The Scientific Temper (2024) Vol. 15 (2): 2021-2030
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.09
https://scientifictemper.com/

RESEARCH ARTICLE

A coffee biochar-mineral NP interaction: Boon for soil health

Isreal Zewide

Abstract

Low soil fertility, attributed to a deficiency in multiple nutrients, is causing a decline in the productivity of potatoes (*Solanum tuberosum*) in the Gawata district of southwestern Ethiopia. To address this issue, a field experiment was conducted during the Belg season (February to May) and Meher season (June to October) of the year 2024. The objective was to assess the response of potatoes to the combined application of nitrogen, phosphorus, and coffee biochar (BC) in relation to specific soil physico chemical properties under rainfed conditions. The treatments comprised various combinations of biochar (2.5, 5, 7.5 t ha^{-1}) and inorganic NP (25, 50, and 75%) of the recommended dose (165 kg N ha^{-1} + 60 kg P ha^{-1} = 100% recommended dose of fertilizer, RDF), along with 20 t ha^{-1} of biochar and 100% inorganic NP, with a no-fertilizer treatment serving as the control. In total, there were 12 treatments and a randomized complete block design with three replications was employed for the experiment. The results indicated that the combined application of 75% inorganic NP and 7.5 t ha^{-1} of biochar significantly increased pH, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, and exchangeable calcium and magnesium. Additionally, it reduced bulk density, exchangeable acidity, exchangeable aluminum, and exchangeable potassium compared to the values obtained from the initial soil test. Consequently, it was concluded that the integrated use of 7.5 t ha^{-1} of biochar and 75% of inorganic NP during the Belg season, or 25% of it during the Meher season, represents an optimal nutrient management strategy for potato production in the study area.

Keywords: Biochar, Inorganic fertilizer, Organic fertilizer, Potato, Soil physico chemical properties.

Introduction

Potato ranks fourth in production behind wheat, rice and maize as a world food crop and occupies the first place among root and tuberous crops (Douches, 2013). It is noted for its high nutritive value and is also a crop leader in terms of protein production and energy value per unit area (FAOSTAT, 2010). It gives a cheap source of human diet, which produces more dry matter and protein per hectare than the major cereal crops (Suvraroy *et al,* 2017).

In the Gawata district of southwestern Ethiopia, potato crop covered 3255 hectares of land with a total yield of 24447 t, registering a productivity of only 7.52 t ha^{-1}, which is far below the average national yield of 13.8 t ha^{-1} (CSA, 2024). Several factors, including low soil fertility, limit potato production (Muthoni and Nyamongo, 2009). Fertilizers are usually applied below the recommended rate (165 kg N + 60 P) for potato production in Gawata district of Keffa zone, southwestern Ethiopia (Isreal *et al.,* 2012). The extent of nutrient depletion is unknown and fertilizer application by farmers is not commensurate with the plant requirements and nutrient levels in the soil. Undoubtedly, potato requires high amounts of nitrogen, phosphorus and potassium for its proper growth and development. Extra use or imbalanced and indiscriminate use of chemical fertilizers creates several adverse effects on soil, water and air, causing their pollution (Muthoni, 2016). Therefore, integrated nutrient management offers a relatively better opportunity for providing nutrients to the potato crop through the inclusion of organic and inorganic nutrients (Kumar *et al*., 2017; Nityamanjar, 2018).

A dominant soil type in southwestern Ethiopia is weathered tropical soil. The inherent properties of these soils, being rich in oxides of Fe and Al, have high P-fixing capacity coupled with high erosion resulting from the high amount of rainfall and poor crop management practices necessitate the increased use of fertilizers. Low soil fertility caused by erosion, nutrient removal by plants, mismanagement of crop residues and lack of proper agronomic management are some of the factors limiting the yield of potatoes in the study area.

Department of Horticulture, College of Agriculture and Natural Resources, Mizan-Tepi University, Ethiopia.

***Corresponding Author:** Isreal Zewide, Department of Horticulture, College of Agriculture and Natural Resources, Mizan-Tepi University, Ethiopia., E-Mail: zewideisreal@gmail.com

How to cite this article: Zewide, I. (2024). A coffee biochar-mineral NP interaction: Boon for soil health. The Scientific Temper, **15**(2):2021-2030.

Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.09

Source of support: Nil

Conflict of interest: None.

Received: 02/04/2024 **Accepted:** 10/05/2024 **Published** : 15/06/2024

In potato production, nutrients can be applied in the form of organic and mineral fertilizers. In this regard, the use of coffee biochar as organic fertilizer can improve growth, yield, and soil properties, but its application as a nutrient amendment in potato production is less well known. Most of the fertilizer studies on potatoes have been conducted using inorganic NP fertilizers and often with older crop varieties. To address these issues, on-farm studies were carried out to estimate the dosage of organic and inorganic nutrients for potato production and soil fertility maintenance. Hence, proper use of biochar and mineral NP fertilizers is a viable and productive approach to control soil fertility limitation (Nityamanjari, 2018). Therefore, this research was planned and executed to evaluate the effect of biochar and mineral NP fertilizers on soil physico chemical characteristics in potato fields.

Materials and Methods

The Study Sites

The experiment was conducted on a farmer's field in Melliyo kebele located at 6058'58'' north latitude and 350 94'71'' east longitude (Figure 1) during the Belg (February to May) and Meher (June to October) cropping seasons of 2024.

A bimodal pattern of rainfall is generally found with the small rainy season in Belg and the main rainy season in Meher. Meher and Belg had total rainfall of 650.2 and 1053.26 mm, respectively. The maximum temperatures varied from 22 (May) to 25°C (February) and 23 (June) to 27°C (October), whereas the minimum temperature varied between 17.13 (May) to 17.54°C (February) and 14.93 (June) to 15.76 °C (October).

Experimental Materials

Urea (46% N) and triple superphosphate (TSP having 20% P) served as inorganic N and P sources, respectively, whereas biochar, an organic fertilizer, was prepared from using the pyrolysis of coffee husk. The potato variety 'Belete' was used for the experiment. The organic carbon, N, P, K, pH, electrical conductivity, Ca, Mg, K, Na, CEC and moisture content of the biochar were analyzed according to the protocols.

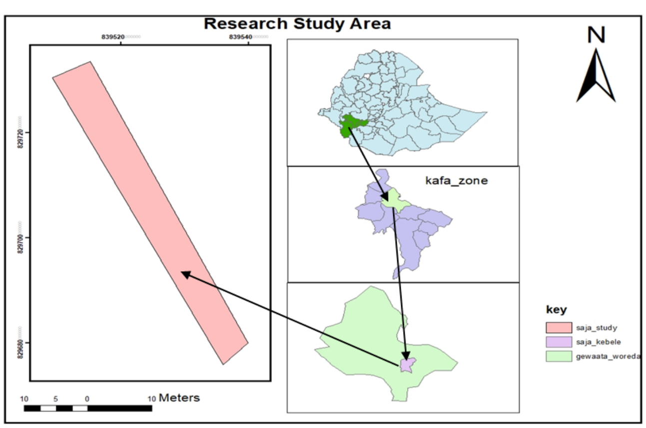

Figure 1: Map of study area

Treatments and Experimental Design

Three rates of biochar (2.5, 5, 7.5 t ha^{-1}) and three rates (25, 50 and 75%) of recommended mineral NP fertilizers were used. In addition, 100% recommended rate of mineral NP fertilizer (165 kg N ha^{-1} and 60 kg P ha^{-1}), 20 t ha^{-1} biochar and no-fertilizer treatment as control were used for comparison. Thus, there were twelve treatments. The experiment was laid out in a randomized complete block design with three replications.

Soil Sampling Before and After Potato Harvest

Prior to the planting as well as after the harvesting of potatoes, surface (0–20 cm) soil samples from 25 spots across the experimental field were collected in a zig-zag pattern and composited. All the collected soil samples were prepared for analyses of selected physicochemical properties, which were performed according to standard procedures as follows:

Soil texture analysis

The soil texture class was determined by calculating the percentages of sand, silt, and clay. This classification was most likely performed using a soil texture triangle, as described by Rowell in 1994.

Soil pH measurement

The pH of a soil-water suspension (1:2.5 ratio) was determined using a pH meter. Organic carbon measurement, the organic carbon content was evaluated using the Walkley-Black method, a fast titration technique developed in 1965.

Total nitrogen (N) analysis

The total nitrogen content of the soil was determined using the Kjeldahl method, which was devised by Jackson in 1967.

C:N ratio

The carbon to nitrogen (C:N) ratio of the soil was also calculated. This ratio gives insight into the relative quantities of carbon and nitrogen in the soil.

Available phosphorus (P) analysis

The available phosphorus level was measured using Olsen's technique.

Cation exchange capacity (CEC) and exchangeable bases

The soil was saturated with 1N ammonium acetate solution to extract CEC and exchangeable bases (calcium, magnesium, potassium, and sodium). This method is based on Chapman's method.

Calcium (Ca) and magnesium (Mg) analysis

The concentrations of calcium and magnesium were determined using an atomic absorption spectrometer.

Potassium (K) and sodium (Na) analysis

The concentrations of potassium and sodium were determined using a flame photometer.

Micronutrient analysis

The amounts of iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) in soil samples were measured. This analysis used the method presented by Lindsay and Norvell in 1978. It entailed utilizing an atomic absorption spectrophotometer to measure the absorbance of various wavelengths of light by the elements, allowing for their measurement.

Exchangeable acidity

The exchangeable acidity of the soil, which includes exchangeable aluminum (Al) and hydrogen ions (H), was determined.

Experimental Procedures

The experimental land was well prepared prior to planting and biochar was spread over designated plots two weeks prior to planting at the designated rate as mentioned earlier. Phosphorus was applied in the form of TSP $hill^{-1}$ and mixed well with the soil, while nitrogen was side-dressed in three split applications, i.e., $1/4^{th}$ at plant emergence, $2/4^{th}$ at mid-stage and $1/4^{th}$ at the initiation of tubers. Pre-sprouted potato tubers of uniform size were planted in February in Belg and June in Meher seasons. The tubers were harvested manually using a hand hoe when 70% of haulms were dried.

Data Analysis

Soil data were subjected to statistical analyses (SAS Institute, 2010). Homogeneity of variances was calculated using the F-test as described by Gomez and Gomez (1984) and since the F-test had shown heterogeneity of the variances of the two seasons for post-harvest soil parameters, a separate analysis was used for the two seasons. The least significant difference (LSD) test at $p < 0.05$ probability level was employed to separate treatment means where significant treatment differences occurred.

Results and Discussion

Biochar Analysis

pH (1:10, Biochar: Water)

The pH values for the biochar-water mixture in a 1:10 ratio are 8.2 and 7.2, respectively. A higher pH number suggests alkalinity, whereas a lower pH level indicates acidity. The fall in pH from 8.2 to 7.2 could indicate a minor decrease in alkalinity. Electrical conductivity (µS cm^{-1}) (1:10 biochar:water): The electrical conductivity of the biochar-water mixture at a 1:10 ratio is 302.33 and 265.67 µS cm^{-1}, respectively. Electrical conductivity is a measurement of a solution's capacity to conduct electricity. A reduction in conductivity from 302.33 to 265.67 µS cm^{-1} could suggest a decrease in dissolved salt concentrations. Carbon (grams per kilogram). The carbon content in the samples is 382 and 361 g kg^{-1}, respectively.

Nitrogen (g kg^{-1})

The nitrogen content in the samples is 29 and 26 g kg^{-1}, respectively. Nitrogen is an essential nutrient for plant growth and plays an important function in many metabolic processes. The C:N ratio the C:N ratios are calculated at 13.95 and 12.43, respectively. The C:N ratio is a key indication of soil organic matter breakdown and nitrogen cycling.

Phosphorus (in grams per kilogram)

The samples have phosphorus content of 16.38 and 12.75 g kg^{-1}, respectively.

The values represent the concentrations of calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) in the samples, measured in centimoles per kilogram. These cations are essential for plant nutrition and soil fertility.

CEC (cmol (+) kg^{-1})

The cation exchange capacity (CEC) values are 46 cmol (+) kg^{-1} and 42 cmol (+) kg^{-1}, respectively. CEC is a measure of the soil's ability to retain and exchange cations, influencing nutrient available.

Moisture content (%)

The moisture content in the samples is 62% and 74%, respectively. Moisture content is crucial for soil physical properties, microbial activity, and plant growth. These results provide valuable insights into the characteristics of the biochar-water mixture and its potential impact on soil properties and plant growth. Further analysis and interpretation may be necessary to understand the implications (Table 1).

Initial Soil Physical Properties

The bulk density (BD) was recorded at 1.37 g cm^{-3} in Belg and 1.38 g cm^{-3} in Meher season and particle density (PD) was 2.58 g cm^{-3} in Belg and 2.60 g cm^{-3} in Meher, while total porosity was 46.80% in Belg and 46.92% in Meher (Table 2). The total porosity of such magnitudes is classified as high

Table 1: Composition of biochar used in the experiment in Belg and Meher seasons

Parameters	*Belg*	*Meher*
pH (1:10, Biochar:water)	8.2	7.2
Electrical conductivity (µ cm^{-1}) (1:10, Biochar: water)	302.33	265.67
Carbon (g kg^{-1})	382	361
N (g kg^{-1})	29	26
C:N	13.95	12.43
Phosphorus (g kg^{-1})	16.38	12.75
Ca (cmol $_{(+)}$ kg^{-1})	10.52	8.624
Mg (cmol $_{(+)}$ kg^{-1})	3.80	3.69
K (cmol $_{(+)}$ kg^{-1})	3.913	5.85
Na (cmol $_{(+)}$ kg^{-1})	0.19	0.17
CEC (cmol $_{(+)}$ kg^{-1})	46	42
Moisture content (%)	62	74

Table 2: Selected physical properties of topsoil of the experimental site before planting of potato

Soil parameters	*Belg season*		*Meher season*		*References*
	Value	*Rating*	*Value*	*Rating*	
Sand	58%		58%		
Silt	17%		14%		
Clay	25%		30%		
Textural class	Sandy clay loam		Sandy clay loam		
BD (g cm^{-3})	1.37	Medium	1.38	Medium	Baruah and Barthakur (1997)
PD (g cm^{-3})	2.58	Medium	2.6	Medium	Baruah and Barthakur (1997)
Total porosity (%)	53.18	High	53.07	High	Hillel (2004)

Table 3: Bulk density (BD) (g cm^{-3}), particle density (PD) (g cm^{-3}) and total porosity (TP) (%) of soil as affected by the combined application of Biochar and mineral NP in Belg and Meher seasons

Treatment	*Belg*			*Meher*		
	BD	*PD*	*TP*	*BD*	*PD*	*TP*
2.5 t BC +25% NP	1.411^{ab}	2.75	51.3^{ef}	1.369^{b}	2.63	52.05^{gf}
2.5 t BC +50% NP	1.401^{abc}	2.74	51.13^{def}	1.363^{b}	2.63	51.83^{ef}
2.5t BC +75% NP	1.391^{abc}	2.70	51.52^{f}	1.349^{c}	2.64	51.10^{de}
5tBC +25% NP	1.374^{bcd}	2.71	50.70^{cdef}	1.347^{c}	2.66	50.64^{de}
5tBC +50% NP	1.354^{cde}	2.71	49.96^{bcde}	1.333^{d}	2.66	50.11^{cd}
5tBC +75% NP	1.334^{de}	2.68	49.78^{bcd}	1.3144^{e}	2.66	49.41^{bc}
7.5tBC +25% NP	1.318^{ef}	2.68	49.18^{abc}	1.3027^{ef}	2.66	48.97^{b}
7.5 t BC +50% NP	1.281^{gf}	2.63	48.71^{ab}	1.2901^{f}	2.66	48.50^{ab}
20 t ha-1 Biochar	1.41	2.74	51.46	1.368	2.62	52.21
7.5 t BC +75% NP	1.268^{g}	2.65	47.85^{a}	1.266^{g}	2.66	47.59^{a}
100% NP	1.418^{ab}	2.76	51.38^{ef}	1.373^{ab}	2.62	52.40^{fg}
No-fertilizer(control)	1.438^{a}	2.78	51.73^{f}	1.386^{a}	2.62	52.90^{g}
LSD (5%)	0.047	NS	1.467	0.013	NS	1.048
Significance	**	NS	**	**	NS	**
CV (%)	2.02	2.08	1.73	0.58	1.12	1.24

Means followed by the same letter within a column are non-significantly ($p > 0.05$) different from each other; ** denotes significant difference at 1% level of probability, NS= non-significant= Biochar.

according to the rating of Hillel (2004), which could be due to continuous cultivation causing disintegration of the soil structure and exposure of surface soil to direct raindrops. Thus, the soil was good for the optimum movement of air and water through it and there seemed no problem with tuber growth and expansion in the soil. Soil particle size analysis results showed that the texture of the soil was sandy clay loam 57% sand, 18% silt and 25% clay in Belg and 56% sand, 16% silt and 28% clay in Meher seasons.

Soil Physical Properties After Potato Harvest

Application of Biochar and mineral NP, highly significantly ($p < 0.01$) affected the bulk density and total porosity of the soil after harvest both in Belg and Meher seasons but there was a non-significant effect on the particle density of soil in either of the seasons (Table 3). The lowest bulk density of 1.268 g cm^{-3} in Belg and 1.266 g cm^{-3} in Meher, respectively with the highest porosity of 52.17 and 52.43% were recorded at the combined application of 7.5 t ha^{-1} biochar with 75% mineral NP. The increase in porosity and decrease in bulk density after harvesting with the application of biochar and mineral NP together could be accountable to the increase in organic matter, which caused a reduction in compaction due to the high doses of biochar that enhanced soil aggregate stability due to increase in porosity and permeability of the soil. This result agrees with those of Chaudhari *et al.* (2013), who obtained a negative relationship between bulk density with organic matter (r = -0.88). Similarly, Davoud *et al.* (2015) explained that additions of biochar at 20 t ha^{-1} with mycorrhizal fungi decreased bulk density (1.2 g cm^{-3}) by

Table 4: Selected chemical properties of topsoil of experimental site before planting of potato

Soil parameters	Belg season		Meher season		
	Value	Rating	Value	Rating	References
pH (1:2.5, soil: water)	5.01	SA	4.8	VSA	Ethio SIS (2016)
OC (g kg^{-1})	12	Low	10.2	Low	Ethio SIS (2016)
N (g kg^{-1})	1	Low	0.8	Low	Ethio SIS (2016)
C: N	12	Low	12.75	Low	Ethio SIS (2016)
Available P (ppm)	5.5	Low	5.0	Low	Ethio SIS (2016)
CEC	20	Medium	19.3	Medium	Ethio SIS (2016)
Exchangeable Ca^{+2}	6.5	Medium	6.3	Medium	Ethio SIS (2016)
Exchangeable Mg^{+2}	2.1	Moderate	1.4	Moderate	Ethio SIS (2016)
Exchangeable K^{+}	0.42	High	0.36	High	Ethio SIS (2016)
Percent base saturation (%)	45.4	Medium	41.7	Medium	Ethio SIS (2016)
Exchangeable Al^{+3}	2.01	High	2.46	High	Ethio SIS (2016)
Exchangeable acidity	3.82	High	3.83	High	Ethio SIS (2016)
Cu (DTPA)	6	High	8	High	Ethio SIS (2016)
Fe (DTPA)	80	High	120	High	Ethio SIS (2016)
Zn (DTPA)	1.2	High	1.5	High	Ethio SIS (2016)
Mn (DTPA)	20	High	25	High	Ethio SIS (2016)

($cmol_{(+)}$ kg^{-1} soil) unit for CEC, Exchangeable Ca^{+2}, Exchangeable Mg^{+2}, Exchangeable K^{+}, Exchangeable Al^{+3} Exchangeable acidity; (mg kg^{-1} soil) unit for Cu, Fe, Zn and Mn; VSA= Very strongly acidic, SA= strongly acidic, DTPA= Diethylene triaminepenta acetic acid.

15.38% and improving soil structure reduced compaction, thereby increasing soil aggregate stability. In addition, Parthasarathi *et al*. (2008) indicated that biochar application at 2.5 t ha^{-1} with 50 kg N ha^{-1} and 24.8 kg P ha^{-1} decreased the bulk density from 1.25 to 1.13 g cm^{-3}, while it increased the total porosity from 40 to 50% on clay loam soils.

The highest total porosities (52.17%) in Belg and 52.43% in Meher were observed when 7.5 t BC + 75% NP were used together, whereas the lowest porosity of 48.26% and 47.11% in Meher were observed in no-fertilizer treatment (control) and there was no significant difference among 100% NP, 2.5 t BC ha^{-1} + 25 or 50% NP, 5 t BC ha^{-1} + 25% NP in Belg and 100% NP, 2.5 t BC ha^{-1}+ 25% NP in Meher season. Jabar (2018) also reported the highest (57.75%) and lowest (52.06%) soil total porosity in the combined fertilization and no-fertilizer treatment (control), respectively.

Initial Soil Chemical Properties

The results of the initial soil chemical test showed that the soil at the site was acidic with pH of 5.01 (strongly acidic) in Belg and 4.8 (very strongly acidic) in Meher season (Table 4). The low status of organic carbon of 12 g kg^{-1} in Belg and 10.2 g kg^{-1} in Meher seasons were recorded. The C: N ratio both in Belg and Meher seasons indicate that there is net mineralization of applied cattle manure and biochar. The status of available phosphorus in the soil (5.5 ppm) in Belg and (5 ppm) in Meher seasons were also low. This could be due to the poor management of crop residues, poor land management practices, slash-and-burn agricultural systems, low soil organic matter, high soil erosion, low inherent fertility of soil and fixation of phosphorus in acidic soil resulting in nutrient reduction and the decline in overall soil fertility. Thus, the added organic and mineral fertilizers were expected to show a positive effect on both the crop and the soil. The low status of total N content of 1.0 and 0.8 g kg^{-1} soil in Belg and Meher seasons, respectively, could possibly be due to either low initial organic matter content of the soil, which contributes about 90 to 95% of soil nitrogen or leaching of nitrate by torrential rainfall prevalent in the experimental areas (Ahmad and Arshad, 2015). The soil analysis also revealed that in both seasons, the CEC values of 20 $cmol_{(+)}$ kg^{-1} soil in Belg and 19.3 $cmol_{(+)}$ kg^{-1} soil in Meher seasons were medium in status. The soil had also relatively medium exchangeable calcium (6.5 $cmol_{(+)}$ kg^{-1} soil) in Belg and 6.3 $cmol_{(+)}$ kg^{-1} soil in Meher; moderate in exchangeable magnesium (2.1 $cmol_{(+)}$ kg^{-1} soil) in Belg and (1.4 $cmol_{(+)}$ kg^{-1} soil) in Meher.

High content of exchangeable acidity (3.83 $cmol_{(+)}$ kg^{-1} soil) in Belg and 3.82 $cmol_{(+)}$ kg^{-1} soil in Meher and exchangeable aluminum (2.01 $cmol_{(+)}$ kg^{-1} soil) in Belg and (2.46 $cmol_{(+)}$ kg^{-1} soil) in Meher season were recorded. High concentration of micronutrient cations Cu (6 mg kg^{-1} soil) in Belg (8 mg kg^{-1} soil) in Meher, Fe (80 mg kg^{-1} soil) in Belg and (120 mg kg^{-1} soil) in Meher, and Zn (1.2 mg kg^{-1} soil) in Belg and (1.5 mg kg^{-1} soil) in Meher seasons and Mn (20 mg kg^{-1} soil) in Belg and (25 mg kg^{-1} soil) in Meher due to increased availability at low pH with cations being less strongly bound to the soil and readily exchangeable (Ethio SIS, 2016)).

Soil Chemical Properties After Potato Harvest

pH of soil

Soil pH was highly significantly ($p < 0.01$) affected by the combined application of mineral NP and biochar in Belg and Meher seasons (Table 5). The lowest pH (4.97) was obtained at no application of fertilizer, while the highest value (5.28) was recorded at 7.5 t ha^{-1} biochar + 75% mineral NP. However, no significant differences among other treatments were found. The increase in pH could be due to the release of basic cations from biochar that raises soil pH in the soil colloidal surfaces. These findings are consistent with those of Sarwar *et al*. (2010), who found that organic amendment released alkaline cations such as Ca^{2+}, Mg^{2+} and $K^{+,}$ which increased CEC and optimized pH levels in the soil.

Table 5: Soil pH after potato harvest as influenced by the combined application of biochar and mineral NP in Belg and Meher seasons

Treatment	*Belg*	*Meher*
	pH	*pH*
2.5 t ha^{-1} BC + 25% NP	5.04^{cd}	5.01^{fgh}
2.5 t ha^{-1} BC + 50%NP	5.06^{cd}	5.03^{fgh}
2.5 t ha^{-1} BC + 75%NP	5.09^{bcd}	5.04^{ef}
5 t ha^{-1} BC + 25%NP	5.16^{abc}	5.06^{de}
5 t ha^{-1} BC + 50%NP	5.12^{abc}	5.06^{cde}
5 t ha^{-1} BC + 75%NP	5.22^{ab}	5.08^{bcd}
7.5 t ha^{-1} BC + 25%NP	5.25^{ab}	5.10^{abc}
7.5 t ha^{-1} BC + 50%NP	5.27^{a}	5.10^{ab}
7.5 t ha^{-1} BC + 75%NP	5.28^{a}	5.14^{a}
20 t ha^{-1} Biochar	5.01^{cd}	5.00^{gh}
100% NP	4.99^{d}	4.99^{gh}
No-fertilizer (control)	4.97^{d}	4.98^{h}
LSD (5%)	0.158	0.038
Significance	**	**
CV (%)	1.80	0.44

Means followed by the same letter within a column are non-significantly ($p > 0.05$) different from each other; ** denotes significant difference at 1% level of probability, BC= Biochar.

Organic carbon content of soil

Organic carbon in the soil after harvest was highly significantly ($p < 0.01$) affected by the combined use of biochar and mineral NP fertilizer both in Belg and Meher seasons (Table 6). The highest organic carbon content of 21.46 g kg^{-1} in Belg and 22.05 g kg^{-1} in Meher were recorded at a combined application of 7.5 t BC ha^{-1} + 75% of mineral NP, which was statistically not different from those of the treatments such as 7.5 t BC ha^{-1} + 50% of mineral NP in Belg and all the treatments expect control in Meher. On the other hand, the lowest organic carbon content (18.23 g kg^{-1}) in Belg and (19.75 g kg^{-1}) in Meher were under the treatment that obtained no-fertilizers. The higher availability of organic carbon in biochar treatment with mineral NP might be due to the fact that biochar increases higher amount of organic carbon to the soil. In line with this result, Kesarwani (2017) reported that the integrated use of 5 t cattle manure ha^{-1} + 5 t poultry manure ha^{-1} + 100% NPK improved organic carbon content (0.66 g kg^{-1}) of soil by 128.78% as compared to 50% NPK improving thereby available nutrients of soil.

Table 6: Organic carbon (OC) (g kg^{-1}), total nitrogen (TN) (g kg^{-1}) and available phosphorus (AvP) (mg kg^{-1}) content of soil after potato harvest as influenced by the combined application of Biochar and mineral NP in Belg and Meher seasons.

Treatment	*Belg*			*Meher*		
	OC	*TN*	*AvP*	*OC*	*TN*	*AvP*
2.5t BC + 25% NP	18.81^{cd}	1.33^{ef}	10.942^{c}	19.83 ^{ab}	1.30^{c}	7.018^{ab}
2.5 t BC + 50%NP	19.05^{cd}	1.34^{ef}	10.988^{c}	20.12^{ab}	1.31^{c}	7.186^{ab}
2.5t BC + 75%NP	19.35^{bcd}	1.43^{de}	11.032^{c}	20.16^{a}	1.31^{c}	7.302^{ab}
5tBC + 25%NP	19.39^{bcd}	1.47^{cd}	11.608^{bc}	20.24^{a}	1.31^{c}	7.302^{ab}
5tBC + 50%NP	19.49^{bc}	1.52^{cd}	11.698^{bc}	16.92^{a}	1.31^{c}	7.928^{ab}
5tBC + 75%NP	19.53^{bc}	1.55^{c}	11.875^{bc}	20.41^{a}	1.31^{c}	8.147^{ab}
7.5tBC + 25%NP	19.64^{bc}	1.68^{b}	15.405^{ab}	20.94^{a}	1.37^{b}	10.721^{a}
7.5 t BC + 50%NP	20.34^{ab}	1.73^{ab}	16.278^{a}	21.75^{a}	1.41^{ab}	10.981^{a}
7.5 t BC + 75%NP	21.46^{a}	1.83^{a}	17.232^{a}	22.05a	1.44^{a}	10.575^{a}
20 t ha^{-1} Biochar	18.82^{cd}	1.29ef	11.83^{c}	19.85^{ab}	1.31^{c}	7.019^{ab}
100% NP	18.72^{cd}	1.27^{f}	10.882^{c}	19.80^{ab}	1.28^{c}	7.018^{ab}
No-fertilizer (control)	18.23^{d}	1.26^{f}	9.698^{c}	19.75^{b}	1.14^{d}	5.420^{b}
LSD (5%)	0.125	0.012	3.821	0.318	0.006	4.00
Significance	**	**	**	**	*	**
CV (%)	3.76	4.78	17.93	9.26	2.76	18.65

Means followed by the same letter within a column are non-significantly different from each other; * and ** denote significant at 5% and 1% level of probability, respectively BC= Biochar.

Total nitrogen content of soil

Integrated use of biochar and mineral NP fertilizer affected ($p < 0.01$) total nitrogen contents of soil after harvest in both seasons (Table 6). The highest total nitrogen contents of 1.83 g kg^{-1} in Belg and 1.44 g kg^{-1} in Meher were recorded from the treatment of 7.5 t BC ha^{-1}+75% mineral NP, which were as good as those of 7.5 t BC ha^{-1}+ 50% NP in Belg and Meher seasons, respectively. However, the lowest total nitrogen contents of 1.26 g kg^{-1} in Belg and 1.14 g kg^{-1} in Meher were obtained under control treatment and were statistically at par with the use of 100% NP, 2.5 t BC ha^{-1} +25 or 50% NP in Belg. The highest total nitrogen content obtained with the addition of biochar was probably due to the fact that it releases nutrients slowly, which may replenish inorganic nitrogen lost through different processes like denitrification, crop removal, volatilization, leaching and runoff. In line with this result, Irungbam *et al*. (2017) reported that increase in available nitrogen by 47% in soil due to combined application of 1/3rd recommended N with each of cattle manure, Biochar, neem cake + Azotobacter + Rock phosphate + phosphorus solubilizing-bacteria and one purely inorganic nutrient treatment as compared to application of 50% NP+ 50% N from cattle manure (0.051 g kg^{-1}).

Available phosphorus of soil

The available phosphorus content of the soil after harvest was highly significantly ($p < 0.01$) affected by the combined use of biochar and mineral NP fertilizer both in Belg and Meher (Table 6). The highest available phosphorus contents of 17.232 mg kg^{-1} soil in Belg and 10.575 mg kg^{-1} soil in Meher were obtained at combined application of 7.5 t BC ha^{-1}+75% of mineral NP, which was statistically at par with those obtained at 7.5 t BC ha^{-1} + 50% mineral NP while, the lowest available phosphorus (9.698 mg kg^{-1} soil) in Belg and 5.420 mg kg^{-1} soil in Meher was obtained at control treatment. The highest available phosphorus with combined application of mineral NP and Biochar might be due to increases in organic matter promoting the activity of microorganisms to produce organic acids, which, in turn, increase the solubility of available phosphorus in soils, thereby enhancing the efficiency of phosphorus availability. The available phosphorus in Belg season was higher than that in Meher due to fast decomposition owing to optimum temperature and moisture. In line with this, Mengistu *et al*. (2017) reported that the application of biochar and mineral NP improved available P in the soil after harvest from 19.71 ppm under no-fertilizer treatment to 25.69 ppm under the application of 78 kg N ha^{-1} + 30 kg P ha^{-1} + 11.25 t ha^{-1} biochar.

Table 7: Exchangeable acidity (Ea) (cmol $_{(+)}$ kg^{-1} soil) and exchangeable aluminum (Eal) (cmol $_{(+)}$ kg^{-1}) of the soil after harvest as influenced by the combined application of biochar and mineral NP in Belg and Meher seasons

Treatment	*Belg*		*Meher*	
	Ea	*Eal*	*Ea*	*Eal*
2.5 t BC ha-1+ 25% NP	2.53^{abc}	1.71^{ab}	3.45^{b}	2.39^{ab}
2.5 t BC ha-1+ 50% NP	2.47^{bc}	1.70^{ab}	3.20^{c}	2.37^{ab}
2.5 t BC ha-1+ 75% NP	2.41^{cd}	1.68^{abc}	3.12^{c}	2.35^{ab}
5 t BC ha-1 + 25% NP	2.36^{cde}	1.66^{abcd}	3.10^{c}	2.33^{ab}
5 t BC ha-1+ 50% NP	2.29^{def}	1.66^{abcd}	2.93^{d}	3.00^{ab}
5 t BC ha-1+ 75% NP	2.23^{ef}	1.65^{cde}	2.81^{de}	2.15^{bc}
7.5 t BC ha-1+ 25% NP	2.16^{f}	1.62^{cd}	2.68^{ef}	1.91^{cd}
7.5 t BC ha-1+ 50% NP	2.14^{f}	1.61^{d}	2.67^{ef}	1.86^{d}
7.5 t BC ha-1+ 75% NP	2.13^{f}	1.60^{d}	2.59^{f}	1.80^{d}
20 t ha^{-1} Biochar	2.54^{abc}	1.72^{ab}	3.46^{b}	2.40^{ab}
100% NP	2.60^{a}	1.72^{ab}	3.74^{a}	2.41^{a}
No-fertilizer (control)	2.68^{ab}	1.73^{a}	3.78^{a}	2.46^{a}
LSD (5%)	0.174	0.069	0.147	0.254
Significance	**	**	**	**
CV (%)	4.33	2.42	2.79	6.74

Means followed by the same letter within a column are non-significantly different from each other; ** denotes significant difference at 1% level of probability, BC= Biochar.

Exchangeable acidity of soil

The exchangeable acidity of the soil after harvest was also highly significantly ($p < 0.01$) influenced by the combined use of biochar and mineral NP in Belg and Meher seasons (Table 7). The highest exchangeable acidity (2.68 cmol $_{(+)}$ kg^{-1} soil) in Belg was recorded under control treatment which was statistically at par with that of 100% NP while, the lower exchangeable acidity (2.13 cmol $_{(+)}$ kg^{-1} soil) was recorded at the combined application of 7.5 t BC ha^{-1} + 75% mineral NP which is statistically at par with several other treatments in Belg and in Meher seasons. This reduction in exchangeable acidity may be due to biochar which decreased the exchangeable acidity on account of binding of free ions of acid-forming cations (Al^{+3} and H^{+}). In this context, Abdissa *et al*. (2018) reported that the application of 5 t BC ha^{-1} and 60 kg P ha^{-1} fertilizer in combination had significantly reduced exchangeable acidity from 2.38 cmol$_{(+)}$ kg^{-1} soil of control treatment to 1.71 cmol $_{(+)}$ kg^{-1} soil which amounted to reduction of 39.18% from no-fertilizer treatment (2.38 cmol $_{(+)}$ kg $^{-1}$).

Exchangeable aluminum of soil

The exchangeable aluminum of soil after harvest was highly significantly ($p < 0.01$) affected by the combined application of biochar and mineral NP fertilizer in both seasons (Table 8).

The lowest exchangeable aluminum contents of 1.60 cmol $_{(+)}$ kg^{-1} soil in Belg and 1.80 cmol $_{(+)}$ kg^{-1} soil in Meher season were obtained by the combined use of 7.5 t BC ha^{-1} and 75% mineral NP, which was statistically at par with those obtained under several treatments. The reduction of soil exchangeable aluminum with biochar and its mixture with mineral NP may be due to biochar which allows a

Table 8: Cation exchange capacity (CEC) (cmol $_{(+)}$ kg^{-1} soil), exchangeable calcium (EX-Ca^{+2}) (cmol $_{(+)}$ kg^{-1} soil) and exchangeable magnesium (EX-Mg^{+2}) (cmol $_{(+)}$ kg^{-1} soil) of soil after potato harvest as influenced by the combined application of biochar and mineral NP in Belg and Meher seasons

Treatment	*Belg*			*Meher*		
	CEC	*EX-Ca^{+2}*	*EX-Mg^{+2}*	*CEC*	*EX-Ca^{+2}*	*EX-Mg^{+2}*
2.5t BC + 25% NP	19.60^{de}	5.74^{bc}	2.32^{def}	18.93^{fgh}	7.12^{efg}	2.26^{fgh}
2.5 t BC + 50% NP	19.75^{cde}	5.79^{abc}	2.32^{cde}	19.33^{efg}	7.17^{efg}	2.43^{efg}
2.5t BC + 75% NP	19.80^{cde}	5.81^{abc}	2.33^{cde}	19.90^{efgh}	7.44^{de}	2.66^{efg}
5tBC + 25% NP	20.03^{ced}	5.83^{abc}	2.34^{bcde}	20.28^{def}	7.56^{cd}	2.82^{def}
5tBC + 50% NP	20.60^{bc}	5.86^{abc}	2.35^{bcde}	20.78^{cde}	7.64^{cd}	3.03^{cde}
5tBC + 75% NP	20.46^{bcd}	5.94^{abc}	2.37^{bcd}	21.20^{bc}	7.86^{bc}	3.20^{cd}
7.5tBC + 25% NP	20.59^{bc}	5.97^{abc}	2.38^{bc}	21.93^{bc}	7.91^{c}	3.50^{bc}
7.5 t BC + 50% NP	21.18^{b}	6.06^{ab}	2.40^{b}	22.80^{ab}	8.21^{b}	3.86^{ab}
7.5 t BC + 75% NP	22.22^{a}	6.07^{a}	2.48^{a}	23.97^{a}	8.69^{a}	4.34^{a}
20 t ha^{-1} Biochar	19.62^{de}	5.76^{bc}	2.34^{def}	18.97f^{gh}	7.14^{efg}	2.28^{fgh}
100% NP	19.36^{e}	5.71^{c}	2.31^{ef}	18.60^{gh}	6.98^{fg}	2.12^{gh}
No-fertilizer (control)	18.40^{f}	5.66^{c}	2.26^{f}	17.73^{h}	6.76^{g}	1.77^{h}
LSD (5%)	0.912	0.321	0.059	1.470	0.355	0.607
Significance	**	**	**	**	**	**
CV (%)	2.65	3.21	1.46	4.21	2.75	12.25

Means followed by the same letter within a column are non-significantly different from each other; ** denotes significant difference at 1% level of probability, BC= Biochar.

continuous supply of Ca^{+2}, Mg^{+2} and other cations that exist in the Biochar (Gazey and Davis, 2009). These cations lead to replace the exchangeable Al^{3+} from soil matrix and form insoluble aluminum. Chau-Minh *et al.* (2010) reported that the contents of titratable acidity, exchangeable Al^{3+} and dissolved Al^{+3} decreased dramatically with increasing amounts of compost amendment.

Cation exchange capacity of soil

Cation exchange capacity of soil after harvest was highly significantly ($p < 0.01$) affected by the combined application of biochar and mineral NP fertilizer in both seasons (Table 8). The highest CEC 22.22 cmol $_{(+)}$ kg^{-1} soil in Belg and 23.97 cmol $_{(+)}$ kg^{-1} soil in Meher were obtained at the combined application of 7.5 t ha^{-1} biochar + 75% mineral NP, while the lowest CEC 18.40 cmol $_{(+)}$ kg^{-1} soil in Belg and 17.73 cmol $_{(+)}$ kg^{-1} soil in Meher were obtained when biochar and mineral NP were not applied. The increased CEC values in biochar and NP-treated plots were mainly due to the presence of humic substances in thebiochar and the solubility of the various organic acids. In line with this result, Abdissa *et al.* (2018) recorded higher cation exchange capacity values of 12.22 cmol $_{(+)}$ kg^{-1} soil with the application of 5 t ha^{-1} biochar and 60 kg P ha^{-1}.

Exchangeable calcium in soil

Exchangeable base Ca^{+2} of soil after harvest was highly significantly ($p < 0.01$) affected by the combined application of biochar and mineral NP fertilizer in both seasons. The highest exchangeable calcium values of 6.07 cmol $_{(+)}$ kg^{-1} soil in Belg and 8.69 cmol $_{(+)}$ kg^{-1} soil in Meher were recorded under the treatment 7.5 t ha^{-1} Biochar with 75% mineral NP which was statistically at par with those of all treatments except for control 100% NP, 2.5 t BC ha^{-1}+25% NP in Belg, while the lowest exchangeable calcium of 5.66 cmol $_{(+)}$ kg^{-1} soil in Belg and 6.76 cmol $_{(+)}$ kg^{-1} soil in Meher were obtained under control treatment which was statistically the same as obtained in all treatments except 7.5 t BC ha^{-1} + 75% NP and 7.5 t BC ha^{-1} + 50 % NP in Belg. The highest exchangeable calcium at the highest rate of biochar and inorganic fertilizer probably enhanced the activities of microbes, resulting in the release of organic substances with particular reference to chelating agent which might have prevented exchangeable calcium from leaching in acid soils. In agreement with this result, Kesarwani *et al.* (2017) showed similar increases in soil exchangeable calcium from 1238.11 ppm in the 100% NPK treatment to 1291.23 ppm in combined application of 75% NPK through inorganic fertilizers + 25% Biochar.

Exchangeable magnesium of soil

Exchangeable base Mg^{+2} of soil after harvest was highly significantly ($p < 0.01$) affected by the combined application of biochar and mineral NP fertilizer in both seasons. The highest exchangeable magnesium contents of 2.48 cmol $_{(+)}$ kg^{-1} soil in Belg and 4.34 cmol $_{(+)}$ kg^{-1} soil in Meher were obtained at the combined application of 7.5 t ha^{-1} biochar with 75% mineral NP (Table 8). In contrast, the lowest

Table 9: Exchangeable potassium (EX-K^+) (cmol $_{(+)}$ kg^{-1} soil), exchangeable sodium (EX-Na^+) (cmol $_{(+)}$ kg^{-1} soil) and percent base saturation (PBS) of soil after potato harvest as influenced by combined application of Biochar and mineral NP in Belg and Meher seasons

Treatment	*Belg*			*Meher*		
	EX-K^+	*EX-Na^+*	*PBS (%)*	*EX-K^+*	*EX-Na^+*	*PBS (%)*
2.5t BC + 25% NP	0.298^{cd}	0.04	42.97	0.18^{fgh}	0.04	50.76
2.5 t BC + 50% NP	0.3^{bc}	0.04	42.88	0.19^{efg}	0.04	50.90
2.5t BC + 75% NP	0.3^{bc}	0.04	42.88	0.20^{defg}	0.05	52.03
5tBC + 25% NP	0.301^{bc}	0.05	42.61	0.21^{def}	0.05	52.47
5tBC + 50% NP	0.302^{abc}	0.05	42.36	0.22^{cde}	0.06	52.67
5tBC + 75% NP	0.303^{abc}	0.01	42.17	0.22^{cd}	0.06	53.51
7.5tBC + 25% NP	0.304^{abc}	0.02	42.17	0.23^{bc}	0.07	53.41
7.5 t BC + 50% NP	0.306^{ab}	0.02	41.55	0.25^{a}	0.08	54.42
7.5 t BC + 75% NP	0.307^{a}	0.02	40.01	0.27^{a}	0.09	55.94
20 t ha^{-1} Biochar	0.299^{cd}	0.02	42.04	0.19^{fgh}	0.09	52.32
100% NP	0.293^{de}	0.02	43.15	0.184^{gh}	0.20	50.10
No-fertilizer (control)	0.289^{e}	0.03	44.87	0.171^{h}	0.12	49.22
LSD (5%)	0.006	NS	NS	0.022	NS	NS
Significance	**	NS	NS	**	NS	NS
CV (%)	2.08	66.65	4.06	6.18	15.70	2.16

Means followed by the same letter within a column are non-significantly different from each other; ** denotes significant difference at 1% level of probability, NS= Non-significant, BC= Biochar.

contents of 2.26 cmol$_{(+)}$ kg^{-1} soil in Belg and 1.77 cmol$_{(+)}$ kg^{-1} soil in Meher were obtained in the control treatment, which is statistically the same as those obtained at 100% NP, 2.5 t BC ha^{-1} + 25% NP in both seasons. This increment may be attributed to the synergistic effects of the biochar and mineral NP fertilizers in encouraging nutrient mobility and increasing exchangeable magnesium. The present result agrees with that of Mengistu *et al*. (2017), who reported that combined application of biochar at 11.25 t ha^{-1} + 75% NP (105 kg N+40 kg P ha^{-1}) fertilizers increased the exchangeable magnesium content of soil by 91% as compared to the no-fertilizer treatment plots (1.52 cmol $_{(+)}$ kg^{-1} soil).

Exchangeable potassium of soil

Exchangeable potassium K^+ contents in initial soil were 0.42 cmol $_{(+)}$ kg^{-1} soil in Belg and 0.36 cmol $_{(+)}$ kg^{-1} soil in Meher while, these amounts varied from 0.289 cmol $_{(+)}$ kg^{-1} soil to 0.307 cmol $_{(+)}$ kg^{-1} soil in Belg and from 0.171 cmol $_{(+)}$ kg^{-1} soil to 0.27 cmol $_{(+)}$ kg^{-1} soil in Meher season after application of 7.5 t BC + 75% NP in both seasons (Table 9). The exchangeable potassium content was statistically the same as with those of 5 t BC ha^{-1}+ 50% NP, 5 t BC ha^{-1}+ 75% NP, 7.5 t BC ha^{-1}+ 25% NP and 7.5 t BC ha^{-1}+ 50% NP in Belg and 7.5 t BC ha^{-1} + 50% NP in Meher season, while the lowest exchangeable potassium contents in both seasons were recorded at zero rates of BC and inorganic NP fertilizers. This increment in exchangeable potassium (Ex-K^+) may be an account of Biochar having enhanced the soil fertility through decomposition by soil microbes making increased bioavailability of exchangeable potassium. Similarly, Kesarwani *et al*. (2017) indicated that combined use of 75% NPK and the remaining 25% from Biochar increased the exchangeable potassium from 250.21 to 256.59 ppm at 100% NPK. Likewise, Ali *et al*. (2017) also found such magnitudes of potassium content in soil by the use of 50% NP through mineral fertilizers combined with cattle manure, biochar, neem cake and biofertilizers. However, sodium levels were very low which did not appear to affect potato growth and yield.

Conclusion

The present study indicated that the soil properties after potato harvest during both seasons responded positively to the combined application of biochar and mineral NP fertilizers. The combined application of 7.5 t BC ha^{-1} + 75% (124 kg N ha^{-1} and 45 kg P ha^{-1}) of inorganic NP fertilizers showed the best performance. The soil analysis indicated higher values of soil pH, OC, TN, available P, CEC, exchangeable calcium, exchangeable magnesium, exchangeable potassium and porosity while, soil bulk density, exchangeable acidity and Al were decreased when Biochar and inorganic NP were used together. Hence, the above-mentioned combination is recommended for the improvement of the physico chemical properties of the soil in the study area and other similar agroclimatic zones.

References

Abdissa Bekele, Kibebew Kibret, Bobe Bedadi, Markku Yli-Halla andTesfaye Balemi. 2018. Effects of lime, Biocharand chemical P Fertilizer on selected properties of acid Soils of Ebantu district, western highlands of Ethiopia. Applied and Environmental Soil Science, 1: 1-13.

Black, C.A., L.E. Ensminger and F.E. Clark. 1965. Methods of soil analysis. Agronomy, 9: 891-901.

Chaudhari, P. R., Ahire, D. V., Ahire, V. D., Chkravarty, M. and Maity, S. 2013. Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Coimbatore Soil. International Journal of Scientific and Research Publications, 3(1): 2250–3153.

Chau-Minh KhoiA, Vo Thi Guong A, Pham Nguyen Minh Trung A, and Ingvar Nilsson S. 2010. Effects of compost and lime amendment on soil acidity and N availability in acid sulfate soil, 2010. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1–6 August 2010, Brisbane, Australia. Published on DVD.

CSA (Central Statistical Agency). 2024. Agricultural Sample Survey Report on Area and Production (Private Peasant Holdings Meher Season. Central Statistical Agency of Ethiopia, Statistical Bulletin.

Davoud Akhzari, Behnaz Attaeian, Abdolhossein Arami, Farnaz Mahmoodiand Fariba Aslani. 2015. Effects of vermicompost and arbuscularmycorrhizal fungi on soil properties and growth of Medicagopolymorpha L.). Compost Science and Utilization, 23(3): 142-153.

Douches, D.S. 2013. Breeding and genetics for the improvement of potato (SolanumtuberosumL.) for yield, quality and pest resistance. http://potatobg.msu.edu/program overview.shtml.

FAOSTAT, 2010. Agricultural data. Provisional 2009 Production and Production Indices Data. Crop primary. Food and Agriculture Organization of the United Nations, Rome, Italy.

Gazey, C. and Davies, S. 2009. Soil Acidity: a guide for WA farmers and consultants. Department of Agriculture and Food 52 pp

Irungbam, P., Pramanick, M. and Sanahanbi, D. T. 2017. Growth and productivity of potato (cv. Kufri Jyoti) and soil nutrient status as influenced by different nutrient management in the new alluvial zone of West Bengal. Journal of Environmental Biology, 39: 1-5.

Isreal Zewide, Ali Mohammed and Solomon Tulu. 2012. Effect of different rate of nitrogen and phosphorus on yield and yield components of potato (Solanum tuberosum L.) at Masha District, Southwestern Ethiopia. International Journal of Soil Science, 7(4): 146-15.

Jabar, S. 2018. Effect of the organic and inorganic fertilizer on some soil properties and corn (Zeamays L.) growth parameters. Thi-Qar University Journal for Agricultural Researches, 7(2): 1-22.

Jackson, M.L.1967. Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi. India. 498p.

Keasrwani, I., Mehraj, S., Ali, M., Hassan, A., Wani, S., Hussain, S. and Bisati, I. 2017. Effect of inorganic and organic fertilizers on yield and soil nutrient status of walnut orchard. International Journal of Plant and Soil Science, 16(2): 1–13.

Kumar, P., Kumar, A., Kumar, N., Ahamad, A. andVerma, M. K. 2017. Effect of Integrated Nutrient Management on Productivity and Nutrients Availability of Potato, International Journal of Current Microbiology and Applied Sciences, 6(3): 1429–1436.

Lindsay, W. L. andNorvell, W. A. 1978. Development of a DTPA Soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal, 42(3): 421–428.

Mengistu, T., Gebrekidan, H., Kibret, K., Woldetsadik, K., Shimelis, B. and Yadav, H. 2017. The integrated use of excreta-based vermicompost and mineral NP fertilizer on tomato (Solanumlycopersicum L.) fruit yield, quality and soil fertility. International Journal of Recycling of Organic Waste in Agriculture, 6(1): 63–77.

Muthoni J., 2016, Soil fertility situation in potato producing Kenyanhighlandscase of Kalro-Rigoni, International Journal of Horticulture, 6(25): 1-11.

Muthoni, J., and Nyamongo, D. O. 2009. A review of constraints to ware Irish potatoes production in Kenya, Journal of Horticulture and Forestry 1(7): 98–102.

Nityamanjari, M. 2018. Effect of fertilizers on growth and productivity of potato. International Journal of Agriculture Sciences, 10(4): 5183-5186.

Raghav, M. and Shashi, Kamal. 2009. Effect of organic sources of nutrients on potato production in Tarai region of Uttarakhand. Pantnagar Journal of Research, 7(1): 69-72.
Rowell, D.L. 1994. Soil Science: Methods and applications. Addison Wesley Longman Limited, England. 350p.

Sarwar G, Schmeisky H, Tahir MA, Iftikhar Y, Sabah NU. 2010. Application of green compost for improving soil chemical properties and fertility status. The Journal of Animal and Plant Sciences, 20: 258 – 260.