Hindawi
Advances in Agriculture
Volume 2022, Article ID 5400431, 10 pages
https://doi.org/10.1155/2022/5400431

Research Article

Levels of Biochar and NPS Fertilizer Rates on Growth, Yield Component, and Yield of Maize (*Zea mays* L.) at Guto Gida, Western Ethiopia

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Received 3 May 2022; Revised 11 June 2022; Accepted 1 July 2022; Published 31 July 2022

Academic Editor: Mirza Hasanuzzaman

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Mixed application of organic and inorganic fertilizers in mixture improves soil fertility and crop productivity. However, the identification of combined application level is important. Therefore, a field experiment was conducted in 2020 in the Guto Gida district to assess the effect of maize cob biochar levels and inorganic NPS fertilizer rates on the growth and yield of maize. The study was conducted in factorial combinations of five rates of maize cob biochar and three rates of inorganic NPS fertilizer using a randomized complete block design with three replications. The main effect of the biochar level and NPS rate significantly affected crop phenology and biomass yield, whereas the number of kernels ear^{-1} was affected by the main effect of NPS rate. The combined application of biochar and NPS fertilizer significantly influenced plant height, leaf area index, ear weight, thousand kernel weight, grain yield, and percentage of grain yield. The interaction of biochar at 8 t·ha^{-1} with 100 kg·ha^{-1} NPS resulted in highest leaf area index (5.56), grain yield (7.03 t·ha^{-1}), and yield increment (18.11%) followed by 8 t·ha^{-1} × 50 kg·ha^{-1} and all biochar levels with 100 kg·ha^{-1} NPS. In addition, the highest values of ear weight (276 g) and thousand kernel weight (47.81 g) were recorded in plots treated with combined application of biochar and NPS fertilizer at rates of 8 t·ha^{-1} × 50 kg·ha^{-1} and 4 t·ha^{-1} × 100 kg·ha^{-1}, respectively, whereas plots not treated with both biochar and NPS resulted in lowest yield followed by 0 t·ha^{-1} × 50 kg·ha^{-1}. In conclusion, integrated application of maize cob biochar at 8 t·ha^{-1} with NPS fertilizer at 50 kg·ha^{-1} improved the yield of maize by about 16.85% with net benefit of 61700.50 ETB ha^{-1} and marginal rate of return 733.68%, and therefore, the application of biochar at this rate with mineral NPS fertilizer at 50 kg·ha^{-1} is considered as suitable for the study area.

1. Introduction

Maize (*Zea mays* L.) is a monocotyledonous annual plant highly produced for the purpose of human food and animal feed, and the leading crop among crops grown in tropical regions of the world [1]. In Ethiopia, it is the most widely cultivated crop and is produced in more than two million hectares [2] and the most important major food crop rank second in area coverage with an average total grain production of 4.24 t·ha^{-1} [3]. The Central Statistical Agency [2] report indicated that maize is grown on acreage of around 2.5 million hectares, accounting for approximately 23.97 percent of all cereal crops areas.

Today, the increasing global population has raised a great deal of interest in food security. Decreasing agricultural productivity due to the decrease in area of cultivable land and climate change has resulted in millions of people living below the poverty line and becoming malnourished [4]. In addition, excessive use of agrochemicals and deep tillage resulted in soil acidity, soil infertility, and contamination of soil quality, leading to reduced soil organic matter content, biodiversity, and productivity. These unsustainable agricultural practices challenge food security and lead to severe economic constraints in developing countries [4, 5].

An alternative method for sustainable and economically viable crop production with minimal environmental contamination or pollution is through fertilizing crops with organic fertilizer from organic matter, which has great potential in improving soil biodiversity and health. There are a number of alternatives and emerging technologies that are widely used in sustainable agriculture in which biochar is the one. Biochar is a carbon-rich organic fertilizer produced from materials such as agricultural crop residues and wood wastes in the process of pyrolysis or thermal degradation under a limited amount of oxygen supply [6, 7]. It is an emerging new technology playing a significant role in reduction of environmental management through enhancing soil quality, waste management and remedying environmental degradation, renewable energy production, climate change alleviation, and crop production [7, 8].

Biochar produced from organic materials releases several essential plant nutrients to the soil solution that significantly determine rate of crop growth and yield in combination with other growth controlling factors. Application of biochar by incorporating with other organic or inorganic fertilizer is more beneficial than single application [9]. Biochar-based fertilizer increases soil organic matter, improves soil nutrient status and crop yield [10], and promotes soil fertility, physical, chemical, biological, or microbial benefits of the soil [11]. In addition, its application with other mineral fertilizers significantly improves the site for cation exchange capacity (CEC), cation retention on the soil surface from depth erosion, nutrient uptake, and water use efficiency [12–14] and improves soil temperature phosphorus fertilizer utilization of plants [15]. Maize cob can produce more than 50% of its mass with biochar as it contains less volatile materials [16]. Currently, the use of biochar to restore soil fertility and improve soil organic matter content, soil microorganism activity, and crop yield in acidic, sandy, and degraded soils has been increasing in Ethiopia [17]. However, endorsed blended utility charge with NPS fertilizers remains unknown. Consequently, this study was conducted to evaluate the effects of different levels of biochar and inorganic NPS fertilizers rate on the growth, yield, and yield components of maize.

2. Material and Methods

2.1. Experimental Site. The study was conducted in Guto Gida district located in the East Wollega Zone of Western Ethiopia during the crop growing season of 2020. The experimental site is located at (09° 11′N–37° 09′E) with an altitude range of 1450–1700 meter above the sea level. The area is characterized by monomial rainfall distribution (1200–1450 mm) with a long rainy season occurring from late April to October and average annual temperature range of 14.6°C–31.5°C. The economic activity of the study area is known by mixed farming system involving rearing of livestock and production of crops such as maize, millet, sorghum, groundnut, soybean, and sesame. The soil in the study area is acidic with a red color of Nitisol, which is the dominant soil type in the western parts of Ethiopia (Guto Gida Agricultural Office, 2020, unpublished data). The topsoil (0–30 cm) of the experimental site was characterized by a sandy clay loam textural class with total nitrogen ($1.12\,g{\cdot}kg^{-1}$), organic carbon ($3.4\,g{\cdot}kg^{-1}$), and pH of 4.74 (Table 1).

2.2. Experimental Material. Low-land hybrid maize "BH-540" variety was used for the experimental study. The maize hybrid BH-540 is a single cross produced from two genetically distinct parents and grows in areas having 1000–2000 meters above sea-level altitude range and 1000–1200 mm rainfall. Depending on the environmental conditions, it can grow to a height of up to 200–240 cm. Average grain yields of 7-8 $t{\cdot}ha^{-1}$ and 4.5–6.0 $t{\cdot}ha^{-1}$ can be harvested on research stations and farmers' fields, respectively.

2.3. Treatments and Experimental Design. The experiment was conducted in two-factor factorial combination each consisting five biochar levels (0, 2, 4, 6, and 8 $t{\cdot}ha^{-1}$) and three inorganic NPS fertilizer rates (0, 50, and 100 $kg{\cdot}ha^{-1}$) in a randomized complete block design (RCBD) with 15 treatments (5×3) and three replications. NPS is compound fertilizer containing highly uniform granule of three important plant nutrients of nitrogen, phosphate, and sulfur with the ratio of 19% N, 38% P_2O_5, and 7% S. The recommended fertilizer rate for maize in the highland of western Ethiopia is 100 $kg{\cdot}ha^{-1}$ of NPS and 200 $kg{\cdot}ha^{-1}$ of urea ($CO(NH_2)_2$). Hence, the amount of nitrogen required at 0, 50, and 100 $kg{\cdot}ha^{-1}$ of NPS fertilizer rate with urea was $0\,kg{\cdot}ha^{-1} + 92\,kg{\cdot}ha^{-1}$ of urea, $9.5\,kg{\cdot}ha^{-1} + 92\,kg{\cdot}ha^{-1}$ of urea, and $18\,kg{\cdot}ha^{-1} + 92\,kg{\cdot}ha^{-1}$ of urea resulting 92, 101.5, and 111 $kg\,ha^{-1}$ of N, respectively. The detail of treatment description is shown (Table 2). Each plot had a length by the width of $4.2\,m \times 3.75\,m$ ($15.75\,m^2$).

2.4. Experimental Procedure. The experimental field was plowed three times by oxen to a fine soil tilth and leveled manually before sowing/planting. Maize seed was planted at a distance space of 0.30 m and 0.75 m within a row and between rows, respectively. Two seeds $hill^{-1}$ were planted, and one week after emergence, it was thinned out to one plant $hill^{-1}$ to maintain the recommended population (44,444 plants ha^{-1}). There were 60 plants $plot^{-1}$, 5 rows in each plot, and 14 plants in each row. Urea ($CO(NH_2)_2$) was applied at 200 $kg{\cdot}ha^{-1}$ in split form; that is, half of the recommended dose (100 $kg{\cdot}ha^{-1}$) was applied during planting, whereas the remaining half (100 $kg{\cdot}ha^{-1}$) was applied 40 days after planting. Biochar was applied one week prior to planting as per the treatment levels, charged, and mixed with the soil to reduce from wind uptake. Inorganic NPS fertilizer was applied at the rate (0, 60, and 120 g $plot^{-1}$) depending on the treatment at the time of planting, and the remaining cultural and agronomic practices were applied uniformly for all treatments according to their recommendations.

2.5. Biochar Preparation and Application. Biochar was prepared from maize cob in pit and grounded to smaller particles for uniform heating. After heating to the required standard or level, it was sieved to 2 mm particle size to

Table 1: Physico-chemical characteristics of study site soil before planting and corn cob biochar nutrient composition at Guto Gida, Western Ethiopia.

Parameters	Presowing soil properties	Nutrient composition of maize cob biochar
Particle distribution (%)		—
Clay	28	—
Silt	18	—
Sand	54	—
Textural class	Sandy clay loam	—
Chemical properties	—	—
pH (H_2O) 1 : 2.5 (w/v)	4.74	8.31
Organic carbon (g·kg^{-1})	3.4	412
Organic matter (g·kg^{-1})	5.9	710
Total nitrogen (g·kg^{-1})	1.12	2.67
Available phosphorus (mg·kg^{-1})	6.92	1.83
Exchangeable Ca (cmol/kg)	4.36	4.41
Exchangeable Mg (cmol/kg)	3.60	3.47
Exchangeable K (cmol/kg)	1.25	6.30
CEC (cmol/kg)	12.43	139

CEC stands for cation exchange capacity.

Table 2: Treatment used for the experiment.

Treatment number	Combination of factors (5 levels biochar + 3 rates of NPS fertilizer)
1	0 t·ha^{-1} maize cob biochar + 0 kg·ha^{-1} NPS
2	0 t·ha^{-1} maize cob biochar + 50 kg·ha^{-1} NPS
3	0 t·ha^{-1} maize cob biochar + 100 kg·ha^{-1} NPS
4	2 t·ha^{-1} maize cob biochar + 0 kg·ha^{-1} NPS
5	2 t·ha^{-1} maize cob biochar + 50 kg·ha^{-1} NPS
6	2 t·ha^{-1} maize cob biochar + 100 kg·ha^{-1} NPS
7	4 t·ha^{-1} maize cob biochar + 0 kg·ha^{-1} NPS
8	4 t·ha^{-1} maize cob biochar + 50 kg·ha^{-1} NPS
9	4 t·ha^{-1} maize cob biochar + 100 kg·ha^{-1} NPS
10	6 t·ha^{-1} maize cob biochar + 0 kg·ha^{-1} NPS
11	6 t·ha^{-1} maize cob biochar + 50 kg·ha^{-1} NPS
12	6 t·ha^{-1} maize cob biochar + 100 kg·ha^{-1} NPS
13	8 t·ha^{-1} maize cob biochar + 0 kg·ha^{-1} NPS
14	8 t·ha^{-1} maize cob biochar + 50 kg·ha^{-1} NPS
15	8 t·ha^{-1} maize cob biochar + 100 kg·ha^{-1} NPS

NPS represents for the fertilizers containing 19% nitrogen, 38% P_2O_5, and 7% sulfur.

increase interaction and cation exchange with other nutrients. Application of biochar to the soil was done in charged or activated form by soaking in water to minimize the dust hazard and accelerate the beneficial properties of biochar when applied to the topsoil.

2.6. Soil Sampling, Analysis, and Biochar Chemical Composition. Soil samples were collected randomly at a depth of 0–30 cm in zigzag pattern before planting. Composite samples were air-dried, prepared, and homogenized for analysis and to determine the soil physicochemical properties such as soil texture, soil pH, organic carbon, organic matter, total nitrogen, exchangeable calcium, magnesium, potassium, cation exchange capacity, and available phosphorus. The soil samples and biochar were grounded and sieved through a 2-mm sieve and analyzed for their chemical composition at Nekemte Soil Testing Laboratory. Soil particle size distribution was determined by hydrometer method [18], and the pH of the soil was determined by using pH meter at 1 : 2.5 soils to water ratio [19]. Soil organic carbon, total nitrogen, and available phosphorus were determined according to the methods developed by Walkley-Black Oxidation [20], Kjeldahl [21], and Bray-I [22], respectively.

2.7. Data Collection and Analysis

2.7.1. Phenology and Growth Parameter. Phenological parameters of maize such as days to 50% tasseling, days to 50% silking, and days to 90% physiological maturity were taken as number of days from the day of planting to when 50% in each plot produced tassel, started producing pollen, and formed a black layer at the point where the kernel attached to the corn cob. Plant height was measured at the physiological maturity stage from randomly sampled 10 plants per net plot as the distance from ground level to the place where tassel formed and started to branch. Leaf area index (LAI) was calculated by dividing total leaf area obtained from 10 plants ($L \times W \times K$) to the land area occupied by the plant ($0.75\,\text{m} \times 0.30\,m = 0.225\,\text{m}^2$) where L = leaf length, W = leaf width, and K = correction factor (0.75) [23].

2.7.2. Yield Components and Yield of Maize. Data for number of ears plant^{-1}, ear weight, and number of kernels ear^{-1} were taken from 10 pretagged plants per net plot area. Thousand grain weights was counted from a bulk of shelled grain and measured at standard moisture level (12.5%) by using electronic grain counter and sensitive balance, respectively. In addition, biological yield (t·ha^{-1}) and grain yield (t·ha^{-1}) were calculated from the total biomass harvested from each experimental plot at the time of harvest and weighing the bulk of grain harvested from the net plot, respectively. Harvest index (%) was calculated by dividing grain yield (t·ha^{-1}) to above-ground biomass yield (t·ha^{-1}).

2.8. Economic Analysis. Partial budget analysis of grain yields for the selection of economically feasible and profitable level of biochar applied to the soil in combination with NPS fertilizer rate was done according to CIYMMIT procedure [24]. The prices for fertilizer of NPS (15.50 ETB kg^{-1}) and cost of application of biochar and NPS fertilizer (0.25 ETB kg^{-1}) were used for partial budget analysis after the grain yield was deducted by 10% to estimate the real yield at farmers' condition. The yield of maize was valued at an average of open market price 10 ETB kg^{-1} in December 2020 at the local market of study area.

2.9. Data Analysis. The various collected data were analyzed according to statistical procedures described by Gomez [25] using Genstat Software 18 [26]. Parameter means having significant difference between treatments were separated at $p = 0.05$ level of probability using fishers protected least significant difference.

3. Result and Discussion

3.1. Experimental Site Physico-Chemical Characteristics of Soil and Biochar. The physico-chemical composition of soil at the experimental site before planting and maize cob biochar used is indicated in Table 1 below. According to Tekalign [27] rating, the experimental soil pH of study site was classified as moderate acid, available phosphorus (6.92 $mg{\cdot}kg^{-1}$) was exist in very low range, and total nitrogen (1.12 $g{\cdot}kg^{-1}$) was exist in medium range, whereas cation exchange capacity of 12.43 was found low (Table 1). In comparison with presowing soil, the values of biochar were relatively high for the pH, organic carbon, organic matter, total nitrogen, calcium, potassium, and cation exchange capacity (Table 1). The pH of biochar prepared from corn cob was found alkaline (8.31). These indicate the application of biochar to the soil has a great potential to improve soil structure, soil pH, and soil porosity and decrease bulk density of the soil via increased level of biochar added to the soil as biochar in nature consists more pore space and lower bulk density when compared to the soil. In line with the current result, Aruna et al. [28] reported high organic carbon, calcium, potassium, and pH from biochar prepared from wood chips.

3.2. Phenology and Growth Parameters of Maize. Analysis of variance had showed the main effects of biochar levels and inorganic NPS fertilizer rates significantly affected days to 50% tasseling, days to 50% silking, and days to 90% physiological maturity, while their interactions were nonsignificant. However, growth parameters such as plant height and leaf area index were significantly influenced by the interaction effect of NPS fertilizer and biochar. The longest days to tasseling (70.56) were recorded from biochar applied at the rate of 8 $t{\cdot}ha^{-1}$ (Table 3), which was at par with biochar rate applied at 6 and 4 $t{\cdot}ha^{-1}$, and the shortest days (69.22) to develop tassel were counted in plot treated with 2 $t{\cdot}ha^{-1}$ and plot not treated by biochar (Table 3). Maize grown under NPS fertilizer applied at a rate of 100 $kg{\cdot}ha^{-1}$ took a maximum of 71.07 to form tassel as compared to control, which was tasseled early (68.87) days (Table 3). In terms of days to 50% silking and days to 90% maturity, maize in the control plot silks and reaches maturity quickly, whereas the highest number of days to 50% silking (75.44 days) was found in the biochar-treated plot with an 8 t ha^{-1} application, which was on par with values from 6 t ha^{-1} and 4 t ha^{-1} of applied biochar. Greater days to 90% maturity (141.9 days) were recorded from biochar applied at 6 $t{\cdot}ha^{-1}$ and on par with all levels of biochar. Similarly, the longest days to silking (75.40) and maturity (141.70) were recorded from the NPS fertilizer rate at 100 $kg{\cdot}ha^{-1}$, which was at par with 50 $kg{\cdot}ha^{-1}$ for both days to 50% silking and days to 90% maturity (Table 3).

Delayed phenological parameters of maize as biochar application rate increased might be due to improved soil fertility and increased nutrient uptake of all essentially important plant nutrients that may respond to the increased vegetative growth period of maize. Prolonged days to tasseling, days to silking, and days of maturity in plots treated with an increased amount of NPS fertilizer 0–100 $kg{\cdot}ha^{-1}$ might be due to increased vegetative growth of maize, leaf expansion, and improved nitrogen use efficiency. In line with this result, Lal [29] reported that increased organic and inorganic sources of nitrogen cause delayed vegetative growth duration (crop phenology).

The study also revealed that growth parameters of maize, that is, plant height and leaf area index (LAI), were significantly influenced as a result of the interaction effect of biochar levels and inorganic NPS fertilizer rate. The maize plant is grown in a plot treated with 100 $kg{\cdot}ha^{-1}$ of NPS fertilizer at zero level of biochar had the tallest plant height of 281 cm, whereas the shortest plant height (251.7 cm) was obtained in the control plot or plot not treated with biochar and NPS fertilizer (Table 4). This observation might be due to the positive effect of mineral nitrogen in NPS fertilizer for vigorous vegetative growth of maize. In addition, nutrient released form biochar with mineral NPS and increased soil pH as a result of biochar added enhances plant nutrient uptake and utilization leading to production of more vegetative growth and parts particularly plant height and leaf blade expansion. Schnitzer [20] reported increased height of maize plant treated with biochar compared to plot unfertilized with biochar. Moreover, [30] a study observed increased maize height by 2.45 cm for every $g{\cdot}kg^{-1}$ of biochar added.

Similarly, the largest leaf area index (5.557) was calculated from a plot treated with biochar at 8 $t{\cdot}ha^{-1}$ combined with 100 $kg{\cdot}ha^{-1}$ NPS fertilizer, whereas the smallest leaf area index (3.837) was recorded from the control plot (plot without biochar and NPS fertilizer) (Table 4). The highest leaf index (5.557) could be related to the direct effect of biochar in releasing more amounts of plant nutrients and timely available nitrogen, which may be highly responsible for vigorous plant growth as compared to other treatments. In line with the current result, Islam et al. [31] reported increased leaf area index from 1.8–6.5 as the amount of biochar prepared form rice husk increased from 1.5–7 $t{\cdot}ha^{-1}$. Concomitant with the current study, Khan et al. [32]

Table 3: The main effect of biochar levels and inorganic NPS fertilizer rates on number of days to 50% days to tassel, number of days to 50% silking, and number of days to 90% physiological maturity of maize in Guto Gida, Western Ethiopia.

Treatments	50% days to tassel	50% days to silk	90% days to maturity
Biochar (t·ha^{-1})			
0	69.22^{b}	74.00^{b}	140.6^{ab}
2	69.22^{b}	74.33^{b}	140.8^{ab}
4	70.22^{a}	74.67^{ab}	141.2^{ab}
6	70.44^{a}	75.33^{a}	140.9^{a}
8	70.56^{a}	75.44^{a}	141.7^{ab}
LSD (0.05)	0.959	0.913	1.20
NPS (kg·ha^{-1})			
0	68.87^{c}	73.80^{b}	140.1^{b}
50	69.87^{b}	75.07^{a}	141.3^{a}
100	71.07^{a}	75.40^{a}	141.7^{a}
LSD (0.05)	0.743	0.707	0.94
CV (%)	1.4	1.3	0.9

LSD = least significant difference; CV = coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significant different at 5% probability level.

Table 4: Interaction effect of biochar levels and inorganic NPS fertilizer rates on plant height (cm) and leaf area index (LAI) of maize in Guto Gida, Western Ethiopia.

Biochar (t·ha^{-1})	NPS (kg·ha^{-1})	Plant height (cm)	Leaf area index
0	0	251.70^{f}	3.837^{h}
0	50	271.90^{b}	4.397^{efg}
0	100	281.00^{a}	4.614$^{b\text{-}f}$
2	0	266.70^{c}	4.227^{g}
2	50	265.50^{cd}	4.209^{g}
2	100	267.80^{c}	4.671$^{b\text{-}e}$
4	0	265.00^{cd}	4.393^{efg}
4	50	267.20^{c}	4.441$^{d\text{-}g}$
4	100	267.00^{c}	4.6970$^{b\text{-}e}$
6	0	265.60^{cd}	4.474$^{c\text{-}g}$
6	50	261.90^{de}	4.735^{bcd}
6	100	268.20^{bc}	4.789^{bc}
8	0	259.00^{e}	4.298^{fg}
8	50	265.60^{cd}	4.942^{b}
8	100	264.50^{cd}	5.557^{a}
LSD (0.05)		3.926	0.335
CV (%)		0.9	4.4

LSD = least significant difference; CV = coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significant different at 5% probability level.

reported increased plant height with increased application level of nitrogen-containing fertilizer. A similar result is found by Reference [33] who reported increased plant height and leaf area with more availability of nitrogen fertilizer throughout the life cycle of maize crop.

3.3. Yield Components and Yield

3.3.1. Ear Weight (g). Analysis of variance showed that combined application of biochar at different levels with blended NPS fertilizer rate significantly affected ear weight of maize plant. Integrated application of biochar level at 8 t·ha^{-1} with inorganic NPS fertilizer rate at 50 kg·ha^{-1} resulted in the highest ear weight (276.00 g), which was at par with the application of biochar at all levels with 100 kg·ha^{-1} except for plots not treated with biochar at the same level of NPS fertilizer rate. Plot not treated with both biochar and NPS fertilizer resulted in the lowest ear weight (235.30 g), which was at par with the result obtained from plot treated without biochar and 50 kg·ha^{-1} inorganic NPS fertilizer rate (Table 5). Increased ear weight with increased NPS fertilizer at levels of biochar might be due to better crop growth and increased dry matter production as a result of improved uptake of nutrients particularly nitrogen from inorganic and biochar (organic) sources. In addition, increased ear weight with increased biochar levels might be due to increased soil organic matter composition through decomposition-mineralization of biochar and thus increased the timely availability of nutrients from synthetic fertilizer (NPS). Integrated use of organic and inorganic sources of fertilizer increased and positively affected ear characteristics

Table 5: Interaction effect of biochar levels and inorganic NPS fertilizer rates on ear weight (g) and thousand kernel weight (g) of maize in Guto Gida, Western Ethiopia.

Biochar ($t{\cdot}ha^{-1}$)	NPS ($kg{\cdot}ha^{-1}$)	Ear weight (g)	Thousand kernel weight (g)
0	0	235.30^{f}	40.16^{e}
0	50	237.80^{ef}	42.84^{cd}
0	100	266.20^{bc}	42.33^{de}
2	0	246.50^{de}	41.40^{de}
2	50	245.80^{de}	42.92^{cd}
2	100	272.80^{ab}	46.05^{ab}
4	0	248.40^{d}	41.61^{de}
4	50	258.50^{c}	43.29^{cd}
4	100	274.30^{ab}	47.81^{a}
6	0	247.20^{d}	42.30^{de}
6	50	266.50^{bc}	45.00^{bc}
6	100	274.70^{ab}	46.77^{ab}
8	0	248.70^{d}	42.51^{d}
8	50	276.00^{a}	46.92^{ab}
8	100	275.10^{ab}	46.77^{ab}
LSD (0.05)		8.971	2.225
CV (%)		2.1	3.0

LSD = least significant difference; CV = coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significant different at 5% probability level.

(ear length and ear weight) with an increased level of organic fertilizer (biochar and farmyard manure) and inorganic fertilizer (NPK) application [12, 13]. Similarly, combined application of biochar and mineral nitrogen increased ear length, ear diameter, and ear weight [34].

3.3.2. Thousand Kernel Weight (g). Thousand kernel weights were significantly affected by the combined application of biochar levels and inorganic NPS fertilizer rates. Integrated application of biochar with blended NPS fertilizer at a rate of 4 $t{\cdot}ha^{-1}$ with 100 $kg{\cdot}ha^{-1}$ resulted in the highest grain weight (47.81 g), which was at par with 8 $t{\cdot}ha^{-1} \times 50$ $kg{\cdot}ha^{-1}$ (46.92), 8 $t{\cdot}ha^{-1} \times 100$ $kg{\cdot}ha^{-1}$ (46.77 g), and 6 $t{\cdot}ha^{-1} \times 100$ $kg{\cdot}ha^{-1}$ (46.77 g). By contrast, the least thousand kernel weight (40.16) was recorded from plot untreated with any of the two fertilizers (Table 5). Heavier thousand kernel weight at a higher level of biochar 4–8 $t{\cdot}ha^{-1}$ combined with 100 $kg{\cdot}ha^{-1}$ NPS might be due to improved soil fertility and increased nutrient uptake combined with an efficient photosynthesis process, which might be assimilated to economic part (grain). The lighter weight recorded in the control plot could be due to lower nutrient levels in the soil and thus less availability of nutrients for optimum and healthy plant growth. In line with current finding, Ndor et al. [35] found increased hundred grain weight from 6.98% as the amount of biochar increased from 5–10 $t{\cdot}ha^{-1}$. As the levels of mineral and organic fertilizers increased, thousand seed weight also increased in linear [32, 36]. Moreover, Ali et al. [37] reported biochar-treated plot improved thousand kernel weight of maize by 17% over plot treated only with mineral nitrogen fertilizer and control.

3.3.3. Number of Kernel Ear^{-1}. Analysis of variance indicated that the main effect of inorganic NPS fertilizer rate had significantly influenced number of kernels ear^{-1}. However, the main effect of biochar levels and its interaction with inorganic NPS fertilizer rates had showed nonsignificant effect. Increased incorporation of NPS rate fertilizer from 0–100 $kg{\cdot}ha^{-1}$ resulted in an increased number of kernels ear^{-1}. Plot treated with 50 $kg{\cdot}ha^{-1}$ and 100 $kg{\cdot}ha^{-1}$ of NPS fertilizer produced a higher number of kernel ear^{-1} as compared to the control plot, which resulted in the lowest number of kernels ear^{-1} (Table 6). Increased number of kernel ear^{-1} at higher rate of NPS fertilizer might be connected with more availability of essential plant nutrient particularly nitrogen and phosphorus. Even though not significant, a number of kernels ear^{-1} showed increasing trend as the level of biochar increases from 0–8 $t{\cdot}ha^{-1}$. This might be due to improved soil bio-physico-chemical properties such as CEC, soil carbon, phosphorus, and nitrogen content of the soil due to biochar application. In addition, biochar increases soil moisture as it is porous material consisting high surface area and hence improves nutrient uptake and utilization efficiency that might lead to higher number of kernels ear^{-1}. Yuanxin et al. [38] reported increased number of grain by 8.1% per cob in plot treated with biochar compared with plot treated only with biochar or mineral fertilizer. Additionally, there was a significant increment in number of spike and increased spikelet in wheat as application biochar rose from 0–5 $t{\cdot}ha^{-1}$ [39].

3.3.4. Above-Ground Biomass ($t{\cdot}ha^{-1}$). The main effect of NPS fertilizer and biochar had significant effect on the biological yield of maize. Applying biochar at a level of 6–8 $t{\cdot}ha^{-1}$ resulted in the higher biomass weight of 18.13–18.22 $t{\cdot}ha^{-1}$. By contrast, plots not treated with biochar gave the lowest above-ground biomass of 16.56 $t{\cdot}ha^{-1}$, which was at par with plot treated with 2 $t{\cdot}ha^{-1}$ and 4 $t{\cdot}ha^{-1}$ (Table 6). Regarding NPS fertilizer rates, the highest and lowest values (18.14 $t{\cdot}ha^{-1}$ and 16.75 $t{\cdot}ha^{-1}$) were recorded

Table 6: The main effects of biochar levels and inorganic NPS fertilizer rates on number of kernel ear^{-1}, biological yield (t·ha^{-1}), and harvest index (%) of maize at Guto Gida, Western Ethiopia.

Treatments	Number of kernels ear^{-1}	Biological yield (t·ha^{-1})	Harvest index (%)
Biochar (t·ha^{-1})			
0	520.64^{a}	16.56^{b}	37.25^{a}
2	538.23^{a}	17.11^{b}	38.01^{a}
4	544.10^{a}	17.47^{ab}	37.80^{a}
6	560.40^{a}	18.13^{a}	36.83^{a}
8	567.76^{a}	18.22^{a}	37.15^{a}
LSD (0.05)	33.136	0.938	2.021
NPS (kg·ha^{-1})			
0	520.50^{b}	16.75^{b}	37.21^{a}
50	553.30^{a}	17.61^{a}	37.05^{a}
100	564.90^{a}	18.14^{a}	37.96^{a}
LSD (0.05)	25.667	0.727	1.565
CV (%)	6.30	5.60	5.60

LSD = least significant difference; CV = coefficient of variation (%). Means in the same column followed by the same letter(s) are not statistically significant different at 5% probability level.

from the application of NPS at 100 kg·ha^{-1} and control, respectively (Table 6). The increased biological yield of maize with an increased amount of NPS could be due to the increased amount of nutrients in the soil, improved nutrient uptake, and timely availability of nitrogen released rapidly from NPS fertilizer. This might be attributed to improved soil fertility, nutrient availability, and water retention as a result of high specific area characteristics of biochar that was added to the soil in addition to NPS fertilizer, and hence increases dry mass of maize growth component such as leaves, sheaths, stems, cobs, and grain, which finally resulted in increased above-ground biomass of the crop. Yin et al. [10] reported increased total dry weight of maize by about 3%–16% with increased amount of biochar from 5.4 t·ha^{-1}–6 t·ha^{-1} compared with maize not treated with biochar fertilizer. Paneque et al. [40] reported sun flower biomass was increased in linear with the amount of biochar added to the soil up to 15 t·ha^{-1}, and also depend on the type of biochar. For every (g·kg^{-1}) of applied biochar, biomass of maize increased by 3% [30]. Furthermore, increased biochar application and other organic fertilizers were increased above-ground biomass [41, 42].

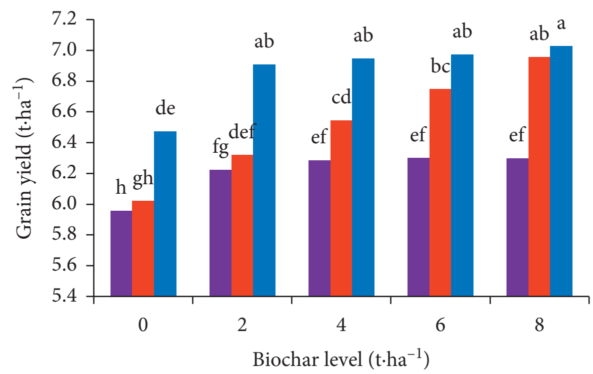

Figure 1: Effect of levels of biochar and NPS fertilizer rates on maize grain yield (t·ha^{-1}).

3.3.5. Grain Yield (t·ha^{-1}). Statistical analysis of variance revealed that the grain yield of maize had shown significant variation due to the interaction effect of organic fertilizer (biochar) and mineral fertilizer (NPS). Integrated application of biochar with blended NPS fertilizer at a rate of 8 t·ha^{-1} with 100 kg·ha^{-1} resulted in the highest grain yield (7.030 t·ha^{-1}), which was at par with the grain yield harvested from plots treated with 6 t·ha^{-1} × 100 kg·ha^{-1}, 8 t·ha^{-1} × 50 kg·ha^{-1}, 4 t·ha^{-1} × 100 kg·ha^{-1}, and 2 t·ha^{-1} × 100 kg·ha^{-1} (Figure 1). However, plot treated with neither biochar nor inorganic NPS fertilizer rates resulted in the lowest grain yield of 5.975 t·ha^{-1} (Figure 1). Increased grain yield at the higher level of biochar might be related to most effectiveness of biochar at higher rates and increased number of kernel ear^{-1} and improved thousand grain weights at this level. In addition, the higher grain yield with increased amount of biochar could be due to the potential of biochar to decrease soil bulk density, reduce exchangeable aluminum and iron, and restrict root growth and nutrient uptake. It might be also due to the role of biochar to improve soil physicochemical properties such as increasing soil pore space, surface area, and increasing soil pH and nutrient availability. Biochar in combination with other minerals increases soil-plant nutrients such as potassium, calcium, and micronutrients such as copper, zinc, and iron that enhance a number of physiological processes in plants. Increased cation exchange capacity of the soil with biochar may also increase nutrient use efficiency and hence resulted in higher grain yields.

Similar to the current study, several findings indicated that integrated application of organic fertilizer with inorganic fertilizer was increased grain yield of corn [36, 43–45]. Njoku et al. [46] reported about 14.8% of maize grain yield increased with increased amount of biochar added compared with control treatment. Moreover, earlier findings also

Table 7: Partial budget analysis of maize yield for the determination of economically profitable level of biochar and NPS fertilizer rate

Treatment	Biochar ($t{\cdot}ha^{-1}$)	NPS ($kg{\cdot}ha^{-1}$)	Grain yield ($t{\cdot}ha^{-1}$)	Adjusted grain yield ($t{\cdot}ha^{-1}$)	Gross benefit (ETB ha^{-1})	TVC (ETB ha^{-1})	Net benefit (ETB$\cdot ha^{-1}$)	MRR (%)
T1	0	0	5.96	5.36	53613	0.00	53613.00	—
T2	0	50	6.02	5.43	54270	712.50	53557.50	D
T3	0	100	6.46	5.82	58167	1425.00	56742.00	446.95
T4	2	0	6.22	5.60	56007	50.00	55957.00	—
T5	2	50	6.32	5.69	56880	762.50	56117.50	22.53
T6	2	100	6.91	6.22	62163	1475.00	60688.00	641.47
T7	4	0	6.29	5.66	56583	100.00	56483.00	—
T8	4	50	6.54	5.89	58887	812.50	58074.50	223.37
T9	4	100	6.95	6.25	62523	1525.00	60998.00	410.32
T10	6	0	6.30	5.67	56700	150.00	56550.00	—
T11	6	50	6.75	6.07	60723	862.50	59860.50	464.63
T12	6	100	6.97	6.28	62757	1575.00	61182.00	185.47
T13	8	0	6.30	5.67	56673	200.00	56473.00	—
T14	8	50	6.96	6.26	62613	912.50	61700.50	733.68
T15	8	100	7.03	6.33	63270	1625.00	61645.00	D

Application cost of biochar and mineral NPS fertilizer = 0.25 ETB$\cdot kg^{-1}$, unit cost of NPS fertilizer = 15 ETB$\cdot kg^{-1}$ = ETB = Ethiopian birr, NPS = fertilizer containing 19% N, 38% P_2O_5 and 7% S, TVC = total variable cost, MRR = marginal rate of return, D = dominated.

showed increased grain yield with increased levels of biochar and its quality [10, 33, 47]. Similarly, Mehnaz et al. [48] concluded increased maize yield in combined application of biochar and mineral fertilizer compared with only applying mineral fertilizer or biochar in their review.

3.3.6. Harvest Index (%). Analysis of variance showed nonsignificant variation in harvest index of maize as a result of the main effect of blended NPS fertilizer, biochar, and their interaction (Table 6). This might be due to increased crop growth rate as a result of improved soil structure and increased soil nutrients released from biochar to the soil solution such as total nitrogen and organic carbon that could be increase leaf blade weight, photosynthetic rate, and then increased dry matter partitioning to grain. Similar to this result, Islam et al. [31] presented higher harvest index increased by 29.14% when biochar was applied at 7 $t{\cdot}ha^{-1}$ compared to plot not treated with biochar, and the lower values obtained when biochar was applied at levels lower than 7 $t{\cdot}ha^{-1}$. In contrast to present finding, Madhavi et al. [49] reported decreased harvest index with increased level of biochar from 0–7.5 $t{\cdot}ha^{-1}$.

3.4. Economic Analysis. Analysis of variance revealed the highest net benefit (61700 ETB ha^{-1}) from mixed application of biochar and mineral NPS fertilizer at 8 $t{\cdot}ha^{-1}$ + 50 $kg{\cdot}ha^{-1}$ with marginal rate of return (733.68%) followed by net benefit (60688 ETB ha^{-1}) recorded from 2 $t{\cdot}ha^{-1}$ to 100 $kg{\cdot}ha^{-1}$ with marginal rate of return of 641.47% (Table 7). The minimum net benefit of 61182 ETB ha^{-1} with a marginal rate of return (185.47%) was obtained from combined application of biochar at 6 $t{\cdot}ha^{-1}$ with NPS fertilizer rate of 100 $kg{\cdot}ha^{-1}$ (Table 7). However, plot treated with NPS fertilizer at 50 $kg{\cdot}ha^{-1}$ without biochar and plot treated with 8 $t{\cdot}ha^{-1}$ and 100 $kg{\cdot}ha^{-1}$ of NPS were dominated (Table 7). Therefore, according to this partial budget analysis, application of biochar at a level of 8 $t{\cdot}ha^{-1}$ combined with 50 $kg{\cdot}ha^{-1}$ of mineral NPS fertilizer rate was found economically profitable for maize production in Guto Gida district, Western Ethiopia.

4. Conclusion

In high land areas of Western Ethiopia, farmers are practicing application of biochar to the soil. However, information concerning about optimum level of biochar in combination with other mineral fertilizer is lacking. Therefore, the aim of this study was to assess various levels of biochar and mineral NPS fertilizer rates on growth and productivity of maize in Guto Gida district, Western Ethiopia. The finding of this study revealed that mixed application of biochar and mineral NPS fertilizer significantly influenced crop phenology, growth, and yield parameters of maize. The application of biochar with mineral NPS fertilizer at 8 $t{\cdot}ha^{-1} \times 100$ $kg{\cdot}ha^{-1}$ increased leaf area index by 44%. The effect of biochar at and above 4 $t{\cdot}ha^{-1}$ with 100 $kg{\cdot}ha^{-1}$ of mineral NPS fertilizer rate increased ear, and thousand kernel weights by 17% and 19%, respectively, compared with unfertilized plot. Similarly, grain yield was improved by 16% and 18% when biochar was applied at 8 $t{\cdot}ha^{-1}$ in combination with mineral NPS fertilizer at 50 $kg{\cdot}ha^{-1}$ and 100 $kg{\cdot}ha^{-1}$, respectively, against the control plot. The analysis of partial budget also confirmed the highest net benefit (61700.50 ETB ha^{-1}) and marginal rate of return (733.68%) from combined application at 8 $t{\cdot}ha^{-1} \times 50$ $kg{\cdot}ha^{-1}$ of biochar and NPS fertilizer. In conclusive, integrated application of biochar and mineral NPS fertilizer at 8 $t{\cdot}ha^{-1}$ + 50 $kg{\cdot}ha^{-1}$ is suggested for the study area as combination of biochar with mineral NPS fertilizer improve soil structure in addition to improving productivity of maize.

Data Availability

The raw data collected and analyzed during the present study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The research was funded by Wollega University, Ethiopia.

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