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Research Article

Response of Garlic (*Allium sativum* L.) Yield to Combined Biochar, Lime, and Inorganic-Fertilizer Rates in the Case of Gimbi District, Western Ethiopia

Solomon Abeba Kenea,[1] **Tolera Abera Goshu**,[2] **and Kinati Chimdessa**[1]

[1]*Department of Natural Resources Management, Wollega University, Shambu, Ethiopia*
[2]*Natural Resources Management Research Process, Ambo Agricultural Research Center, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia*

Correspondence should be addressed to Solomon Abeba Kenea; solomonab@wollegauniversity.edu.et

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Soil degradation due to acidity is a serious problem in western Ethiopia, which would lower soil productivity and crop production. Implementing integrated soil fertility management is the most efficient approach for enhancing agronomic efficacy and boosting crop output while addressing the issue of soil acidity. This experimental study aimed to investigate the effect of combined coffee husk biochar (CHB), soil test-based value lime (STV), and inorganic-fertilizer (NPSB-fertilizer) rates on the optimum yield of garlic in Gimbi district, western Ethiopia. The field experiment was conducted during the 2022 cropping season on two sites. The experiment comprised 14 treatments laid out in a randomized complete block design with three replicates. Application of integrated biochar, lime, and inorganic-fertilizer rates showed a highly significant impact ($p < 0.01$) on the yield and yield components of garlic. The treatment unit with T11 ha^{-1} had the significantly highest total fresh biomass yield (TFBY) per plant for both Farm-1 (65.9 g) and Farm-2 (75.3 g). Bulb yield fresh weight per plant (BWp) was highest in treatments of T4 and T8 ha^{-1} in Farm-1 (27.7–28.1 g) and in treatments of T4 and T11 ha^{-1}, in Farm-2 (31.4–31.6 g). Marketable bulb yield (MBY) was significantly highest in treatments; T4, T7, T8, and T11 ha^{-1} in Farm-1 (8.5–9.3 tons ha^{-1}) and Farm-2 (10.1–10.5 tons ha^{-1}). Therefore, by combining, the application of 10 tons of biochar (CHB) + 75% of lime (STV) + 75% of inorganic-fertilizer (NPSB-fertilizer) ha^{-1} in strongly acid soil, and 7.5 tons of CHB + 50% of STV + 50% of NPSB-fertilizer ha^{-1} rates in very strongly acid soil are recommended for garlic production in Gimbi district, western Ethiopia, and similar areas. In order to draw firm conclusions, future research on more sites is necessary because this study was logically limited to two sites.

1. Introduction

Worldwide, garlic is a very important vegetable crop. It is one of the most significant and commonly farmed crops. It is a vegetable crop that is notable for its productivity and economic value [1]. Due to its strong flavor, it is frequently used as a seasoning or condiment throughout the world. In Ethiopia, garlic is an essential component of many foods, vitamins, and medicines. In addition, it is a rich source of silicon, fiber, calcium, potassium, phosphorus, sulfur, and iodine. It is also high in sugar, protein, and fat [2]. Despite its importance, garlic's productivity is low in many parts of the world [3].

In Ethiopia, garlic crop yields are low, due to biotic and abiotic reasons [2, 3]. These factors include several genetic and environmental problems, such as improved seed variety, declining soil fertility from unbalanced nutrient supply and ineffective fertilizer use, and poor agronomic practices [3]. In Ethiopia, the infertility of soils is mostly to blame for the crop's low productivity, both nationally and regionally [3, 4]. Currently, the leaching of soil nutrients that results from infertility in the highlands of the northwest, southwest, and midlands areas of Ethiopia, generally affects the growth, nutrient uptake, and yield of all crops, including garlic [4].

In agriculture, chemical fertilizers have been considered the main method of improving crop yield productivity [5]. Nitrogen and phosphorus are usually referred to as the key macronutrients [6]. This could be because plants absorb them from the soil in higher amounts than other nutrients, which have a substantial impact on the development and productivity of crops. However, not as usual, crop productivity has decreased year over year, even with the application of these mineral fertilizers [3]. To increase crop production, proper fertilizer application (types, timing, and rate) is crucial [7]. The growth and production of garlic are significantly impacted by the application of different types, timings, and rates of fertilizer [5, 8].

The western parts of Ethiopia's soils are well suited for growing a wide range of crops [9]. However, in the present few decades, because of the high degree of nutrient mining by leaching, the imbalanced use of chemical fertilizer as agricultural inputs is a main factor in low crop productivity [10]. The yield of a crop varies dramatically with soil fertility [8, 11]. This demonstrates that, with the appropriate soil fertility management techniques, it is feasible to produce optimum crop yields. Similar to the south–western, north–western, and middle regions of the nation, the majority of smallholder farmers in western Ethiopia plant the crop by applying mineral fertilizer alone with a blind recommendation rate [12]. These users were only drawn by the simplicity of its use [13]. In such practices, soils are no longer as receptive to this conventional farming practice [12]. Because chemical fertilizer contains NH_4^+, which releases H^+, it will contribute to the acidity of the soils. As there is fast leaching and volatilization in chemical fertilizer, minimal nutrient uptake by plants is expected [14–18]. Besides this, currently, subsistence farmers cannot pay fertilizer prices, which have increased with time [14]. For crop production to be as affordable as possible, finding alternate fertilization practices is an option [10].

To increase soil productivity, liming interacts positively and synergistically with various fertilizers [10, 19–21]. For soils suffering from acidity, it provides the fundamental cations [22]. Lime can be utilized on acidic soils for 3–5 years after application [23]. Therefore, lime is valuable, yet it is expensive to transport, which can restrict its usefulness. Recommendations for certain soil types, crop types, cation imbalances brought on by liming, and the detrimental impacts of trace element deficits are lacking [24].

Compared to applying solely inorganic-fertilizer and lime, combining them with organic fertilizers considerably improves soil properties and plant biomass [10, 25]. Vegetables have a better response to soil improved with organic fertilizer [26]. Many authors have depicted the significant improvement in garlic yield by the use of integrated fertilizers [27]. Looking for nearby, easily accessible resources like mulching, compost, manure, and biochar may be an alternative to improving soil fertility [10, 11, 19, 20].

Biochar is a carbon-rich material produced by the pyrolysis of biomasses [4, 10, 28]. Numerous studies have examined how biochar improves the characteristics of soil and the yields of plants [4, 29–31]. However, the materials of biochar and the temperature of pyrolysis could have a major impact on biochar qualities [10]. The properties of soil may be improved by biochar, as it can affect the heavy metal toxicity, transport, and fate of soils [31, 32]. There are surplus native materials in the western region of Ethiopia that can be used as raw materials for the manufacturing of biochar, particularly coffee husks in the coffee-growing regions [19, 21]. Most of these coffee byproducts are burned in large stacks or poured into waterways, creating greater environmental risks [19]. However, turning these coffee waste products into biochar through pyrolysis might help with acidic soil issues [4, 10].

The research done on the effect of applying combined biochar, lime, and inorganic-fertilizer rates on garlic yield is indiscernible in Gimbi district, western Ethiopia. However, employing this acid soil ameliorant in this location may be a good choice for growing garlic and may assist in addressing the problems of the study area with fertilizer accessibility. Including the availability of raw materials like biochar, the accelerating soil acidity problems, and constraints in inorganic-fertilizer and lime would also call for integrated fertilizer research as a means of crop production for the current and future populations. Therefore, the purpose of this study was to investigate the effects of applying combined biochar, lime, and inorganic fertilizer rates on garlic production in the Gimbi district, western Ethiopia.

2. Material and Methods

2.1. Characterization of Experimental Site. The experiment was carried out in Gimbi district, western Ethiopia, 441 km west of Addis Ababa. The geographic position is 9°10°–9°17° North latitude and 35°44°–36°09° East longitude, respectively with an altitude range from 1,200 to 2,222 m.a.s.l. The minimum and maximum temperature ranges from 10 to 30°C, and the mean annual rainfall ranges from 1,000 to 1,800 mm per year [33]. There are 89,243 people living in the district, and 97% of smallholder farmers there are rural residents who depend on agriculture for a living. According to a number of studies the undulated topography of western Ethiopian is the main reason why nitisols, a type of soil formed from badly eroded acidic volcanic rock, are most prevalent there [33, 34]. The study area is divided into three ecological zones: 70% highland, 10% midland, and 20% lowland [33–37].

The research areas contain a variety of land use types [37]. Farmers have responded to the leaching and degradation to their agricultural soils by using inorganic fertilizers to improve crop output. In addition to this inorganic-fertilizer, lime has recently been created and is now being used on the bulk of the agricultural soils. As a result, the research area is included in the production potential of bulb crops, since the bulb crops are active in the elevation and rainfall of study area. However, the crop yield and bulb production are constrained by the acidity of the soil [38]. As a result, the majority of smallholder farmers only cultivate bulb crops nearby their homesteads for local consumption, however, area have condition that allowing them to explore for additional strategies to boost crops [34].

2.2. Description of Experimental Material and Site

2.2.1. Trial Crop. Garlic (*Allium sativum L.*) was sown at a rate of 600 kg ha^{-1} [11]. The garlic seed was purchased from a neighboring farmer, and separately, garlic seeds were grown on local farmers' fields in the study area 2 years ago (2020–2021). The rationale behind the selection of the local variety is discussed by various researchers, especially in relation to disease control and adoption of other environmental factors [1, 11, 39–41].

2.2.2. Biochar and Its Properties. The biochar (coffee husk biochar; CHB) used in this experiment study was made from coffee husks in a soil pit kiln and analyzed in the laboratory as referenced and mentioned in Abeba Kenea et al. [10]. Biochar had a soil pH value of 10.61 and was extremely strongly alkaline. With the exception of Mg^{+2} (7.77 cmol $_{(+)}$ kg^{-1}), which had a high content, the exchangeable bases Ca^{+2} (58.30 cmol $_{(+)}$ kg^{-1}), K^+ (3.10 cmol $_{(+)}$ kg^{-1}), and Na^+ (4.47 cmol $_{(+)}$ kg^{-1}), had base saturation values that were extremely high (91.91%). The biochar has a extremely high cation exchange capacity (80.10 cmol $_{(+)}$ kg^{-1}), total nitrogen (2.03%), and organic carbon (31.26%). The carbon-to-nitrogen ratio was 15.39%. Wogi et al. [42] demonstrated that nitrogen occurs in organic molecules; hence, this source of nitrogen concentration in biochar might be a result of that fact. The available phosphorous of 16.8 mg kg of $soil^{-1}$, which had a low concentration of extractable phosphorous, was recovered from the total phosphorous of 138.01 mg kg of $soil^{-1}$. This might be explained by the fact that the biochar under study is rather alkaline [10].

2.2.3. Lime and Inorganic-Fertilizer. The lime ($CaCO_3$) which soil test-based value lime (STV) materials were chosen for the treatment based on the research site's bulk density (after unit of gcm^{-3} converted to $mg\,m^{-3}$) and exchangeable acidity (cmol $_{(+)}$ kg^{-1}) concentrations were used in accordance with Kamprath's [23] guidelines. The inorganic-fertilizer (NPSB) contains the 18.9 nitrogen in the form of NH_4, P; 37.7 P_2O_5 in the form of P_2O_5, S; 6.95 sulfur in the form of SO_4, and $B = 0.1$ Boron in the form of B_3O_3 [43], which is the first fertilizer type for the study area, followed by Ethos [44] as per the full rate of fertilizer recommendation given for garlic of 242 kg ha^{-1} as described by Ministry of Agriculture [45], followed by the MoA, was used.

2.3. Experimental Treatments and Design. The experiment was carried out on farmer's fields in two different kebeles in the Gimbi district of western Ethiopia. The "Farm-1" and "Farm-2" farm fields of Wondimu Tasisa and Girma Burayu were chosen from Chuta Georgis and Cuta Gochi kebele, respectively. The altitudes ranged from 1,700 to 2,000 m.a.s.l., the soil ranges from strong to very strong acid, the rain fall defaults to 1,700 mm $year^{-1}$, and the experimental plot land was uniform (slope at 0%). The randomized complete block design with three replications was used. In the treatments, the rate of STV and NPSB-fertilizer rates at 50%, 75%, and 100% was combined with CHB rates at 10, 7.5, and 5 tons ha^{-1}. These treatments were shown in the table (Table 1). The studies were carried out in 2022's cropping season. Garlic (*A. sativum L.*) was planted in June 2022, and the garlic bulb was harvested in October 2022.

2.4. Experimental Procedure and Field Management. The experimental field was plowed and harrowed by oxen. Each treatment was assigned at random to the experimental units within a block, with the plots leveled at a ridge about 20 cm high. Blocks and plots were separated by 1 and 0.5 m, respectively. Each experimental plot measured 3.20 m × 3.80 m (12.16 m^2) in size. In each plot, 10 cm of row length was left at the end of each row to prevent the border effect. The net plot size was 3.00 m × 3.6 m (10.80 m^2), and the first row from each side was deemed to be the border. There are six ridges on each plot, spaced 40 cm apart, as described in Ayalew et al. [40] and Totić and Čanak [46]. Two parallel, equal rows of 38 garlic seeds (cloves of middle size of 2–2.5 g) were sowed on each ridge. Twenty centimetres between rows and 10 cm within rows were used to space the garlic seeds, according to described in Nourai [47].

A field layout was created in line with the design specification prior to the planting of the garlic seeds, and the experimental plot was then given a thorough application of lime ($CaCO_3$) and biochar by hand before being hoed into the ground. The garlic seed was then manually planted at a depth of 3–4 cm and covered with soil after a month of applying biochar and lime. Each treatment plot received dosages of 242 and 129 kg of NPSB and urea fertilizer, respectively, ha^{-1} rate, in accordance with the Ministry of Agriculture [45] followed by MoA recommendations for the study area for garlic cultivar. Half of the urea fertilizer was added during the plant's germination, and the other half was added 37 days later. Every plot received the same treatment for weeding, insect, disease, and pest management, all of which were approved agronomic management practices.

Table 1: Treatments combinations and code.

Code	Treatment combination
T0	Control ha^{-1}
T1	100% of NPSB- fertilizer ha^{-1}
T2	100% of STV + 100% of NPSB-fertilizer ha^{-1}
T3	10 tons of CHB + 100% of NPSB-fertilizer ha^{-1}
T4	10 tons of CHB + 75% of STV + 75% of NPSB-fertilizer ha^{-1}
T5	10 tons of CHB + 75% of STV + 50% of NPSB-fertilizer ha^{-1}
T6	10 tons of CHB + 50% of STV + 75% of NPSB-fertilizer ha^{-1}
T7	10 tons of CHB + 50% of STV + 50% of NPSB-fertilizer ha^{-1}
T8	7.5 tons of CHB + 75% of STV + 75% of NPSB-fertilizer ha^{-1}
T9	7.5 tons of CHB + 75% of STV + 50% of NPSB-fertilizer ha^{-1}
T10	7.5 tons of CHB + 50% of STV + 75% of NPSB-fertilizer ha^{-1}
T11	7.5 tons of CHB + 50% of STV + 50% of NPSB-fertilizer ha^{-1}
T12	5 tons of CHB + 75% of STV + 75% of NPSB-fertilizer ha^{-1}
T13	5 tons of CHB + 75% of STV + 50% of NPSB-fertilizer ha^{-1}

NPSB-fertilizer, inorganic-fertilizer; STV: soil test-based value lime; and CHB: coffee husk biochar.

2.5. Data Collection

2.5.1. Soil Sampling and Analysis Pre and Post Garlic Harvest. The soil sample was collected using clean tools mixing cores, sampling depth, and enough samples before the treatment application from the study site and after garlic harvest from each treatment plot. A composite of approximately 1 kg of soil sample, was made from five soil subsamples that were taken by the Zigzag method at a depth of 20 cm by using an auger from each plot per frequency of sampling [10, 48]. In addition to this, the separated undisturbed soil samples at each 5 cm of depth of 20 cm were taken separately by a core sampler for soil bulk density determination by following per the from sampling plot. Moreover, as per the sample of soils, ice box was used to engage the soil sample for analysis of ammonium nitrogen (NH_4—N) and nitrate nitrogen (NO_3—N) [42].

The main factors, such as sampling intensity per unit area of the site sampled and the sampling design, were usually considered when developing soil sampling protocols to monitor changes in major soil property parameters. In addition, to minimize error factors, representative soil samples were kept free from contamination, leaves, litter, dead plants, furrows, manures, wet spots, and compost pits. Finally, soil samples were air dried, crushed, mixed well, and passed through a 2 mm-sized sieve, prepared, properly labeled, packed in a plastic bag, and then transported to the laboratory to analysis of the selected parameter of soil physic-chemical properties as described in [48, 49].

(1) Soil Physical Properties. Bulk density (BD), soil porosity (Po), and soil moisture content (MC) were analyzed to determine the selected soil physical properties. The soil BD (gcm^{-3}) was determined by the core method after drying a defined volume of soil in an oven-dried at 105°C for 24 hr [50]. Po was determined by Danielson and Sutherland [51]. Soil MC (%) was measured after drying in an oven at 105°C for 24 hr and dried to a constant weight, according to Gardner [52]. Water content $= (W_1 - W_2)/W_2 \times 100$, where W_1 represents the W_1 and W_2 represents the oven-dried weight of the soil. The soil particle size distribution was pretreated with H_2O_2 (30%) to remove any organic material and sodium hexametaphosphate to disperse clay. The density of the soil suspension was determined by the hydrometer (Bouyoucos) method to read in grams of solids per liter after the sand settled out and again after the silt settled. A correction will be made for the density and temperature of soil–water suspension and was identified for the percentage of particle size classes according to the USDA textural triangle [53].

(2) Soil Chemical Properties. To estimate the selected chemical properties of soil, soil pH value (soil pH), organic carbon (OC), organic matter (OM), total nitrogen (TN), carbon ratio to nitrogen (C/N), cation exchangeable capacity (CEC), available phosphorous (P), exchangeable acidity (EA), exchangeable aluminum (EAl), ammonium nitrogen (NH_4—N), and nitrate nitrogen (NO_3—N) were analyzed. Accordingly, soil pH (H_2O) was extracted by the soil : water ratio of 1 : 2.5 and determined by the potentiometric method [54]. Soil organic carbon percent was extracted by the wet oxidation method [55] and determined by the titration method [56]. Soil organic matter percent will be calculated by using the Van Bemmelen factor of 1.724. The total nitrogen percent was digested by the Kjeldahl method and analyzed by the titration method [57]. The carbon-to-nitrogen ratio was determined from the carbon and nitrogen obtained. The distillation–titration method was used to extract the cation exchange capacity ($cmol_{(+)}\,kg^{-1}$) from ammonium acetate pH at 7 [58]. Available phosphorous ($mg\,kg^{-1}$) was extracted by Bray's method II and determined using the spectrophotometric method [59]. The exchangeable acidities, Al^+ and H^+, as extracted by the KCl, and determined by the titration method [60]. Exchangeable bases (Ca^{+2}, Mg^{+2}, K^+, and Na^+) were estimated by ammonium acetate at pH of 7, while K^+ and Na^+ were analyzed by flame photometric, while the Ca^{+2} and Mg^{+2} was by AAS technique [61]. Nitrate nitrogen (NO_3—N) was extracted by phenoldisulphonic acid and analyzed by the spectrophotometric method [62], whereas the NH_4—N was extracted by copper sulfate and analyzed by the distillation–titration method [63].

2.5.2. Crop Parameters. Data on yield and yield component characteristics were gathered. Ten garlic plants were randomly chosen from 10 central rows to collect these data from the net plot of each treatment in order to eliminate border effects as described by Yayeh et al. [41].

(1) Garlic Yield and Yield Component. Cloves per bulb (C/B) were counted at physiological maturity [64]. Using a slider caliper, the diameter of the garlic bulb (Bdi) was measured [65]. Using a sensitive balance, the total weight of each measured plant from the above- and below-ground biomass per plant was used to calculate the total fresh biomass yield (TFBY) of garlic. Total dry weight (TDW) was calculated after oven drying of the TFBY. The bulb yield fresh weight per plant (BWp) was calculated by weighing and dividing the total weight of the bulbs by the total number of bulbs. By weighing all of the harvested bulbs and figuring out the yield ha^{-1}, the total bulb yield (TBY) was obtained. The dry weight of the bulb (BDW) was measured after the fresh bulbs (g) were weighed and kept in an oven at 70°C until they reached a constant weight.

$$\text{BDW}(\%) = \left(\frac{\text{BDW}}{\text{BW}_\text{p}}\right) \times 100, \tag{1}$$

where BDW%, BDW, and BWp area represented by bulb dry weight percent, bulb dry weight, and bulb fresh weight per plant, respectively.

By splitting the TBY that translated into yield ha^{-1}, marketable (MBY) and nonmarketable portions (UMBY) of bulb yields were obtained. The dry matter yield weight of the entire bulb divided by the dry matter yield of the total biomass was multiplied by the 100 to determine the harvest index (HI).

$$\text{HI}(\%) = \left(\frac{\text{BDW}}{\text{TDW}}\right) \times 100, \tag{2}$$

where HI (%), BDW, and TDW are harvest index percent, bulb dry weight, and total dry weight, respectively.

2.6. Statistical Analysis. The collected data was subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of the statistical analysis system software version 9.3 [66]. The least significant difference (LSD) test was used to separate significantly different treatment means after the main effect at the 5% probability of significance value.

3. Results and Discussion

3.1. Pre Soil Physicochemical Properties of the Experimental Site. Physically, the soils of Farm-1 had a loam texture, while Farm-2 was sandy loam texture. The soil bulk density of Farm-1 was 1.26 g cm^{-3} and that of Farm-2 was 1.41 g cm^{-3}. Farm-1 soils have surface mineral content and are not compacted well, whereas the soils of Farm-2 are known to restricts root and exhibit extremely variable clay characteristics. This finding is confirmed by many authors [10, 42, 67–70], and they described the properties of mineral soils related to compaction. Farm-1 and Farm-2 had moisture contents of 30.5% and 23.6%, respectively. The low soil organic matter and high bulk density of the soil may be the causes of the low soil moisture content. Soil organic matter and bulk density are the main determinants of soil moisture content [42, 71, 72].

The soil pH-values of Farm-1 and Farm-2 were 5.2 and 4.63, respectively, and are characterized by strongly acid (Farm-1; soil pH value of 5.1–5.5) and very strongly acidic soil (Farm-2; soil pH-value of <5). As shown from the result, in both farms (Farm-1 and Farm-2) soil of the study area has low fertility, as its basic cations are low content in general. Except for potassium (0.7 cmol$_{(+)}$ kg^{-1}), which is high, the soil of Farm-1 calcium (4.1 cmol$_{(+)}$ kg^{-1}), magnesium (0.4 cmol$_{(+)}$ kg^{-1}), and sodium (0.2 cmol$_{(+)}$ kg^{-1}) which ranged in low content. Similarly, in Farm-2, a very low content of calcium (4.1 cmol$_{(+)}$ kg^{-1}) and magnesium (0.4 cmol$_{(+)}$ kg^{-1}) and medium potassium (0.4 cmol$_{(+)}$ kg^{-1}) and sodium (0.3 cmol$_{(+)}$ kg^{-1}) was recorded. According to the range given for cation exchange capacity by Wogi et al. [42], a low content of cation exchange capacity (5–15 cmol$_{(+)}$ kg^{-1}) was recorded in both Farm-1 (10.43 cmol$_{(+)}$ kg^{-1}) and Farm-2 (9.06 cmol$_{(+)}$ kg^{-1}). In both Farm-1 and 2, the medium range of soil organic carbon and total nitrogen was recorded, as carbon to nitrogen was 8.38 and 11.11, value. However, a very low content of total nitrogen was obtained in Farm-1 (1.14 mg$_{(+)}$ kg^{-1}), and Farm-2 (0.91 mg$_{(+)}$ kg^{-1}). The soil exchangeable acid result was 4.46 cmol$_{(+)}$ kg^{-1} for Farm-1 and 5.13 cmol$_{(+)}$ kg^{-1} for Farm-2; and this extremeness of soil acidity may perish the basic cations and exacerbate the potentials of aluminum toxicity. In such soils, the exchangeable acidity and hydrogen were not quite limited [38, 71]. Therefore, such soils need alternative options for reclamation [69–72], and forwarding integrated soil fertility management may be a solution [4, 10].

3.2. Effect of Combined Biochar, Lime, and Inorganic-Fertilizer Rates on Garlic Yield and Yield Components. The investigation revealed a significant ($p<0.01$) difference in the yield of garlic after using biochar, lime, and inorganic-fertilizer rates. Garlic yields and its constituent yield components were considerably impacted by the ameliorating acidic soil by a mixed biochar, lime, and inorganic-fertilizer rate. As shown in Tables 2–4, the statistical analysis showed the effect of combined CHB, STV, and NPSB rates. The garlic yield and yield component parameters; TFBY, BWp, Bdi, C/B, TBY, MBY, and HI%, had a significant difference ($p<0.05$). In a study by Ma et al. [73], a similar yield gain with organic amendment on acid soil was noted.

Table 2: Effect of combined biochar (CHB), lime (STV), and inorganic-fertilizer (NPSB) rates on garlic yield components: total fresh biomass yield (TFBY), bulb yield fresh weight per plant (BWp), bulb diameter (Bdi), and clove per bulb (C/B).

Treatments	TFBY (g)	BWp (g)	Bdi (cm)	C/B (Nu)
		Farm-1		
T0	48.7^{g}	12.7^{h}	2.9^{i}	7.17^{e}
T1	50.5^{fg}	21.6^{efg}	3.6^{efg}	10.9^{bcd}
T2	57.5^{c}	27.2^{ab}	4.0^{cd}	11.4^{abcd}
T3	54.5^{d}	22.1^{ef}	3.1^{hi}	11.6^{abc}
T4	64.2^{ab}	28.1^{a}	4.7^{a}	11.9^{ab}
T5	53.8^{de}	23.0^{def}	3.5^{fg}	11.4^{abcd}
T6	57.1^{c}	20.2^{fg}	3.7^{defg}	11.4^{abcd}
T7	62.7^{b}	26.3^{abc}	4.3^{bc}	11.5^{abcd}
T8	64.2^{ab}	27.7^{a}	4.4^{b}	11.4^{abcd}
T9	57.4^{c}	23.9^{cde}	3.9^{de}	12.2^{a}
T10	54.5^{d}	24.1^{bcde}	3.8^{def}	10.3^{d}
T11	65.6^{a}	25.4^{abcd}	4.0^{cd}	10.7^{bcd}
T12	59.6^{c}	21.5^{efg}	3.4^{gh}	10.6^{cd}
T13	51.7^{ef}	18.7^{g}	3.0^{i}	11.0^{abcd}
LSD (0.05)	2.55**	3.28**	0.32**	1.24**
CV (%)	2.65	8.47	5.15	6.76
		Farm-2		
T0	54.3^{h}	17.0^{f}	3.7^{hi}	8.2^{f}
T1	59.5^{g}	24.9^{cde}	3.6^{i}	11.1^{cde}
T2	64.1^{ef}	26.1^{cd}	4.1^{cdefgh}	11.8^{bcd}
T3	66.2^{de}	23.9^{de}	3.9^{fghi}	11.7^{bcde}
T4	69.2^{cd}	31.6^{a}	4.7^{a}	12.8^{ab}
T5	62.2^{fg}	24.9^{cde}	3.9^{efghi}	12.8^{ab}
T6	61.3^{fg}	25.3^{cde}	3.8^{ghi}	10.6^{de}
T7	71.6^{bc}	30.4^{ab}	4.6^{ab}	11.7^{bcde}
T8	73.3^{ab}	30.9^{ab}	4.5^{abc}	12.8^{ab}
T9	70.0^{bc}	27.8^{bc}	4.4^{abcd}	12.6^{abc}
T10	64.1^{ef}	24.3^{de}	4.3^{bcde}	11.2^{bcde}
T11	75.3^{a}	31.4^{a}	4.6^{ab}	13.6^{a}
T12	63.9^{ef}	24.3^{de}	4.3^{bcdef}	10.7^{de}
T13	59.9^{g}	22.4^{e}	4.0^{defgh}	10.5^{de}
LSD (0.05)	3.34**	3.35**	0.38**	1.66**
CV (%)	3.04	7.63	5.40	8.71

ns: nonsignificant, *: significant ($p<0.05$), **: highly significant ($p<0.01$), 100% recommended inorganic-fertilizer = 242 kg ha^{-1}, 100% recommended STV for Farm-1 = 4.22 tons ha^{-1}, and 100% recommended STV for Farm−2 = 5.43 tons ha^{-1}.

Regarding Farm-1, the lowest total fresh biomass per plant (48.7 g) and greatest total fresh biomass per plant (65.6 g) were found in T11, respectively. In contrast to T0 (the control

Table 3: Effect of combined biochar (CHB), lime (STV), and inorganic-fertilizer (NPSB) rates on garlic yield: total bulb yield (TBY), marketable yield (MBY), and harvesting index (HI).

Treatments	TBY (ton ha^{-1})	MBY (ton ha^{-1})	HI (%)
	Farm-1		
T0	4.5^{h}	2.7^{f}	0.57^{ef}
T1	7.6^{efg}	5.8^{d}	0.83^{a}
T2	9.6^{ab}	6.2^{bc}	0.60^{de}
T3	7.8^{ef}	6.3^{bc}	0.73^{bc}
T4	9.9^{a}	9.3^{a}	0.80^{ab}
T5	8.1^{def}	6.1^{bcd}	0.70^{c}
T6	7.1^{fg}	5.1^{de}	0.50^{f}
T7	9.3^{abc}	8.7^{a}	0.83^{a}
T8	9.7^{a}	9.2^{a}	0.83^{a}
T9	8.4^{cde}	7.1^{b}	0.70^{c}
T10	8.5^{bcde}	6.0^{cd}	0.60^{de}
T11	9.0^{abcd}	8.5^{a}	0.80^{ab}
T12	7.6^{efg}	6.2^{bcd}	0.67^{cd}
T13	6.6^{g}	4.6^{e}	0.53^{ef}
LSD (0.05)	1.16^{**}	1.04^{**}	0.08^{**}
CV (%)	8.52	9.50	0.26
	Farm-2		
T0	6.1^{f}	3.6^{g}	0.70^{bc}
T1	8.8^{cde}	7.5^{bc}	0.80^{ab}
T2	9.2^{cd}	9.9^{ef}	0.48^{e}
T3	8.5^{de}	6.8^{cde}	0.67^{c}
T4	11.1^{a}	10.4^{a}	0.85^{a}
T5	8.8^{cde}	6.6^{cd}	0.66^{cd}
T6	8.9^{cde}	6.4^{def}	0.61^{cd}
T7	10.7^{ab}	10.1^{a}	0.86^{a}
T8	10.9^{ab}	10.2^{a}	0.80^{ab}
T9	9.8^{bc}	8.2^{b}	0.69^{c}
T10	8.6^{de}	6.1^{def}	0.51^{e}
T11	11.1^{a}	10.5^{a}	0.85^{a}
T12	8.5^{de}	7.0^{cd}	0.69^{c}
T13	7.9^{e}	5.5^{f}	0.57^{de}
LSD (0.05)	1.18^{**}	1.06^{**}	0.09^{**}
CV (%)	7.62	7.47	8.39

ns: nonsignificant, *: significant ($p < 0.05$), **: highly significant ($p < 0.01$), 100% recommended inorganic-fertilizer = 242 kg ha^{-1}, 100% recommended STV for Farm-1 = 4.22 tons ha^{-1}, and 100% recommended STV for Farm-2 = 5.43 tons ha^{-1}.

treatment), which had the lowest bulb yield weight (12.7 g) and TBY (4.5–tons–ha^{-1}) values, T4 and T8 both had the highest values of bulb yield weight (27.7–28.1 g) and the highest value of TBY (9.7–9.9 tons ha^{-1}). Bdi was highest in T4 (4.47 cm) and lowest in T0 and T13 (2.9–3.0 cm). The amount of clove produced per bulb was highest in T9 (12.2) and lowest in T0 (7.17). The T0 (2.7 tons ha^{-1}) recorded the lowest MBY (8.5–9.3 tons ha^{-1}), followed by the T4, T7, T8, and T11 treatments. In an area (site) with strongly acidic soil, the application of treatments from T4 to T9 significantly ($p < 0.05$) increased the yield of marketable bulbs by 46.55%–60.34% as compared to NPSB alone. The T6 ha^{-1} recorded the lowest HI% (0.50%), while T1, T7, and T8 all achieved the highest HI% (0.83%). The benefits of integrated fertilizers, particularly by the organic input and lime combined with mineral fertilizers were identified by many scholars [74–76].

Similar to Farm-1, in terms of Farm-2, the T0 had the lowest total fresh biomass per plant (54.3 g), while the T11 had the greatest (75.3 g). The MBY weight per plant (31.6–31.4 g) was found in the T4 and the T11, while the lowest bulb yield weight per plant (17.0 g) was found in the T0 treatment. The results showed that the T0 (8.2) had the fewest cloves per bulb, whereas the T11 had the most cloves per bulb (13.6). The maximum TBY was measured in T4 and T11, while the lowest was recorded in T0 (6.1 tons ha^{-1}) with a value of 11.1 tons ha^{-1}. The highest MBY (10.1–10.5 tons ha^{-1}) was found in T4, T7, T8, and T11, while the lowest MBY (3.6) was found in the T0 treatment. The MBY analysis suggests that the application of combined T4–T9 could have improved the MBY up to 34.67%–40.00% as compared with T1 in areas with very strongly acidic soil. The treatments at T2 and T10 had the lowest HI% (0.48%–0.51%), while T7 and T11 had the highest HI% (0.85%–0.86%). Challenging soil acidity in Ethiopia incorporates alternative and optimum organic fertilizers, and this finding is confirmed by several authors [77–80].

In Farms-1 and 2, respectively, T4 and T11 yielded the highest marketable bulb output (9.3 tons ha^{-1}). Comparing farm fields revealed that Farm-2 produced more garlic yield than Farm-1 on average, but Farm-2 similarly contained more sand and was more acidic. Due to the ease with which the soil can be expanded, sand soils could important for bulb growth. However, in these instances, the nutrient may be greatly helped by the native phosphorus. Similar to the current finding, other researchers have noted that soils with higher sand contents provide better yields of garlic [3, 71, 81].

Garlic productivity is low both nationally and regionally, primarily as a result of poor soil fertility. The differences in growth and yield of crops that occur due to nutrient shortages were reported by many authors [82–85]. It is common knowledge that a crop's ability to absorb nutrients depends on both the expected yield and the nutrients present in it. Furthermore, it has been claimed that higher plants often collect nutrients in quantities proportional to those integrated into protein [86–88].

Garlic's yield and yield-related characteristics rose when biochar, lime, and fertilizer were applied together. The T4, T7, T8, and T11 treatments considerably boosted marketable bulb production in both Farm-1 and 2. Total fresh biomass per plant, bulb yield weight, bulb diameter, cloves per bulb, and total bulb yield are the most important yield components that emerged. These may be the result of excessive nutrient intake. It is true that minerals like phosphorus, sulfur, and nitrogen found in fertilizers are crucial for crop productivity, particularly garlic cultivars [41]. Therefore, the presence of nutrients from fertilizer, biochar, and lime for soil amending could be the cause of the increase in yield of garlic.

Table 4: Mean squares of analysis of variance for total fresh biomass weight per plant (TFBY), bulb neck diameter (BND), bulb diameter (Bdi), bulb yield fresh weight per plant (BWp), number of clove per bulb (C/B), clove weight (CW), total dry biomass weight per ha^{-1} (TDW), bulb dry weight per ha^{-1} (BDW), marketable bulb yield per ha^{-1} (MBY), total bulb yield per ha^{-1} (TBY), adjusted yield per ha^{-1} (AY), and harvest index % (HI) as affected by rates of combined biochar (CHB), lime (STV), and inorganic-fertilizer (NPSB) rates application.

Source of variance	Df	Farm-1											
		TFBY	BND	Bdi	BWp	C/B	CW	TDW	BDW	MBY	TBY	AY	HI
Replication	2	6.89	0.61	0.04	8.89	1.85	0.17	1.26	0.63	0.51	1.10	0.90	0.00
Treatment	13	87.42	1.70	0.82	51.07	4.39	0.22	12.90	183.08	10.18	6.36	5.14	0.04
MSE	26	2.50	0.16	0.03	3.82	0.55	0.02	1.45	0.41	0.40	0.47	0.38	0.00
LSD (0.05)	—	2.55	0.68	0.32	0.28	1.24	0.26	2.02	1.08	1.06	1.15	1.04	0.08
CV	—	2.65	3.49	5.14	8.47	6.75	7.43	12.07	9.20	9.54	8.47	8.47	7.07
p-Value	—	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Fcal	—	37.86	10.18	21.94	13.35	7.99	8.77	8.86	33.95	25.42	13.36	13.35	17.18
		Farm-2											
Replication	2	4.85	0.34	0.00	1.12	0.45	0.00	2.66	0.00	1.36	0.13	0.11	0.00
Treatment	13	104.84	2.64	0.39	49.45	5.67	0.09	16.51	18.52	13.37	6.16	4.98	0.04
MSE	26	3.96	0.26	0.05	3.98	0.98	0.04	2.01	0.41	0.31	0.49	0.40	0.00
LSD (0.05)	—	3.34	0.86	0.38	3.35	1.66	0.35	2.38	1.07	0.94	1.18	1.06	0.09
CV	—	3.04	4.00	5.40	7.63	8.71	8.97	12.46	8.07	7.47	7.62	7.61	8.39
p-Value	—	0.0001	0.0001	0.0001	0.0001	0.0001	0.0459	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Fcal	—	26.46	10.06	7.58	12.41	5.74	2.16	8.18	45.10	42.26	12.45	12.46	13.57

4. Conclusion

This finding investigated the improvements in garlic yield and its component under the condition of adding the rate of combined biochar and lime, or the sole with the mineral fertilizer, in regions where soil acidity is a problem in Gimbi district, western Ethiopia. Comparative to others treatments analyzed in this study, the total fresh biomass, bulb yield weight, bulb diameter, clove per bulb, and total bulb yield of garlic were improved in treatments receiving the combined CHB of 7.5–10 tons, STV of 50% to 75%, and NPSB fertilizer of 50% to 75% rates per hectare in both farm fields, similarly and statistically at $p < 0.05$. Following these parameters, total bulb yield, marketable yield, and harvest index were significantly $p < 0.05$ increased in both Farm-1 and 2. Statistically $p < 0.05$, the similar total bulb yield of 9–9.9 tons ha^{-1} in Farm-1 and 10.7–11.1 tons ha^{-1} in Farm-2, marketable bulb yield of 8.5–9.3 tons ha^{-1} in Farm-1 and 10–10.5 tons ha^{-1} in Farm-2, and harvest index of 80%–83% in Farm-1 and 80%–86% in Farm-2 were recorded in treatments of T4, T7, T8, and T11 in Farm-1 and 2. This could be the result of improved soil properties from integrated inputs, as nutrient accessibility in mineral fertilizer, and the facilitation of soil characteristics in biochar and lime's application on soils.

For the achievement of optimum garlic yields, based on the present study result, it is advised to apply the combined CHB, STV, and NPSB rate of 10 tons + 75% + 75% per ha^{-1} in strongly acid soil, and 7.5 tons + 50% + 50% ha^{-1}, in very strongly acid soils in Gimbi district, western Ethiopia and similar areas. In order to draw firm conclusions, future research on more sites is necessary because this study was logically limited to two sites.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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