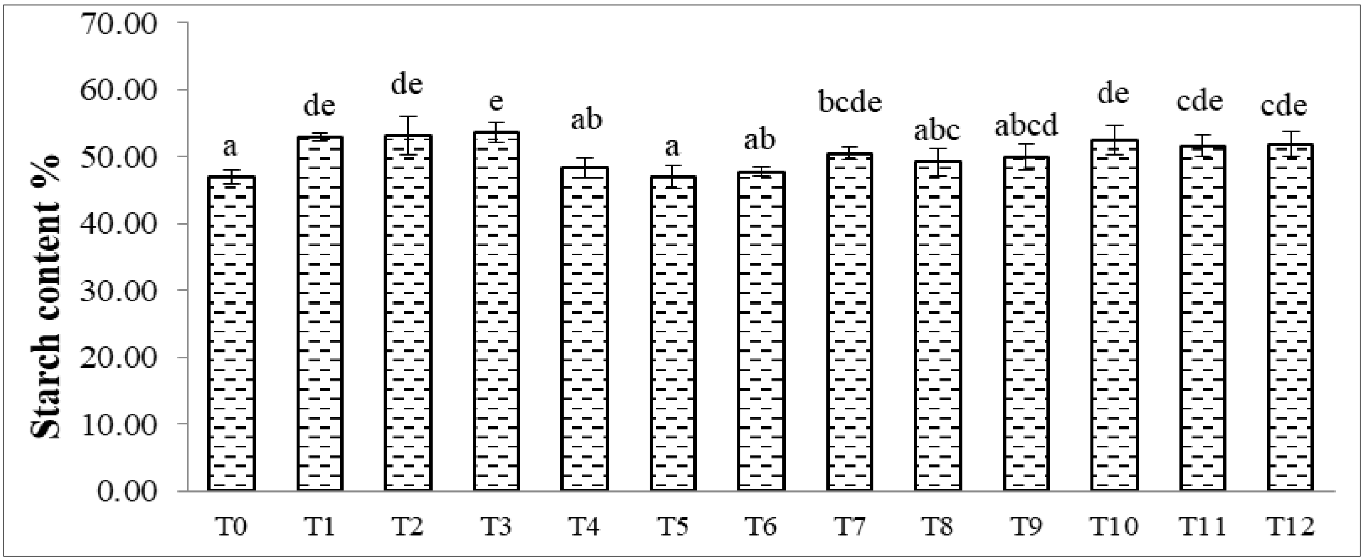

Fig. 7. Effect of organic amendments on starch content (%) of potato tuber.

carbon (µg g^{-1}) and release of nitrogen (kg ha^{-1}) however, the T_2 was observed for the P_2O_5 and K_2O (kg ha^{-1}) (Fig. 2 and 3). Findings of the study directly indicated that the maximum increase in OC, soil microbial biomass carbon, and release of nutrients in the soil was at the pH and EC received in T_3 and T_2 due to the application of biochar-based organic amendments. The findings of the study are according to (18), who proposed that the release of nutrients in the soil is a consequence of a pH-dependent process, especially an ammonical form of nitrogen than a nitrate form of nitrogen (19). Moreover, biochar-based amendments as a treatment had a positive link in favor of pH improvement (20). The presence of basic compounds, *i.e.,* K, Ca, Mg, and Na, in applied biochar may be one of the reasons for the improvement in pH (21). The results are also correlated with the findings of (22), who extended that biochar-based amendment not only improves the pH of soil, but subsequently improves the status of organic carbon and soil microbial biomass carbon, which is used to know the biological potential in the soil, because it can influence several other processes like release of nutrient, pH, OC and water holding capacity (23). Thus, the collective efforts of these parameters create a positive environment around the rhizosphere to release nutrients in the soil and facilitate the process of nutrient uptake by the plant, because it is a pH-dependent process.

The findings regarding labile carbon and particulate organic carbon (POC) reveal that the amendments of biochar-based organic resources, especially the combination used in $T_{3,}$ had additional benefits to enhance both the kind of carbon in the soil (Fig. 4 and 5). Studies (24) are well related to the findings of the current study, which reported that the accumulation of carbon in the soil helps in stabilizing the supply of energy to the microbes; hence, the microbes present in the soil convert organic-based material efficiently into the useable forms of nutrients, while similar results were also reported by (25).

Quality of potato in terms of starch content and potato grading was carried out wherein the treatment combinations T_3 were recorded as the most effective and beneficial for the quality improvement (Fig. 6 and 7). The quality improvement in potatoes might be due to the positive environment created by the optimum range of pH, EC, the transformation of OC, improvement in soil microbial biomass carbon, nutrients release, and accumulation of carbon in the soil. Similarly, the starch content is improved due to the use of organic amendment along with biochar in potato tubers (26). Being a tuber crop, potatoes need a positive environment surrounding the rhizosphere, which is not only good for the mineralization and uptake of nutrients, but also helps in improving tuber size via manipulating the morphological growth of the potato (27-29).

Conclusion

The focusable part of this study was to identify efficient organic-based sources employed during the study to align the basic needs of soil to provide a sustainable harvest of the potato crop, *i.e.,* pH and EC, and thereby facilitate the rest of the biochemical process efficiently to enrich the soil health through optimizing OC, soil microbial biomass carbon, nutrients availability, sequestration of carbon in the soil. Among the treatment combinations, $T_{3,}$ *i.e.,* 25 % RDF + 75 % (BM+VC+PM) + 40 % biochar, was recorded as the most significant and potential treatment combination not only for the soil physical, biological, and biochemical parameters but also for the betterment of tuber quality in terms of starch content and grades of potato.

Acknowledgements

The authors gratefully acknowledge Lovely Professional University for providing a decent environment, place of work, and advanced laboratory to conduct the research work, while the assistance of technical staff Mr. Robin Paul was also remarkable.

Authors contributions

All the authors equally contributed and coordinated the planning, execution, biochemical analysis, statistical analysis, and drafting of the research work.

Compliance with ethical standards

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

Ethical issues: None.

References

1. Shahane AA, Shivay YS. Soil health and its improvement through novel agronomic and innovative approaches. Front Agron. 2021; 3: 680456. https://www.frontiersin.org/articles/10.3389/fagro.2021.680456/full
2. Lévesque V, Oelbermann M, Ziadi N. Biochar in temperate soils: opportunities and challenges. Can J Soil Sci. 2021;102(1): 1-26. https://cdnsciencepub.com/doi/full/10.1139/cjss-2021-0047
3. Tenic E, Ghogare R, Dhingra A. Biochar—a panacea for agriculture or just carbon. Horticulturae. 2020; 6(3): 37. https://www.mdpi.com/2311-7524/6/3/37
4. Diatta AA, Fike JH, Battaglia ML, Galbraith JM, Baig MB. Effects of biochar on soil fertility and crop productivity in arid regions: a review. Arab J Geosci. 2020;13: 1-17. https://www.semanticscholar.org/paper/Effects-of-biochar-on-soil-fertility-and-crop-in-a-Diatta-Fike/b15b5d1767932a41c59e7bae3faa00870e661a0c
5. Cen R, Feng W, Yang F, Wu W, Liao H, Qu Z. Effect mechanism of biochar application on soil structure and organic matter in semi-arid areas. J Environ Manage. 2021;286: 112198. https://pubmed.ncbi.nlm.nih.gov/33621846/
6. Scott HL, Ponsonby D, Atkinson CJ. Biochar: an improver of nutrient and soil water availability-what is the evidence. CABI Reviews. 2014; 1-19. https://www.cabidigitallibrary.org/doi/10.1079/PAVSNNR20149019
7. Tauqeer HM, Turan V, Farhad M, Iqbal M. Sustainable agriculture and plant production by virtue of biochar in the era of climate change. In Managing plant production under changing environment. 2022; (pp. 21-42). Singapore: Springer Nature Singapore.https://link.springer.com/chapter/10.1007/978-981-16-5059-8_2
8. Singh J, Siddique A. Impact of biochar base organic amendment on morphological changes and yield of potato (*Solanum Tuberosum* L.). Spec Ugdym. 2022; 2(43): 865-871. http://www.sumc.lt/index.php/se/article/view/1293
9. Hoover NL, Law JY, Long LAM, Kanwar RS, Soupir ML. Long-term impact of poultry manure on crop yield, soil and water quality, and crop revenue. J Environ Manage. 2019; 252: 109582. https://pubmed.ncbi.nlm.nih.gov/31614262/
10. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 1934; 37(1): 29-38. https://journals.lww.com/soilsci/Citation/1934/01000/AN_EXAMINATION_OF_THE_DEGTJAREFF_METHOD_FOR.3.aspx
11. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Bioch. 1987; 19(6): 703-707. https://www.sciencedirect.com/science/article/abs/pii/0038071787900526
12. Subbiah BV, Asija GL. A rapid method for the estimation of nitrogen in soil. Curr Sci. 1956; 26: 259-260. https://www.scirp.org/(S(i43dyn45teexjx455qlt3d2q))/reference/ReferencesPapers.aspx?ReferenceID=2138694
13. Olsen SR. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture; 1954. https://archive.org/details/estimationofavai939olse/page/n1/mode/2up.
14. Jackson ML. Soil chemical analysis, Prentice Hall of India Private Limited, New Delhi, India. 1973;498: 151-154. https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1453838
15. Weil RR, Islam KR, Stine MA, Gruver JB, Samson-Liebig SE. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Amer J Altern Agric. 2003;18(1): 3-17. https://www.cambridge.org/core/journals/american-journal-of-alternative-agriculture/article/abs/estimating-active-carbon-for-soil-quality-assessment-a-simplified-method-for-laboratory-and-field-use/811A21F65E6E272FAC2B76231DD90EDE
16. Cambardella C, Elliott ET. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci Society Amer J. 1992; 56: 777-783. https://www.scirp.org/(S(i43dyn45teexjx455qlt3d2q))/reference/ReferencesPapers.aspx?ReferenceID=1928940
17. McCready RM, Guggloz J, Silviera V, Owens HS. Determination of starch and amylose in vegetables. Anal Chem. 1950; 22, 1156. https://pubs.acs.org/doi/10.1021/ac60045a016
18. Silber A, Levkovitch I, Graber ER. pH-dependent mineral release and surface properties of corn straw biochar: agronomic implications. Environ Sci Technol. 2010; 44: 9318-9323. https://pubmed.ncbi.nlm.nih.gov/21090742/
19. Zheng H, Wang Z, Deng X, Zhao J, Luo Y, Novak, J, Herbert S, Xing B. Characteristics and nutrient values of biochars produced from giant reed at different temperatures. Bioresour Technol. 2013;130: 463-471. https://www.ars.usda.gov/ARSUserFiles/60820500/Manuscripts/2013/Man918.pdf
20. Mollick OA, Paul AK, Alam I, Sumon MM. Effect of biochar on yield and quality of potato (*Solanum tuberosum*) tuber. IJBSM. 2020; 11(5): 445-450. https://www.pphouse.org/upoad_article/69099694_4_IJBSM_October_2020_Mollick_et_al.pdf
21. Yuan J, Xu R, Zhang H. The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresour Technol. 2011;102: 3488-3497. https://pubmed.ncbi.nlm.nih.gov/21112777/
22. Yadav NK, Kumar V, Sharma KR, Choudhary RS, Butter TS, Singh G, Kumar R. Biochar and their impacts on soil properties and crop productivity: a review. J Pharmacogn Phytochem. 2018; 7(4): 49-54. https://www.phytojournal.com/archives/2018/vol7issue4/PartB/7-3-678-801.pdf
23. Schulz H, Dunst G, Glaser B. Positive effects of composted biochar on plant growth and soil fertility. Agron Sustain Develop. 2013; 33(4): 817-827. https://hal.science/hal-01201399/file/13593_2013_Article_150.pdf
24. Thorburn PJ, Meier EA, Collins K, Robertson FA. Changes in soil carbon sequestration, fractionation and soil fertility in response to sugarcane residue retention are site-specific. Soil Tillage Res. 2012; 120: 99-111. https://www.cabdirect.org/cabdirect/abstract/20123129548
25. Prabha S, Renuka R, Sreekanth NP, Babu P, Thomas AP. A study of the fertility and carbon sequestration potential of rice soil with respect to the application of biochar and selected amendments. Ann Environ Sci. 2013;7: 17–30. https://openjournals.neu.edu/aes/journal/article/view/v7art2
26. Das SK, Ghosh GK, Avasthe R. Valorizing biomass to engineered biochar and its impact on soil, plant, water, and microbial dynamics: A review. Biomass Converv Biorefin. 2020;1-17. https://www.springerprofessional.de/valorizing-biomass-to-engineered-biochar-and-its-impact-on-soil-/18136288
27. Saini I, Kaushik P, Al-Huqail AA, Khan F, Siddiqui MH. Effect of the diverse combinations of useful microbes and chemical fertilizers on important traits of potato. Saudi J Biol Sci. 2021; 28(5):

2641-2648. https://www.sciencedirect.com/science/article/pii/S1319562X21001406

28. Song J, Kong ZQ, Zhang DD, Chen JY, Dai XF, Li R. Rhizosphere microbiomes of potato cultivated under *Bacillus subtilis* treatment influence the quality of potato tubers. Int J Mol Sci. 2021; 22(21): 12065. https://www.mdpi.com/1422-0067/22/21/12065

29. Asfaw F. Effect of integrated soil amendment practices on growth and seed tuber yield of potato (*Solanum tuberosum* L.) at Jimma Arjo, Western Ethiopia. J Nat Sci Res. 2016; 6(15): 38-63. https://core.ac.uk/download/pdf/234656534.pdf