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Fertilization Effects on Soil Physico-Chemical Properties, Maize Growth and Yield in Southeast Sulawesi Dryland, Indonesia

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ABSTRACT

Maize plays a prominent role in fulfilling food and fodder demands in the industry. This study aimed to determine the effect of NPK fertilization on soil chemical properties and maize productivity. The study used a Randomized Block Design (RBD) with five levels of NPK, organic, and $CaCO_3$ fertilization treatments, each with five replications. Statistical analysis was performed using ANOVA, followed by DMRT and Tukey's test at $P<0.05$. The research results demonstrated the following initial soil chemical and physical characteristics: neutral soil pH, low organic carbon content, very low nitrogen (N) content, moderate phosphorus (P), potassium (K), and magnesium (Mg) contents, moderate cation exchange capacity (CEC), very high calcium (Ca) content, and sandy clay loam texture. After fertilization with N, P, K, organic matter, and $CaCO_3$, the following changes were observed: decreased soil pH, organic carbon, Ca content, CEC, and silt content, along with a significant increase in N, P, K, Mg, sand, and clay contents. The highest organic carbon, P, and K contents in maize biomass were achieved with 75% and 100% NPK fertilization, while the highest N content was observed with 50, 75, and 100% NPK fertilization. The best C/N ratio and the most optimal maize growth and productivity were obtained from 100% NPK fertilization. The highest maize yields were recorded with 75% (7,610kgha^{-1}) and 100% (7,690kgha^{-1}) NPK fertilization. The highest maize yields were recorded from 75% (7,610kgha^{-1}) and 100% (7,690kgha^{-1}) fertilization.

Keywords: Maize; Fertilization; Soil chemical contents; Biomass material; Productivity.

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INTRODUCTION

Indonesia's land covers an area of 191.09Mha, of which 144.47Mha is dry land and the remaining 34.12Mha is wetland (Ritung et al., 2015; Hasanah, 2020). Southeast Sulawesi has significant dry land potential, totaling 914,245ha, predominantly composed of less fertile ultisol and partially composed of alluvial soil or sandy clay loam. Of the total dry land area, 632,553ha has been used for agricultural commodity developments, while the remaining 281,692ha remains underutilized. Within Indonesia's total dry land area, 7.36Mha is designated for food crop development, including 231,805ha in Sulawesi (Ritung et al., 2015).

Dryland areas in Southeast Sulawesi present a promising opportunity for agricultural expansion, especially for maize cultivation. However, to achieve high productivity,

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according to Rejekiningrum et al. (2022), in these conditions, effective soil management practices are needed due to the inherent limitations of dry soils, such as low nutrient content, poor water retention, and susceptibility to erosion. Fertilization has emerged as a critical solution to overcome these challenges and improve maize yields in dry land agriculture.

Dry land soils, particularly ultisol, are characterized by their low organic matter content, poor structure, and high acidity. These factors limit nutrient availability and reduce plant root development. Additionally, ultisol soils are prone to nutrient leaching, further compounding the challenge of sustaining crop growth (Pratamaningsih et al., 2024; Ishak et al., 2024). The degradation of fertile agricultural land due to continuous planting without adequate soil improvement strategies has exacerbated this issue. Without intervention, maize yields in such conditions are unlikely to meet national production targets, posing a risk to food security.

Maize plays a crucial role in supporting Indonesia's food security agenda. As a staple food and essential ingredient for livestock feed and industrial processing, maize demand continues to grow (Azrai et al., 2016). Increasing maize production is vital to reduce Indonesia's dependency on imports and improve domestic food self-sufficiency. According to FAO (2018), 821 million people worldwide were malnourished, highlighting increased food vulnerability, malnutrition, and famine risks during the COVID-19 pandemic. This condition underscores the importance of enhancing maize production as a strategic food security measure.

Global maize production is led by the United States (52.2%), followed by Asia (29.3%), Europe (11.2%), Africa (7.2%), and Oceania (0.1%) (FAOSTAT, 2021). In 2019, the global maize planting area reached 197,204,250ha, producing 799,754,997.65tons of maize (FAOSTAT, 2021). In Indonesia, Java Island dominates maize production, accounting for 65% of the country's total maize planting area, while the remaining 35% is distributed across other regions. Indonesia's national maize production was recorded at 18,548,872tons from a total harvested area of 3,786,376ha, resulting in an average productivity of 4.899 tons ha-1 (Ekowati & Nasir, 2011).

The national maize production from a harvesting land area of 3.786.376ha was 18.548.872.00tons, meaning that the average productivity was as low as 4,899 tonsha^{-1} (Ekowati & Nasir, 2011). Some findings showed that maize yields from BIMA 2, 4, and 5 varieties in dry land were within the range 6,290-11,660kgha^{-1}, higher than the yields from BISI 2 and BISI 18 varieties, which were in the range 3,720-4,500kgha^{-1} (Fahmi & Sujitno, 2015). Based on statistical data, the national maize production was categorized as low (3.630kgha^{-1}). Research in Nigeria reported the maize yield from dry land amounted to 444-3.022kgha^{-1} (Adebayo & Menkir, 2014). Such a condition has necessitated maize importation from the world's largest maize producers, which amounted to 1.1 million tons, to meet the national maize need of 2 million tons per annum.

The soil fertility status change in the research location from very low to low set an impediment to maize productivity increases efforts. The status can be increased by fertilization. Fertilization is intended to provide nutrients at a given balanced dose sustainably to support plant growth (Fahrurrozi et al., 2016; Hussain et al., 2027; Perchlik & Tegeder, 2017). Efficient fertilization can support plant growth, marked by increased plant biomass. Findings indicated that biochar and NPK fertilizer application could improve the hydrophysical and chemical properties of the soil and thus improve maize growth, biomass, and yield (Skonieski et al., 2017; Faloye et al., 2019). High biomass indicates high productivity.

In addition to improving soil fertility, fertilization strategies should consider the appropriate balance of macronutrients, including nitrogen (N), phosphorus (P), and potassium (K). Nitrogen is essential for vegetative growth and chlorophyll formation, phosphorus supports root development and energy transfer processes, and potassium enhances plant water regulation and stress tolerance. Integrating organic fertilizers with NPK can further enhance nutrient availability, improve soil microbial activity, and increase long-term soil fertility sustainability. Research in drylands shows that optimal corn yields are achieved by applying balanced NPK fertilization at recommended doses of 75% and 100%. This treatment has been shown to produce the highest organic carbon, P, and K content in corn biomass, accompanied by an increase in the C/N ratio, resulting in optimal plant growth and productivity. The highest corn yields were recorded quite large for 75 and 100% NPK fertilization, indicating that both treatments can effectively support corn production in drylands (Gul et al., 2015; Ojeniyi et al., 2024; Mhoro et al., 2025). In addition to NPK fertilization, organic amendments such as manure or compost can provide supplementary nutrients, improve soil structure, and enhance microbial activity. This combination improves soil fertility and promotes long-term sustainability by reducing the dependency on chemical fertilizers.

Efforts to improve maize productivity in dry land regions like Southeast Sulawesi should prioritize integrated soil fertility management approaches. These strategies should combine balanced NPK fertilization, organic amendments, and biochar application to enhance soil structure, improve nutrient availability, and promote sustainable crop production. Furthermore, adopting conservation tillage practices, crop rotation, and intercropping systems can further support soil fertility restoration and ensure long-term agricultural productivity in dryland areas.

Increasing corn productivity in the drylands of Southeast Sulawesi requires a comprehensive approach that combines efficient fertilization practices with soil improvement strategies. This is because several studies have shown that the application of 75% and 100% NPK fertilizers has significant potential to increase soil fertility, growth, and corn yields (Catherine et al., 2017; Dewi et al., 2024). Future research should explore additional strategies for improving soil organic matter content, optimizing fertilizer application rates, and adopting sustainable agricultural practices to maximize maize productivity in challenging dry land conditions (Amaducci et al., 2016; Soleymani, 2017; Abera et al., 2017; Sheng et al., 2018). By implementing these strategies, Indonesia can reduce its reliance on maize imports, strengthen national food security, and support rural livelihoods in dry land regions.

Based on the problem above, an innovation to enhance fertilizing technology through soil fertility improvement is needed. Fertilization of the maize crop with N, P and K (nitrogen, phosphorus and potassium) fertilizers application to improve the chemical and physical properties of soil can increase maize biomass and productivity. This study aimed to evaluate the effects of N, P, K, organic, and CaCO3 fertilization on soil physico-chemical properties, maize growth, and yield in dryland conditions in Southeast Sulawesi, Indonesia. Specifically, the study sought to determine the optimal fertilization rate that enhances soil fertility, improves maize biomass nutrient content, and maximizes maize productivity in this region.

MATERIALS & METHODS

The materials used in this research were BIMA 20 URI maize seeds and NPK fertilizer. The soil sample was obtained from several locations in Southeast Sulawesi, Indonesia, 20 cm deep from the soil surface. Geographically shown in the following Fig. 1.

As stated by Cui et al. (2023), organic fertilization, including the use of mineral fertilizers such as NPK, can be done to change the physicochemical properties of the soil. In this study, an initial analysis of the chemical and physical properties of the soil was carried out to determine the nutritional status of the soil which will be the basis for recommending the dose of NPK fertilizer needed for corn plants. Continued by the provision of of $CaCO_3$ and organic fertilizers as control at 1t/ha each was performed before planting. If the N and P nutritional statuses in the soil were very low and low, respectively, then the amount of N fertilizer needed for the maize crop was 350kg of Urea ha^{-1}, which was equal to 163kg of Nha^{-1} and the amount of P fertilizer needed was 175kg of SP36, which was equal to 63kg of P ha^{-1}. Since the K nutritional status was low, then the amount of K fertilizer needed was 75kg of KCl ha^{-1}, which was equal to 45kg of K ha^{-1}. The fertilizers were applied below the soil surface to prevent evaporation and erosion during the rainy season (Gill, 2022; Jamilah & Osronita, 2024).

Soil cultivation started with weeding using herbicide. The soil was then cultivated using a tractor until the soil levelled and loose. Two different treatment plots were divided by drainage for draining water during the rainy season. $CaCO_3$ fertilizer and organic fertilizer were applied as basic fertilizers, each at $1tonsha^{-1}$. Maize planting was performed at the end of March, in coincidence with the rainy season. To prevent attacks by pests and diseases before maize seeds planting, Furadan 3G and Benlate were applied. NPK fertilizer was applied to the maize crop three times. First, second and third nitrogen, phosphorus and potassium fertilization was performed at 100%, 75%, 50% and 25% dosages.

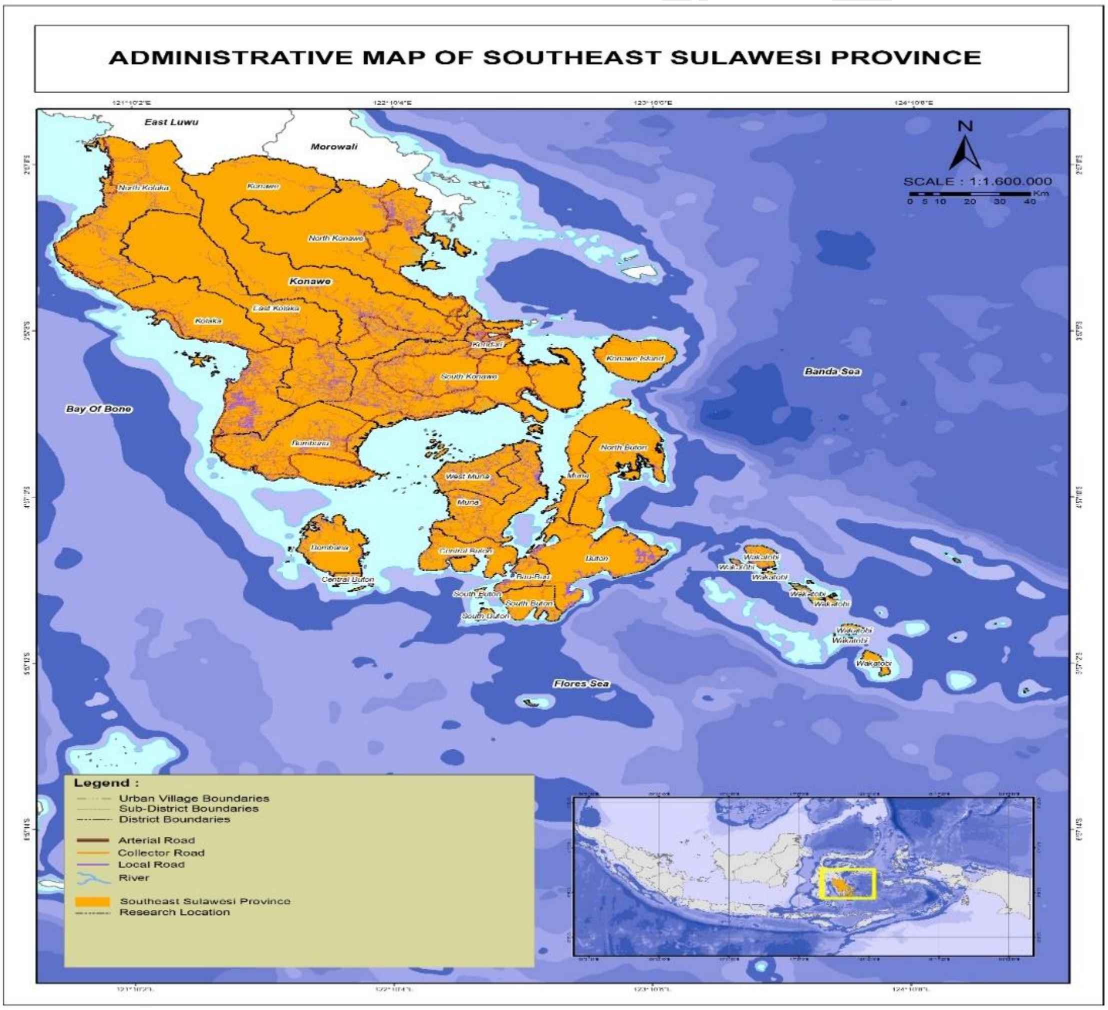

Fig. 1: Location of Southeast Sulawesi Province

Referring to the experiment conducted by Abdo et al. (2022), Battisti et al. (2023) and Wang et al. (2024), the fertilization treatment in this study was carried out in three stages: the first, second, and third applications, with nitrogen, phosphorus, and potassium doses of 25, 50, 75%, and 100%. These applications were conducted at 10, 30, and 50 days after planting the corn. The first fertilization took place during the early growth stage in April when the corn plants were 10 days old. The second fertilization was applied when the plants were 30 days old. The third fertilization was conducted when the plants were 50 days old, coinciding with the generative phase or the period of flower and husk formation.

The variables observed consisted of the chemical and physical properties of the soil as well as plant biomass. The growth characteristics consisted of plant height and the number of leaves. Productivity encompassed the number of cornhusks, length of maize cob, number of lines per maize cob, kernel weight per maize cob, weight per 1.000 kernels and yield. Growth characteristics analysis was performed following the procedures by Ceccarelli (2015); Azimi et al. (2018). Data analysis with ANOVA was aided by SAS 9.2. If the ANOVA results indicated a significant effect, Duncan's multiple range test (DMRT) and Tukey's test were then carried out at a 0.05 level (Tang & Zhang, 2013). Determination of soil pH, organic carbon content, nitrogen content, phosphorus content, potassium content, calcium content, magnesium content, cation exchange capacity (CEC) and soil texture was based on the soil laboratory analysis method (Agus et al., 2005).

Determination of Soil pH

Soil pH was determined following standard procedures to ensure accurate measurements. Similar to the method described by Sollen-Norrlin & Rintoul-Hynes (2024), which involved cooling, freezing, and oven-drying techniques, our experiment utilized 10 g of soil samples placed into each of two separate shakers. To each shaker, 50mL of deionized water and 50mL of 1 M KCl solution were added to assess the soil's water pH and KCl pH. The use of deionized water helps measure the active acidity present in the soil solution, while the KCl solution is employed to evaluate potential acidity by displacing exchangeable hydrogen and aluminum ions. This combined approach provides a comprehensive understanding of the soil's acid-base status, which is essential for effective soil management. The mixtures in the shakers were then agitated using a shaker machine for 30 minutes to achieve thorough homogenization. After shaking, the pH of each solution was measured using a pH meter that had been calibrated with standard buffer solutions of pH 7.0 and pH 4.0 to ensure precise readings. This dual calibration process is crucial for minimizing measurement errors and enhancing result reliability. The combination of deionized water and KCl solution provides a comprehensive understanding of the soil's acid-base balance, which is essential for determining appropriate soil management practices such as liming or fertilization.

Determination of Organic Carbon Content in the Soil

As much as 0.500 g of soil sample measuring <0.5mm was inserted into a 100mL volumetric flask added with 5mL of 1N K_2Cr2O_7 and shaken. Then, the mixture was added with 7.5mL of thick H_2SO_4, shaken and left to stand for 30 minutes. The solution was then diluted with deionized water to a volume of 100mL. On the next day, the sample's absorbance was measured using a spectrophotometer at a wavelength of 561 nm. As a benchmark, a 5,000ppm C standard solution was made in serial concentrations of 0, 50, 100, 150, 200 and 250ppm. In each concentration, the standard was treated in the same manner as the sample.

Determination of N Content in the Soil

As much as 0.500g of soil sample extract measuring <0.5mm was inserted into a digestion tube and added with 1 g of selenium reagent mixture and 3mL of thick sulfuric acid, then destructed to a temperature of 350°C (3-4 hours). Destruction was complete when white vapor was issued, and the clear extract was obtained (after approximately 4 hours). The tube was lifted and cooled down, and the extract was diluted with deionized water to a volume of 50mL exactly. The mixture was then shaken until reaching homogeneity and left to stand overnight to let the particles settle. N content was determined colorimetrically.

Determination of P, K, Ca and Mg Contents

P-content was determined by taking 5mL of soil sample extract and P standard solution (each in concentrations of 0, 2, 4, 6, 8, and 10ppm) into a test tube and adding 1mL of P dye reagent. The solution was then shaken and left to stand for 30min. P in the solution was measured with a spectrophotometer at a wavelength of 889 nm. K, Ca, and Mg contents were determined by taking 1mL of soil sample extract and standard solution for each element into a test tube and adding 9mL of 0.25% La solution. Afterward, the solution was shaken until homogeneity was reached. Ca and Mg were measured with an AAS (atomic absorption spectrophotometer), while K was measured with a flame photometer.

Determination of Cation Exchange Capacity (CEC)

As much as 2.5g of soil sample was inserted into a 50mL beaker glass, added with 5-7.5g quartz sand, and stirred until homogeneity was reached. Afterward, the soil sample mixture was added with 5g of quartz sand and inserted into a prepared percolation tube. Percolation was performed with 2 x 25mL of ammonium acetate solution at pH 7 (the percolate being removed).

The sample and sand in the percolation tube were washed with 100mL of ethanol and then subjected to percolation with 50mL of 10% NaCl solution; the percolate was held in a 50mL volumetric flask for CEC determination. As much as 20mL of percolate was inserted into a distillation boiling flask and added with 80ml of deionized water, a little liquid paraffin, and a boiling stone. An Erlenmeyer flask filled with 10mL of 1% boric acid and three drops of Conway indicator was used as a distillate container. Distillation was carried out by adding 10ml of 40% NaOH solution and ended after 75mL of distillate was obtained. The distillate was then titrated with 0.05 N H_2SO_4 standard solution until the solution changed color from green to pink. Blank determination was also carried out.

Determination of Soil Texture

Organic materials were oxidized with H_2O_2 and easily soluble salts were removed from the soil with HCl while being heated. The remainder consisted of minerals with sand, dust and clay. Sand could be separated by wet sieving, while dust and clay were separated by sedimentation.

RESULTS

Initial Soil Nutritional Status

The initial chemical and physical properties of the soil in the research location are presented in Table 1. Based on Table 1, the chemical and physical properties of the soil were categorized as very low to moderate, with the soil being of the sandy clay loam type. The carbon and nitrogen contents in the research location were categorized as very low to low, while the potassium, phosphorus, and magnesium contents were moderate. The soil had a neutral pH and moderate cation exchange capacity (CEC). The determination of fertility status based on the chemical properties of the soil refers to the CEC, pH, base saturation, and organic materials and potassium contents available in the soil (Bakri et al., 2016). The research results showed that the nitrogen content in the soil was very low, thereby requiring nitrogen fertilizer application to meet the nitrogen needs of the crop. Based on the results of the analysis, the nutrients in the soil were very low. The nitrogen need of the maize crop amounted to 350kgha^{-1}. The phosphorus and potassium needs in this research were moderate, amounting to 175kgha^{-1} and 75kgha^{-1}.

Table 1: Initial soil chemical and physical properties in the research location

Nutrients and physical condition of the soil	Initial chemical and physical properties of the soil	Category
Soil pH	6.78	Neutral
Organic carbon (%)	1.34	Low
N (%)	0.07	Very Low
P_2O_5 (mg/100g)	1.59	Moderate
K (me/l00g)	0.56	Moderate
Ca (me/l00g)	54.40	Very high
Mg (me/100g)	1.35	Moderate
CEC (me/100g)	22.18	Moderate
Texture:		Sandy clay loam
Sand (%)	28.24	-
Dust (%)	53.24	-
Clay (%)	18.52	-

Soil Chemical and Physical Properties and Maize Biomass

Based on the soil analysis results, the chemical and physical properties of the soil in the research location after fertilization experienced some changes in the sandy clay loam soil type (Table 2). It is known that the standard deviations in sandy clay loam soil type after N, P, K, organic and CaCO3 fertilization on average statistically indicated differences at P<0.05.

The pH of the soil decreased slightly after fertilization (from 6.78 to 6.4). A slight decrease in pH can be expected by applying certain fertilizers, particularly those that are acidic or contain calcium carbonate ($CaCO_3$). This change suggests that the soil may have become slightly more acidic after fertilization, which could influence nutrient availability.

Table 2: Chemical and physical properties of the soil

Nutritional contents and physical properties of the soil	Initial chemical and physical properties of the soil	Chemical and physical properties of the soil after fertilization	Fertilizing dosage thresholds
pH	6.78	6.4 (0.46)[a]	5.5–7.8
Organic carbon %	1.34	1.12 (0.42)[a]	0.5–5.0
Total N %	0.07	10.46 (4.34)[ab]	0.22
P (ppm)	1.59	10.12 (4.20)[ab]	21.0
K (cmolc kg^{-1})	0.56	10.34 (5.07)[ab]	0.26
Ca (cmolc kg^{-1})	54.40	7.28 (3.62)[a]	6.4
Mg (cmolc kg^{-1})	1.35	2.34 (1.10)[a]	2.3
KTK (cmolc kg^{-1})	22.18	10.68 (3.10)[a]	3–12
Sand (%)	28.24	46.82 (1.42)[a]	-
Dust (%)	53.24	35.44 (6.88)[b]	-
Clay (%)	18.52	24.98 (1.44)[a]	-

Note: Different letters indicate differences (a), and indicate significant differences (b) at P<0.05. Numbers in parentheses indicate standard deviations.

There was a reduction in organic carbon content from 1.34 to 1.12%. This decrease could be attributed to the mineralization of organic matter due to fertilization, leading to the breakdown of organic carbon. However, it remains within a reasonable range for supporting plant growth. The nitrogen content increased significantly, from 0.07 to 10.46%. This significant increase likely reflects the application of nitrogen-based fertilizers. The N content in the soil was substantially higher post-fertilization, indicating the positive impact of fertilization on soil fertility.

Phosphorus (P) content also showed a marked increase, from 1.59 to 10.12ppm. This is consistent with the addition of phosphorus fertilizer, which plays a key role in promoting root development and overall plant health. The Potassium (K) content increased from 0.56cmolc/kg to 10.34cmolc/kg, showing a significant boost due to fertilization. Potassium is crucial for plant growth, particularly for water regulation and disease resistance.

Calcium (Ca) content decreased slightly from 54.40 to 7.28cmolc/kg. This could be due to leaching or the chemical reactions between the soil and fertilizing agents, particularly with the use of fertilizers like $CaCO_3$, which may alter the soil's calcium balance. Magnesium (Mg) increased from 1.35 to 2.34cmolc/kg, positively impacting the soil's fertility. Magnesium is vital for photosynthesis and overall plant health. Cation Exchange Capacity (KTK) increased from 22.18 to 10.68cmolc/kg, indicating improved soil's ability to hold and exchange essential nutrients, benefiting plant growth. The soil's sand content increased dramatically (from 28.24 to 46.82%), while dust decreased (from 53.24 to 35.44%), and clay content remained relatively stable (18.52 to 24.98%). These changes suggest a shift in soil texture, which could affect water retention and nutrient availability. The shift toward more sand in the soil could improve drainage but may also reduce the soil's ability to retain nutrients.

The dosage thresholds provided (e.g., pH 5.5–7.8, organic carbon 0.5–5.0%, total N 0.22%, etc.) are useful for guiding future fertilization practices. The values indicate the optimal ranges for improving soil fertility and maize productivity.

Table 2 shows a clear impact of fertilization on soil properties, particularly in terms of nutrient content and texture. The observed changes indicate that the soil fertility improved, with increased nitrogen, phosphorus, potassium, and magnesium contents. However, the changes in pH and calcium and the increased sand content should be carefully monitored to ensure long-term soil health and optimal crop growth. The results indicate that N, P, and K fertilization significantly enhances the soil's chemical and physical properties, leading to increased maize biomass and yield. However, it is crucial to consider the long-term impact of such fertilization on soil sustainability, emphasizing the importance of adopting balanced and environmentally responsible fertilization practices. The statistical analysis of the chemical contents in maize biomass revealed significant differences at $P<0.05$ (Table 3). Table 3 shows that as fertilization levels (N, P, K) increase, maize biomass content in terms of carbon, nitrogen, phosphorus, and potassium also increases, demonstrating the positive impact of fertilization on maize growth. The 100% NPK treatment shows the highest values for C, N, P, K, and the C/N ratio, indicating that the optimal fertilization level results in the best overall maize biomass and nutrient content.

The carbon content in maize biomass increases significantly as fertilization levels rise, from 0.08% in the control group to 4.21% in the 100% NPK treatment. This suggests that higher fertilization rates lead to greater biomass production, corresponding to an increase in carbon content.

Nitrogen content increases progressively with the fertilization treatment, from 0.02% in the control group to 1.67% in the 100% NPK group. This increase is expected due to the application of nitrogen fertilizers, which directly contribute to nitrogen availability for maize growth. Phosphorus (P) content also rises with increased fertilization, from 0.07% in the control to 1.05% at 100% NPK fertilization. Phosphorus is essential for root development and energy transfer within the plant, and its increase likely reflects improved nutrient availability from fertilization. Potassium (K) content in maize biomass increases significantly with higher fertilization rates, especially in the 100% NPK treatment (1.18%). Potassium plays a crucial role in regulating plant metabolism and water balance, and its higher levels suggest improved plant health and stress resistance under optimal fertilization. The C/N ratio shows an interesting trend. The control group has a very low C/N ratio (0.40), while the ratio increases significantly with the application of NPK fertilizers, peaking at 23.75 in the 100% NPK treatment. A higher C/N ratio in the fertilized treatments indicates improved nitrogen assimilation and growth, which are essential for better biomass production.

Maize Growth and Yield

The treatment of N, P, K, organic and CaCO3 fertilization resulted in plant heights and total numbers of leaves presented in Fig. 2a and 2b. Fig. 2 shows that treatments at 100%, 75%, 50% and 25% N, P and K fertilization doses resulted in greater plant heights and greater numbers of leaves than treatments with organic and $CaCO_3$ fertilizers.

The application of N, P, K, organic and $CaCO_3$ fertilizers yielded differences in the number of maize husks and length of maize cob as can be seen in Fig. 3a and 3b. According to Fig. 3, the highest number of maize husks (2a) and longest maize cob (2b) were observed with 100% and 75% N, P, and K fertilization, followed by 50%, 25%, and organic and $CaCO_3$ fertilization as control treatments. The 75% and 100% N, P, and K fertilization levels were most effective in enhancing both the number of maize husks and the length of the maize cob, yielding the best results.

Table 3: Average chemical contents of maize biomass after N, P, K, organic, and CaCO3 fertilization in sandy clay loam soil type

Fertilization Treatments	C	N	P (%)	K	C/N
Control (organic and CaCO3 fertilizers)	0.08 (0.41)a	0.02 (0.04)a	0.07 (0.30)a	0.22 (0.09)a	0.40 (0.31)a
25% nitrogen (N), phosphorus (P), and potassium (K)	1.32 (0.43)a	1.06 (0.34)a	0.68 (0.40)a	0.51 (0.20)a	11.53 (0.22)a
50% nitrogen (N), phosphorus (P), and potassium (K)	2.64 (0.46)a	1.21 (0.51)b	0.72 (0.43)a	0.55 (0.31)a	10.82 (0.37)a
75% nitrogen (N), phosphorus (P), and potassium (K)	3.91 (0.54)b	1.45 (0.67)b	0.82 (0.53)b	0.47 (0.56)b	14.51 (0.40)a
100% nitrogen (N), phosphorus (P), and potassium (K)	4.21 (0.56)b	1.67 (0.71)b	1.05 (0.62)b	1.18 (0.62)b	23.75 (0.51)b

Note: Different letters indicate differences (a), and indicate significant differences (b) at $P<0.05$. Numbers within parentheses indicate standard deviations.

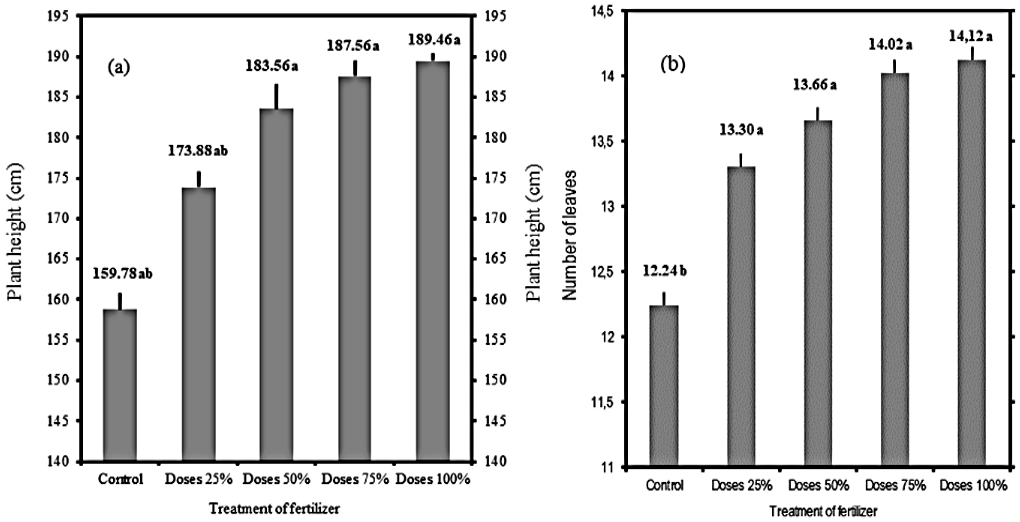

Fig. 2: Average plant heights (a) and numbers of leaves (b) of the maize crop.

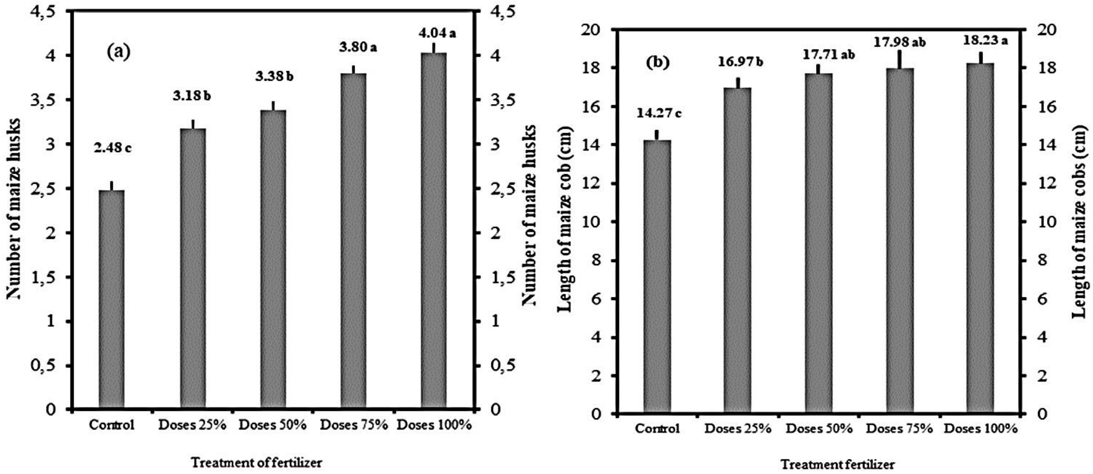

Fig. 3: Average number of cornhusks (a) and length of maize cob (b).

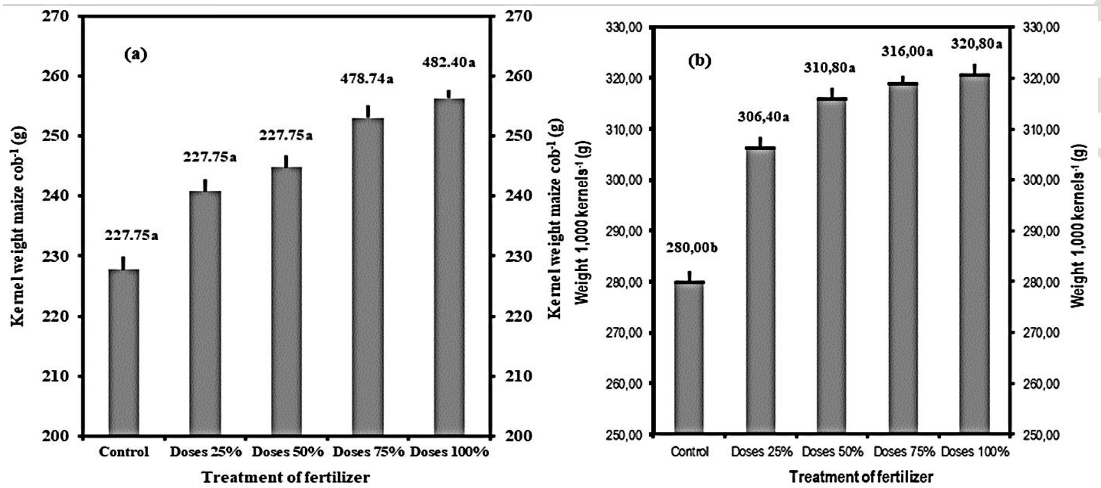

Fig. 4: Average number of lines maize cob^{-1} (a) and number of kernels maize cob^{-1}.

According to Fig. 4, the highest number of lines (3a) and kernels (3b) per maize cob were achieved with 100% and 75% N, P, and K fertilization, followed by 50%, 25%, and organic and $CaCO_3$ fertilization treatments. Application of N, P and K fertilizers at 100%, 75%, 50% and 25% dosages was highly suitable for increasing the number of lines and kernels per maize cob. Applying N fertilizer at 190-205kgha-1 and phosphorus fertilizer at 28-56kg/ha to the maize crop in dry land could increase the number of kernels per maize cob by 10% (Catherine et al., 2017).

Applying N, P, K, organic, and CaCO3 fertilizers resulted in significant differences in kernel weight per maize cob (Fig. 4a) and weight per 1,000kernels (Fig. 4b), as shown in the respective figures. Application of N, P, K, organic and CaCO3 fertilizers demonstrated differences in the maize yield, as presented in Fig. 5.

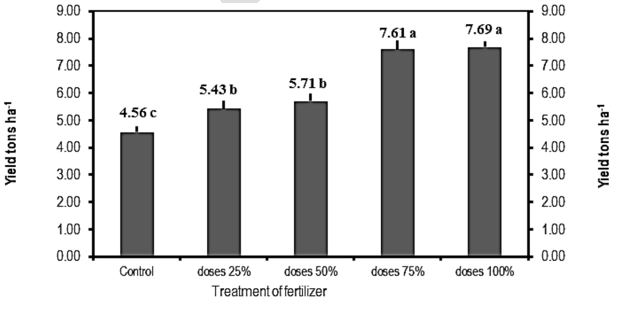

Fig. 5: Average maize yield.

DISCUSSION

The soil pH at the research site was within the neutral range, creating favorable conditions for maize growth. However, the low carbon content indicated a need for organic fertilizer application prior to NPK fertilization. Organic fertilizer is essential for improving soil fertility, enhancing microbial activity, and promoting nutrient availability. Its application has been shown to improve the growth and yield of sweet corn (Fattah et al., 2019). The research site's cation exchange capacity (CEC) was moderate, signifying an adequate capacity to retain and exchange essential nutrients. Increasing CEC by adding organic fertilizers and CaCO3 can further enhance nutrient retention and availability. The combined application of organic fertilizer, CaCO3, and NPK fertilizers has positively affected maize growth and production (Fattah et al., 2019). Magnesium and calcium levels in the soil were found to be sufficient to support maize growth. Magnesium is vital for chlorophyll formation and the synthesis of carbohydrates, fats, and oils. It also facilitates phosphorus transport in plants. Meanwhile, calcium is crucial for strengthening plant cell walls, promoting root hair and seed formation, and neutralizing harmful soil compounds. Ensuring sufficient levels of these nutrients is essential for optimal maize development.

These findings align with previous research highlighting the benefits of combining organic and inorganic fertilizers to improve corn growth and yield. For example, Satria et al. (2021) reported that applying NASA liquid organic fertilizer at 10mL per liter of water, combined with 50% or 75% of the recommended NPK dose, significantly enhanced sweet corn height, cob weight, cob length, and cob diameter. Similarly, Wirayuda & Koesriharti (2020) demonstrated that integrating 10 tons of chicken manure per hectare with 250kg/ha of NPK fertilizer or combining chicken manure with liquid organic fertilizer and NPK doses of 200 kg and 250 kg per hectare, improved sweet corn growth and yield parameters. Soil texture analysis at the research site indicated a sandy clay loam composition consisting of 28.24% sand, 53.24% silt, and 18.52% clay. The soil classification was conducted at 0–30cm depth, considering both chemical and physical properties, including pH, organic carbon content, nutrient levels, CEC, and texture (De-Feudis et al., 2019). These characteristics align with findings by Azidun et al. (2023), who reported that soil in the study area had a neutral pH, low organic carbon content, very low nitrogen content, moderate phosphorus, potassium, and magnesium levels, moderate CEC, very high calcium content, and a sandy clay loam texture. Statistical analysis indicated a decline in soil pH, organic carbon content, calcium content, and CEC, while nitrogen, phosphorus, potassium, and magnesium levels increased, albeit insignificantly. The reduction in soil pH following NPK fertilization was attributed to sulfur in the fertilizer reacting with water molecules, oxygen, and CO_2, producing sulfate and H+ ions (Ganti et al., 2023). Changes in soil physical properties were also observed, with slight increases in sand and clay content and a significant decrease in silt content.

Sandy clay loam soil is generally acidic and deficient in nitrogen, phosphorus, potassium, and organic content. Consequently, applying NPK, organic, and $CaCO_3$ fertilizers is necessary to improve maize growth conditions. Fertilization enhanced the soil's physical and chemical properties by increasing nitrogen, phosphorus, potassium, organic content, and CEC. Sand and clay content increased by 18.58 and 6.46%, respectively, while silt content decreased significantly by 17.8%. Studies by Faloye et al. (2019) and Jamidi et al. (2022) have confirmed that applying NPK and organic fertilizers enhances soil properties by increasing potassium content, CEC, soil pH, and total nitrogen content. Statistical analysis of maize biomass nutrient content showed significant differences at $P<0.05$. The highest organic carbon, phosphorus, and potassium contents were achieved with 75 and 100% NPK fertilization, while the best nitrogen content was recorded with 25, 50, and 75% NPK fertilization. The optimal carbon-to-nitrogen (C/N) ratio was obtained with 75% NPK fertilization. Increasing NPK fertilization positively correlated with improved maize biomass nutrient content.

Nitrogen fertilization effectively improved the growth, biomass, and yield of maize, barley, and sorghum. Asibi et al. (2019) reported that applying nitrogen fertilizer at an optimal dosage increased maize biomass by 25–42%. Similarly, De-Feudis et al. (2019 & 2020) demonstrated that nitrogen, phosphorus, and potassium fertilization significantly improved nitrogen, phosphorus, potassium, and organic carbon content in plant biomass. The highest maize biomass nutrient contents were achieved with 100% NPK fertilization for carbon, phosphorus, and potassium; 50%, 75%, and 100% NPK fertilization for nitrogen; and 100% NPK fertilization for the best C/N ratio. Maize is also rich in essential nutrients such as magnesium, phosphorus, potassium, and vitamins A, B, E, and K (Nikolić1 et al., 2019).

Ensuring adequate nitrogen, phosphorus, and potassium supply is crucial for improving maize plant height, leaf count, and overall growth. NPK fertilization enhances soil fertility and nutrient availability (D'Amato et al., 2019; De-Feudis et al., 2019; De-Feudis et al., 2020; Maulidi et al., 2022). Nitrogen and phosphorus fertilizers have been shown to improve maize growth and increase yield significantly. Optimal maize cob production was achieved with 100% and 75% NPK fertilization. These treatments also produced the highest kernel weight per cob and 1,000-kernel weight. Fertilization during the generative phase notably improved kernel formation, flower production, and kernel filling. Additionally, optimal kernel weight was achieved on peat land, where improved nutrient uptake, physiological processes, and photosynthesis contributed to enhanced yield. Fertilizing phosphorus and nitrogen at 100–200kg/ha effectively increased maize yield on dry land (De-Feudis et al., 2020). Gheith et al. (2022) also reported improved grain production with fertilization.

The highest maize yields were recorded with 100% NPK fertilization (7,690kg/ha), followed by 75% (7,610kg/ha), 50% (5,710kg/ha), and 25% (5,430kg/ha) NPK fertilization. The control treatments had the lowest yield (4,560kg/ha). Previous research has consistently shown that nitrogen, phosphorus, and potassium fertilization significantly increase maize yields (Asibi et al., 2019; Efendi et al., 2020). Notably, Efendi et al., (2020) reported that NPK fertilization increased NASA 29 maize yield to 11,500kg/ha, with yield increases reaching 9,300–9,610kg/ha compared to control yields of 2,550–5,630kg/ha. Insufficient nutrient availability was identified as a key factor limiting yields in treatments with 50% and 25% NPK applications (Gheith et al., 2022).

Conclusion

The initial chemical and physical properties of the soil were as follows: neutral soil pH, low organic carbon content, very low N content, moderate P, K and Mg contents, moderate CEC, very high Ca content, and sandy clay loam soil physical properties. After the application of N, P, K, organic and $CaCO_3$ fertilizers, the soil pH, organic C and Ca contents, CEC and dust content decreased, while N, P, K, Mg, sand and clay significantly increased. The greatest organic carbon, P and K contents and the greatest maize biomass were obtained at the treatment of 75% and 100% N, P and K fertilization and the highest N content was obtained at the treatment of 50%, 75%, and 100% N, P, and K fertilization. The best C/N ratio was obtained at the treatment of 100% N, P, and K fertilization. The best maize growth and productivity were obtained at the treatment of 50%, 75% and 100% N, P and K fertilization, while the highest yield was obtained from 75% (7.610kgha^{-1}) and 100% (7.690kgha^{-1}) N, P and K fertilization.

Scientific Contribution (Novelty): The latest novelty perspective of this finding that significantly contributes to science underlines that dryland management engineering for corn plants begins with three approaches. The first is soil pH, organic carbon content, and integration of organic fertilizer with NPK treatment in increasing corn growth and yield. While soil pH is ideal for corn cultivation, low organic carbon content requires the application of organic fertilizer before NPK fertilization. Second, the importance of increasing the cation exchange capacity (CEC) with organic fertilizer and $CaCO_3$, which significantly increases corn productivity. The soil texture, identified as sandy clay loam, was changed through fertilization, optimizing physical properties to support plant development. Third, the application of NPK, organic, and $CaCO_3$ fertilizers not only supports the chemical and physical properties of the soil but also directly affects plant performance, emphasizing the effectiveness of an optimized fertilization strategy for sustainable corn production.

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Data Availability: The data is available from the corresponding author based upon a reasonable request.

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