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IMPACT OF APPLICATION COMBINATION OF MORINGA LEAF POWDER AND ZINC ON GROWTH AND QUALITY OF MAIZE

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Abstract: A field experiment was conducted on Ain mara, Derna, Libya during the growing season of 2023/2024 to investigate the effect of application combination of Moringa leaf powder and zinc sulfate on growth, yield, and chemical composition of maize cv. "Hybrid 3062". The experiment consists of 9 treatments (control, 5 MLP+ 0.5 $ZnSO_4$, 10 MLP+ 0.1 $ZnSO_4$, 15 MLP+ 0.1 $ZnSO_4$, 20 MLP+ 0.1 $ZnSO_4$, 25 MLP+ 0.1 $ZnSO_4$, 30 MLP+ 0.1 $ZnSO_4$, 35 MLP+ 0.1 $ZnSO_4$ and 40 MLP+ 0.1 $ZnSO_4$, kg/ha) arranged in Randomized Complete Block Design with three replications. Moringa leaf powder (MLP) and $ZnSO_4$ were applied to soil at during preparing the soil for agriculture. The results showed increasing combination of Moringa leaf powder and zinc sulfate were significant effect of all studied traits, which the treatment of 40 MLP+ 0.1 $ZnSO_4$, kg/ha recorded the higher values of all vegetative growth were studied i.e. plant height, number of leaves / plant, leaf area index and dry weight of shoot, also, increased all yield traits i.e. cob length, cob diameter, number of grains/ cob, number of grains/ raw, 100-grains weight, grain yield and harvest index, additionally, increased chemical composition of maize such as nitrogen, phosphorus, potassium, protein, zinc, iron and manganese, followed by treatment of 35 MLP+ 0.1 $ZnSO_4$, as compared with the control treatment which recorded the lower values of all studied traits during 2025 seasons. In conclusion, 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, further research should be carried out under field conditions, over multiple years, and locations to provide conclusive recommendations.

Keywords: Maize, green manure, $ZnSO_4$, vegetative growth, yield, chemical composition

1. Introduction

After rice and wheat, maize, a cereal crop in the Poaceae family, is the third most significant crop in the world's agricultural economy (Parameshnaik et al., 2024). According to the endosperm of the kernels, different types of maize are classified as baby corn, popcorn, sweet corn, and dent corn (Raddy et al., 2022). One of the most common food crops, maize (*Zea mays*), is the most widespread cereal and plays a significant role in human nutrition and livestock feed (Liu et al., 2020). Maize is and will remain the most produced crop in East Africa because it is used by many smallholder farmers as both a cash crop to generate household incomes and a staple food (Tandzi & Mutengwa, 2020; Mugi-Ngenga et al., 2021).

It is a versatile crop that can be grown in a variety of agro-climatic zones, from 58°N to 40°S latitudes, at elevations ranging from sea level to over 3000 m, with annual rainfall ranging from 250 mm to 5000 mm. It is commonly referred to as the "queen of cereals" because it has the highest yield potential among cereal crops, and it is an essential staple crop that ranks third globally in production after wheat and rice (Bhaumik et al., 2025). In addition to providing nutrients, maize contains phytochemicals such carotenoids, phenolic compounds, and phytosterols that are important in avoiding chronic illnesses (Demeke, 2018). One of the main cereal crops cultivated in Sub-Saharan Africa and the humid tropics is maize. According to the Food and Agriculture Organization, it is a crop with several uses and ranks third globally in terms of output, behind rice and wheat (Abdulkadir et al., 2025). Originally flourishing on the natural fertility of soils, agriculture has long been a cornerstone of human society. However, the nineteenth-century introduction of synthetic fertilizers transformed farming methods as the need for greater agricultural productivity increased. The sustainability of traditional farming practices is called into question because, even though these fertilizers greatly increased crop yields, their widespread use has also resulted in major environmental problems like soil degradation, water pollution, and biodiversity loss (Krasilnikov et al., 2022; Zhou et al., 2022). Due to insufficient replenishment of soil nutrients through organic and inorganic inputs, many agricultural fields are no longer sustainable, especially in smallholder farming systems. Consequently, it has been challenging to achieve potential agricultural yields in these systems (Mhoro et al., 2025).

Crop yield, environmental sustainability, and soil health are all greatly impacted by the decision between organic and inorganic fertilizers. Despite their gradual nutrient release, organic fertilizers help to strengthen the structure of the soil. Conversely, inorganic fertilizers offer easily accessible nutrients, but they can also present hazards including water contamination and soil deterioration. Because of their minimal negative effects on the environment and human health, organic fertilizers are being utilized more in sustainable agriculture (Aadel, 2017). According to Koopmans and Bloem (2018), recent research on the application of organic amendments as soil fertilizer has shown promising outcomes in terms of increased yields that are on par with chemical fertilization. However, the generalizability of the results is limited because the capacity of organic fertilizers to supply nutrients to crops is dependent on the kind of plant, organic matter, and the prevailing agro-climatic conditions in the field for later decomposition (Abobi et al., 2014). The locally accessible, affordable, long-lasting, environmentally friendly, and readily available material could be utilized to maintain soil quality in agro-ecosystems in a sustainable manner. Co-products from agriculture are typically used to make organic fertilizers. Thus, one of the main concerns for sustainable development is their valuation (Yao et al., 2025). In a world where soil fertility is decreasing, green manures offer an alternative to increase nitrogen availability for plant nutrition (Ghiorghe & Turek-Rahoveanu, 2024). In addition to their high cost, farmers' reliance on inorganic fertilizers as a source of plant nutrients is linked to environmental contamination and the degradation of land and soil. Finding safe, alternative natural sources of plant nutrients is therefore always necessary (Mona, 2013).

A potential supplement or replacement for inorganic fertilizers, *Moringa oleifera* is one such alternative that is being researched to determine its impact on crop development and productivity. As a result, farmers may be encouraged to use it. Additionally, several studies have shown that *M. oleifera* is a highly prized plant with benefits that are multifunctional. In plants grown in saline conditions, Moringa oleifera, a unique natural biostimulant for plant growth, may help increase drought tolerance (Abd El-Mageed et al., 2017). Grown extensively in tropical and subtropical regions, *M. oleifera* is a multipurpose tree (Balakumbahan & Kavitha, 2019). Nitrogen, calcium, potassium, magnesium, copper, iron, and other phytohormones like auxins are among the macro and micronutrients that are abundant in *Moringa oleifera* (Hekmat et al., 2015; Zaki & Rady, 2015).

Consequently, the moringa plant has become a popular organic source in agriculture in recent years, and its extract is being promoted as a bio-foliar product that boosts the development, growth, and yield of numerous field crops at the most affordable price (Merwad, 2018). The leaves of the Moringa tree, also referred to as the drumstick tree or the miracle tree due to its many advantageous qualities are used to make moringa leaf powder, which contains vital nutrients that can enhance plant growth. Moringa leaf powder is a good organic fertilizer for plants since it contains vital plant nutrients like calcium, phosphorus, potassium, and nitrogen (Leone et al., 2016). Since it contains zeatin, a naturally occurring cytokinin derivative, proteins, vitamins E, phenolics, ascorbic acid, essential amino acids, and various mineral components, it is a natural plant growth regulator and may even be a natural growth booster (El-Hack et al., 2018), as well as having high levels of potassium, calcium, phenolic compounds, and ascorbatesall of which are utilized as exogenous plant growth stimulants (Waqas et al., 2017). Moringa leaf powder, when used as an organic fertilizer, has the potential to enhance soil health (Adebayo et al., 2021). Additionally, Adekiya et al. (2021) demonstrated that the powder is a valuable organic material that enhances the structure, texture, and water-holding capacity of soil. It also contains advantageous microorganisms that aid in the breakdown of organic matter and release nutrients into the soil, allowing plants to absorb them. It has been discovered that moringa leaf powder boosts plant productivity and development. Another eco-friendly substitute for chemical fertilizers is powdered moringa leaves. Depletion of soil nutrients is a global environmental problem that has detrimental effects on soil quality and food security. Loss of organic matter and decreased soil nutrient levels are two symptoms of soil nutrient depletion (Osujieke et al., 2020). Loss of agricultural fields and decreased crop productivity could result from this. Soil quality must be maintained for long-term, sustainable productivity and a better farming environment (Johnston and Poulton, 2018). Micronutrients are necessary in trace amounts for crop growth and metabolic processes, and maize crops have relatively low micronutrient requirements, with a relatively narrow range between deficiencies and toxicities in plants and soils (Bhangare et al., 2019). When essential nutrients are deficient, maize can develop hidden hunger symptoms (Aryal et al., 2024). For plants to grow and develop to their full potential, micronutrients are necessary components. Small amounts are required; these are frequently expressed in milligrams per kilogram of biomass or soil or in grams per hectare (Alloway, 2013). Micronutrients, especially zinc, boron, and sulfur, should be applied to maize fields to improve crop yield and quality and attain the best possible outcomes (Chopde et al., 2015). Micronutrients are essential for crop development and metabolic processes, and they are needed in trace levels. According to Aryal et al. (2024), maize is vulnerable to micronutrient deficits and displays covert signs of hunger when these vital nutrients are absent. By maintaining membrane integrity within its system, zinc (Zn) supplementation improves the plant's resistance to heat stress. According to Xie et al. (2018), it is crucial in reducing chilling stress in plants. The structural integrity of proteins, membrane lipids, different biological components, and DNA depends on zinc. It also makes ion transport in plants easier (Nadeem and Farooq, 2019). The objective of this work was to study the influence of application combination of Moringa leaf powder and zinc on growth, yield and chemical components of maize cv. "Hybrid 3062.

2. Materials and Methods

A field experiment was conducted on Ain mara, Derna, Libya during the growing season of 2023/2024 to investigate the effect of application combination of Moringa leaf powder and zinc sulfate on growth, yield and chemical composition of maize cv. "Hybrid 3062". The experiment consists of 9 treatments (control, 5 MLP+ 0.5 $ZnSO_4$, 10 MLP+ 0.1 $ZnSO_4$, 15 MLP+ 0.1 $ZnSO_4$, 20 MLP+ 0.1 $ZnSO_4$, 25 MLP+ 0.1 $ZnSO_4$, 30 MLP+ 0.1 $ZnSO_4$, 35 MLP+ 0.1 $ZnSO_4$ and 40 MLP+ 0.1 $ZnSO_4$, kg/ha) arranged in Randomized Complete Block Design with three replications. Moringa leaf powder (MLP) and $ZnSO_4$ were applied to soil at during preparing the soil for agriculture.

Table 1. Mineral contents of dried Moringa leaf (MLP) used in the study per 100g

Components	Value (%)
Moisture	9.60
Calories	30.10
Crude protein	19.57
Fats (g)	2.24
Carbohydrate (g)	47.92
Fibre (g)	9.12
Ash	8.09
Calcium (mg)	3.63
Copper (mg)	0.07
Iron (mg)	18.2
Potassium (mg)	20.52
Magnesium (mg)	0.48
Phosphorus (mg)	0.29
Sulphur (mg)	0.03

2.1 Preparation of Moringa Leaf Powder

Fresh moringa leaves were collected from a fully mature moringa tree. 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.

2.1.1 Studied attributes

A) Vegetative growth

Plant height (cm): Plant height was measured to the nearest centimeter using a measuring tape from the base to the highest growing point.

Number of leaves/ plants: The leaf number was determined by counting the number of the opened leaves starting from the base of the plant upwards.

Shoots dry weight (g): The stem girth was measured at the base of the maize plant with the aid of Vernier calipers to the nearest millimeter.

Leaf area index (cm^2): The leaf area was measured by tape using the non-destructive analysis method: Length x Width x 0.75 according to Duke and Dulelar as reported by Enujeke (2013) i.e: LA (cm^2) = 0.75 x L x W.

B) Yield and yield components

Cob length (cm)

Cob diameter (cm)

Number of grains/cob: was evaluated by counting the number of grains in each harvested cob in the sample areas of each plot.

Number grains/ row

100-grain weight (g)

Grain yield (t/ha^{-1}): At physiological maturity, fresh cobs were harvested per treatment and dried to 14% moisture content and weighed using a weighing scale and converted to t/ha^{-1}.

Harvest index (%): The harvest index was calculated according to the equation (Donald and Hamblin 1976). The harvest index was estimated from the following formula, Harvest index (%) = (grain yield / biological yield) x 100.

C) Chemical composition

N (%): Total nitrogen was determined in the grains extract using the micro-Kjeldahl according to the method of Allen et al. (1986).

P (%): The methods adopted for extraction of phosphorus were essentially those described by Barker and Mapson (1964).

K (%): Potassium content was measured according to the method described by Motsara and Roy (2008).

Protein (%): It was calculated after estimating the nitrogen concentration in the grains using the Microkeldal apparatus and extracted according to the (Thachuk *et al.*, 1977). The percentage of protein in grains = N × 6.25.

Microelements (Zn, Fe and Mn) were determined by (Bingham, 1982; Ryan et al., 2001).

2.2 Statistical Analysis

All the data collected were statistically analyzed of variance procedure outlined by SAS (2010) computer program and means compared by LSD method to Snedecor and Cochran, (1980).

3. Results and Discussion

A) Vegetative Growth

Results presented in Table (2) and Fig. (1) showed that increase concentrations of combination of Moringa leaf powder (MLP) and zinc ($ZnSO_4$) significantly increasing all vegetative growth were studied (plant height, shoot dry weight, number of leaves/ plant and leaf area index) of maize during 2025 season. However, the treatment of 40 MLP+ 4.0 $ZnSO_4$ (kg/ha) recorded the highest values of plant height (218.01 cm), shoot dry weight (591.54 g), number of leaves/ plant (12.54) and leaf area index (4.16 cm^2), followed by 35 MLP+ 3.5 $ZnSO_4$ (kg/ha) recorded plant height (213.50 cm), shoot dry weight (568.74 g), number of leaves/ plant (11.78) and leaf area index (4.00 cm^2), and plant height (209.64 cm), shoot dry weight (540.65 g), number of leaves/ plant (10.95) and 30 MLP+ 3.0 $ZnSO_4$ (kg/ha) which recorded leaf area index (3.94 cm^2), as compared to control treatment which recorded the lower values of plant height (159.60 cm), shoot dry weight (400.02 g), number of leaves/ plant (9.85) and leaf area index (2.87 cm^2), respectively. Ekene et al. (2014) found that increasing the amount of fresh moringa leaves from 50 to 100 g pot-1 at 28 days after planting in a greenhouse boosted the height of maize plants from 40 to 55 cm and the leaf area from 65 to 100 cm2. The rising rates of MLP application are responsible for notable gains in crop growth. This might be because moringa leaves contain phytohormones such gibberellin, zeatin, and indole acetic acid (IAA). Zeatin, for example, is an essential phytohormone that promotes cell division and overall plant growth (Elzaawely et al., 2017; Alkuwayti et al., 2020).

Adequate micronutrient absorption and utilization, which enhanced nutrient uptake and the production of growth-promoting hormones, particularly auxin. This might have resulted in more growth and internodes, which would have boosted the main shoot's development and raised the sweet corn plant's height (Yogesh et al., 2022). Similar observations and results in maize were reported by Adarsha et al. (2019). Favorable impacts on a variety of biochemical processes at the cytoplasm, membrane, and cell wall may also be the cause of this. These impacts include increased rates of respiration and photosynthesis, increased synthesis of proteins, and plant hormone-like activity that stimulates the growth of shoots and roots. These results are consistent with (Hassan et al., 2019; Khan et al., 2019; Mahmood et al., 2020; Abd-Rabboh et al., 2020).This conclusion was also in line with Prashant (2021), which suggested that more cell division and elongation may have been a major factor in the plant's increased height because of balanced and more readily available nutrients.

Studies by (Karrimi et al., 2018; Jolli et al., 2020) found that the main factor causing the increased plant height was a high amount of auxin biosynthesis, which includes indoleacetic acid (IAA). Furthermore, zinc plays a crucial role in the synthesis of tryptophan, the building block for the synthesis of IAA, and is an essential portion of many enzymes' catalytic components. Cell elongation and differentiation are influenced by IAA. These results are consistent with Verma et al. (2006). Because the micronutrient application source absorbed more main nutrients, it produced a larger leaf area per plant than the control, stimulated growth, and raised the physiological and metabolic activities of the plant. Similar results were found in maize by (Bhangare et al., 2019; Adarsha et al., 2019). The growth and development of roots and shoots are facilitated by zinc and iron stimulating plant enzymes involved in glucose metabolism, maintaining the integrity of cellular membranes, protein synthesis, and auxin production regulation (Jolli et al., 2020). In a similar vein, Karrimi et al. (2018) observed that increased leaf area was linked to the foliar application of zinc and iron at booting and silking in addition to RDF. Senescence and abscission were postponed due to enhanced nutrition absorption and translocation.

The treatment of micronutrients had no effect on the height or leaves of the plants. These results are consistent with those of Tunebo et al. (2021), who observed that plant height was unaffected by $ZnSO_4$ treatment. Elevated levels of the amino acid tryptophan and the hormone indole acetic acid, which are both associated with the expansion of leaf area as altered by the administration of micronutrients, can be attributed to the increase in leaf area (Adarsha et al., 2019). Zinc's role in tryptophan synthesis and the production of other metabolic and storage compounds makes micronutrients beneficial to plant growth. By encouraging cell division, development, and expansion, these substances raise the leaf area index (Huthily et al., 2020). Higher levels of $ZnSO_4$ in the soil can increase the number of leaves in a plant by allowing it to take in more nutrients. This increased availability of nutrients helps the plant to produce more chlorophyll which leads to higher activity of photosynthesis process. So higher levels of $ZnSO_4$ in the soil can lead to an increase in the number of leaves in a plant. The findings of this study are also consistent with previous research showed that zinc is an important nutrient for the growth of plants and can promote the growth of leaf area (Kaya & Higgs, 2002; Cakmack, 2002).

Table 2. Effect of Moringa leaf powder (MLP) and zinc ($ZnSO_4$) on some vegetative growth of maize during 2025 season

Treatments	Plant height (cm)	Shoot dry weight (g)	No. of leaves/ plant	Leaf area index (cm^2)
Control	159.60	400.02	9.85	2.87
5 MLP+ 0.5 $ZnSO_4$ (kg/ha)	167.84	442.80	9.95	3.13
10 MLP+ 0.1 $ZnSO_4$ (kg/ha)	177.15	484.57	10.09	3.21
15 MLP+ 1.5 $ZnSO_4$ (kg/ha)	189.65	497.54	10.36	3.37
20 MLP+ 2.0 $ZnSO_4$ (kg/ha)	195.39	513.08	10.55	344
25 MLP+ 2.5 $ZnSO_4$ (kg/ha)	205.20	527.56	10.61	3.56
30 MLP+ 3.0 $ZnSO_4$ (kg/ha)	209.64	540.65	10.95	3.94
35 MLP+ 3.5 $ZnSO_4$ (kg/ha)	213.50	568.74	11.78	4.00
40 MLP+ 4.0 $ZnSO_4$ (kg/ha)	218.01	591.54	12.54	4.16
$LSD_{(0.05)}$	**9.52**	**17.37**	**0.53**	**0.23**

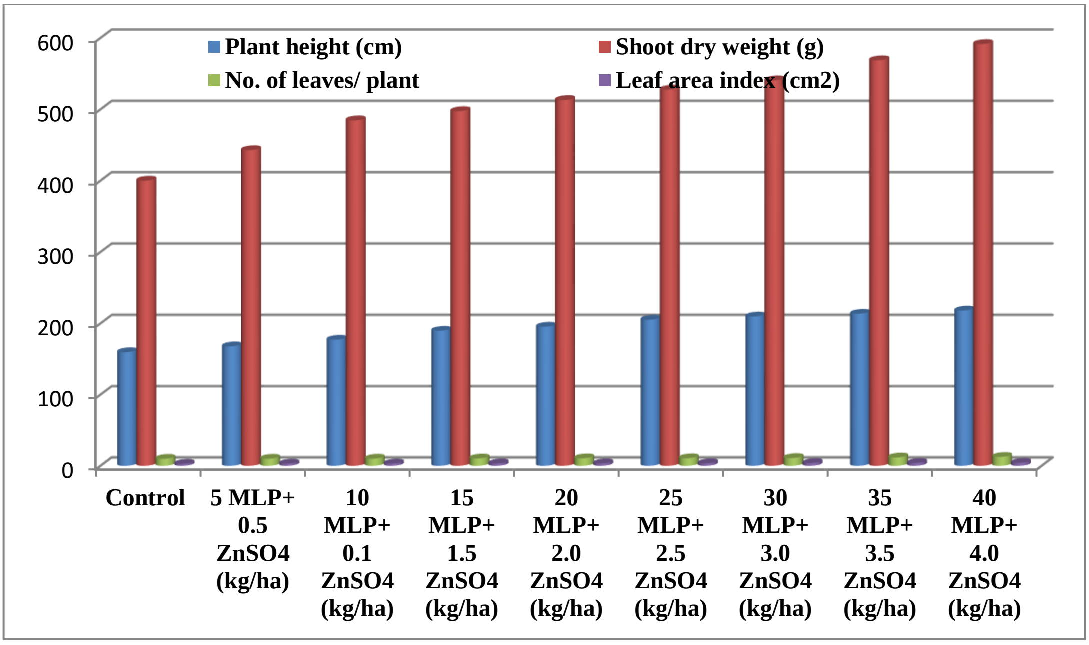

Figure 1. Effect of Moringa leaf powder (MLP) and zinc ($ZnSO_4$) on some vegetative growth of maize during 2025 season

B) Effect of the bio stimulants treatments on yield characters

Results presented in Table (3) and Figure (2) showed that increased concentrations of a combination of Moringa leaf powder (MLP) and zinc (ZnSO4) significantly increased yield and yield components of maize during the 2025 season. The study focused on cob length, cob diameter, number of grains/cob, number of grains/row, 100-grain weight, grain yield and harvest index. However, the treatment of 40 MLP+ 4.0 $ZnSO_4$ (kg/ha) recorded the highest values of cob length (16.06 cm), cob diameter (16.17 cm), number of grains/ cob (479.55), number of grains/ row (33.32), 100-grain weight (35.85 g), grain yield (8.44 t/ha) and harvest index (47.63 %), followed by 35 MLP+ 3.5 $ZnSO_4$ (kg/ha) recorded cob length (15.89 cm), cob diameter (15.51cm), number of grains/ cob (470.82), number of grains/ row (32.04), 100-grain weight (35.33g), grain yield (7.91 t/ha) and harvest index (45.65 %), and 30 MLP+ 3.0 $ZnSO_4$ (kg/ha) which recorded cob length (15.46 cm), cob diameter (14.22 cm), number of grains/ cob (443.53), number of grains/ row (29.14), 100-grain weight (34.33 g), grain yield (7.33 t/ha) and harvest index (42.45 %), as compared to control treatment which recorded the lower values of cob length (12.75 cm), cob diameter (13.45cm), number of grains/ cob (359.52), number of grains/ row (25.01), 100-grain weight (30.923g), grain yield (5.89 t/ha) and harvest index (35.60 %), respectively. In this studies, the increase in number of grains per cob and 1000-grain weight were due to improved soil fertility as evident from higher soil OM, soil OC and rhizosphere nutrient pool (N, P, K) which led to healthier plant with better photosynthesis and assimilates formation and translocation towards developing grains (Aziz et al., 2010; Laekemariam & Gidago, 2012). Micronutrients played a crucial role in preserving the equilibrium of internal mechanisms of plant growth and development through their interactions with significant metabolic activities. As a result, the source-sink connection within the plant is optimized and photoassimilates are encouraged to move to the sink, such as kernels. Zinc as foliar could be appropriate for the stimulation of photosynthesis and led in a considerable rise in grains yield and its component of maize, according to El-Aref et al. (2004), who reported that the highest grains output, was achieved with 150 kg per faddan.

The notably increased output of fresh cob and green fodder was mainly caused by the administration of a micronutrient mixture, which enabled maize plants to achieve maximum yield and yield characteristics (Jolli et al., 2020). The more effective combined application of micronutrients has been shown to improve photosynthetic characteristics and increase grain yield (Esfahani et al., 2014). This result is in line with findings by Hisham et al. (2021), who reported that applying zinc can increase ear diameter and length as well as the number of kernel rows by as much as 20%. All physiological and yield metrics, including the number of grain rows/ cob, showed positive impacts when micronutrients and their combinations were applied to maize. Similar results were published by (Venkatesh et al., 2023; Riwad & Alag, 2023), showing that the addition of boron in addition to macronutrients enhances the number of grain rows per cob in maize. The ear weight is increased when zinc is applied foliarly or through soil. Berhe and Marie (2020) obtained a similar result, suggesting that the favorable interactions between macronutrients and micronutrients could increase grain weight using blended fertilizers.

The boost in biological yield could be attributed to increases in grain output, leaf area, and chlorophyll levels. The use of micronutrients, which stimulate several physiological processes such as stomatal control, chlorophyll synthesis, enzyme activation, and other biochemical functions, is responsible for this effect (Younis et al., 2020). To assist plants, absorb more nutrients from the soil and grow larger, zinc plays a crucial function in controlling the concentration of auxin, which raises most of the physiological and metabolic activities of plants (Mian et al., 2021).

Zinc helps to increase biological yield by speeding up the process of photosynthesis and the movement of photoassimilates (Shaaban et al., 2023). Furthermore, zinc preserves the integrity of cellular membranes, promotes the synthesis of proteins and auxins, and activates plant enzymes involved in the metabolism of glucose all of which are essential for plant growth and increase grain yields (Abednego et al., 2023). Zinc also increases agricultural productivity per unit area, germination rates, and product quality (Lamlom et al., 2024). These observations are in line with earlier research by Fecenko and Lozek (1998), who noted that applying zinc greatly increases maize grain output. Zinc's function as a co-factor in the enzymatic processes of the anabolic pathway in maize plant development and yield may be the cause of this outcome. These findings are consistent with those of El-Aref et al. (2004), who reported that the highest grain yield was achieved with 150 kg of zinc per faddan. They suggested that zinc applied topically could be useful for boosting photosynthesis and lead to a notable increase in grain yield and its component of maize. 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 (Abd El-Hack et al., 2018; Ekene & Uchenna, 2023).

Table 3. Effect of Moringa leaf powder (MLP) and zinc sulfate on yield and yield components of maize during 2025 season

Treatments	Cob length (cm)	Cob diameter (cm)	NO. of grains/ Cob	No. grains/ row	100-grain weight (g)	Grain yield (t/ha)	Harvest index (%)
Control	12.75	13.45	359.52	25.01	30.92	5.89	35.60
5 MLP+ 0.5 $ZnSO_4$ (kg/ha)	13.87	13.81	381.78	25.77	31.17	6.45	36.11
10 MLP+ 0.1 $ZnSO_4$ (kg/ha)	14.22	14.28	390.36	26.29	32.16	6.54	37.25
15 MLP+ 1.5 $ZnSO_4$ (kg/ha)	14.60	14.56	435.60	26.63	32.21	6.85	38..33
20 MLP+ 2.0 $ZnSO_4$	14.96	14.78	412.26	26.91	32.66	7.29	

(kg/ha)							39.67
25 MLP+ 2.5 $ZnSO_4$ (kg/ha)	15.01	14.89	426.36	28.19	33.88	7.45	40.02
30 MLP+ 3.0 $ZnSO_4$ (kg/ha)	15.46	14.22	443.53	29.14	34.33	7.33	42.45
35 MLP+ 3.5 $ZnSO_4$ (kg/ha)	15.89	15.51	470.82	32.04	35.33	7.91	45.65
40 MLP+ 4.0 $ZnSO_4$ (kg/ha)	16.06	16.17	479.55	33.32	35.85	8.44	47.63
$LSD_{(0.05)}$	**0.65**	**0.48**	**20.34**	**1.23**	**1.07**	**0.23**	**0.75**

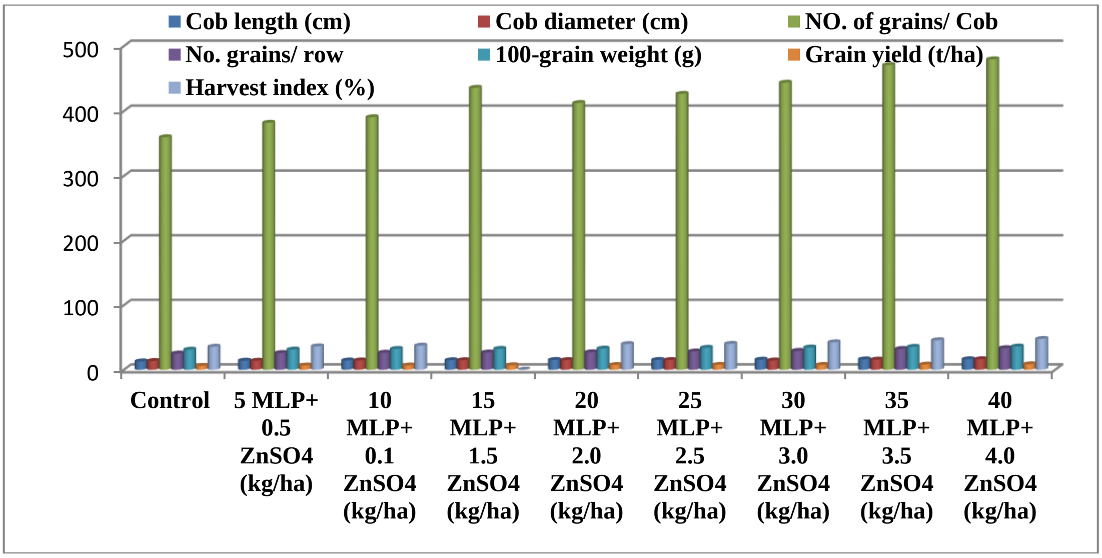

Figure 2. Effect of Moringa leaf powder (MLP) and zinc sulfate on yield and yield components of maize during 2025 season

C) Chemical Composition

Results presented in Table (4) and Figure (2) showed that increase concentrations of combination of moringa leaf powder (MLP) and zinc ($ZnSO_4$) significantly increasing macro and micro nutrients were studied (N, P, K, protein percentages and Zn, Fe and Mn mg/l) of maize during 2025 season. However, the treatment of 40 MLP+ 4.0 $ZnSO_4$ (kg/ha) recorded the highest values of N (1.85 %), P (0.385 %), K (3.39 %), protein (11.56 %) and Zn (30.80 mg/l), Fe (9.92 mg/l) and Mn (5.14 mg/l) , followed by 35 MLP+ 3.5 $ZnSO_4$ (kg/ha) which recorded N (1.81 %), P (0.371 %), K (3.18 %), protein (11.31 %) and Zn (28.77 mg/l), Fe (9.82 mg/l) and Mn (4.99 mg/l), and 30 MLP+ 3.0 $ZnSO_4$ (kg/ha) which recorded N (1.85 %), P (0.385 %), K (3.39 %), protein (11.56 %) and Zn (30.80 mg/l), Fe (9.92 mg/l) and Mn (5.14 mg/l) , followed by 35 MLP+ 3.5 $ZnSO_4$ (kg/ha) which recorded N (1.57 %), P (0.326 %), K (2.87 %), protein (9.81 %) and Zn (26.11 mg/l), Fe (8.41 mg/l) and Mn (4.36 mg/l), as compared to control treatment which recorded the lower values of N (0.96 %), P (0.197 %), K (1.59 %), protein (6.00 %) and Zn (0.08 mg/l), Fe (7.06 mg/l) and Mn (3.46 mg/l) , respectively. Green manure (GM) significantly improved the soil OM and OC as green manure addition in soil increased microbial population and respiration which increases the decomposition of added material and results in significant improvement in soil OC and OM contents (Nawaz et al., 2017) as was recorded in this study.

Green manuring also significantly improved the total soil N, P and K contents during both years as the addition of GM into the soils is even effective in releasing nutrients up to three years of plantation (Talgre et al., 2012).

Sesbania crop forms symbiotic relationships with the gram-negative rhizobia which led to formation of N fixing nodule on the plant root and stem therefore, increased the N pool in the soil (Capoen et al., 2010) as maximum N, P and K was recorded in the plots where GM was done during both years. Likewise, Ali et al. (2012) noticed that sesbania manuring improves the soil OM, NPK status, soil porosity and decreased the soil pH. Moreover, GM considerably increased the soil P and K status as the incorporation of GM crops in the soil increased the activities of important micro-organism which increased the mineralization process and therefore, increased the release availability of N, P and K in soil (Adekiya et al., 2017). The application of different N rates and GM also improved the agronomic N efficiency during both years of experimentation as the conjunctive use of chemical and organic fertilizers improves the soil health and plant nutrient availability (Ayeni et al., 2008). The application of nutrient in an integrated manner ensures the maximum use of native N components as OM, crop residues, and biological nitrogen fixation along with improvement in N recovery (Olesen et al., 2004).This outcome is in line with Ekene et al. (2014), who found that adding dry moringa leaves (50–150 g/pot) enhanced the chemical characteristics of the soil more than adding fresh leaves. Both six weeks after incubation and after maize harvesting, the levels of all evaluated soil chemical parameters were lower in the control and CF treated soils than in the MLP-treated soil. The high concentration of mineral components in moringa leaves, which are released into the soil during decomposition, may be the cause of these notable improvements in the chemical characteristics of the soil. Crop growth and yield are increased because of this improvement in soil nutrient content (Ekene et al., 2014; Abay et al., 2016).
These findings are consistent with those of Yanai et al. (1998), who discovered that the addition of zinc, either foliarly or in the soil, increased the amount of nitrogen in wheat. Hassan (1996) demonstrated that zinc application, specifically foliar, increased the amount of phosphorous in wheat grains and straw, while potassium content increased through the addition of both nitrogen and zinc (Thalooth et al., 2006). These findings are consistent with those of Alloway (2004). The crucial role zinc plays in the assimilation process of protein synthesis and nucleic acid may be the reason for this action. According to Marschner (1995), zinc is essentially required for protein synthesis. A zinc deficiency subsequently results in decreased RNA polyerase activity and increased RNA degradation, which can significantly lower the protein content of maize grains.

Table 4. Effect of Moringa leaf powder (MLP) and zinc sulfate on chemical composition

Treatments	N (%)	P (%)	K (%)	Protein (%)	Zn (mg/l)	Fe (mg/l)	Mn (mg/l)
Control	0.96	0.197	1.59	6	0.08	7.06	3.46
5 MLP+ 0.5 $ZnSO_4$ (kg/ha)	1.02	0.216	1.83	6.38	15.9	7.11	3.50
10 MLP+ 0.1 $ZnSO_4$ (kg/ha)	1.19	0.244	2.09	7.44	21.2	7.24	3.68
15 MLP+ 1.5 $ZnSO_4$ (kg/ha)	1.22	0.253	2.23	7.63	22.7	7.31	3.79
20 MLP+ 2.0 $ZnSO_4$ (kg/ha)	1.31	0.278	2.36	8.19	18.29	8.18	4.03
25 MLP+ 2.5 $ZnSO_4$ (kg/ha)	1.53	0.314	2.69	9.56	24.38	8.33	4.23
30 MLP+ 3.0 $ZnSO_4$ (kg/ha)	1.57	0.326	2.87	9.81	26.11	8.41	4.36
35 MLP+ 3.5 $ZnSO_4$ (kg/ha)	1.81	0.371	3.18	11.31	28.77	9.82	4.99
40 MLP+ 4.0 $ZnSO_4$ (kg/ha)	1.85	0.385	3.39	11.56	30.80	9.92	5.14
$LSD_{(0.05)}$	**0.06**	**0.01**	**0.10**	**0.38**	**0.15**	**0.66**	**0.18**

of maize during 2025 season

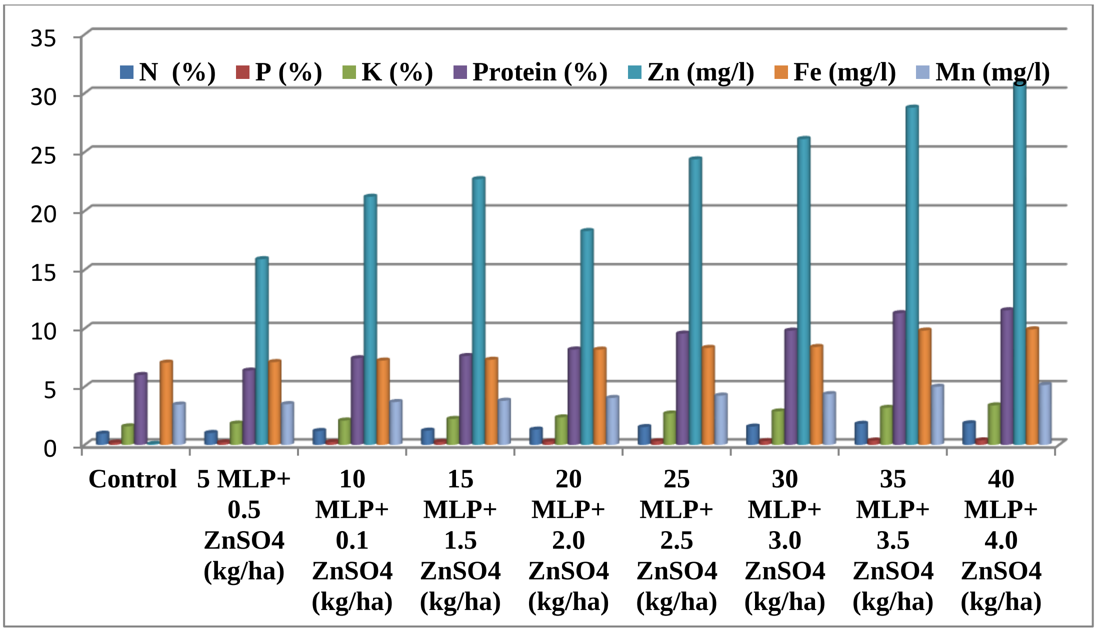

Figure 3. Effect of Moringa leaf powder (MLP) and zinc sulfate on chemical composition of maize during 2025 season

4. 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 40 MLP+ 0.1 $ZnSO_4$, kg/ha). 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. Moreover, all tested soil chemical parameters reached their highest values with increased rates of MLP application plus ZnSO4 at high concentration. This finding confirms that the application of MLP at high concentration improved maize growth, yield components and soil chemical parameters.

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