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Research Article

Biochar of *Prosopis juliflora* for Improving Crops Germination and Growth on Sandy–Loam Soil

Jamal Ali, Ali Seid Mohammed, and Amare Bitew Mekonnen

Department of Biology, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

Correspondence should be addressed to Amare Bitew Mekonnen; amarebitew8@gmail.com

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Prosopis juliflora (Sw.) DC. is an invasive alien species (IAS) damaging agricultural and natural ecosystems that threat biodiversity in Ethiopia. This IAS can be managed by utilizing it as a resource in agricultural production. This study analyzed the role of *P. juliflora* biochar on germination and growth performance of maize and wheat under field conditions in Wollo, Ethiopia. A randomized complete block design (RCBD) was used to test the effect of biochar on sandy–loam soil with and without fertilizer. In this experiment, biochar from *P. juliflora* was applied on the above two crops at 5, 10, and 20 t/ha with and without N–P fertilizers. From the result, a 100% germination and high growth of test crops were observed from 10 t/ha biochar with fertilizer mixed treatments. The shoot dry weight of both maize and wheat showed significant differences among treatments. While a single dosage (10 t/ha) increased maize dry weight by 21% without fertilizer, but it reduced dry weight by 10% when used with fertilizer. In the case of wheat, single and double dose biochar with NPS treatments increased shoot dry weight by 22.2% and 30%, respectively. This showed that application of biochar up to 20 t/ha in combination with fertilizers can significantly improve crop growth. Thus, it can be concluded that the application of biochar of *P. juliflora* is a good soil amendment option and, thus, this IAS can be managed by utilization.

1. Introduction

Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to pyrolysis, thermochemical conversion at relatively low temperatures (about 350–600°C) in a little or no oxygen condition [1]. The production of charcoal, as a solid fuel and metallurgical reductant, is one of the oldest industries. Charcoal making via traditional means is renowned in using very high temperature and in creating large air pollution [2, 3]. However, the newly updated pyrolysis technology facilitates the heating of biomass (organic sources of solid carbon) in a very low oxygen environment to temperatures over 400°C with low air pollution [4]. During pyrolysis, the thermal decomposition yields solid char, liquid bio-oils and tars, and syngas. The reaction conditions of the pyrolysis production process engineered to change the product ratios and properties [4, 5].

Biochar is a term used to describe to char applied for environmental management and soil productivity benefits [4]. Chemically, biochar is not a pure carbon, but rather mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and ash in different proportions [6]. Thus, application of biochar can have different purposes such as agriculturally to enhance soils nutrient retention and water-holding capacity, for climate change mitigation as permanent carbon sequestration, and greenhouse gas emissions reduction particularly nitrous oxide (N_2O) and methane (CH_4) release [3, 4].

Beneficial effects of biochar in terms of increased crop yield and improved soil quality have been reported [7, 8]. However, review of previous research showed a huge range of biochar application rates (0.5–135 t/ha of biochar), as well as a huge range of plant responses (−29% to +324%) [7].

Generally, effectiveness of biochar application depends on the method of application [9]. Type of biochar application into soil depends on farming systems, available machinery, and labor. In deep banding applications, biochar applied beneath the soil surface to a depth, which ranges from 0.1 to 0.2 m. Apart from eliminating dust, this method of biochar application in soil also creates both good soil–biochar–plant contacts [9]. However, in top-dressed biochar applications, biochar is added to the soil surface.

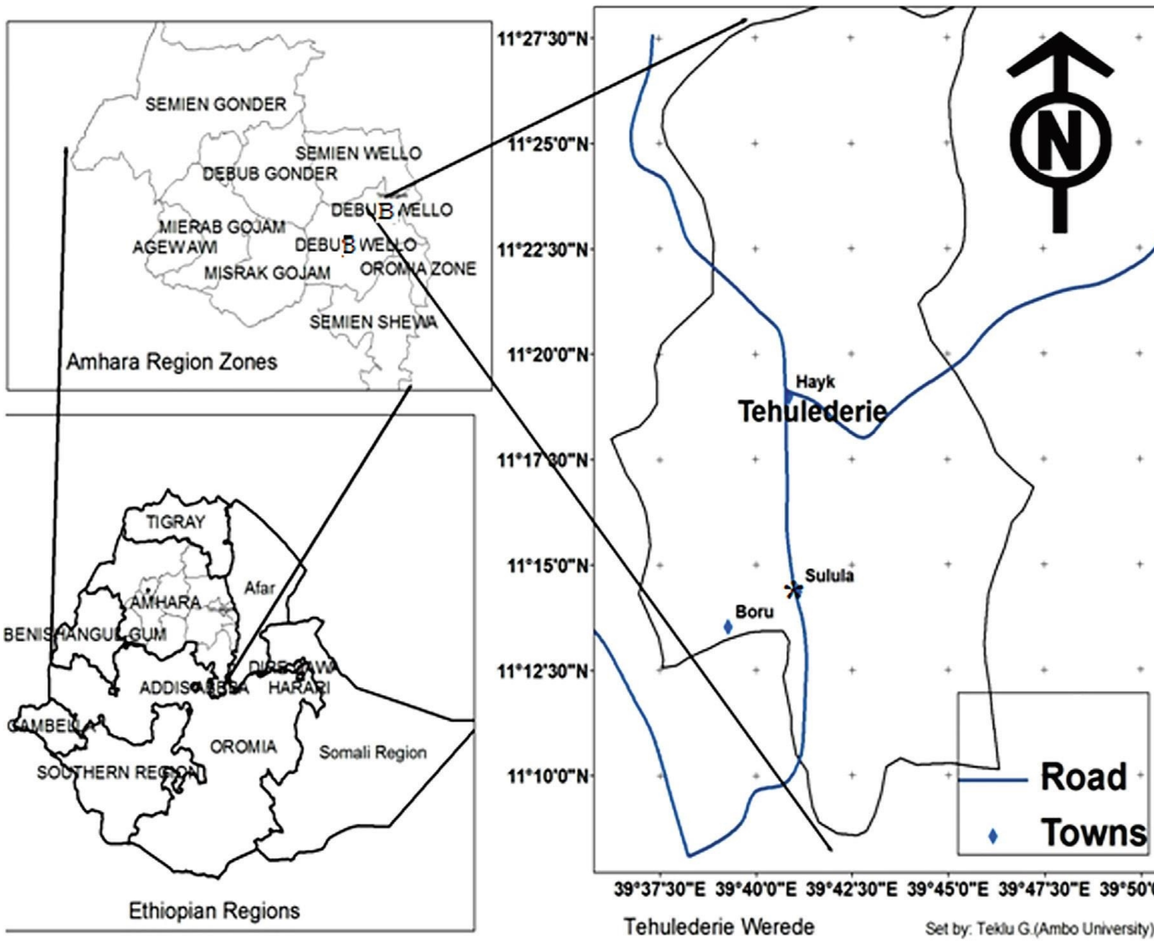

Figure 1: Location map of the study area, Sulula *The significance of this asterisk is to point out it is a town (Look the key) and to point out where it is found in the map.

Biochar is currently a subject of active research worldwide because the potential as carbon sink and benefits for crops production [8]. In Ethiopia, little has been published on how biochar uses and it's potential. Among the major environmental challenges in the sub-Saharan developing countries like Ethiopia are food insecurity as a result of soil fertility problems, soils nutrient depletion, and land degradation. On one hand, there are evidences of fertilizer use inefficiency especially loss of nitrogen due to leaching from the crop producing highlands. On the other hand, the exotic invasive plants like *Prosopis juliflora* are destroying the eastern lowlands of Ethiopia as a result of its invasion. The ecology of the rangelands changed to disastrous ecosystems affecting biodiversity and the life of pastoralists [10, 11].

Prosopis juliflora (Sw.) DC., belongs to the Family *Fabaceae*, adapted to many soil types and wide range of climatic conditions, often as xerophytic [12]. The charcoal made from *P. juliflora* wood tends to be hard, burns slowly, and excellent in heating. The plant is used for constructing houses, to make hand tools, household materials, and to produce high quality charcoal for its heartwood is strong and durable in small scale industries [13]. These uses and its invasion often create controversies in Afar region [14, 15].

Thus, the major objective of this research was to assess the role of different concentrations of biochar, made from *P. juliflora* feedstock, in improving germination and early growth of two crops. The result of this study is expected to benefit highland farmers to use biochar in their farms soil management and improve crop yields, as well as lowland pastoralists to manage their invasive species through utilization.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in Sulula District, South Wollo of Ethiopia. It is located near Dessie, the zonal town about 400 km from Addis Ababa. Geographically at 11°, 17′ N and 39°, 40′ E (Figure 1) and has an altitude of 1,400–2,900 m above sea level. The mean annual maximum and minimum temperatures are 21 and 9°C, respectively. The mean annual rainfall of the study area is 1,030 mm. The soil characteristics of study site were sandy loam. Soil classification of the study area includes Haplic Leptosols, Leptic Cambisols, Vertic Luvisols, and Stagnic Vertisols (FAO, 2006).

2.2. Biochar and Test Seeds Preparation. The research was conducted in 2018 after *P. juliflora* wood was collected from commercial sellers around Mille town in Afar Regional State

(East Ethiopia). The moisture content of the wood was reduced from approximately 45% to close to zero by drying in open sunlight. Then, the woods were first sorted into similar diameters and lengths and combusted in small earth kilns method made on flat ground. Then, the stack was covered with soil and burned very slowly for several days. After 2–8 days, the charred material (biochar) quenched by sprinkling water on the hot char and dried in the sun for a few days [3, 6]. Then, last, the dry biochar was crushed and sieved through a 2-mm sieve and stored until use [16].

Maize (*Zea mays* cv. BH540) and wheat (*Triticum aestivum* var. C2) seeds were collected from the zonal seed enterprise and farmers, respectively. The maize germination percentage, purity, and moisture content were 92%, 99%, 10%, respectively, as certified by the seed agency. The wheat germination percentage and vigor were evaluated using the standard germination test with 10 seeds (three replicates) per petri dishes in Bahir Dar University Biology Laboratory.

2.3. Experimental Design and Treatments. The field experiment was conducted using randomized complete block design (RCBD) with three biochar concentrations (5, 10, 20 t/ha) with and without nitrogen, phosphate, and sulfate (NPS) fertilizer [17]. Prior to sowing, the land was prepared by tilling two times and a good seedbed preparation as recommended for the test crops. Triplicate treatments were randomly distributed into blocks. A total of 24 experimental plots (eight plots for each) of 1 m^2 area were established, with three replicates and seven treatments plus a control group. The treatments were: T1, controls (zero biochar and no NPS); T2, biochar (5 t/ha); T3, biochar (10 t/ha); T4, biochar (20 t/ha); T5, biochar (5 t/ha) with NPS; T6, biochar (10 t/ha) with NPS; T7, biochar (20 t/ha) with NPS; and T8, NPS only (Figure 2).

The treatment biochar and fertilizer were added on the same day during planting. The biochar was added up to 10–15 cm soil depth by hand hoeing. The amounts of nitrogen and phosphate fertilizer were determined by district agricultural office. The levels of diammonium phosphate (DAP) for wheat and maize were 120 kg and 100 kg ha^{-1}.

All agronomic practices were kept uniform for all treatments as recommended. Fertilizer was applied at planting time (P and N) and for N one-third (100 kg/ha), respectively. Plants were watered uniformly to all plots every morning and evening and weeded and thinned by hand after 15 days. Observation was made for germination and growth parameters every week.

2.4. Data Collections. The number of seeds germinated in each treatment was counted on 9th day after sowing, and the germination percentage was calculated by using the formula developed by International Seed Testing Association [18]. The total number of the healthy leaves per plant at maturity was counted. Shoot heights were measured with ruler, and dry weight was determined by gravimetric method using sensitive balance (mg accuracy). Eight weeks after planting, the plants were cut at the soil level and weighed, oven-dried for 24 hr at 80°C, and weighed again to obtain the biomass. After moistening the soil, roots were removed and washed, and length and biomass were measured.

2.5. Data Analysis. Statistical differences among treatments were determined by analysis of variance (ANOVA) for completely randomized block designs (CRBD) and Tukey's honestly significant difference test ($P < 0.05$) using SPSS 20.0. Means compared using least significant difference (LSD) test and presented values followed by same letters in a column as not significantly different ($P \leq 0.05$).

3. Results and Discussion

3.1. Effect of P. juliflora Biochar on Seed Germination of the Test Crops. There was a significant difference in germination percentage of crops between treatments (Table 1). The germination of maize and wheat was significantly stimulated by varying doses of biochar ($P = 0.02$) and ($P = 0.03$), respectively. The highest germination percentage (100%) was recorded in 10 t/ha BC + NPS fertilizer and 20 t/ha biochar without fertilizer for the crops maize and wheat, respectively. While the lowest germination percentage for maize was 5 t/ha in biochar with and without NPS (83.3%), for wheat, it was in control group (86.1%).

Physically, the ability of biochar to retain moisture [9] could have played a role in germination success. This result could be supported by the finding of Rillig et al. [19] and Free et al. [20] who reported that increasing biochar content proportionally increased germination. In other words, seeds that are sown in biochar-amended soils germinate faster. Biochar change in surface reflectance translates into a substantial increase in soil temperature [21]. An increase in soil temperature, due to application of biochar, could have positive impacts on seed germination, crop establishment, and early crop growth [22].

Germination percentage of wheat seeds significantly increased at higher biochar application (92.7%–100%) than the control group (86.1%). In line with this, it has been reported that wheat seeds germination treated with paper mill biochar was increased with a single dose of 10 t/ha [23]. According to some authors, biochar can improve germination rate [20, 24].

Biochar improves soil fertility by increasing soil pH, organic carbon, phosphorus, and potassium that stimulate seed germination [25]. In addition to this, others observed that application of biochar alters organic matter mineralization, which links with the release of nutrients such as nitrogen [26, 27]. The reduction of N by leaching up to 60% with an accompanying 20% fertilizer will be minimized and 10% seeds savings will be done by the application of biochar [28]. As biochar increases, the efficiency of seed and nutrient savings or uptake/leach ratio will be higher [26]. Thus, all the above changes could explain both seed germination and seedling growth of the test crops in this study.

3.2. Effect of P. juliflora Biochar on Shoot Biomass of the Test Crops. The shoot dry weight data of both maize and wheat showed significant differences among the treatments (Table 2). The results also showed that the application of a single dosage of *P. juliflora* biochar (10 t/ha) increased maize dry weight by 21% together with fertilizer. In the case of wheat, single and double dose biochar with NPS treatments increased shoot dry weight by 22.2% and 30%, respectively. While insignificant increase observed from half and single dose treatments, there was slight (3%) decrease from double dose biochar without NPS.

Figure 2: Photographs of experimental setup and results to compare shoot and root growth of the two crops. *Note*. The weight of biochar added is only per each small plots not per hectare.

Biochar can also improve soil water-holding capacity [29], facilitating seedling biomass gain [9]. Plant growth responses can be altered by biochar-induced changes in soil nutrient conditions, particularly the cycling of P and K [30]. Plant resistance was greater with biochar additions to soil [31, 32]. Similar studies confirmed that a better seed germination (30% enhancement), shoot height (24%), and biomass production (13%) among seven native woody plants on soils under charcoal kilns reported as compared to undisturbed Alfisols and Ultisols [33]. However, some biochar (biosolid) feedstocks have been reported to contain high concentrations of heavy metals and toxic substances, which might reduce seed germination and seedling growth with consequentially effects on crop establishment and yield [34].

Similar to the present study, Van Zwieten et al. [23] reported that wheat biomass production on an acid tropical soil increased linearly up to an application of 10 t ha^{-1} (2.2%). This growth was attributed to direct nutrient additions such as P, K, and Cu from biochar. Others attributed the positive plant growth to changes in soil biogeochemistry

Table 1: Germination percentage after 8 days with *P. juliflora* biochar (BC) treatment.

Treatment	TGP (%) of maize	TGP (%) of wheat
Control	94.4 ± 0.33^{a}	986.1 ± 1.67^{d}
5 t/ha BC	83.3 ± 0.57^{b}	95 ± 2.08^{b}
10 t/ha BC	94.4 ± 0.33^{a}	92.7 ± 1.33^{bd}
20 t/ha BC	88.0 ± 0.88^{ab}	100 ± 0^{a}
5 t/ha BC + NPS	83.3 ± 0.57^{b}	95.5 ± 0.88^{b}
10 t/ha BC + NPS	100 ± 0^{a}	95.5 ± 1.20^{b}
20 t/ha BC + NPS	94.4 ± 0.33^{a}	98.8 ± 0.67^{b}
NPS	83.3 ± 0.57^{b}	87.2 ± 1.20^{c}

Note: TGP refers to mean total germination percentage. Values of TGP with different letters between treatments along each column denote significant differences at $P < 0.05$.

Table 2: Effect of *P. juliflora* biochar on shoot dry weight (SDW) after 8 weeks.

Treatment	Maize (g)	Wheat (g)
Control	55.94 ± 6.27^{d}	8.01 ± 0.77^{b}
5 t/ha BC	58.47 ± 7.62^{d}	8.63 ± 0.81^{b}
10 t/ha BC	67.57 ± 5.09^{c}	8.63 ± 0.80^{b}
20 t/ha BC	64.83 ± 10.30^{c}	7.78 ± 0.63^{c}
5 t/ha BC + NPS	75.05 ± 9.42^{b}	6.26 ± 0.62^{d}
10 t/ha BC + NPS	72.68 ± 4.75^{b}	9.75 ± 0.93^{a}
20 t/ha BC + NPS	69.84 ± 5.53^{b}	10.37 ± 0.81^{a}
NPS	81.60 ± 6.61^{a}	7.98 ± 0.79^{c}

Note: Means were compared using LSD test. Values followed by same letters in a column are not significantly different ($P \leq 0.05$).

resulting from biochar additions [27]. In addition to this, increased micronutrient concentrations, namely molybdenum (Mo) and boron (B), were thought to be responsible for enhanced biological N_2 fixation (BNF) by rhizobia in legumes grown in biochar but the same may not hold for abundance of rhizobia [35]. There is variation in plant responses from the application of biochar relative due to the variability of soil systems studied [36].

Similar to our finding, it has been reported that the addition of biochar led to about 20%30% increase in durum wheat biomass compared with the use of the mineral fertilizer alone [8] and biomass yield of maize increased 44% on charcoal site soils compared to adjacent field soils [37]. Besides, not all soils react the same to biochar, and it may take time to observe significant changes in soil and crop attributes after biochar addition [38].

3.3. Effect of P. juliflora Biochar on Root Growth Parameter. The results showed that there is a significant difference between the different treatments and the plant root length ($P \leq 0.05$). The highest root length of maize was recorded in 5 t/ha BC + NPS (39.8 cm) followed by 10 t/ha BC (37.2 cm), and the lowest root length was recorded in treatment control (Table 3).

This result also showed the positive effect of *P. juliflora* biochar on root growth parameter (Figure 2). This can be attributed to the ability of biochar to improve soil properties,

Table 3: Effect of *P. juliflora* biochar treatments on root length after 8 weeks.

Treatment	Root length (cm)	
	Maize	Wheat
Control	33.26 ± 1.29^{b}	10.94 ± 0.47^{c}
5 t/ha BC	33.39 ± 1.61^{b}	11.69 ± 0.36^{b}
10 t/ha BC	37.23 ± 0.72^{a}	12.11 ± 0.42^{a}
20 t/ha BC	33.67 ± 1.37^{b}	11.73 ± 0.41^{b}
5 t/ha BC + NPS	39.86 ± 1.29^{a}	11.70 ± 0.52^{b}
10 t/ha BC + NPS	34.24 ± 1.08^{ab}	12.57 ± 0.52^{a}
20 t/ha BC + NPS	34.57 ± 1.10^{ab}	11.63 ± 0.40^{b}
NPS	36.57 ± 1.23^{a}	12.25 ± 0.42^{a}

Note: Means were compared using LSD test. Values followed by same letters in a column are not significantly different ($P \leq 0.05$).

such as porosity and pH, which may indirectly improve root growth [4]. In agreement with this study, the experiment of *Betula pendula* showed more than six times higher uptake of nitrogen, significantly higher total biomass and enhanced shoot-to-root ratio after biochar augmentation on a site with ericaceous vegetation, acidic, and nutrient poor soil [27]. Similarly, very different properties of biochar in comparison to surrounding soil in most known case improved root growth [4]. In addition to this, many reports that a rhizosphere increase in biochar-amended soil and root length intensity approximately doubled [27, 39–41] also reported that rice grew better with more tillers, height, root, and finally yield with biochar application.

In line with this study, not only a significant increase in root biomass (47%) but also root tip number (64%) increased within a layer of char from a forest fire with larch twigs, birch twigs, and shoots of dwarf bamboo buried in a dystric Cambisol [42]. Others have observed that the number of storage roots of *Asparagus* also increased with coconut biochar additions to a tropical soil [43]. This might be due to enhanced the symbiotic associations of mycorrhizal fungi (MF) and terrestrial plants demonstrations of the positive response of plant growth and nutrient availability because of enhanced MF colonization following BC additions in soils have been reported [42]. Root growth and aboveground biomass of *Larix gmelinii* (Gmelin larch) both increased with applied BC alone and were greatest when BC was applied with MF.

3.4. Effect of P. juliflora Biochar on Crop Height. The results showed the highest shoot growth was recorded in NPS fertilizer treatment (16.36, 27, 34.28, 45.18, 62.1, 81.2, and 102.13 cm) at week 2–8 after planting, respectively, and the lowest was recorded in control treatment after planting (Figure 3(a)). The results also showed a significant growth difference of wheat plant height between treatments by measuring height every week after planting (Figures 2 and 3(b)). The highest shoot growth was recorded in 10 t/ha BC treatment, while the lowest shoot growth was recorded in control treatment (Figure 3(b)). In line with this study, Hoshi [44] reported that a 20% increase in volume and 40% increase in height of tea trees after biochar additions. Similarly, Zhang et al. [41] also reported that the rice net photosynthetic rates of biochar treatments were higher than in control treatments.

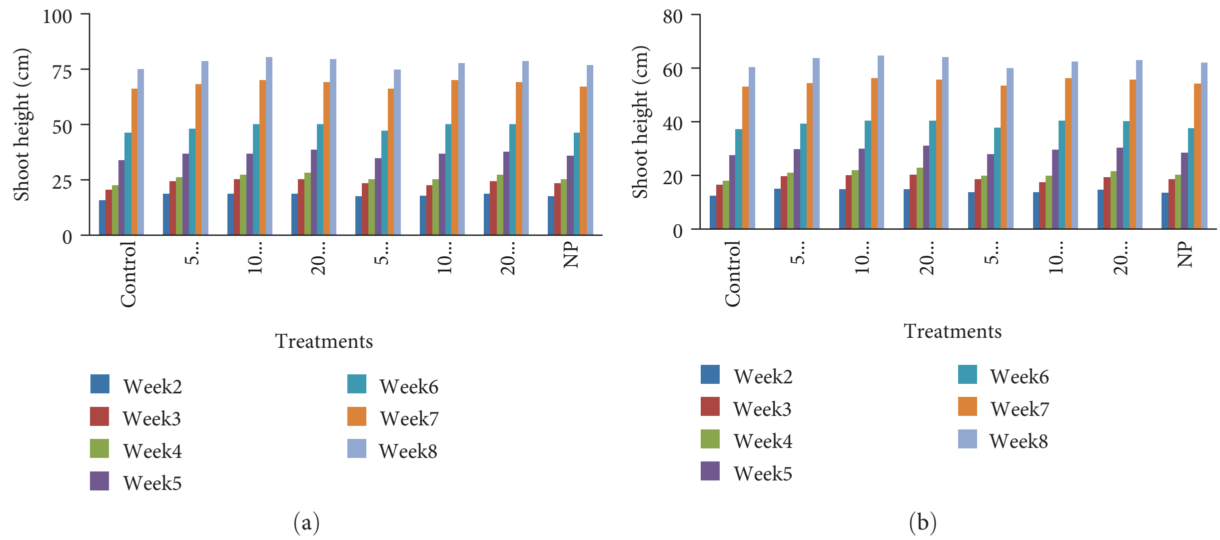

Figure 3: Effect of biochar on height (cm) of maize (a) and wheat (b) per weeks.

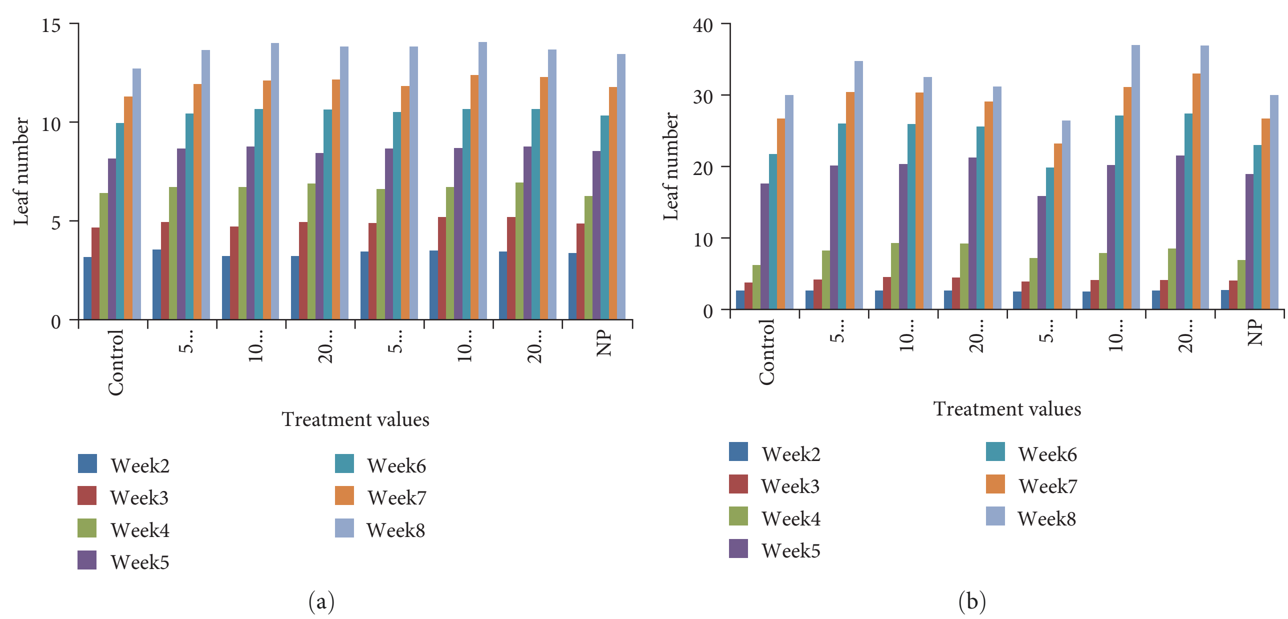

Figure 4: Effect of *P. juliflora* biochar treatments on leaf number of maize (a) and wheat (b) in 8 weeks.

Van Zwieten et al. [36] also reported that the application of biochar to soil significantly increases N uptake of plants. This finding is in agreement with the study conducted by Van Zwieten et al. [23] who reported that application of biochar has beneficial effect on soil properties, which include reduced acidity, increased cations exchange and water-holding capacity, reduced soil strength, and enhanced activity of beneficial microbes. The results could also be supported by Sadeq et al. [45] who found the amount of soil N, P, Mg, and organic matter was significantly higher in understory of live *P. juliflora* juliflora than uncanopied adjacent areas. These all findings confirmed that the application of biochar increases crop height, biomass, and productivity through soil fertilization and amendments.

Some authors have indicated that crop yields could be enhanced to greater extent when biochar is applied together with other inorganic or organic fertilizers [7, 46]. In addition to improving fertilizer retention for plant growth [35], the dissolved salts that are readily available in biochar are also act as fertilizer [7]. According to Cao et al. [47], a slow-release phosphorus fertilizer has been developed by using dairy manure as a biomass feedstock. Additionally, the physical structure of biochar provides a framework for building a slow-release NPK fertilizer as proposed by Day et al. [48]. Another study showed that in the paddy fields with applied biochar, there was an improvement of soil fertility with more tillers, greater plant height, better roots, and finally more yield of paddy [41].

3.5. Effect of P. juliflora Biochar on Number of Leaves. The results showed a significant difference among the different treatments effect on maize seedlings leaf number in 8 weeks after planting (Figure 4(a)). The highest plant leaf number was recorded in treatment 10 t/ha + NPS fertilizer followed by 10 t/ha 8 weeks after planting and the lowest leaf number was recorded in control treatment. Application of biochar as a seed treatment on maize significantly ($P \leq 0.05$) affected the number of leaves of maize seedlings. Maize seedling treated by 10 t/ha BC and NPS fertilizer showed averagely better performance (14.05 leaves/plant) than any other treatments. The average leaf numbers of untreated (control) maize seedling were 12.7 leaves/plant, which were relatively lower than any treated seeds (Figure 4(a)). The highest wheat leaf number was recorded in treatment 10 t/ha +NPS fertilizer followed by 20 t/ha + NPS fertilizer and the lowest plant leaf number was recorded in control treatment (Figure 4(b)).

The present result is supported by the finding of Lehmann et al. [28] who reported that the addition of biochar improves plant productivity directly as a result of its nutrient content and indirectly through improved nutrient retention. Similarly, Yeboah et al. [49] reported a similar result that crop growth rate and nutrient uptake were enhanced with greater biochar application rate. Ali et al. [50] also reported that the application of biochar treatment increases the number of leaves and leaf turnover to faster protein turnover and. therefore. a faster pace in rice development compared to the control group.

Some authors believe that biochar does not directly provide nutrients [7, 51], but it improves soil structure, with a consequent increase in water retention and enhance nutrient uptake. However, all of the above benefit helps to increase crop production. Some other researchers include that disease resistance becomes greater with biochar additions [31, 32].

4. Conclusions

The application of *P. juliflora* biochar in the field experiment showed significant effects on seed germination and the growth parameters of wheat and maize as compared to garden soil (control). The results also indicated that a significant rise in seed germination percentage as we applied more *P. juliflora* biochar in a given farm land. The study also showed an increase in crop biomass or yield performance by using *P. juliflora* biochar alone and/or in combination with chemical fertilizer. The application of this IAS biochar also increases the shoot and root growth of the crops and then enhance crops yield through improving the physico-chemical and biological properties of the soils that are likely the reasons why biochar has contributed to increase plant productivity. It is possible to conclude that the highland leaching soils can be improved by biochar amendment in a sustainable manner. Application of *P. juliflora* biochar alone can improve dry matter yield (crop biomass) equivalent to NPS fertilizer.

Based on the results of the study, it can be recommended that the application of *P. juliflora* biochar in the farm improves the seed germination potential and crop growth performance and dry matter yield with or without fertilizer. Moreover, the experiments have supported that we can manage the lowland IAS such as *P. juliflora* by utilizing it as biochar for crop production in the highlands. The findings also implicated that an optimum amounts of the *P. juliflora* biochar need to be used at the regional and national soil amendments projects. Especially, when other amendments applied alongside the biochar, long-term soil fertility can be improved. However, further experiments of application of *P. juliflora* biochar on soil physical and chemical analysis should be done before it can be scaled up.

Data Availability

The datasets used and/or analyzed in the study are available from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jamal Ali: conceptualization, data collection, analysis, and administration. Ali Seid Mohammed: conceptualization, data curation, analysis, and administration. Amare Bitew: conceptualization, data collection, analysis, and investigation. All authors read and approved the final manuscript.

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