Potato yield enhancement by combined use of NPS blended fertilizer and coffee husk biochar and its economic analysis

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Potato (*Solanum tuberosum* L.) is an important tuber crop in Ethiopia, however its yield is far below the potential yield due to different constraints, soil fertility being main among them. Therefore, a study was conducted at Masha district, south-western Ethiopia to find out the optimum combination of NPS blended fertilizer and coffee husk biochar (organic source) for the best economic yield and quality of potato. The treatment consisted of four levels of NPS (0, 121, 242, 363 kg ha^{-1}) and four levels of coffee husk biochar (0, 4, 8, 12 t ha^{-1}). The experiment was arranged in randomized complete block design with three replications. Results revealed that the combined application of NPS and biochar significantly ($p<0.05$) influenced almost all parameters except average tuber weight, large sized-tuber number, unmarketable tuber number and yield. The highest mean values of days to 50% flowering (75 days), days to 90% physiological maturity (105 days), plant height (98 cm) and the main stem number (10 hill^{-1}) were recorded from the treatment which received 363 kg NPS ha^{-1} + 12 t coffee husk biochar ha^{-1}. Also, the highest marketable tuber number (14.8 hill^{-1}) and total tuber number (16.2 hill^{-1}) were recorded under the treatment receiving combined application of 363 kg NPS ha^{-1} blended fertilizer with 4 t biochar ha^{-1}. The combined application of 363 kg NPS ha^{-1} + 8 t coffee husk biochar ha^{-1} produced the highest marketable tuber yield of 47.8 t ha^{-1} and the highest total tuber yield of 49.5 t ha^{-1}. The tuber specific gravity of 1.098 g cm^{-3} and dry matter content of 41.4% were recorded from the treatment which received 363 kg NPS ha^{-1} + 12 t coffee husk biochar ha^{-1}. The proportion of small-sized tuber number (55%) recorded from control treatment and medium-sized tuber number (53.3%) were recorded under treatment consisting of combined application of 363 kg NPS ha^{-1} + 8 t ha^{-1} coffee husk biochar. Based on partial budget analysis the combined application of 363 kg NPS ha^{-1} with 8 t biochar ha^{-1} gave an optimum net return of 287112 ETB ha^{-1} (ETB 1= USD 0.03) and 3820% MRR (marginal rate of return). Summarily, the combined use of NPS with coffee husk biochar significantly increased potato growth, yield and physical quality.

Keywords: Blended fertilizer, cost-benefit ratio, marginal rate of return (MRR), marketable tuber, tuber yield

Potato is an important vegetable crop constituting the fourth most important food crop in the world following wheat, rice and maize and first among root and tuber crops (Douches 2013). It is a high potential food security crop due to its high yield potential, nutritional quality, short growing period and wide adaptability and it can play an important role in improving food security and cash income of smallholder potato growers in developing countries, including Ethiopia (Adane et al. 2010). It has been cultivated in Ethiopia for over 150 years and is currently grown in many parts of the country. Its production area has reached about 66,926 ha, with total production of 921,403.2 tonnes cultivated by over 1.2 million households. However, the productivity of this crop in the country is very low (13.9 t ha^{-1}) as compared to the world's average yield of 19 t ha^{-1} (CSA 2018). In the other African countries of Algeria, Egypt and Malawi, its productivity is 30.9, 26.4, and 18.4 t ha^{-1}, respectively (FAOSTAT 2020). Potato has been considered as a strategic crop by the Ethiopian government aiming at enhancing food security and economic benefits to the country. While national average yield is far below those attainable, there exist ample opportunities to unleash this crop's potential for increased food security and income generation (Teklemariam 2014). Inadequate agronomic management practices like faulty agronomic management practices and inappropriate application of fertilizers, low nutrient reserves in arable soils, a negative nutrient balance in crop, diseases and insect pests are some of the factors contributing to the low yield of potato in the study area Degele in Masha district.

This crop is a heavy feeder requiring

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relatively large quantities of fertilizers. In the study area, use of only chemical fertilizers without supplementing them with organic sources, accompanied by high rainfall tends to cause leaching of most of the macro and micro-nutrients significantly reducing soil fertility, thereby adversely affecting crop productivity (Isreal et al. 2018**)**. Therefore, to enhance the productivity of potato, soil fertility management has to be the primary goal of the producers. The soil of the study area is deficient in nitrogen, phosphorus, and sulphur nutrients as indicated in the Ethio-SIS map (Ethio-SIS 2016). Farmers need better technologies, more sustainable practices, and fertilizers to improve and sustain crop productivity. However, the cost of chemical fertilizers and their associated risks on environmental safety have become unaffordable (Mojtaba et al. 2013).

To alleviate these problems, an easily available and an environmentally friendly soil amendment, like biochar, is of very high significance to increase agricultural productivity and ensure food security. Biochar is different from other charcoals as it is a fine-grained highly porous charcoal that can be formed as a result of the pyrolysis of biomass in complete absence or limited presence of oxygen and can be used as a soil amendment (Gaunt et al. 2014). Currently, biochar has been widely accepted and given great attention, not only due to its contribution to mitigating climate change, but also as a desirable soil amendment material that can enhance fertility (Helene 2016). Though it is made from various types of plants, biochar made from the coffee husk is relatively high in potassium which could lower or replace imported sources of potassium. It also has high cation exchange capacity (CEC) as compared to other types of biochar which can increase the nutrient holding capacity of soils, leading to reduced fertilizer requirement (Domingues et al. 2017). In the study area, there is a wide production of potato but the productivity is low, the basic reason for this is low soil fertility and increased soil acidity, in addition to other factors (Isreal et al. 2018). In the study area there is a high amount of land cover with coffee plantation and each year thousands of tons of coffee are processed and the by-product (coffee husk) remains unused. Farmers burn this husk, instead of reusing it for agricultural purposes, which contains a high amount of essential nutrients for plants. This also causes environmental pollution.

This study, therefore, was designed to use the coffee husk biochar to improve the physicochemical properties and ultimately increase potato productivity. No study on the effect of the application of biochar, along with mineral NPS blended fertilizer on the growth, yield and physical quality parameters of potato, has been done in the study area. Therefore, this study aimed to develop a recommendation on the use of coffee husk biochar, along with mineral NPS blended fertilizer for the optimum production of potato.

Materials and methods

Description of the experimental site

This experiment was conducted in the main cropping season of 2019 at the Degele area, Masha district of south-western Ethiopia on farmer’s field geographically located at 7°24'–7°52' N latitude and 35°13'–35°35' E longitude at an elevation of about 2500 m.a.s.l. (Figure 1). Rainfall spreading over the February to October period ranged from 950-1270 mm. The monthly mean maximum and minimum temperatures ranged from 24°C to 26.5°C from June to September and from 12°C in June to 15°C in August, respectively (MMS 2019). The soil was sandy- loam and very acidic.

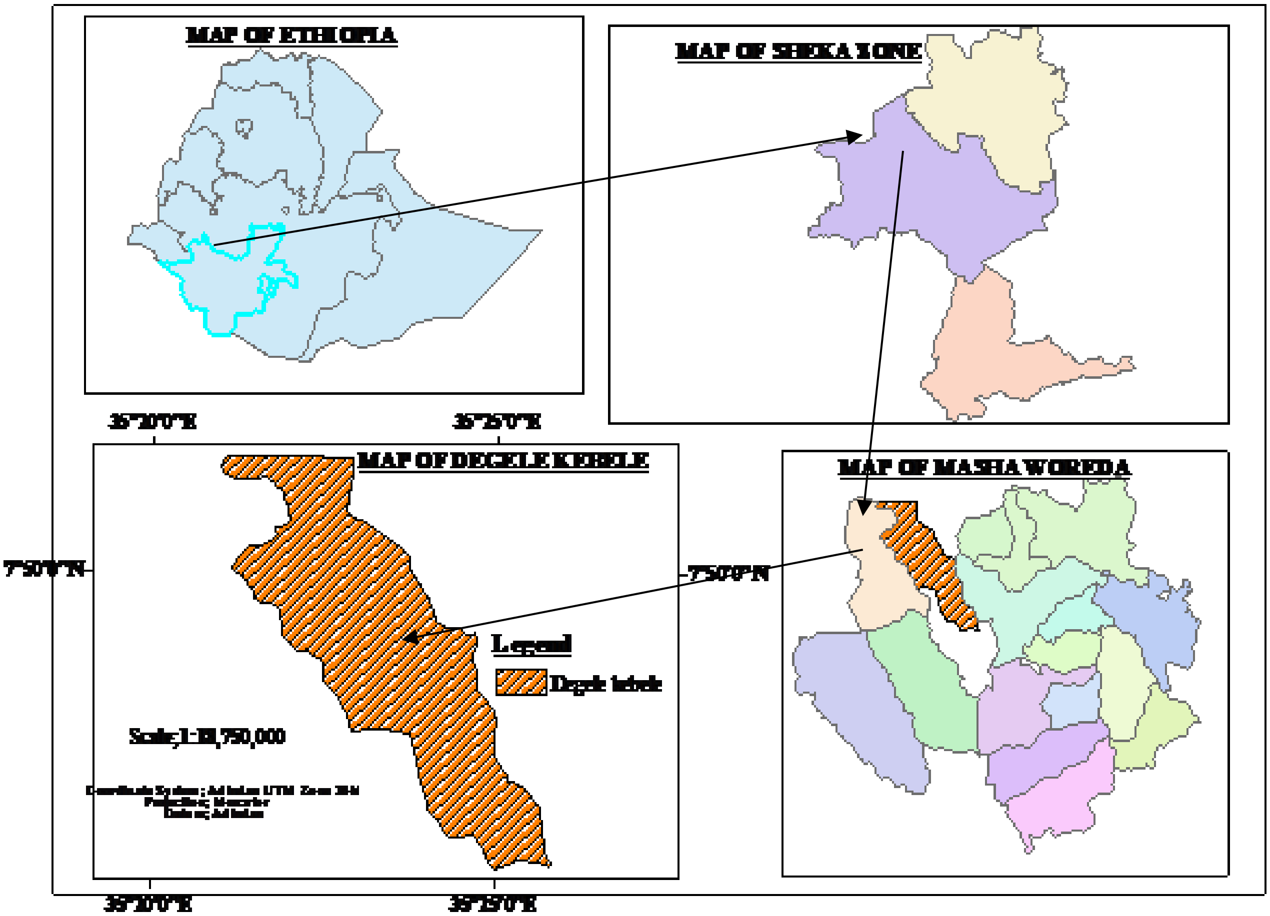

Figure 1: Map of the study area located in the south-western Ethiopia.

Description of experimental materials

Potato variety '*Belete*' was used as a test crop which matures in 110-120 days. Blended NPS fertilizer containing N, P and S (19:38:7) was used along with urea as an additional nitrogen source. The coffee husk was obtained from the coffee processing industry. The total amount of biochar needed for this experiment was 466 kg, which was ground to small granules and passed through 2 mm sieve in order to have a uniform particle size.

Treatments and experimental design

Treatments consisted of four levels of coffee husk biochar (0, 4, 8, 12 t ha $^{-1}$) and four levels of inorganic blended mineral fertilizer NPS (0, 121, 242, and 363 kg ha^{-1}) totalling sixteen treatment combinations. The field experiment was laid out in a randomized complete block design with three replications. Each plot accommodated six rows, spaced 75 cm apart with 12 plants row^{-1} maintaining intra-row spacing of 30 cm.

Soil sampling for initial physico-chemical properties

Before planting, the physical and chemical properties of the experimental field soil were determined. Soil samples were collected from the experimental site from 21 locations across the experimental field randomly in a zigzag pattern at the depth of 0-20 cm. The working samples were air-dried, ground, and passed through a 2 mm-sieve for physico-chemical analysis. The soil analysis included the determination of total nitrogen, available phosphorus, soil pH, cation exchange capacity, organic carbon and textural composition, i.e. sand, silt and clay (Piper 2019). Chemical properties of coffee husk biochar were also determined.

Experimental procedure and crop management

Degraded biochar was applied to the designated plots by spreading uniformly and then incorporated into the soil (0-20 cm) a month before planting. NPS blended fertilizer was applied by drilling along the furrow s and mixed well with the soil at the time of planting. Pre-sprouted potato tubers were planted at a depth of 5 cm at specified spacing. After 110 days of planting, dehaluming was done to thicken tuber periderm when the plants reached physiological maturity and senesced.

Data collection

Days to 50% flowering, days to 90% physiological maturity, number of main stem per hill and plant height at 90% physiological maturity were measured. Data on yield and yield components were recorded on tubers harvested from 40 hills per plot and averaged for tuber numbers per hill. Tubers free from diseases and insect pests and weighing 25 g or more were considered as marketable tubers. Tubers which were unhealthy or injured by insect pests or weighing less than 25 g were considered as unmarketable tubers. Tuber weight (g tuber^{-1}) was obtained by dividing the total weight of fresh tubers at harvest from the net area to the total numbers of fresh tubers recorded from the net area.

Harvested tubers were graded into three groups for physical quality parameters based on the size of the tuber such as <35 gm (small), 35-55 gm (medium) and >55 gm (large) (Abbas et al. 2012). For the determination of specific gravity of tubers (g cm^{-3}), the bulk tuber samples consisting of all sizes weighing about 5 kg were randomly taken from each plot and washed with water. The specific gravity was determined according to Kleinkopf et al. *(*1981):

$$SG = \frac{Wa}{Wa - Ww}$$

where, SG= Specific gravity (g cm^{-3});

Wa= Weight (g) in the air;

Ww= Weight (g) in water

For determining percentage dry matter content of tubers, five potato tubers were randomly selected from each plot, chopped into small 1-2 cm pieces, mixed thoroughly, and two sub-samples each weighing 200 g were drawn and designated as fresh weight. Each sub-sample was dried in an oven at 70 ^{0}C until a constant dry weight was attained. The samples were then placed in desiccators to attain room temperature, then weighed to determine the dry matter content.

Data analysis

The analysis of variance was done using SAS version 9.3 statistical software (SAS 2012). When the ANOVA showed significant differences means of NPS, coffee husk biochar and interaction effects were compared by using least significant difference (LSD) value at 5% significance (Gomez and Gomez 1984).

Partial budget analysis

The economic analysis was done using the partial budget analysis described by CIMMYT (1988). Net return Ethiopian Birr (ETB) ha^{-1} (1ETB~0.03 USD) and cost:benefit ratio for different treatment combinations were calculated by considering the sale price of potato and cost of fertilizers and labour for all field activities done. The treatment which was non-dominated and having a MRR of greater or equal to 100% with the highest net benefit was taken to be economically profitable.

Results and discussion

Certain properties of experimental soil and biochar

The textural class of soil belonged to the group sandy-clay-loam (Table 1) and the cation exchange capacity of the soil was moderate (Hazelton and Murphy 2007). The soil had low available phosphorus that is probably associated with the pH value (4.96) which is very strongly acidic (Olsen 1954). Further, the soil had low total nitrogen and medium organic carbon (Tekalign et al. 1991) and the C:N is characterized as medium (Hazelton and Murphy 2007). The biochar had relatively high contents of phosphorus and organic carbon and the pH was alkaline.

Table 1: Physico-chemical properties of the experimental site

	Soil	**Biochar**
Parameter	**Value**	**Value**
Soil texture		
Sand		
Clay	24%	
Silt	12%	
Textural class	Sandy-loam	
pH	4.96	8.1
Organic carbon (g kg^{-1})	24.7	4045
Total N (g kg^{-1})	1	170
Total K (cmol$_{(+)}$ kg^{-1})		24
Carbon : Nitrogen (C:N)	1:24.7	1:23.7
Available P (ppm)	9.46	2850
CEC (cmol$_{(+)}$ kg^{-1})	16.34	38

Phenological variables

Flowering and maturity

The combined application of NPS blended fertilizer and coffee husk biochar highly significantly ($p<0.01$) influenced the days to 50% flowering (Table 2). The maximum number of days to 50% flowering (75 days) was recorded under the treatment having the combined application of 363 kg NPS ha^{-1}+12 t ha^{-1} of coffee husk biochar. This is, however, statistically similar to that of combined application of 363 kg NPS ha^{-1} with 8 t ha^{-1} of coffee husk biochar while, the minimum period to 50% flowering (60 days) was recorded in unfertilized treatment. Melkamu and Minwyelet (2018) also reported similar results for potato crop.

Table 2: Interaction effect of NPS blended fertilizer and coffee husk biochar (BC) on phenology and growth variables of potato

Treatment		Phenology and growth parameters			
NPS	BC	DF	DPM	NMS (hill^{-1})	PH (cm)
0	0	60.0^{i}	82.0^{h}	6.0^{g}	67.0^{j}
	4	61.3^{hi}	84.0^{gh}	7.0^{fg}	70.0^{i}
	8	62.7^{hg}	86.7^{gfh}	7.1^{efg}	75.0^{h}
	12	63.7^{fg}	87.3^{gfh}	7.7^{cdef}	75.0^{h}
121	0	62.3^{hg}	88.3^{fg}	7.4^{cdef}	77.0^{g}
	4	63.3^{fg}	89.7^{ef}	8.1^{cdef}	79.0^{f}
	8	63.7^{fg}	91.0^{ef}	7.3^{defg}	81.0^{e}
	12	64.7^{ef}	90.7^{ef}	8.4^{bcde}	81.0^{e}
242	0	64.3^{f}	94.3^{ed}	8.6^{bcd}	91.0^{d}
	4	66.0^{e}	96.7^{cd}	7.9^{cdef}	93.0^{c}
	8	67.7^{e}	98.0^{bcd}	8.0^{cdef}	93.3^{c}
	12	69.0^{d}	99.0^{bcd}	8.8^{bc}	94.0^{bc}
363	0	72.3^{c}	101.3^{abc}	8.4^{bcde}	95.0^{b}
	4	73.7^{bc}	103.0^{ab}	8.4^{bcdef}	95.3^{b}
	8	74.3^{ab}	103.3^{ab}	9.6^{ab}	95.0^{b}
	12	75.0^{a}	105.0^{a}	10.0^{a}	98.0^{a}
LSD ($_{0.05}$)		1.4	5.3	1.3	1.5
CV (%)		1.3	3.4	9.8	1.0

Where, DF= days to flowering, DPM= days to physiological maturity, NMS= number of main stem, PH= plant height. Means superscripted by the same letter are not significantly different

The physiological maturity of potato was highly significantly ($p<0.01$) influenced by the combined use of NPS blended fertilizer and coffee husk biochar (Table 3). The maximum number of days to physiological maturity (105 days) was recorded under the treatment consisting of combined application of 363 kg NPS ha^{-1} with 12 t ha^{-1} of coffee husk biochar, parallel to the trend of flowering. This could be due to the fact that increasing NPS fertilizer rates might have promoted the vegetative phase of potato plants that may, in turn, have prolonged the maturity of potato plants. The results clearly indicated that increasing NPS blended fertilizer and coffee husk biochar rates delayed physiological maturity of potato by 28% as compared to the control of no NPS fertilizer and no coffee husk biochar. The application of phosphorus and nitrogen fertilizer significantly delayed days to physiological maturity of potato (Nigussie et al. 2016).

Growth parameters

Plant height and number of main stems per hill

The combined application of NPS blended fertilizer with coffee husk biochar highly significantly ($p<0.01$) influenced the plant height of potato (Table 2). The tallest plants (98 cm) were obtained under the treatment receiving 363 kg NPS ha $^{-1}$ and 12 t ha^{-1} of coffee husk biochar, while the shortest plant height (67 cm) was recorded from the control treatment. Application of highest rates of NPS blended fertilizer and coffee husk biochar increased the plant height by 46.3% compared to the control. This result is similar to those of Melkamu et al. (2019) who reported that combination of 245.1 kg NPS ha^{-1} with 13.5 t ha^{-1} farmyard manure (FYM) increased plant height by 70% while, that of 245.1 kg NPS ha^{-1} with 9.0 t ha^{-1} FYM increased by 65.4% as compared to the control plants.

The number of main stems per hill was significantly ($p<0.05$) affected by the interaction effect of NPS blended fertilizer and coffee husk biochar (Table 3). The highest number of main stems (10 hill^{-1}) was recorded under the treatment having combined application of 363 kg NPS ha^{-1} blended fertilizer and 12 t ha^{-1} of coffee husk biochar which is similar to the results obtained from the use of 363 kg NPS ha^{-1}+8 t ha^{-1} coffee husk biochar. Thus, the application of highest rates of NPS blended fertilizer and coffee husk biochar increased the stem number by 66% compared to the control. The application of biochar loaded with nitrogen and phosphate fertilizers could be a great source to improve soil fertility by slow release of fertilizer to the soil (Shaaban et al. 2018).

Yield and yield components

Total tuber number per hill

The combined use of NPS blended fertilizer and coffee husk biochar significantly ($p< 0.05$) influenced the total tuber number (Table 3). The highest total tuber numbers (16.2 hill^{-1}) were recorded with the application of 363 kg NPS ha^{-1}+4 t ha^{-1} biochar followed by those receiving the same amount of NPS fertilizer with either 8 t or 12 t of biochar with total tuber numbers being 14 and 12 hill^{-1}, respectively.

Table 3: Interaction effect of NPS blended fertilizer and coffee husk biochar (BC) on yield components and yield of potato

Treatment NPS	BC	TTN (hill^{-1})	MTN (hill^{-1})	UMTN (hill $^{-1}$)	TTY (t ha^{-1})	MTY (t ha^{-1})	UMTY (t ha^{-1})	ATW (g tuber^{-1})
0	0	10.9^{d}	7.6^{f}	3.3	24.9^{e}	19.9^{e}	4.9	49.6
	4	11.1^{d}	7.6^{f}	3.4	28.2^{bcde}	26.6^{bcde}	1.6	57.4
	8	11.8^{cd}	7.4^{f}	4.4	25.5^{de}	23.3^{de}	2.6	51.4
	12	12.0^{bcd}	9.1^{def}	2.9	30.5^{bcde}	27.5^{bcde}	2.9	56.5
121	0	12.2^{bcd}	9.1^{def}	3.1	27.6^{cde}	25.2^{cde}	2.3	50.0
	4	11.1^{d}	9.4^{def}	1.7	33.5^{bcde}	31.2^{bcde}	2.2	66.5
	8	11.4^{cd}	8.6^{ef}	2.8	30.5^{bcde}	29.1^{bcde}	1.3	59.4
	12	13.5^{bc}	11.6^{bc}	1.9	33.7^{bcde}	30.9^{bcde}	2.8	56.4
242	0	13.0^{bcd}	10.6^{bce}	2.4	32.5^{bcde}	30.3^{bcde}	2.1	55.8
	4	13.4^{bc}	11.1^{bcd}	2.3	38.5^{abc}	36.6^{abc}	1.9	64.0
	8	13.3^{bc}	11.1^{bcd}	2.2	37.8^{abcd}	34.8^{bcd}	2.2	63.9
	12	11.8^{cd}	10.1^{cde}	1.6	34.2^{bcde}	31.6^{bcde}	2.5	65.1
363	0	11.8^{bcd}	9.8^{cde}	2.0	34.4^{bcde}	33.1^{bcd}	1.3	69.1
	4	16.2^{a}	14.8^{a}	1.4	39.9^{ab}	38.5^{ab}	1.4	56.0
	8	14.0^{b}	12.5^{b}	1.4	49.4^{a}	47.8^{a}	1.6	78.8
	12	12.3^{bcd}	10.8^{bcd}	1.4	30.2^{bcde}	28.8^{bcde}	1.3	57.3
$LSD_{(0.05)}$		2.1	2.0	NS	11.9	12.4	NS	NS
CV (%)		10.2	12.2	23.0	11.5	14.5	23.0	20.6

Where, TTN= total tuber number, MTN= marketable tuber number, UMTN= unmarketable tuber number, TTY= total tuber yield, MTY= marketable tuber yield, UMTY= unmarketable tuber yield, ATW= average tuber weight. Means superscripted by the same letter are significantly different, NS= not significant.

Combined application of 363 kg NPS ha^{-1} with 4 t ha^{-1} of coffee husk biochar increased the total tuber number by 48% as compared to control treatment. This result is similar to the findings of Isreal et al. (2018) and Melkamu et al. (2019), who stated that the increase in the total tuber number $plant^{-1}$ takes place in response to the increased application of NP and organic fertilizer (cattle manure) due to the increased photosynthetic activity and translocation of photosynthate to the root which probably helped in the initiation of more stolen in potato.

Marketable tuber number per hill

Marketable tuber number was significantly ($p<0.05$) affected by the combined use of NPS blended fertilizer and coffee husk biochar (Table 3). The highest marketable tuber number (14.8 $hill^{-1}$) was recorded under the combined application of 363 kg NPS ha^{-1} with 4 t ha^{-1} of coffee husk biochar while, the lowest marketable tuber number (7.6 $hill^{-1}$) was recorded from the control treatment. Thus, the application of 363 kg NPS ha^{-1} blended fertilizer with 4 t ha^{-1} coffee of husk biochar increased marketable tuber number by 94.7% compared to control. Increase in marketable tubers due to applied nitrogen, sulphur and phosphorus was associated with a decrease in number of the small-sized tubers and increase in the weight of individual tubers. The application of 180 kg N along with 50 kg S increased the number of marketable tubers by 43% (Singh et al. 2016). The possible reasons for the maximum marketable tuber number $hill^{-1}$ obtained from the higher combined application of NPS blended fertilizer and coffee husk biochar could be due to the presence of an adequate amount of nitrogen which resulted in better vegetative growth and greater photo-assimilate for the production of marketable tubers.

Total tuber yield

The combined application of NPS blended fertilizer and coffee husk biochar significantly influenced ($p<0.05$) the total tuber yield of potato (Table 3). The total tuber yield increased with combined application of NPS blended fertilizer and coffee husk biochar as compared to the sole application of either NPS fertilizer or coffee husk biochar. The highest total tuber yield of 49.5 t ha^{-1} was obtained from the combined application of 363 kg NPS with 8 t ha^{-1} of coffee husk biochar followed by other treatments like 363 kg NPS ha^{-1} with 4 t ha^{-1} of coffee husk biochar and 242 kg NPS ha^{-1} with 4 t ha^{-1} of coffee husk biochar which gave yields of 40 and 38.6 t ha^{-1}, respectively. The lowest total tuber yield (24.9 t ha^{-1}) was recorded in the control treatment. Use of 363 kg NPS ha^{-1} with 8 t ha^{-1} of coffee husk biochar gave the yield advantage of 98.3% as compared to that of control. The probable reason for the increase in tuber yield with increasing sulphur levels might be attributed to its role in better partitioning of the photo-assimilates in the shoot and tubers. Another probable reason might be that the addition of phosphorus which enhances the development of roots particularly lateral and fibrous rootlets which, in turn, contributed to nutrient absorption, photosynthesis and general physiological processes. Melkamu et al. (2019) also reported that the application of 245.1 kg NPS ha^{-1} combined with 13.5 t FYM ha^{-1} recorded the highest total tuber yields of 47 t ha^{-1}.

Marketable tuber yield

Marketable tuber yield of potato was affected significantly ($p<0.05$) by the combined use of NPS blended mineral fertilizer and coffee husk biochar (Table 3). The highest marketable tuber yield (47.8 t ha^{-1}) was obtained by the application of 363 kg NPS ha^{-1} with 8 t ha^{-1} of coffee husk biochar followed by those of 363 kg NPS ha^{-1} and 4 t ha^{-1} of coffee husk biochar and 242 kg NPS ha^{-1} and 4 t ha^{-1} of coffee husk biochar which produced 38.5 and 36.7 t ha^{-1}, respectively. However, the lowest marketable tuber yield (20 t ha^{-1}) was recorded from the control treatment. Application of 363 kg NPS ha^{-1} fertilizer and 8 t ha^{-1} of coffee husk biochar increased marketable tuber yield by 139.4% compared to unfertilized treatment. This might be due to an increase in the phosphorus availability in the soil on account of the presence of biochar. Therefore, when the available phosphorus increases in the soil it improves the soil fertility and hence, the marketable yields of potato also increased (Nigussie et al. 2016).

Quality parameters

Specific gravity of potato tuber

Specific gravity may give an insight into estimating the starch content of potato tuber because it is the major component of the dry matter, usually comprising 65-75 % of the total soluble solids. The combined use of NPS blended mineral fertilizer and coffee husk biochar highly significantly ($p<0.01$) influenced the specific gravity of potato tuber (Table 4). The highest tuber specific gravity (1.098 g cm^{-3}) was obtained with the combined application of NPS blended fertilizer rate of 363 kg NPS ha^{-1} and 12 t ha^{-1} of coffee husk biochar followed by a treatment consisting of 363 kg NPS ha^{-1} and 8 t ha^{-1} of biochar. The lowest tuber specific gravity (1.041 g cm^{-3}) was recorded from the control treatment. This explains that significant increase in specific gravity with the increase in the application of mineral NPS and coffee husk biochar might be attributed to the release of macro and micronutrients from coffee husk biochar. The results are similar to that of Ahmed et al. (2015) who reported that potato growth and quality were affected by the combination of both sources of fertilizers. Kandil et al. (2015) also found improved specific gravity (1.064 g cm^{-3}) with 60% mineral N (238 kg N ha^{-1}) when combined with 40 % organic chicken manure (158 kg N ha^{-1}).

Table 4: Interaction effect of NPS blended fertilizer and coffee husk biochar (BC) on certain physical quality parameters of potato

Treatment		SG	DM (%)	Tuber size category		
		(g cm^{-3})		< 35 g	35-55 g	> 55 g
NPS	BC			SST(%)	MST(%)	LST(%)
0	0	1.04^{i}	29.0^{j}	44.9^{a}	28.2^{d}	26.8
	4	1.05^{hi}	29.9^{j}	44.0^{ab}	31.9^{abcd}	24.0
	8	1.06^{g}	31.6^{i}	39.6^{ab}	39.0^{bcd}	21.3
	12	1.06^{gh}	32.3^{hi}	33.1^{abcd}	38.6^{abcd}	28.2
121	0	1.07^{f}	33.1^{gh}	37.1^{de}	38.3^{abc}	24.6
	4	1.08^{ef}	34.0^{fg}	34.1^{de}	41.9^{abcd}	23.9
	8	1.08^{def}	34.8^{f}	34.5^{a}	44.3^{cd}	21.0
	12	1.08^{cde}	35.0^{f}	28.9^{bcd}	46.4^{abc}	24.6
242	0	1.07^{f}	35.0^{f}	33.8^{abc}	47.1^{ab}	18.9
	4	1.09^{bc}	36.5^{e}	25.1^{bcd}	45.7^{abcd}	29.0
	8	1.09^{ab}	37.4^{de}	21.5^{abc}	48.9^{a}	29.4
	12	1.08^{bcd}	38.4^{cd}	20.7^{bcd}	46.7^{bcd}	32.5
363	0	1.08^{ef}	39.6^{bc}	22.1^{6ab}	48.8^{abc}	29.0
	4	1.09^{ab}	40.8^{ab}	21.9^{cde}	49.5^{abc}	28.5
	8	1.09^{ab}	40.4^{ab}	15.1^{cdef}	53.3^{a}	31.5
	12	1.09^{a}	41.4^{a}	17.4^{cd}	50.5^{ab}	32.0
LSD ($_{0.05}$)		0.0073	1.3	1.6	1.96	NS
CV (%)		0.41	2.1	19.8	23.9	26.5

Where, SG= specific gravity, DM= dry matter content, SST= small-sized tuber, MST= medium-sized tuber, LST= large-sized tuber. Means superscripted by the same letter are not significantly different, NS= not significant

Dry matter content of potato tuber

Dry matter content is affected by various factors, among which the most significant are tuber maturity, growth character, plant nutrients and water uptake. Highly significant ($p<0.01$) differences were noted for dry matter content due to the combined use of NPS blended fertilizer and coffee husk biochar (Table 4). The highest percent of dry matter content (41.4%) was observed under the treatment of the combined application of 363 kg NPS ha^{-1} blended fertilizer and 12 t ha^{-1} coffee husk biochar. However, the lowest tuber dry matter content (29.0%) was obtained from the control treatment. Potato grown with combined application of 363 kg NPS ha^{-1} blended fertilizer with 12 t ha^{-1} of coffee husk biochar increased dry matter content by 42.8% as compared to control.

Potato tuber size

Small-sized tuber (%)

The production of small-sized tubers was significantly ($p<0.05$) influenced by the combined application of NPS blended fertilizer and coffee husk biochar (Table 4). The maximum proportion of small-sized tuber (45%) was obtained in control treatment while, the lowest proportion of small-sized tuber (15.1%) was obtained from the application of 363 kg NPS blended fertilizer ha^{-1} with 8 t ha^{-1} of coffee husk biochar. It was concluded that at low nutrient dosage bulking rate of individual tubers decreased and this situation resulted in the higher proportion of small-sized tubers. Biruk et al. (2015) reported that the number of small-sized tubers was reduced by increasing the nutrient dosage. Isreal et al. (2018) found that the minimum small-sized tuber number was obtained with the combined application of 7.5 t ha^{-1} of cattle manure and 75% of recommended dose of fertilizer).

Medium-sized tuber (%)

The combined use of NPS blended fertilizer with coffee husk biochar significantly ($p<0.05$) influenced the percentage of medium-sized tubers harvested (Table 4). The highest percentage of medium-sized tubers (53.4%) was obtained at 363 kg NPS blended fertilizer ha^{-1} and 8 t ha^{-1} of coffee husk biochar whereas, the lowest percentage of medium-sized potato tubers (28.2%) was found in control treatment. This indicates that increase of coffee husk biochar and NPS blended fertilizer increased the tuber size due to high nutrient dosage as there could be no competition for water and nutrients and this situation increased photo-assimilate production and its redistribution to the tubers finally reducing the number of small-sized tubers.

Large-sized tuber (%)

The proportion of large-sized tubers in general increased with the increase in NPS fertilizer and biochar doses (Table 4). However, the percentages of large-sized tubers were less than those of medium-sized tubers.

Partial budget analysis

The results of the partial budget analysis revealed that the highest net return of Birr 287112 (1 ETB= 0.03 USD) was obtained from the treatment that received 363 kg NPS ha^{-1} in combination with 8 t ha^{-1} of coffee husk biochar followed by those of 363 kg NPS ha^{-1} with 4 t ha^{-1} of coffee husk biochar and 121 kg NPS ha^{-1} with 12 t ha^{-1} of coffee husk biochar which fetched Birr 229812 and 221994 net return, respectively (Table 5). However, the lowest net return of Birr 125930 was obtained from the control treatment. The optimum marginal rate of return (3820%) was recorded from the use of 363 kg NPS ha^{-1} and 8 t ha^{-1} of coffee husk biochar followed by those of 8 t or 12 t ha^{-1} of coffee husk biochar which gave 1673.3% and 1458.7%, respectively (Table 6).

Dominance analysis was thus carried out by first listing the treatments in order of increasing costs and any treatments that had net benefits and were less than or equal to those of treatment with lower costs was considered to have dominated (CIMMYT 1988).

Table 5: Result of partial budget analysis of the effect of NPS blended fertilizer and coffee husk biochar (BC) on tuber yield and other factors of potato production

Treatment NPS	BC	ATY	AY	GFB	CBP	CBA	CF	CFA	TVC	NB	Dominance
0	0	19.9	17.9	125930	0	0	0	0	0	125930	D
	4	23.3	20.9	146930	1500	1000	0	0	2500	144430	ND
	8	27.5	24.7	173530	3000	1000	0	0	4000	169530	ND
	12	31.5	28.1	196910	4500	1000	0	0	5500	191410	ND
121	0	26.6	23.9	167930	0	0	1936	500	2436	165494	D
	4	29.1	26.2	183820	1500	2000	1936	500	5936	177884	D
	8	30.3	27.3	191240	3000	2000	1936	500	7436	183804	D
	12	36.6	32.9	230930	4500	2000	1936	500	8936	221994	ND
242	0	25.2	22.7	159110	0	0	3872	1000	4872	154238	D
	4	34.8	31.3	219730	1500	3000	3872	1000	9372	210358	D
	8	31.6	28.5	199640	3000	3000	3872	1000	10872	188768	D
	12	33.1	29.7	208530	4500	3000	3872	1000	12372	196158	D
363	0	30.9	27.8	194950	0	0	5808	1500	7308	187642	D
	4	38.5	34.6	242620	1500	4000	5808	1500	12808	229812	ND
	8	47.8	43.0	301420	3000	4000	5808	1500	14308	287112	ND
	12	28.8	25.9	181930	4500	4000	5808	1500	15808	166122	D

Where, ATY= average tuber yield (t ha^{-1}), AY= adjusted yield (t ha^{-1}), GFB= gross field benefit (ETB ha^{-1}), CBP= cost of biochar preparation (50 Birr $man\text{-}day^{-1}$), CBA= cost of biochar application (50 Birr $man\text{-}day^{-1}$), CF= cost of fertilizers(16 Birr kg^{-1}) , CFA= cost of fertilizer application (50 Birr $man\text{-}day^{-1}$), TVC= total variable cost (Birr ha^{-1}), NB= net benefit (Birr ha^{-1}), D= dominated, ND= non-dominated, 1Ethiopian Birr≈ 0.03USD.

Table 6: Marginal rate of return from NPS fertilizer and coffee husk biochar application for potato production

Treatment NPS	BC	TVC	MC	NB	MNB	MRR(%)
0	4	2500	1500	144430	18500	1233.3
0	8	4000	1500	169530	25100	1673.3
0	12	5500	1500	191410	21880	1458.0
121	12	8936	3436	221994	30584	890.1
363	4	12808	3872	229812	7818	201.9
363	8	14308	1500	287112	57300	3820.0

Conclusion

The present study clearly indicated that the combined application of NPS blended mineral fertilizer and coffee husk biochar improved growth, yield and physical quality parameters of potato. Maximal tuber yield was obtained from the combined application of 363 kg NPS ha^{-1} blended mineral fertilizer and 8 t ha^{-1} of coffee husk biochar. From an economic point of view, the combined application of 363 kg NPS ha^{-1} and 8 t ha^{-1} coffee husk biochar was found to have given the highest net benefit followed by those of 363 kg NPS ha^{-1} with 4 t ha^{-1} coffee husk biochar and 121 kg NPS ha^{-1} with 12 t ha^{-1} coffee husk biochar. Therefore, an economically feasible combined dosage of 363 kg NPS ha^{-1} and 8 t ha^{-1} coffee husk biochar is recommended for potato growers of south-western Ethiopia with particular reference to Degele area in Masha district.

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