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Original Research

Application of Moringa (*Moringa stenopetala* Bak. Cuf.) Leaf Powder Enhanced Maize (*Zea mays* L.) Growth, Yield Components, and Soil Chemical Properties

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Abstract

This study was aimed to determine the effects of different rates of MLP application on maize growth, yield components, and soil chemical properties under greenhouse conditions. The experiment consisted of four treatments having 0 (control), 25g, 50g, and 75g of MLP, along with 2.1 g of Di-ammonium phosphate and 2.1g of UREA. The treatments were assigned in a randomized complete block design and replicated three times. The analysis of variance indicated that most maize growth parameters at 40, 70, and 100 days after planting (DAP) were significantly (P<0.05) influenced by MLP application rates. The highest maize growth parameters at all growth stages were recorded in pots treated with 75g of MLP. However, most of the maize yield components were higher under CF. Results also revealed that almost all tested soil chemical parameters at six weeks of incubation and 100 DAP were significantly (P<0.05) influenced by MLP application rates, with the highest values recorded in pots treated with 75g of MLP. In conclusion, the highest maize growth, yield components, and soil chemical properties were obtained from the pots treated with 75g of MLP. The results of this study suggest that the application of MLP at a rate of 75g can enhance maize growth and improve soil chemical properties under greenhouse conditions. However, further studies should be conducted on economic feasibility under field conditions to provide conclusive recommendations.

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INTRODUCTION

Maize (*Zea mays* L.) is an important food crop that provides essential sources of nourishment in several developing countries including Ethiopia. It is crucial for food security, particularly in sub-Saharan African countries where it is a staple diet (Santpoort, 2020), used for animal feed and industrial applications (Abate *et al*., 2015). Maize is the second major cereal crop in terms of production area coverage and yield, following wheat in the world (Santpoort, 2020). However, in Ethiopia, maize ranks first in terms of its production and productivity with about 2.55 million hectares and 10.2 million tons produced in 2022, respectively. The national average yield of about 4.0 t ha^{-1} (FAOSTAT, 2022), is by far lower than the world average yield of 5.8 t ha^{-1} (Erenstein *et al*., 2022). This disparity in maize yield is often attributed to poor agronomic practices among resource-poor farmers who rely on maize for subsistence. Moreover, Santpoort (2020) and Abate *et al.* (2015) have noticed that maize production and productivity are largely constrained by inadequate inputs such as fertilizers, improved varieties, and other agrochemicals in the country.

According to ATA (2014) report, most of the agricultural land in Ethiopia is deficient in several essential plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), copper (Cu), zinc (Zn) and boron (B). The depletion of soil fertility in smallholder farms is a result of improper agricultural practices such as inadequate fertilizer use, complete removal of crop residues, and continuous cropping systems. These practices contribute to the decline in per capita food production in the country (Aleminew & Alemayehu, 2020). Among several soil fertility management practices, the application of commercial fertilizers is commonly used for cereal crop production, including maize, in the country. However, this practice demands a high cost that resource-poor farmers cannot afford. A report from, Spielman *et al*. (2013) shows that only 30-40% of smallholder farmers apply on average 40 kg of UREA and Di-ammonium phosphate (DAP) per hectare of land, which is significantly below the recommended rate of 100 kg of DAP and 100 kg of UREA ha^{-1} for cereal crop production in the country. This could have a negative effect on maize production and productivity. The availability of these inputs also poses a major challenge for smallholder farmers in remote areas (Zerssa *et al*., 2021) due to limited transportation. Abate *et al*. (2015) reported that approximately 23% of imported commercial fertilizers such as DAP and UREA were specifically used for maize production during the years 2004-2013. Although its supply of cereal crops is inadequate, there is a growing demand for commercial fertilizers to meet the increasing food demand driven by population growth (Erenstein *et al*., 2022).

On the other hand, organic fertilizers such as compost, green manure, and farmyard manure have been reported to have a substantial effect on soil fertility, crop growth, and yield improvements (Abate *et al*., 2015). Despite this, locally available organic materials are often wasted without proper utilization, particularly in the humid and sub-humid agro-ecologies of Ethiopia where it is available in sufficient amounts. Moreover, a report from Zerssa *et al*. (2021) also indicated that the application of organic fertilizers, particularly to cereal crops is decreasing over time in the country. This reduction may be attributed to the need for larger quantities of organic fertilizers on small plots, as well as the laborious and time-consuming preparation activities required for organic fertilizers such as compost (Muluneh *et al*., 2022). On the other hand, improper use of chemical fertilizers can also have negative environmental consequences. Moreover, chemical fertilizers have short-term effects on soil fertility, crop growth and yield compared to organic fertilizer sources. This is because the nutrients are released into the soil environment immediately after being supplied to the soil. Nevertheless, there is a need for reducing smallholder farmers' dependence on commercial fertilizers, and supplement crop and soil nutrient requirements with nutrient-rich organic fertilizers that are economically viable and environmentally safe. Therefore, the application of moringa tree leaves to agricultural land could serve as an important alternative source of plant nutrients that enhance plant growth, yield and soil properties.

Moringa is a plant that belongs to the family *Moringaceae.* It is the most widely cultivated tree for its young seed pods and leaves (Foidl *et al*., 2001). The leaves are the most nutritious and commonly used as vegetables (Abay *et al*., 2015; Kumssa *et al*., 2017), used in traditional herbal medicine or pharmaceutical processes (Seid, 2013; Seifu, 2015), for income generation (Kumssa *et al*., 2017), and as animal feed (Jiru *et al*., 2006). The seeds are also used for water purification (Kumssa *et al*., 2017) and oil extraction (Haile *et al*., 2019). Several authors have stated that *Moringa stenopetala* (*M. stenopetala*) is a native tree to Ethiopia, Kenya and Somalia among the thirteen species (Abuye *et al*., 2003; Jiru *et al*., 2006). Whereas *Moringa oleifera (M. oleifera)* is native to the sub-Himalayan regions of northern India was introduced into Eastern African countries at the beginning of the 20th century (Foidl *et al*., 2001). A report from Jiru *et al*. (2006) shows that *M. stenopetala* exhibits broad adaptability to both arid and humid climates, with varied potential for cultivation across various land use classes, such as marginal and poor soil. Moreover, the tree is widely cultivated in the Gedeo, Sidama, Wolaita, Konso, and Gamu-Gofa of the southern region (Abuye *et al*., 2003), in Guji, Hararghe, Bale, Borana, and Jimma of Oromia as well as in Tigray regions (Yisehak *et al*., 2011; Abay *et al*., 2015). The *M. stenopetala* tree is more vigorous and produces large seeds and leaf biomass compared to *M. oleifera* (Abay et al., 2015). Thus, a single *M. stenopetala* tree is able to support large family as a food product for several years (Abuye *et al*., 2003; Yisehak *et al.,* 2011).

Among the multitudinous uses of moringa that make it of great scientific interest is that the leaves are good sources of essential nutrients such as potassium, phosphorus, calcium, magnesium, iron, Zinc and manganese (Abuye *et al*., 2003; Kumssa *et al*., 2017). Additionally, the leaves contain amino acids, vitamins, and plant growth-promoting hormones such as zeatin (which governs the top differentiation and growth of plants), gibberellic acid (which promotes cell elongation and flowering) and also proteins (Alkuwayti *et al*., 2020). Foidl *et al*. (2001) and Abd El-Hack *et al.* (2018) reported that both *M. stenopetala and M. oleifera* species share common characteristics such as compositions of essential mineral elements, plant growth stimulants and proteins. However, *M. oleifera* is most widely studied for its use as organic fertilizer (Undie *et al*., 2013; Ekene & Uchenna, 2023) and as bio-stimulants (Elzaawely *et al*., 2017; Alkuwayti *et al*., 2020). A report from Aluko *et al*. (2017) depicted that dried moringa leaf constitutes higher mineral elements such as N, available P, exchangeable K, Ca and Mg than that of poultry manure. According to Undie *et al*. (2013) report, the incorporation of dried moringa leaf into agricultural land at a rate of 5-15 t ha^{-1} improved soil nutrients and the growth and yields of several crops such as maize (Ekene *et al.,* 2014), garden egg (Undie *et al*., 2013) and okra (Aluko *et al*., 2017).

In Ethiopia, cultivation of *M. stenopetala* is increasing and the tree is gaining more research attentions, particularly in the fields of human nutrition and health (Abuye *et al*., 2003; Kumssa *et al*., 2017). Moreover, the moringa tree is mostly grown in agroforests, particularly in the southern part of Ethiopia where it is use as food diversification, and its socio-economic and environmental benefit is well understood (Jiru *et al.,* 2006). On the other hand, it's potential use as green manure has not yet been explored, and smallholder farmers including moringa growers in the country and in the Jimma zone lack awareness of the benefits of moringa tree leaves for improving soil fertility, crop growth, and yield, and heavily rely on commercial fertilizers. It is, therefore, imperative to conduct a preliminary experiment to gather evidence and bridge the research gap. According to Abay *et al*. (2015), it is also not only the green leaves that can be used for other purposes; the incorporation of fallen moringa leaves has shown improvements in soil fertility. This suggests that using moringa leaves as green manure is not only economically affordable and environmentally sound, but also provides valuable information that can help the farmers understand its benefits. This knowledge may even motivate smallholder farmers to expand moringa tree cultivation and improve their overall benefits. Therefore, the current study was carried out to (1) determine the influence of different rates of moringa leaf powder application on maize growth performance and soil chemical properties, and (2) identify the optimal rate of moringa leaf powder for enhancing maize yield and soil fertility.

MATERIALS AND METHODS

Descriptions of the Experimental Site

The study was conducted in 2019 at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) under greenhouse conditions. The experimental area is geographically situated at 7^0 33' North latitude, 36^0 57' East longitude, and an altitude of 1710 meters above sea level. The mean annual maximum and minimum temperatures of the study area are 26.8°C and 11.4 °C, respectively, and the mean annual rainfall is about 1500 mm. The soil type and textural class of the experimental area are characteristically reddish-brown and clay, respectively, with a pH range of 5.07 to 6.

Experimental Materials

The maize variety BH660, adapted to the mid-altitude moist and transitional highland maize agro-ecologies was used in this study. This variety is widely cultivated and accounts for over 50% of hybrid seed sales in the country (Worku *et al*., 2012). *Moringa stenopetala* leaves collected from Jimma Agriculture Research Centre (JARC) were used as the experimental material for this study.

Experimental design and treatments

The pot experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. Four rates of moringa leaf powder (MLP): 0 (control), 25g, 50g and 75g were used as experimental treatments. In addition to MLP application rates, the recommended rate of commercial fertilizer (CF) was used as a local practice. The chemical fertilizer sources, such as Di-ammonium phosphate (contains 18 % N and 46 % P_2O_5) and UREA (contains 46 %N), commonly used for maize production in the study area applied were used at a rate of 2.1 g of Di-ammonium phosphate and 2.1 g of UREA per pot. This rate is equivalent to 100 kg of each fertilizer source supplied to maize per hectare of land. They were used separately to compare their effects with those of MLP application rates on maize growth, yield components and soil chemical properties. Each experimental unit (pot) consisted of three plants arranged in a 5*3*3, with a total of 45 plants. The spacing between the plants (pots) and the blocks was about 30 cm and 100 cm, respectively.

Preparation of Moringa Leaf Powder

Fresh moringa leaves were collected from a fully mature moringa tree available at Jimma Agricultural Research Center (JARC) and transported to the soil laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM). The green leaves were immediately separated from the petioles, and old or damaged leaves were removed. The leaves were air-dried in a shade house for about 6 days. Once uniformly dried, the leaves were then ground using a mortar and pestle and then sieved with 1 mm mesh. Prepared moringa leaf powder was carefully packed into a plastic container and stored in a dry and cool place until it was used as an experimental treatment.

Experimental procedure

Potting medium top soil was collected from a depth of 0-20 cm, from JUCAVM Horticulture Garden following a zigzag pattern. The soil was thoroughly mixed to form a composite soil, air-dried, cleaned, grounded and sieved with a 2mm sieve. Plastic buckets (pots) with a capacity of 5 liters were perforated at the bottom, labeled and filled with 4 kg of soil on March 22, 2019. The pots were arranged in a Randomized Complete Block Design (RCBD) and replicated three times. Each pot received different amounts of MLP: 0, 25, 50 and 75g, in addition to pots labeled as the control and CF were incubated for six weeks. The basis for using different rates of MLP was the research conducted by Ekene *et al. (*2014). Apart from varying MLP application rates, all agronomic practices were consistently applied to each pot as needed throughout the incubation period. After six weeks of incubation (on the 7th of May, 2019), soil samples were collected from each pot to determine soil chemical properties. Afterward, three maize seeds of the BH660 variety were sown at a depth of 5 cm in each pot. Commercial fertilizers at a rate of 2.1 g DAP and half the dose of UREA were only supplied to the pots labeled as CF at sowing time. The remaining half dose of UREA was supplied at the knee height of maize. Seedlings were thinned out two weeks after emergence, leaving a single vigorous plant in each pot. Plants were uniformly managed until the final data collection time.

Data collection

Soil sample collection, preparation and analysis

The soil media used for growing maize under greenhouse conditions was collected from the JUCAVM Horticulture Garden and prepared for pot filling following the standard procedure mentioned under section 2.5 above. Parts of the composite soil sample (top-soil collected from different points and prepared for pot filling) were analyzed for their chemical properties. Accordingly, organic carbon (%OC) was determined following the Walkley Black method (Walkley & Black, 1934), and organic matter (% OM) was obtained by multiplying % OC with 1.724 (Pribyl, 2010). Soil pH was measured using a digital pH meter in 1:2.5 soils to water suspension. Total nitrogen (N) was analyzed following Kjeldahl procedure, and Cation exchange capacity (CEC) was determined following Ammonium Acetate method. All laboratory activities including soil analysis before MLP application (Table 1), at six weeks of incubation (Table 6) and at harvesting (Table 7) were done in JUCAVM soil laboratory.

Table 1. Chemical characteristics of potting media before the experiment execution

Some soil chemical parameters	Values obtained from top soil (0-20 cm depth)	Optimum value	Classification	References
pH (H_2O)	6.52	6.6-7.3 (neutral)	Moderately acidic	Tadesse *et al*. (1991)
Organic Carbon (%)	2.34	2-10 (medium)	Medium	Landon (1991)
Total Nitrogen (%)	0.31	0.3-0.55	High	Tadesse *et al*. (1991)
Organic Matter (%)	4.03	3-7	High	Tadesse *et al*. (1991)
Cation Exchange Capacity (meq/100g)	20.59	15-25	High	Landon (1991)

Maize growth and yield data collection

Maize growth parameters were collected from three plants in each replication at 40, 70 and 100 days after planting (DAP). The **height** of the three plants was measured from ground level to the top-most growth point using a tape meter, and the average data were recorded. The **number of leaves per plant** was counted and recorded. **Average leaf length** data were recorded by measuring the length of three leaves per plant from the lower, middle and upper parts of the plant. The **length of leaves** of each of the three was measured using a tape meter from the end of each leaf sheath to the leaf tip, and average data were used. Similarly, the **maximum leaf width** of each of the three leaves used for leaf length data recording was measured using a tape meter, and average values of leaf width per plant were recorded. The **number of nodes per plant** was recorded through counting. **Leaf area (LA)** was calculated from the leaf length (LL), leaf width (LW) and the maize plant coefficient factor (which is about 0.75 and specific to cultivars and canopy classes). Thus, LA was calculated following the formula (LA=LL*LW*0.75) (Jordan-Meille & Pellerin, 2004). Moreover, the average **stem diameter** (stem thickness) data was measured using a digital caliper. In addition to plant growth parameters, yield related data were collected at 100 DAP from three plants of each replication. Immediately after harvesting, the above-ground (shoot parts) of each of the three plants were weighed on a balance, and the average shoot fresh weight data were recorded. After collecting the shoot parts, the roots from each of the three pots were collected, washed with tap water, immediately weighed on a balance and the **average fresh root weight** data was recorded. After recording the **shoot and root fresh weight**, the root and shoot parts were placed in a paper bag, labeled according to their treatments, oven dried at 70 ºC for 24 hours, weighed, and the average dry weight of the shoot and root were recorded. The total biomass data was calculated from the shoot and root dry weight. The root-to-shoot ratio was calculated by dividing the root dry weight by the shoot dry weight.

Data Analysis

Data were subjected to analysis of variance (ANOVA) (Gomez & Gomez, 1984) using SAS version 9.3. Differences between treatment means were separated using the least significant difference (LSD) at a probability level of P <0.05.

RESULTS

The analysis of variance (ANOVA) showed that most of the maize growth parameters were significantly (*P*<0.05) influenced by MLP-application rates at 40, 70, and 100 days after planting (DAP) (Tables 2, 3, and 4). Similarly, almost all maize yield components were significantly (*P*<0.05) influenced by MLP-application rates (Table 5). Moreover, MLP application rates significantly (*P*<0.05) influenced all tested soil chemical parameters except the carbon-to-nitrogen ratio (C: N) both at six weeks after incubation and after maize harvesting, and also the total nitrogen (%TN) at harvesting time (Tables 6 and 7).

Moringa leaf powder application rates effects on maize growth at 40 DAP

Maize growth parameters such as stem diameter (SD), plant height (PH), leaf length (LL), leaf width (LW), leaf number per plant (LN) and leaf area (LA) were used to evaluate the effects of different rates of MLP application. The highest SD (16.70 mm), PH (76.99 cm), LL (90.77 cm), LN (8.00) and LA (120.19 cm^2) were obtained from the plants treated with 75 g of MLP (M3) when compared with the control (M0) and plants treated with commercial fertilizer (CF). Results also revealed that the values of SD and LA were comparable, with no statistically significant differences observed among M2, M3, and CF at 40 DAP (Table 2).

Table 2. Maize growth as influenced by moringa leaf powder application rates at 40 days after planting

Treatments	Maize growth parameters at 40 DAP						
	SD(mm)	PH(cm)	LN(count)	NN(count)	LL(cm)	LW(cm)	LA(cm^2)
M0	14.53 ^{b}	68.10^c	6.66 ^{b}	3.33	78.39^c	1.51^d	89.20 ^{c}
M1	14.62^b	69.77^{bc}	7.00^b	4.00	81.22^{bc}	1.65^c	100.98 ^{b}
M2	16.44^a	73.10^b	8.00^a	4.00	86.00^{ab}	1.84^a	119.12^a
M3	16.70^a	76.99 ^{a}	8.00^a	3.33	90.77^a	1.76^b	120.19 ^{a}
CF	16.36^a	68.88^c	7.00^b	3.33	85.88^{ab}	1.77 ^{ab}	114.05^a
LSD $_{(5\ \%)}$	1.46	3.47	0.87	NS	5.08	0.08	8.62
CV (%)	4.93	2.59	6.35	15.21	3.20	2.39	4.21

CV= Coefficient of variance, CF=commercial fertilizer, DAP= days after planting, LN= leaf number, LSD= Least significant difference, PH=plant height, LL=leaf length, LW=leaf width, LA=leaf area, M0, M1, M2, M3 indicates 0, 25, 50 and 75 g of moringa leaf powder, NN= node number, SD=stem diameter. Means in the column with same letter(s) superscript are not significantly (NS) different at *P*<0.05.

Moringa leaf powder application rates effects on maize growth at 70 DAP

At 70 days after planting, maize exhibit the highest value of SD (18.40 mm) under the plants treated with commercial fertilizer (CF) compared to the control. The value is comparable to the plants treated with 50 g and 75 g of MLP, however, no significant differences were observed among M2, M3, and CF treatments compared to the control (M0) and 25 g of MLP supplied plant (M1). Similarly, the maximum value of LN (10.10) was obtained from CF treated plants, and this is also comparable to the result observes under M3 treated plant with no statistically significant differences. The maximum values of NN (7.10) and LL (97.49 cm) were, however obtained from 50 g and 75 g of MLP treated plants, respectively compared to the control and CF treated plant at the age of 70 DAP. Similarly, the highest values for PH (151.22 cm), and LA (459.83 cm^2) were observed under 75 g of MLP treated plants compared to the control and CF treated plant at the age of 70 DAP; however no statistical differences were observed (Table 3).

Table 3. Maize growth parameters as influenced by MLP application rates at 70 DAP

Treatments	Maize growth parameters at 70 DAP						
	SD(mm)	PH(cm)	LN(count)	NN(count)	LL(cm)	LW(cm)	LA(cm^2)
M0	13.89^c	134.78	8.33^b	6.00^c	85.25^{cd}	5.03	321.89
M1	15.96^b	135.66	8.33 ^{b}	6.00^c	84.61^d	5.35	339.88
M2	18.01^a	145.22	8.21^b	7.10^a	89.88^{bc}	6.22	420.00
M3	18.12^a	151.22	9.55^a	6.77^{ab}	97.49^a	6.30	459.83
CF	18.40^a	131.77	10.10^a	6.55^{bc}	90.94^b	6.36	433.45
LSD$_{(5\ \%)}$	1.34	NS	1.08	0.55	4.87	NS	NS
CV (%)	4.23	5.91	6.48	4.54	2.89	12.21	13.88

Means in the column with same letter(s) superscript are not significantly (NS) different at P<0.05.

Moringa leaf powder application effect on maize growth at 100 DAP

Result revealed that maize growth parameters such as plant height (PH), leaf number (LN), and node number (NN) were significantly (P<0.05) influenced by different rates of MLP application at 100 days after planting (DAP) (Table 4). The highest PH (272.56 cm), LN and NN (16.00 for each) were obtained from plants treated with 75g of MLP compared to those treated with the commercial fertilizer (CF) and the control plants. In addition to this, at 70 and 100 DAP (Tables 3 and 4), the highest and most similar values for all maize growth parameters were observed in plants treated with 75g of MLP, followed by 50g of MLP and the CF applications. The highest values of stem diameter (SD) at 18.54 mm and leaf width (LW) at 6.80 cm, were observed in plants treated with CF. On the other hand, plants treated with 75 g MLP had the highest values of leaf length (LL) and leaf area (LA) at 98.03 cm and 481.85 cm^2, respectively. However, these growth parameters (SD, LL, LW, and LA) were not statistically influenced by any of the treatments applied at 100 DAP (Table 4).

Table 4. Maize growth parameters as influenced by MLP application rates at 100 DAP

Treatment	Maize growth parameters at 100 DAP						
	SD(mm)	PH(cm)	LN(count)	NN(count)	LL(cm)	LW(cm)	LA(cm^2)
M0	14.02	229.00^b	14.66^{bc}	14.66^{bc}	92.47	5.25	365.17
M1	16.29	261.28^a	14.33^c	14.33^c	91.55	5.89	404.98
M2	18.28	255.11^a	14.66^{bc}	14.66^{bc}	90.15	6.10	413.19
M3	18.18	272.56^a	16.00^a	16.00^a	98.03	6.54	481.85
CF	18.54	269.78^a	15.66^{ab}	15.66^{ab}	88.44	6.80	451.07
LSD$_{(5\ \%)}$	NS	22.85	1.58	1.05	NS	NS	NS
CV (%)	8.00	4.71	3.73	3.73	4.19	13.81	15.77

Means in the column with same letter(s) superscript are not significantly (NS) different at P<0.05.

Moringa leaf powder application effect on maize yield components at 100 DAP

Maize yield components such as: shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW), root dry weight (RDW) and the total biomass dry weight (TBDW) were statistically significant (P<0.05), with maximum values observed under CF treatment followed by the M3 treated plants (Table 5). For instance, the highest values for SFW (529.97 g), RFW (144.73 g), SDW (116.50 g) and TBDW (137.77 g) were obtained from CF treated plants when compared with the control (M0). The highest value of about RDW (22.86 g) was observed in M3 treated plants, followed by CF treated plants compared to the control.

Table 5. Maize yield components as affected by MLP application rates at 100 DAP

Treatments	Maize yield components at 100 DAP					
	SFW(g)	RFW(g)	SDW(g)	RDW(g)	TBDW (g)	R:S
M0	392.87^c	96.04^c	69.72^d	14.61^b	84.33^d	0.20
M1	405.94^c	109.08^c	74.45^{cd}	16.36^b	90.81^{cd}	0.22
M2	466.01^b	123.50^b	94.70^{bc}	18.93^{ab}	113.63^{bc}	0.20
M3	521.42^a	138.59^a	106.09^{ab}	22.86^a	128.94^{ab}	0.21
CF	529.97^a	144.73^a	116.50^a	21.26^a	137.77^a	0.18
LSD$_{(5\ \%)}$	42.55	13.45	21.47	4.75	23.83	NS
CV (%)	4.88	5.84	12.36	13.43	11.40	13.91

SFW= shoot fresh weight, RFW=root fresh weight, SDW= shoot dry weight, RDW=root dry weight, TBDW= total biomass dry weight, R:S= root to shoot ratio, NS= not significantly different at P<0.05.

Effect of moringa leaf powder applications on soil chemical properties

Soil analysis revealed that almost all tested soil chemical parameters such as pH (H_2O), organic carbon (%OC), total nitrogen (%TN), soil organic Matter (% SOM) and cation exchange capacity (CEC in meq/100g) were significantly (P<0.05) influenced by MLP application rates at six weeks of incubation (Table 6). The highest values of soil pH (6.85), OC (3.18 %), TN (0.27 %), and OM (5.48 %) were observed in soil/pots treated with 75 g of MLP. Likewise, the highest CEC (20.38 meq/100g of soil) was obtained from the soil treated with 25 g of MLP compared to the control or CF treated soil. Moreover, there was a noticeable increase in soil pH from 6.73 to 6.85 (approaching to the neutral point) with increasing MLP application rates from 25g to 75 g pot^{-1}. In contrast, the pH of CF treated soil and the control pot was lower, with no statistically significant differences compared to the M1, M2, and M3 treated soil.

The ANOVA results also revealed that most of the soil chemical parameters such as pH, %OC, %OM and CEC (meq/100g) were statistically ($P<0.05$) influenced by MLP application rates at 100 DAP (Table 7). Accordingly, the highest values of pH (6.98) and OC (2.57%) were obtained from the soil treated with 75 g of MLP, while the highest OM (4.82 %) and CEC (18.40 meq/100g) were obtained from the soil treated with 50 g and 25 g of MLP, respectively compared to the CF supplied soil or the control. Moreover, the result shows that the values of pH, OC, and OM, obtained from the soil treated with increasing rates of MLP application, and collected both at six weeks after incubation and at 100 DAP were higher than that of soil analysis results before the experiment (Table 1).

Table 6. Moringa leaf powder application rates effect on soil chemical properties at six weeks after incubation

Treatments	Soil chemical properties at six weeks of incubation					
	pH(H_2O)	OC (%)	TN (%)	OM (%)	CEC(meq/100g)	C:N
M0	6.60^{c}	2.12^{d}	0.17^{b}	3.65^{d}	14.57^{b}	12.13
M1	6.73^{b}	2.92^{b}	0.25^{a}	5.04^{b}	20.38^{a}	11.60
M2	6.84^{a}	2.64^{c}	0.26^{a}	4.56^{c}	18.62^{a}	10.14
M3	6.85^{a}	3.18^{a}	0.27^{a}	5.48^{a}	19.11^{a}	11.60
CF	6.57^{c}	2.12^{d}	0.19^{b}	3.66^{d}	14.09^{b}	11.26
$LSD_{(5\%)}$	0.10	0.15	0.02	0.27	2.13	NS
CV (%)	0.80	3.17	6.45	3.21	6.53	6.27

CEC= cation exchange capacity, OC= organic carbon, OM=organic matter, NS=not significantly different at $P<0.05$, pH (H_2O) = soil pH in water, TN= total nitrogen, %= percentage.

Table 7. Effect of MLP application rates on soil chemical properties at 100 DAP

Treatments	Soil chemical properties at 100 Days after Planting					
	pH(H_2O)	OC (%)	TN (%)	OM (%)	CEC(meq/100g)	C:N
M0	6.60^{c}	2.17^{c}	0.20	3.75^{c}	12.72^{b}	10.72
M1	6.79^{b}	2.38^{bc}	0.26	4.10^{bc}	18.40^{a}	9.29
M2	6.85^{b}	2.80^{a}	0.28	4.82^{a}	18.16^{a}	10.06
M3	6.98^{a}	2.57^{ab}	0.21	4.44^{ab}	15.78^{ab}	12.09
CF	6.54^{c}	2.11^{c}	0.19	3.64^{c}	13.54^{b}	10.88
$LSD_{(5\%)}$	0.07	0.27	NS	0.47	3.11	NS
CV (%)	0.60	6.07	15.82	6.03	10.53	10.18

Means in the column with same letter(s) superscript are not significantly (NS) different at $P<0.05$.

DISCUSSION

The current findings revealed that all maize growth parameters such as stem diameter, plant height, leaf number, leaf length, leaf width and leaf area were positively influenced by increased rates of MLP application ranging from 25 to 75 g pot^{-1} at different growth stages (Tables 2, 3 and 4). This finding is in agreement with Ekene *et al*. (2014) who reported an increase in maize plant height from 40 to 55 cm and the leaf area from 65 to 100 cm^2 with increased application of fresh moringa leaves ranging from 50 to 100 g pot^{-1} at 28 days after planting under greenhouse conditions. Similarly, Aluko *et al*. (2017) reported that dried moringa leaf application to the soil at 50 g pot^{-1} and 1.2 t ha^{-1} enhanced maize and okra growth, respectively. A piece of report from Undie *et al*. (2013) also shows that an increased application of fresh moringa leaves ranging from 5-20 t ha^{-1} resulted in higher dry matter and number of fruits per plant of garden egg across locations and years in Nigeria.

Significant improvements in crop growth can be attributed to the increasing application rates of MLP. This could be due to the composition of phytohormones such as Gibberellin, Zeatin, and Indole acetic acid (IAA) found in moringa leaves. Among these phytohormones for instance, Zeatin plays a vital role in stimulating cell division and promoting overall plant growth (Foidl *et al*., 2001; Elzaawely *et al*., 2017; Alkuwayti *et al*., 2020). Moreover, improvements in maize growth and yield components achieved in the current study could be directly associated with the essential plant nutrient composition of dried moringa leaves, which are released into the rhizosphere through mineralization. The assumption is supported by Undie *et al*. (2013), Aluko *et al.* (2017) and Ekene & Uchenna (2023), who examined the contributions of moringa in soil fertility and crop production improvements. Moreover, Ekene *et al*. (2014) identified that dried moringa leaves constitute higher mineral nutrients than fresh leaves, which can improve soil fertility as well as productivity.

Similar to that of MLP application rates effect on maize growth parameters, this study also revealed that application of commercial fertilizer resulted in the highest shoot fresh weight and shoot dry weights, root fresh weight and the total biomass dry weight (Table 5). Nevertheless, their values achieved under CF treated were not statistically different from those treated with 75 g of MLP. This implies that supplying both CF and MLP to the soil can improve soil nutrient, promote crop growth and yield due to their essential nutrient composition. Moreover, improvement in maize growth and yield parameters with the application of chemical fertilizer may be attributed to the short-term nutrient release and subsequent nutrient uptake by the growing crops (Abebe *et al.,* 2022), in comparison to the nutrient release from organic fertilizer sources, which require time for decomposition.

The highest root dry weight and remarkable maize yield components were obtained from the plants supplied with MLP; this may be attributed to the potential role of moringa leaves as a source of essential plant nutrients and growth-promoting hormones. This result is consistent with Undie *et al*. (2013) and Aluko *et al*. (2017), who reported the highest dry matter and fruit yield of garden egg and okra with 20 t ha^{-1} fresh moringa and 1.2 t ha^{-1} dried moringa leaf incorporations, respectively. Several scholars have also reported that moringa tree leaves applied in the forms green manure, leaf extracts to agricultural land or growing plants enhanced crop growth and yield (Foidl *et al*., 2001; Undie *et al*., 2013; Ekene *et al*., 2014; Abd El-Hack *et al*., 2018; Ekene & Uchenna, 2023).

Regarding the soil chemical properties, the current findings revealed that almost all tested soil chemical parameters at six weeks of incubation and at 100 DAP were influenced by MLP application rates (Table 6 and 7). For instance, increment in the soil pH that approaches to the desirable ranges for agricultural production: (6.60 - 6.85) and (6.60 - 6.98) were observed with increasing application from 25 to 75 g of MLP at six weeks of incubation and at 100 DAP, respectively. Whereas the soil pH of the study area (topsoil) illustrated in Table (1) is characterized as moderately acidic and desirable for most crops with some management practices as described by Tadesse *et al*. (1991). The current finding revealed a remarkable improvement in soil pH due to application of MLP; which indicates the beneficial effects of MLP application for improving soil quality. It also indicates that MLP can be used as an alternative input for managing acid soil. This result is also consistent with Ekene *et al*. (2014) who reported an increase in the soil pH (7.2-8.5) with the application of different rates of MLP (0 to 100 g pot^{-1}) after six weeks of incubation. Contrary to this, Undie *et al*. (2013) reported a slight reduction in soil pH within 30 days after the incorporation of fresh moringa leaf into the soil. The authors reported that the application of fresh moringa leaves increased soil pH as the days after incubation increased from 30 to 90 days, however become constant from 90-140 days.

The current study also revealed remarkable values of soil organic carbon (OC), and organic matter (OM) with increasing MLP application rates from 25 to 75 g pot^{-1}, in comparison to the result of soil analysis employed before the experiment and that of the control. This result is consistent with Ekene *et al*. (2014) who observed increment in soil chemical properties with increased supply of dry moringa leaves ranging from 50 to 150 g pot^{-1} than the fresh leaves. A piece of evidence from Abay *et al*. (2015) shows that higher values of OC, OM, TN, available phosphorus and CEC were observed under the canopy of the moringa tree compared to the adjacent open fields in the Tigray region of Ethiopia. However, in the current findings the values of TN and CEC were higher in the soil used for pot filling (as indicated by pre-experiment soil analysis result) than in the soil treated with various rates of MLP, both after six weeks of incubation (pre-planting) and 100 days post-planting. The reduction in TN at 100 days after planting under the soil treated with different rates of MLP could be attributed to the higher nitrogen absorption of maize, which could also result in a reduction in the CEC of the soil, particularly at 100 days after planting.

The values of all tested soil chemical parameters were lower in both the control and CF treated soil compared to the soil treated with MLP, both at six weeks after incubation and after maize harvesting. Such remarkable improvements in soil chemical properties with the application of moringa leaves could be attributed to the high composition of mineral elements in moringa leaves that are released into the soil through decomposition. This improves the soil nutrient content, thereby enhancing crop growth and yield (Foidl *et al*., 2001; Undie *et al*., 203; Ekene *et al*., 2014; Abay *et al*., 2015). The current findings confirms that application of moringa tree leaves to the soil as green manure is a promising alternative nutrient source for improving soil properties and crop yield. This may be due to its remarkable composition of essential nutrients and growth-promoting hormones. However, scientific evidence indicating the effects of moringa leaf powder application on agricultural soil in general, and on maize farms in particular, for improving soil nutrient content or maize growth and yield components is currently unavailable in Ethiopia.

CONCLUSION

The results of this study indicated that the application of different rates of moringa leaf powder significantly influenced maize growth and yield related parameters at various growth stages. Most of the maize growth parameters reached their maximum values when supplied with 50 g and 75 g of MLP. Maize yield components attain their maximum values under commercial fertilizer-supplied plants followed by MLP; however, the results were not statistically different from MLP-supplied plants. In this regard, MLP can be used as an alternative organic fertilizer, particularly as green manure to improve crop growth and yield. Similar to maize growth and yield components, improvements in soil chemical properties were observed with increasing application rates of MLP per pot. Moreover, all tested soil chemical parameters reached their highest values with increased rates of MLP application (25 g to 75 g pot^{-1}). This finding confirms that the application of MLP at a rate of 75 g pot^{-1} improved maize growth, yield components and soil chemical parameters. The current findings also reveal fundamental new insights into the use of moringa tree leaves for improving soil quality and crop yield. However, the study had several limitations: it was not conducted over multiple years, field trials were not implemented, and the effects of combining MLP with chemical fertilizers were not assessed. Moreover, since the research was conducted in a greenhouse, further research should be carried out under field conditions, over multiple years and locations to provide conclusive recommendations.

Authors' contributions

Biyeshi Ayansa Abdissa contributed research idea conceptions, designed and established the experiment, analyzed and interpreted and wrote the manuscript. Dawit Dereje, Adise Feyisa and Fernuse Gebiyaw: established the experiment and collected data, Gerba Daba reviewed and edited the manuscript.

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Data Availability

All data generated are included within the article. Furthermore, datasets are available from the corresponding author upon request.

Conflicts of Interest:

The authors declared no conflict of interest.

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