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Potential of Manure and Urea Fertilizer on Maize (*Zea mays* L.) Productivity and Soil Quality in the Northern Highlands of Tanzania

Lydia Mhoro [1,2,*], Akida Ignas Meya [1], Nyambilila Abdallah Amuri [2], Patrick Alois Ndakidemi [1], Karoli Nicholas Njau [3] and Kelvin Mark Mtei [1]

1 School of Life Sciences and Bioengineering, The Nelson Mandela African Institute of Science and Technology, Arusha P.O. Box 447, Tanzania
2 College of Agriculture, Sokoine University of Agriculture, Morogoro P.O. Box 3008, Tanzania
3 School of Materials, Energy and Environmental Sciences, The Nelson Mandela African Institute of Science and Technology, Arusha P.O. Box 447, Tanzania
* Correspondence: mhorol@nm-aist.ac.tz or mhoro.lydia@sua.ac.tz

Abstract: Many agricultural fields are no longer sustainable due to inadequate replenishment of soil nutrients through organic and inorganic inputs, particularly in smallholder farming systems. As a result, achieving potential crop yields in these systems has proven to be difficult. Field trials were conducted in two long rainy growing seasons in 2021 and 2023 to assess the effects of urea fertilizer and cattle manure as sources of nitrogen (N) on (i) maize crop yields and (ii) soil chemical properties at two sites (Kwa Sadala and Mungushi) located in Hai district, northern Tanzania. The trials employed a randomized complete block design with three replicates, including eight treatments. The treatments were: 0 fertilizer (control), 25, 50, 75 kg N ha^{-1} (sole urea), 12.5 kg N (urea) + 12.5 kg N (cattle manure), 25 kg N (urea) + 25 kg N (cattle manure), and 50 and 75 kg N (sole cattle manure). Results show that the highest application rate of urea (75 kg N ha^{-1}) produced the highest grain yields of 4.21 and 4.09 t ha^{-1} in the 2021 season and 4.32 and 4.04 t ha^{-1} in the 2023 season at Kwa Sadala and Mungushi, respectively. The application of cattle manure at the highest rates increased the soil pH by 3.15 and 2.26% at Kwa Sadala and Mungushi, respectively. Similarly, soil total N, OC, available/extractable P, and exchangeable K increased by 100%, 56.3%, 52.36%, and 19.67%, respectively, at Kwa Sadala and by 16.67%, 18.13%, 20.95%, and 6.76%, respectively, at Mungushi. The use of urea alone at the higher rates or in combination with cattle manure at 50% each resulted in the highest net benefit (NB) in all sites. The findings from this study suggest that a comprehensive approach to managing soil nutrients, such as combining inorganic and organic inputs, may improve crop yields while maintaining soil health.

Keywords: cattle manure; urea; lowlands; land degradation; smallholder farming

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1. Introduction

Maize (*Zea mays* L.) is and will continue to be the most produced crop in East Africa because it serves a dual purpose for most smallholder farmers, i.e., it is used as a staple food and a cash crop for generating households' incomes in smallholder farmers [1,2]. In Tanzania, maize is ranked as the first cereal crop grown in the country, estimated to cover about 4.12 million hectares (ha) (approximately over 45%) of cultivated land with an annual production tonnage of about 6.5 metric [3]. Despite its contribution to food security in

Tanzania, the average maize yield in smallholder fields is 1.4 tons per hectare (ha^{-1}), much below the present potential yield of up to 6 tons ha^{-1} [4–6]. Numerous problems have been identified as impeding the production of maize in small holdings. These include low soil fertility, pests, diseases, the use of simple farm equipment, drought, and low inputs like local varieties or improved seeds that are recycled [6]. Nevertheless, insufficient soil fertility has been the primary constraint on small-scale holdings following drought in rain-fed environments [7,8].

The use of inorganic fertilizers by smallholder farmers is very limited, with their high utilization costs being the biggest constraint for most smallholder farmers [9]. Moreover, a number of drawbacks are linked to inorganic fertilizers, including the escalation of environmental pollution in the form of runoff and leaching that pollutes groundwater, especially in highly resourced farms [10,11]. Certain fertilizers, such as those based on ammonium, are also said to cause land degradation by raising the acidity of the soil [12]. Consequently, the majority of smallholder farmers rely entirely on natural soil fertility and/or small applications of organic inputs such as animal manure or crop residues (if any) [13].

Maize requires a large quantity of nutrients, especially nitrogen (N), for improved production [14]. Many compounds involved in crop physiological growth, such as enzymes, dry matter formation, chlorophyll, and nucleic acid, depend on N [15]. On the other hand, sufficient N content in the soil has been demonstrated to enhance the uptake of other nutrients like P, K^+, Ca^{2+}, Mg^{2+}, Na^+, and Zn^{2+}, depending on the crop type, agronomic techniques, and environmental factors [15–17]. Increasing N inputs with chemical fertilizers alone has proven to be a huge challenge, particularly for poor-resource-endowed smallholder farmers, who are the major crop producers in Tanzania. Research has shown that combining mineral and organic fertilizers enhances soil quality while simultaneously increasing crop productivity [11,13]. Organic fertilizers come from a variety of sources, including crop residues and animal manure. Cattle manures, like any other organic fertilizer, are well known for their benefits as soil amendments; in addition to offering all necessary nutrients, they also serve as a source of carbon for micro-fauna in soils and enhance several physical characteristics such as bulk density, aeration, water retention, and porosity [18]. Earlier studies have shown that applying manure to agricultural land improves soil quality and crop yield gradually and sustainably [13,19,20]. This suggests that manure can enrich soil with essential plant nutrients, such as N, P, K, and SOM, even after application years.

The Hai district in the Kilimanjaro region, like any other district in Tanzania, depends heavily on agriculture for the economic development of the area, which accounts for over 80% of peoples' livelihoods [21]. Two primary farming systems are prevalent in the area: one is a home garden, where the main crop is bananas mixed with other crops like coffee, legumes, and/or vegetables. The home garden is usually integrated with livestock such as dairy cattle, goats, chickens, pigs, and sheep, with cattle being the dominant livestock [22]. This system is mainly predominant on the highland slope of Mt. Kilimanjaro (1000–1900 m above sea level). This system has been operating for over a century, and it has been managed using animal manure [23]. Smallholder farmers in the region are compelled to search for land elsewhere to make up the shortfall since the system is no longer sustainable due to land constraints [24]. As a result, the lowland farming system, which is dominated by maize and common beans (*Phaseolus vulgaris*), has become the region's primary second farming system [7,24]. The cultivated land for maize in the district is approximately 22,000 ha, which accounts for about 30% of the cultivated land [7,25]. The district has seen a decline in maize yield over the years, with yields varying from 0.8 to 1.5 t ha^{-1}, depending upon the management strategies employed by individual smallholder farmers [7,25].

In lowland areas (maize-based farming systems), farmers harvest both crop grains and residues, leaving the land bare and exposing it to soil erosion [26]. This practice has led to huge land degradation in the lowlands and posed many challenges to people's livelihood, among others, declining soil fertility, which in turn resulted in low crop yields in the area [26]. Nevertheless, in lowland (maize-based field) areas, farmers solely use inorganic fertilizers, which are applied at rates below recommended [27]. Research pertaining to the application of livestock manure either alone or in combination with inorganic fertilizers revealed significant increases in maize yield and enhanced soil fertility in other areas [12,13]. The use of manure in the lowland maize-based farming systems on the slopes of Mount Kilimanjaro has not been documented, despite the fact that it is a frequent practice in the highland banana agricultural systems. Our hypothesis was that the incorporation of inorganic fertilizer along with organic manure would help restore the degraded land and improve maize yields in maize-based farming on the slopes of Mount Kilimanjaro. Tanzania's population is expected to increase from its current 60 million people to 150 million by 2050 [28]. With this projection, it suggests that maize will continue to be in high demand in the future. Because soil fertility is declining quickly and food constraints are increasing, agricultural stakeholders and researchers must act decisively to feed the expanding population. Therefore, the purposes of this study were to investigate the potential effect of N fertilization through urea, cattle manure, and combinations of urea and manure on improving maize yield and soil quality in smallholdings on the slope of Mt. Kilimanjaro.

2. Material and Methods

2.1. Characteristics of the Study Site

The study was conducted in Hai district, Kilimanjaro region, on the southern foot slopes of Mt. Kilimanjaro, northern Tanzania, between 750 and 1050 m above sea level (m.a.s.l.). The district is located between 3°09′60.00″ S and 37°09′60.00″ E [7]. The area is characterized by semi-arid conditions, with an annual rainfall ranging between 500 and 900 mm and a mean annual temperature of 23 °C [25]. The district experiences bimodal rainfalls, with the long rainy season starting in March and ending in June, while the short rainy season starts in November and ends in December [25]. The relative humidity in the district is approximately 74%, with a wind speed of 12 km/h. Farmers often grow maize in association with common bean during the long rainy season, with short-term plants such as common beans dominating during the short rainy season. Rainfall data were collected from the nearby Kilimanjaro airport meteorological station during the long rainy growing seasons of 2021 and 2023 in order to compare crop yields between seasons (Figure 1).

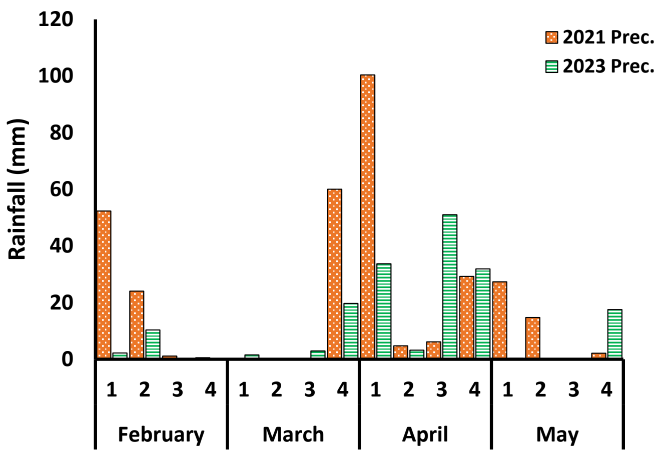

Figure 1. Monthly rainfall distribution during long rainy cropping seasons for 2021 and 2023 in Hai district, Kilimanjaro region, central–northern Tanzania. NB: numbers (1–4) weekly data; Prec. = precipitation.

2.2. Site Selection, Soil Sampling, and Analysis

Two sites in the lowland areas of Hai district, geographically distributed, were selected for the establishment of field experiments. The sites were located 10 km apart in order to see the responsiveness of maize to the applied fertilization treatments. Before the establishment of the field experiment, topsoil samples (0–30 cm surface layer) were taken from each experimental field for a general soil fertility assessment. On each experimental field, one composite soil sample was collected. To make one composite sample, sub-samples were collected from five points within a field. The soil samples were air dried, ground, and sieved through a 2 mm mesh to obtain fine earth for laboratory analysis. The soil samples were analyzed for particle size distribution using the hydrometer method (ref), while soil pH was in a 1:2.5 soil/water ratio using the glass electrode of a pH meter. Total N was determined by the Kjeldhal method and organic carbon (OC) was determined by the dichromate wet oxidation method. Available P was determined by Bray and Kurtz, and ammonium acetate was used to determine exchangeable K. In addition, the cattle manure was analyzed for N, P, and K contents in the two consecutive cropping seasons before being applied to the experimental plots. The physicochemical characteristics of the soil and manure properties at the study sites are presented in Table 1 below.

Table 1. Study site geographical coordinates, soil, and manure properties.

Parameter	Location	
	Kwa Sadala	**Mungushi**
Geographical coordinates	03°18′930″ S 037°10′972″ E	03°17′935″ S 037°09′279″ E
Altitudes (m.a.s.l.)	998	1004
Soil property		
Sand (%)	32.5	34.8
Silt (%)	12.8	19.7
Clay (%)	54.7	45.5
Textural class	Clay	Clay
Soil pH (1:2.5, water:soil)	6.67	6.62
Total N (%)	0.112	0.244
OC (%)	1.19	1.93
Ext. P (mg kg^{-1})	12.6	23.2
Exch. K cmol$_+$ kg^{-1}	0.609	0.738
Cattle Manure property	Season 1	Season 2
Total N (%)	1.07	1.03
Total P (%)	0.187	0.242
Total K (%)	0.563	0.625

2.3. Experimental Layout, Fertilization Treatments, and Field Management

Field experiments were conducted in two long rainy cropping seasons to assess the response of maize to the applied urea and cattle manure. The first field experiment was conducted in the year 2021. However, due to the long drought spell experienced in the year 2022 cropping season, the second experiment was shifted to the year 2023 cropping season. The fields were ploughed using a tractor-mounted disc plough. The experiments were laid out in a randomized complete block design (RCBD) with eight fertilizer treatments and three replications. Different rates of N (25, 50, and 75 kg N ha^{-1}) were applied as per assigned treatment. In the area, the recommended N fertilizer prescription is 50 kg N ha^{-1}. Therefore, the assigned treatments used for the current experiment were half lower and half higher than the prescribed rate. The control (no fertilizer) and 25 kg N ha^{-1} treatment rates were chosen based on the practices of smallholder farmers in the area, who use very little or no N fertilizer at all. On the other side, the 75 kg N ha^{-1} used for this treatment was to compare the yield results with the recommended rate since the rate is blanket for the entire zone (Northern zone of Tanzania) and has been last for over three decades. The source of nitrogen fertilizer was Urea and cattle manure. The size of the experimental plot was 4 by 3 m (12 m^2). Eight treatments were formulated, as shown in Table 2 below.

Table 2. Nitrogen fertilization treatments.

Treatment	Treatment Description
T1	0 kg N (control)
T2	25 kg N ha^{-1} from urea [50% below the recommended N rate (farmers' practice)]
T3	50 kg N ha^{-1} from urea (recommended N rate)
T4	75 kg N ha^{-1} from urea (50% above recommended N rate)
T5	12.5 kg N ha^{-1} from cattle manure + 12.5 kg N ha^{-1} from urea (50% below recommended N rate)
T6	25 kg N ha^{-1} from cattle manure (50%) + 25 kg N ha^{-1} from urea (50%) (recommended N rate)
T7	50 kg N ha^{-1} from cattle manure only (recommended N rate), equivalent to 5 t of cattle manure ha^{-1}
T8	75 kg N ha^{-1} from cattle manure only (50% above recommended N rate), equivalent to 7.5 t of cattle manure ha^{-1}

Phosphorus was blanketed at 20 kg ha^{-1} in each treatment plot (except the control). Cattle manure and inorganic P fertilizer were applied once at planting time to facilitate decomposition and solubility, respectively. An improved maize hybrid variety, SC 403, which is well adopted by smallholder farmers in the study area, was used as a test crop. The variety takes about 75–90 days to mature, with an average potential yield of up to 6 t ha^{-1}. In each experimental plot, the maize seeds were planted at a spacing of 0.30 by 0.75 m with five rows and 10 plants per row, making a population of 50 maize plants per plot. Maize planting was completed on March 25 for the cropping season of 2021 and on April 2 for the cropping season of 2023. The N fertilizer was applied in two equal splits, whereby half of the fertilizer budget was applied as side-dressed 21 days after planting, and the remaining half was applied 42 days after planting. Basal placement was used for the inorganic P fertilizer, while cattle manure was broadcasted and incorporated in the respective treatment plots. Weeding was conducted twice with a hand hoe, three and six weeks following planting. Identification of any disease or insect attack was done visually, and any unusual observations were corrected immediately during the plant growth period.

2.4. Plant Data Acquisition and Analysis

2.4.1. Plant Height and Leaf Area per Plant

Plant height and leaf area were assessed in 18 randomly selected plants in the central rows at 100% tasseling stage from each treatment plot. Plant height (cm) was measured from the base of the plant to the tassel tip with the use of a meter rod. Leaf area was determined by measuring the total length and maximum width of each leaf at tasseling [29]. Data on leaf length and width were used to calculate leaf area using Equation (1) below.

$$S = \sum_{n=1}^{i} (L \times W \times 0.75) \quad (1)$$

where S is the total area of a fully expanded maize leaf (cm^2), L is the length of the leaf (cm), W is the maximum width of the leaf, and i is the number of leaves per plant.

2.4.2. Plant Yield and Yield Components

At crop harvest, 18 randomly chosen plants from central rows in each treatment plot were cut off at the base for yield and yield component measurements. Following the removal of the husks, the cob length (cm) and grain number per cob were measured. Nevertheless, the maize stovers were chopped and weighed at field moisture content for the biomass quantification. The maize grains were threshed from the cobs and sun-dried to a moisture content of 13%. The total grain weight in each treatment plot and the 1000 kernel weight were measured using an electronic weighing balance. The grain yields in each treatment plot were expressed as t ha^{-1} using Equation (2) below [30].

$$GY\left(\text{t ha}^{-1}\right) = Grain\ weight \times 10 \times \frac{\frac{(100 - MC)}{(100 - adjusted\ MC)}}{Plot\ area} \quad (2)$$

where GY is grain yield (t ha^{-1}), grain weight is in kg, MC is moisture content expressed in percentage (%), and plot area is in m^2.

2.4.3. Economic Analysis of the Fertilizer Use from Experimental Site

A cost–benefit analysis of the current urea fertilizer and manure usage as a source of N was conducted. Over the course of the experiment with the two cropping seasons, the costs and benefits of inverting fertilizer application rates were assessed using the inventory of cash flow from production costs, which includes labor, inputs, land preparation, and agronomic expenditures. Interviews with farmers and market vendors provided information on input costs (price of seeds, fertilizers, manure, labor, and transportation) and output costs (price of maize grains at the farm and the local market). The cost of urea and cattle manure and their labor application costs were taken into consideration. The cost of N from urea was equivalent to 1.32 and 2.07 USD kg^{-1} N for the growing seasons of 2021 and 2023. This variation was due to fertilizer price fluctuations between the two growing seasons. On the other hand, the cost of manure did not differ between the two cropping seasons, which was 32.7 USD t^{-1}. The labor application costs for urea were 17.5 USD ha^{-1}, while the manure application costs varied between 19.5 and 24.8 USD ha^{-1} based on the bulkiness of the manure. Although the same field was employed, the output (grain yield) was reduced by 10% less on the theory that a farmer employing the same technology would achieve a yield drop of 10% larger than that from the experiment [31]. The economic analyses were conducted similarly to those by [32], which involved calculating total production costs (TC), net benefits (NB), gross benefits (GB), and gross benefit/cost ratios (BCRs), as expressed in the formulas (Equations (3) and (4)) below:

$$Net\ benefit\ (\text{BN}) = Gross\ benefit\ (\text{GB}) - total\ cost\ (\text{TC}) \quad (3)$$

$$Benefit\ cost\ ratio\ (\text{BCR}) = \frac{Gross\ benefit\ (\text{GB})}{Total\ cost\ (\text{TC})} \quad (4)$$

2.5. Soil Analysis After N Fertilization Trial

Following the two cropping seasons, samples of soil were collected from each fertilizer treatment plot for laboratory analysis. The purpose was to examine the effect of fertilizers (urea and cattle manure) on soil properties. In each treatment plot, one composite soil sample taken from five spots within the plot was taken for lab analysis. The samples were air dried, ground, and sieved to a 2 mm mesh to obtain fine earth. The samples were analyzed for pH, total N, OC, extractable P, and exchangeable K using normal lab procedures as described in Section 2.2 above.

2.6. Statistical Analysis

All acquired data were subjected to analysis of variance (ANOVA) using Genstat software (15th edition). Tukey multiple range test was used to separate the means. Microsoft Excel 2010 was used to produce the graphs.

3. Results

3.1. Soil Properties After N Fertilizer Amendments

The impact of N fertilization on the soil properties at the study sites is shown in Figures 2 and 3. At the Kwa Sadala, sole urea applications (T2–T4) resulted in soil pH reductions of 1.20%, 2.25%, and 3.30% from the initial soil pH for the treatments received at 25, 50, and 75 kg N ha^{-1}, respectively. On the other hand, applications of cattle manure alone (T7 and T8) or in combination with urea (T6) raised the pH of the soil by 1.95%, 3.15%, and 1.2%, respectively (Figure 2A). Unlike urea only, applications of cattle manure at the recommended and highest N rates (T7 and T8) resulted in a significant ($p < 0.001$) increase in other soil properties, including total N, OC, P, and K. Application of cattle manure alone at the recommended rates of 50 kg N ha^{-1} and the highest rate of 75 kg N ha^{-1} resulted in a twofold increase in the soil total N content. In addition, applications of cattle manure alone at the highest N rate increased soil OC, P, and K by 56.3%, 52.4%, and 19.8%, respectively (Figure 2). Comparable results were also observed at the Mungushi, where the applications of urea alone at the recommended (T3) and highest N rate (T4) resulted in a 0.45% and 3.78% reduction in soil pH, respectively. Nevertheless, the addition of cattle manure alone (T7 and T8) or in combination with urea (T6) increased the soil pH by 1.67%, 2.26%, and 1.06%, respectively (Figure 3). Applications of cattle manure only also showed increases in other soil characteristics, such as N, OC, P, and K. For instance, the use of the highest N rate derived from cattle manure only (T8) increased soil N, OC, P, and K by 16.7%, 18.1%, 21.0%, and 6.76%, respectively (Figure 3).

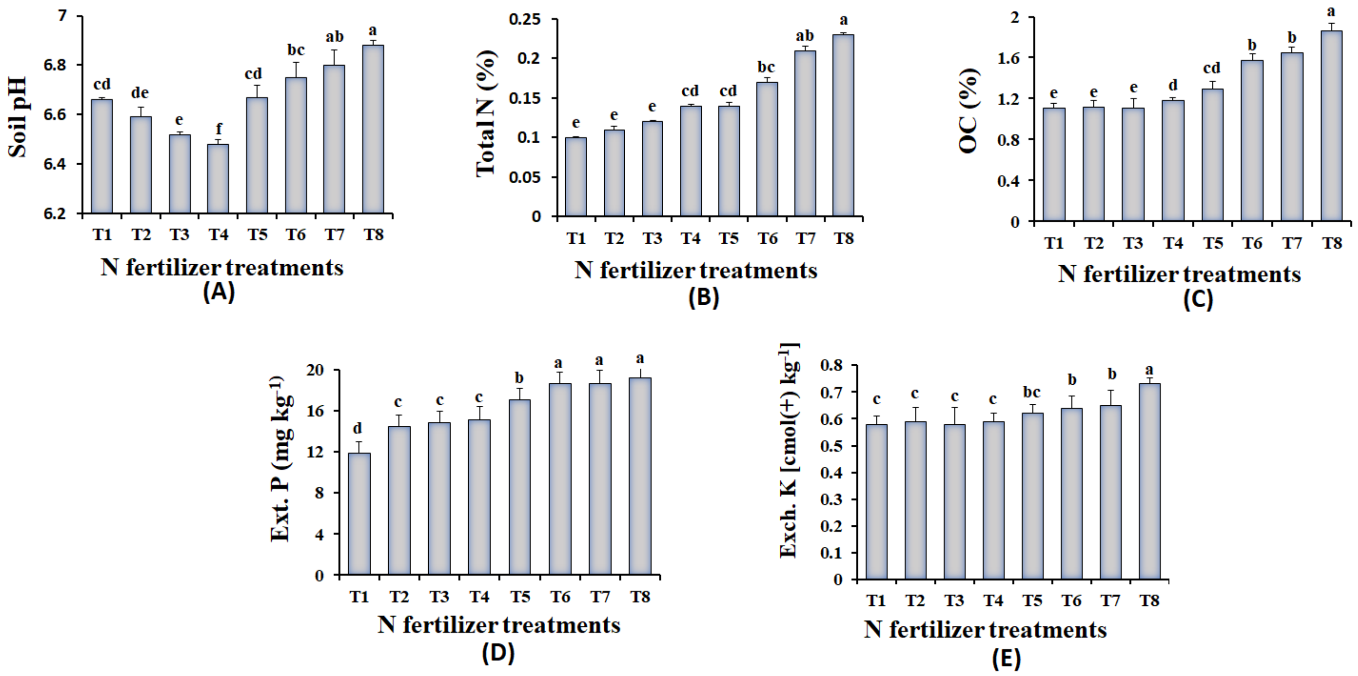

Figure 2. Effect of N fertilization treatments on soil properties; (**A**) soil pH, (**B**) total N, (**C**) OC, (**D**) ext. P, and (**E**) exch. K at Kwa Sadala site after two maize cropping seasons on the slope of Mt. Kilimanjaro, in Hai district, Kilimanjaro region, central–northern Tanzania. Vertical bars sharing a common letter(s) are not significantly different at $p < 0.001$. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

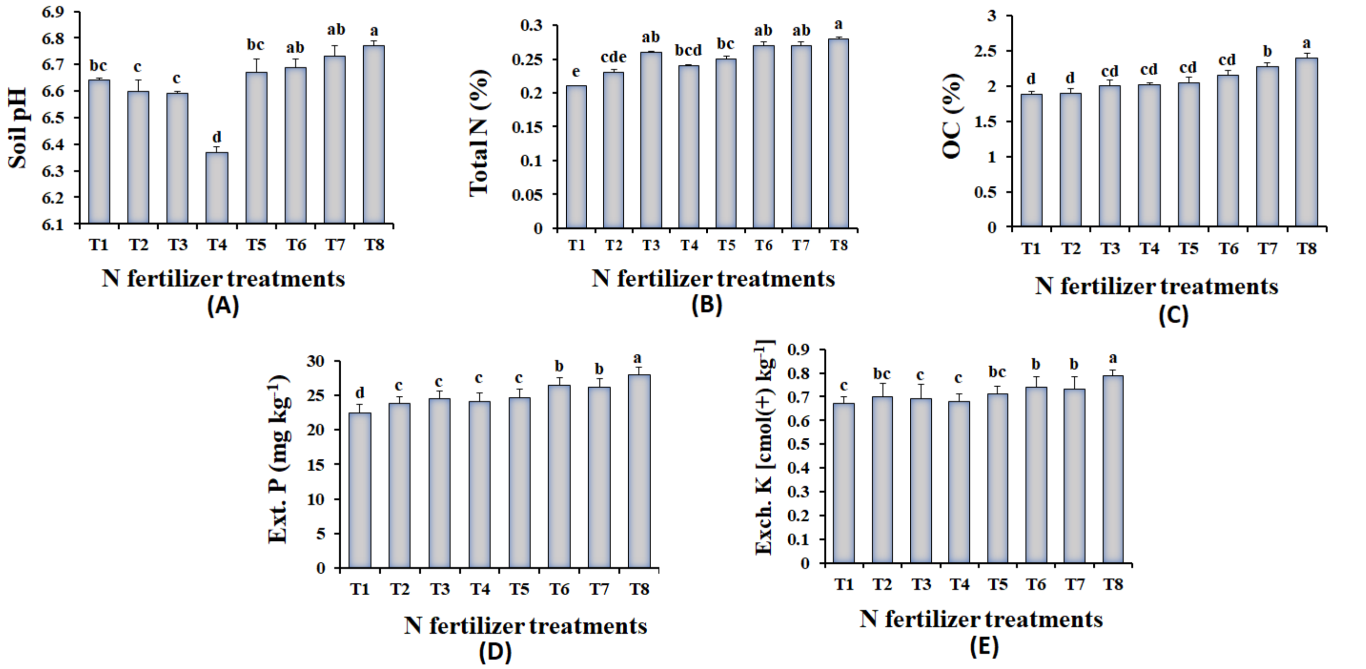

Figure 3. Effect of N fertilization treatments on soil properties; (**A**) soil pH, (**B**) total N, (**C**) OC, (**D**) ext. P, and (**E**) exch. K at Mungushi site after two maize cropping seasons on the slope of Mt. Kilimanjaro, in Hai district, Kilimanjaro region, central–northern Tanzania. Vertical bars sharing a common letter(s) are not significantly different at $p < 0.001$. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

3.2. Effect of N Fertilization on Maize Plant Growth Parameters

3.2.1. Plant Height

The values for plant height observed in all N fertilization treatments were considerably ($p < 0.001$) higher than those in the control treatment across the sites and cropping seasons (Figure 4). The highest values of plant height were found in treatments that received the highest N rate from urea alone (T4), the recommended N levels from urea alone (T3), and a mixture of urea and cattle manure at 50% each (T6) across all sites and seasons. However, compared to all N fertilized treatments, maize plants grown under the highest N levels derived from urea alone (T4) recorded considerably ($p < 0.001$) taller plants over the 2021 and 2023 growing seasons in all sites (Figure 4). In contrast to the absolute control (T1), the plant height increased by 35.9% and 27.4%, respectively, at the Kwa Sadala site for the cropping seasons 2021 and 2023 in the treatment that received the highest N fertilization rate from urea alone (T4). At the Mungushi site, a similar pattern was also recorded: for the cropping seasons 2021 and 2023, plant height increased by 38 and 36.9%, respectively, in the treatments that received the highest rate (T4) derived from sole urea in comparison to the control treatments.

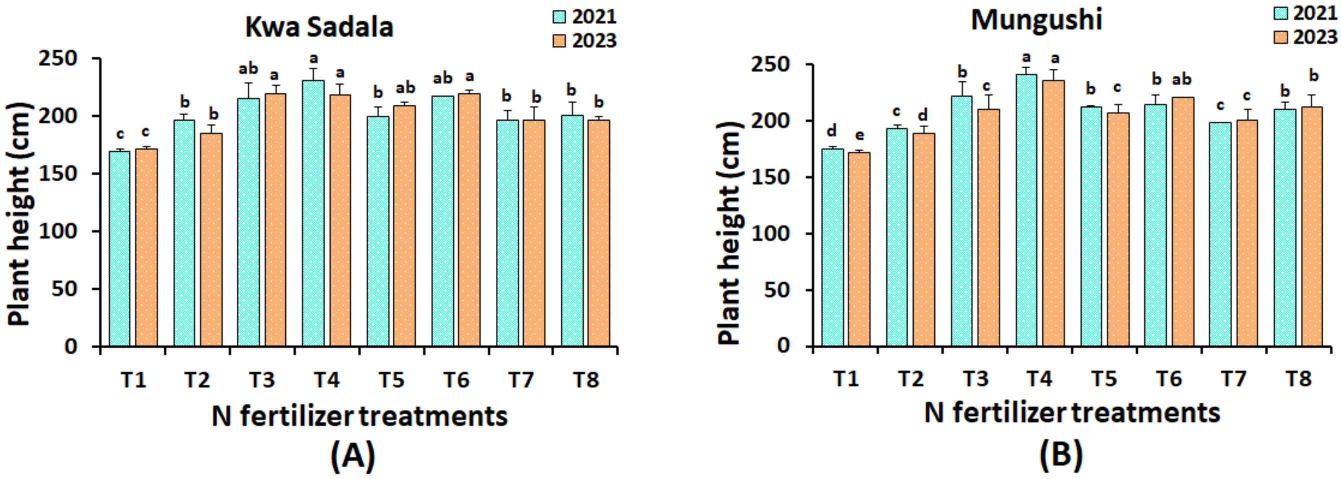

Figure 4. Effect of N fertilization treatments on maize plant height; (**A**) Kwa Sadala and (**B**) Mungushi sites on the southern slopes of Mount Kilimanjaro in Hai district, Kilimanjaro region, central–northern Tanzania. The different letter(s) indicate the significant difference ($p < 0.001$) between treatments. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

At the Kwa Sadala site, the results further indicated there was no significant difference ($p < 0.001$) in plant height between treatments that received urea alone at the lowest rate (T2) from those that received cattle manure alone at the recommended and highest application rates (T7 and T8, respectively) in both the 2021 and 2023 cropping seasons. Moreover, no significant difference ($p < 0.001$) in plant height between the treatment that received N fertilizer at the prescribed rate derived from urea alone (T3) and the treatment that received N fertilizer at the recommended rate from a mixture of urea and manure (T6) in both cropping seasons. On the other hand, at the Mungushi site, there was no significant difference ($p < 0.001$) between treatments that applied N fertilizer at the recommended rate of urea alone (T3), a combination of manure and urea (T6), and the highest rate of manure only (T8) during the 2021 cropping season. In the 2023 cropping season, however, the plot receiving a combination of manure and urea at the recommended rate (T6) displayed significantly ($p < 0.001$) taller plants than the plot receiving the same rate derived from urea alone (Figure 4B).

3.2.2. Leaf Area

The effect of N fertilizer applications on leaf area is shown in Figure 3. In comparison to the control treatment, the application of urea alone at varying rates (T2–T4) resulted in a significant ($p < 0.001$) increase in leaf area per plant during both growing seasons across the sites (Figure 5). The treatment with the highest N level derived from urea alone (T4) had the largest leaf area with an average percentage increase of up to 68 and 83 at the Kwa Sadala and Mungushi sites, respectively. Nevertheless, no significant difference ($p < 0.001$) in leaf area per plant was encountered between treatments received with cattle manure alone and the control treatment for the growing season of 2021 at the Kwa Sadala site. In addition, across the two cropping seasons, the values of leaf area in treatments that received urea fertilizer alone at the recommended rates (T3) did not differ substantially ($p < 0.001$) from treatments that received a combination of urea and cattle manure at the same rates (T6) (Figure 2A).

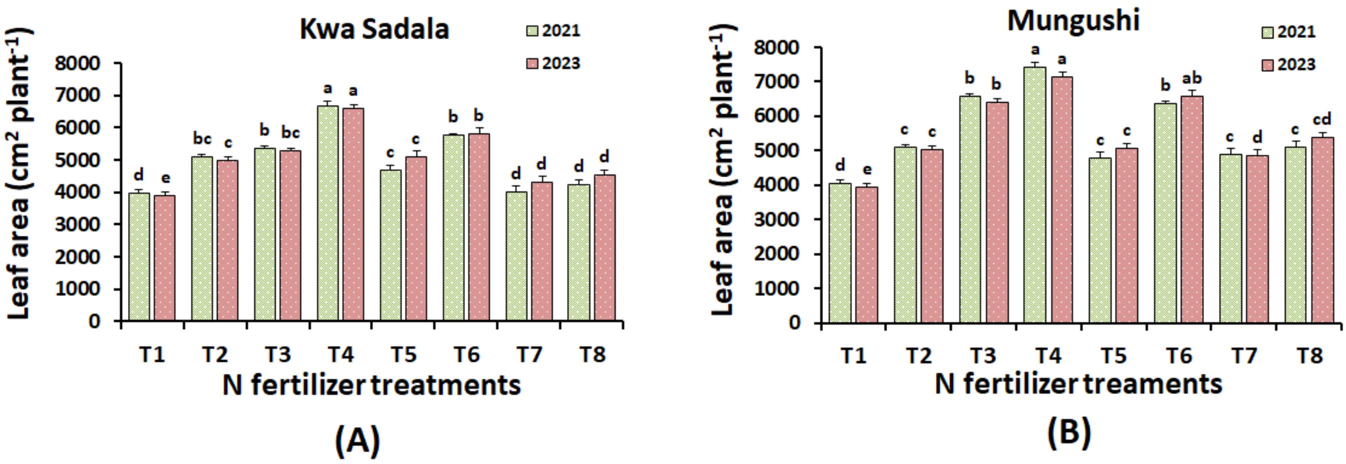

Figure 5. Effect of N fertilization treatments on maize leaf area; (**A**) Kwa Sadala and (**B**) Mungushi sites on the southern slopes of Mount Kilimanjaro in Hai district, Kilimanjaro region, central−nortern Tanzania. The different letter(s) indicates a significant difference ($p < 0.001$) between treatments. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

On the other hand, at the Mungushi site, a significant increase ($p < 0.001$) in leaf area per plant was observed when urea and cattle manure were applied in both the 2021 and 2023 growing seasons. No significant difference in leaf area per plant was recorded when urea alone (T2) or in combination with cattle manure (T5) was applied at the lowest level. Similarly, when urea was applied at the prescribed rate, the leaf area per plant did not differ significantly ($p < 0.001$) with the treatment that received a mixture of manure and urea at the recommended rate in both the 2021 and 2023 growing seasons (Figure 5B).

3.3. Effect N Fertilization on Maize Yield

3.3.1. Yield Components

The sources and rates of N fertilizers significantly increased the yield components of maize at both sites and seasons (Table 3). The Kwa Sadala site did not show a significant ($p < 0.001$) difference in the number of kernels between treatments that received the highest rate (T4) of urea and the treatment that received urea at the recommended level (T3) during the 2021 cropping season, with these two treatments recording the largest number of kernels. On the other hand, at the Mungushi location, maize plants received the highest N fertilization rate (T4) derived from urea alone, which recorded a considerably ($p < 0.001$) large number of kernels relative to the recommended N rate (T3). For the cropping season of 2021, however, the number of kernels was considerably ($p < 0.001$) larger in the treatments that received N fertilizer at the recommended rate (T3) from sole urea as opposed to a mixture of urea and cattle manure across the sites. The applications of urea alone at the recommended and highest rates (T3 and T4, respectively) resulted in significantly ($p < 0.001$) higher kernels per cob than the application of sole cattle manure at the same rates in the growing season of 2021 (Table 3). In the 2023 growing season, however, the number of kernels did not differ significantly ($p < 0.001$) in the treatments that received the recommended rates both from urea alone (T4) and a combination of urea with cattle manure (T6) and the treatments that received the highest N levels from urea alone (T4) and cattle manure only (T8) (Table 3). In the 2023 cropping season, the results showed a decrease in the number of kernels when sole urea was applied and an increase in the number of kernels when cattle manure was applied either in combination or alone. For instance, at the Kwa Sadala site, the application of sole manure resulted in a decrease in the number of kernels by 6.21, 5.89, and 3.83% for T2, T3, and T4, while the application of cattle manure alone or in combination increased the number of kernels by 2.96, 8.24, and 14.0% for T6, T7, and T8, respectively. On the other hand, at the Mungushi site, the application of sole urea also resulted in a decrease in the number of kernels by 4.39, 5.4, and 4.95% for T2, T3, and T4, in that order, while the application of manure either in combination or solely led to an increase in the number of kernels by 4.96, 3.94, and 2.95% for T6, T7, and T8, respectively (Table 3).

Table 3. Effect of N fertilization treatments on maize yield components in two long rainy cropping seasons in Hai district, Kilimanjaro region, central–northern Tanzania.

Treatment	Kwa Sadala				Mungushi			
	2021 Cropping Season		2023 Cropping Season		2021 Cropping Season		2023 Cropping Season	
	Kernels per Cob	1000 Kernel Weight (kg)	Kernels per Cob	1000 Kernel Weight (kg)	Kernels per Cob	1000 Kernel Weight (kg)	Kernels per Cob	1000 Kernel Weight (kg)
T1	321 ^{f}	0.281 ^{d}	310 ^{d}	0.272 ^{c}	330 ^{e}	0.280 ^{d}	312 ^{f}	0.272 ^{c}
T2	483 ^{b}	0.314 ^{bc}	453 ^{b}	0.291 ^{bc}	433 ^{d}	0.334 ^{bc}	414 ^{e}	0.301 ^{bc}
T3	509 ^{a}	0.332 ^{b}	479 ^{ab}	0.310 ^{ab}	537 ^{b}	0.342 ^{ab}	508 ^{bc}	0.321 ^{ab}
T4	522 ^{a}	0.363 ^{a}	505 ^{a}	0.333 ^{a}	586 ^{a}	0.361 ^{a}	557 ^{a}	0.343 ^{a}
T5	438 ^{c}	0.301 ^{c}	457 ^{b}	0.311 ^{ab}	464 ^{cd}	0.291 ^{d}	481 ^{cd}	0.302 ^{bc}
T6	491 ^{b}	0.311 ^{bc}	506 ^{a}	0.322 ^{ab}	498 ^{c}	0.330 ^{bc}	524 ^{b}	0.341 ^{a}
T7	345 ^{e}	0.291 ^{c}	376 ^{c}	0.311 ^{ab}	439 ^{d}	0.292 ^{d}	457 ^{d}	0.311 ^{ab}
T8	412 ^{d}	0.292 ^{c}	479 ^{ab}	0.310 ^{ab}	460 ^{d}	0.303 ^{d}	474 ^{d}	0.324 ^{ab}
Mean	438	0.309	445	0.309	468	0.311	466	0.311
CV	1.47	3.03	5.12	3.58	2.46	3.38	2.31	3.84
SED	5.28 ***	0.010 ***	18.6 ***	0.008 ***	9.74 ***	0.011 ***	8.74 ***	0.010 ***

*** Significant at $p < 0.001$. SED = standard error of differences between means of treatments, CV = coefficient of variation. The different letters in the same column indicate the significant difference between treatments. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

The 1000 kernel weight also displayed a significant difference ($p < 0.001$) between treatments at both the Kwa Sadala and Mungushi sites (Table 3). The treatment that received the highest rate of N derived from urea had the highest 1000 kernel weight in all seasons and sites. However, the general results have shown that the use of urea alone at the highest rate resulted in a high 1000 kernel weight compared with the use of cattle manure alone. In addition, the combined application of urea and cattle manure at the recommended rate (T6) resulted in the highest 1000 kernel weight in the 2023 cropping season.

3.3.2. Maize Grain and Stover Yields

The use of urea and cattle manure significantly ($p < 0.001$) increased maize grain yield over the control treatment. The results indicate that maize grain yield increased with N fertilization rate (T1–T4) in both sites (Table 4). Nitrogen fertilization at the highest rate via urea only (T4) resulted in the highest maize grain yields of 4.21 and 4.09 t ha^{-1} at Kwa Sadala and 4.32 and 4.04 t ha^{-1} at Mungushi in the 2021 and 2023 cropping seasons, respectively. The average percentage grain yields for the two growing seasons increased up to 379.8% and 305.8% at the Kwa Sadala and Mungushi sites, respectively, when the highest N fertilization rate (T4) was applied compared to the absolute control. Likewise, the application of cattle manure either solely (T7 or T8) or in combination with urea (T5 and T6) significantly ($p < 0.001$) increased maize grain yield. In contrast to the control treatments, the highest grain yields were recorded in maize plants fertilized with a mixture of urea and cattle manure at 50% each (T6), having an average percentage increase of up to 319% and 267% at Kwa Sadala and Mungushi, respectively, across the cropping seasons.

However, maize grain yields attained in cattle manure alone or in combination with urea were low compared with those obtained in sole urea at the highest application rate (T4).

Table 4. Maize grain and stover yields (kg ha^{-1}) under different fertilizer treatments in two long rainy growing seasons in Hai district, Kilimanjaro region, central–northern Tanzania.

Treatment	Kwa Sadala				Mungushi			
	2021 Cropping Season		2023 Cropping Season		2021 Cropping Season		2023 Cropping Season	
	Grain Yield (t ha^{-1})	Stover Yield (t ha^{-1})	Grain Yield (t ha^{-1})	Stover Yield (t ha^{-1})	Grain Yield (t ha^{-1})	Stover Yield (t ha^{-1})	Grain Yield (t ha^{-1})	Stover Yield (t ha^{-1})
T1	0.923 ^{f}	1.94 ^{d}	0.814 ^{f}	1.85 ^{f}	1.09 ^{e}	2.07 ^{e}	0.961 ^{f}	1.96 ^{f}
T2	2.13 ^{de}	3.84 ^{c}	2.00 ^{e}	3.56 ^{e}	2.25 ^{d}	3.97 ^{d}	2.07 ^{e}	4.32 ^{de}
T3	3.63 ^{b}	5.30 ^{b}	3.47 ^{b}	5.05 ^{b}	3.85 ^{b}	5.80 ^{b}	3.56 ^{b}	5.22 ^{c}
T4	4.21 ^{a}	6.45 ^{a}	4.09 ^{a}	5.98 ^{a}	4.32 ^{a}	6.61 ^{a}	4.04 ^{a}	6.40 ^{a}
T5	2.05 ^{e}	3.65 ^{c}	2.40 ^{d}	4.01 ^{cd}	2.64 ^{d}	4.72 ^{d}	2.69 ^{c}	4.91 ^{c}
T6	3.47 ^{b}	5.13 ^{b}	3.76 ^{ab}	5.79 ^{ab}	3.62 ^{b}	5.57 ^{bc}	3.95 ^{a}	5.94 ^{b}
T7	2.25 ^{d}	3.94 ^{c}	2.63 ^{cd}	3.95 ^{d}	2.37 ^{d}	3.75 ^{d}	2.54 ^{d}	4.04 ^{e}
T8	2.58 ^{c}	4.08 ^{c}	2.96 ^{c}	4.29 ^{c}	2.74 ^{c}	4.16 ^{cd}	2.91 ^{c}	4.72 ^{d}
Mean	2.66	4.29	2.77	4.31	2.86	4.58	2.84	4.69
CV	2.41	5.70	3.78	6.49	3.71	2.74	3.47	2.28
SED	0.061 ***	0.208 ***	0.086 ***	0.232 ***	0.104 ***	0.113 ***	0.107 ***	0.112 ***

*** Significant at $p < 0.001$. SED = standard error of differences between means of treatments, CV = coefficient of variation. The different letters in the same column indicate the significant difference between treatments. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

Conversely, maize stover yield increased significantly ($p < 0.001$) with N fertilization rates (T1–T4) (Table 4). Nitrogen fertilization at the highest rate through urea only (T4) produced the highest maize stover yield of up to 6.28 and 6.34 t ha^{-1}, respectively, at the Kwa Sadala and Mungushi sites in the growing season 2021, with a percentage increase of 232 and 219 relative to control treatments. Nevertheless, combined applications of cattle manure and urea at the prescribed rate (T6) resulted in a comparable maize stover yield (6.36 t ha^{-1}) at the Mungushi site in the 2023 cropping season (Table 4).

3.4. Economic Analysis

The overall results of the two growing seasons are shown in Tables 5 and 6. In each location, the production costs increased significantly ($p < 0.001$) with the N fertilization rate, whereby the highest N fertilization rate through cattle manure alone (T8) was more costly. The retail price of urea varied between the two growing seasons, with the 2023 growing season recording the highest price, which increased N utilization costs, especially for the treatment received via urea alone or in combination (Tables 5 and 6). Although the two sites were close to each other (10 km apart) and shared the same market center (Kwa Sadala town), the total production costs differed across the study sites (Tables 5 and 6) due to the differences in farm operation costs. The NB increased significantly ($p < 0.001$) with increasing N fertilization rates in both sites and seasons, with the largest NB being recorded in the treatment receiving the highest rate of N fertilizer derived from sole urea (T4). The treatments that received integrated N fertilization from manure and urea at recommended rates (50% each) (T6) also demonstrated favorable NB in both sites, especially in the 2023 cropping season. The results further indicate that there was an increase in the NB in the 2023 growing season in both sites as opposed to the 2021 growing season (Tables 5 and 6). This could be attributed to an increase in the farm gate price of maize from USD 0.281 kg^{-1} in 2021 to USD 0.363 kg^{-1} in 2023. In comparison to the no-N fertilization treatment, the BCR significantly ($p < 0.001$) rose as the N fertilization rate increased across all sites and seasons (Tables 5 and 6). Treatments received with N fertilizer from urea alone at the recommended and highest rates (T3 and T4, respectively) recorded a relatively higher BCR compared to those received with N fertilizer derived from cattle manure alone at the same rates (T7 and T8).

Table 5. Economic analyses for the use of urea and cattle manure as a source of N in maize production at Kwa Sadala in the 2021 and 2023 cropping seasons on the slope of Mt. Kilimanjaro in Hai district, Kilimanjaro region, central-northern Tanzania.

N Fertilization Treatment	Total Cost (USD ha^{-1})			Gross Benefits (USD ha^{-1})			Net Benefits (USD ha^{-1})			Benefit–Cost Ratio (USD/USD)		
	2021	2023	Mean	2021	2023	Mean	2021	2023	Mean	2021	2023	Mean
T1	245	245	245	229	283	256	−16	38	11	0.935	1.15	1.04
T2	297	318	308	554	684	619	257	366	311	1.87	2.15	2.01
T3	331	375	353	1028	1271	1149	697	896	697	3.11	3.39	3.25
T4	366	431	399	1197	1478	1337	831	1047	831	3.27	3.43	3.35
T5	373	383	378	488	587	538	116	204	160	1.31	1.53	1.42
T6	444	466	455	987	1201	1094	544	735	640	2.22	2.58	2.40
T7	444	444	444	681	822	751	237	378	307	1.53	1.85	1.69
T8	563	563	563	805	975	890	242	412	327	1.43	1.73	1.58
Mean						829			436			2.09
SED (T)						17.3 ***			17.3 ***			0.046 ***
SED (S)						8.73 ***			8.68 ***			0.031 ***
SED (T × S)						24.5 ***			24.5 ***			0.067 ns

*** Significant at $p < 0.001$. SED = standard error of differences between means of treatments (T), season (S), treatment and season (T × S), and ns = not significant. Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

Table 6. Economic analyses for the use of urea and cattle manure as a source of N in maize production at Mungushi in the 2021 and 2023 cropping seasons on the slope of Mt. Kilimanjaro in Hai district, Kilimanjaro region, central–northern Tanzania.

N Fertilization Treatment	Total Cost (USD ha^{-1})			Gross Benefits (USD ha^{-1})			Net Benefits (USD ha^{-1})			Benefit–Cost Ratio (USD/USD)		
	2021	2023	Mean	2021	2023	Mean	2021	2023	Mean	2021	2023	Mean
T1	253	253	253	273	262	267	20.0	9.00	14.5	1.07	1.04	1.06
T2	305	336	321	653	755	704	347	420	384	2.14	2.25	2.20
T3	340	388	364	1026	1241	1134	686	854	770	3.02	3.20	3.11
T4	375	440	407	1224	1417	1321	850	977	913	3.26	3.22	3.24
T5	381	392	387	734	941	837	353	549	451	1.93	2.40	2.17
T6	453	461	457	1085	1397	1241	632	935	784	2.40	3.03	2.72
T7	453	453	453	687	893	791	235	442	338	1.52	1.97	1.75
T8	572	572	572	929	1224	1077	358	653	505	1.62	2.14	1.88
Mean						921			520			2.3
SED (T)						16.8 ***			16.8 ***			0.041 ***
SED (S)						8.38 ***			8.38 ***			0.018 ***
SED (T × S)						23.8 ***			23.8 ***			0.057 ***

*** Significant at $p < 0.001$. SED = standard error of differences between means of treatments (T), season (S), and treatment and season (T × S). Treatments: T1 = control, T2 = 25 kg N (urea), T3 = 50 kg N (urea), T4 = 75 kg N (urea), T5 = 12.5 kg N (urea) + 12.5 kg N (cattle manure), T6 = 25 kg N (urea) + 25 kg N (cattle manure), T7 = 50 kg N (cattle manure), and T8 = 75 kg N (cattle manure).

4. Discussion

4.1. Soil Properties After N Fertilizer Amendments

The findings of this study revealed that N fertilizer amendments had a significant impact on soil characteristics across the study sites. For instance, applications of urea at the highest rate resulted in a reduction of soil pH by 3.30 and 3.78% at Kwa Sadala and Mungushi, respectively. Earlier studies, e.g., by [33,34], have demonstrated that excessive applications of N fertilizers, especially ammonium-based resources, tend to reduce soil pH. Urea is hydrolyzed to ammonium upon entering the soil matrix, where it takes on properties similar to those of ammonium-based N fertilizers. The ammonium is transformed into nitrate (NO_3^-) by microbial oxidation or nitrification, which releases hydrogen ions (H^+). Because of the extra H^+ ions, the soil solution's overall charge becomes positive, causing soil acidification [33,35]. On the other hand, the use of cattle manure alone and in combination with urea increased the soil pH over the two cropping seasons across the study sites. The increase in soil pH could be explained by the increase in basic cations (Ca^{2+} or Mg^{2+}) and anions (OH^-) from manure, with the cations providing a buffering state [26] while the anions neutralize the H^+ in the soil solution [36].

At the Kwa Sadala site, the application of urea alone decreased OC content, contrary to the Mungushi site, where OC increased when urea was applied at the recommended rate and highest rate. There are some discrepancies in results from different studies on the effect of inorganic N fertilization on soil OC content. Some studies indicate that the soil OC content in crop fields is significantly impacted by increasing crop residues and root exudates following prolonged use of mineral N fertilizer [14,37,38]. However, other research has shown that adding more mineral N fertilizer has a negative or no effect on soil OC [19]. Variations in the initial soil OC fractions between the two sites can account for the inconsistent results obtained from this study after the application of N fertilizer derived from urea. On the other hand, the applications of manure, either alone or in combination with urea, appeared to increase the soil OC in all respective treatment plots across the study site. Reports by earlier studies, e.g., [19,36], show that the use of manure not only enhances soil nutrients after mineralization but also increases soil organic matter, which raises soil OC in the end. The increase in soil OC observed in this study is consistent with the findings of [19,39,40] that manure applications significantly increased soil OC. Applications of urea alone resulted in a slight increase in soil N compared to cattle manure alone. For instance, applications of cattle manure at the recommended N rate seemed to boost soil total N by up to twofold. The increase in N content seen following the application of cattle manure may be explained by the N mineralization of manure, which releases the N into the soil matrix. A study by [41] reported that the applications of cattle manure at a rate of 20 t ha^{-1} increased soil N content by up to 27% over mineral N fertilizer alone. A similar observation was also noted by [42], whereby the application of farmyard manure appeared to improve soil N contents significantly in comparison to inorganic NPK fertilizer.

In addition, the findings of this study revealed that the soil's extractable P increased with an increase in application rates of urea and cattle manure, with the highest soil P residual effect observed at the highest manure application rate. The highest level of residual soil P observed in the treatment that received the highest amount of cattle manure can be due to the residue effect of the mineralized P from the cattle manure. For instance, a study by [43] showed that applications of composted dairy cow manure at 70 Mg ha^{-1} caused the soil's P content to increase tenfold. Furthermore, the findings of this study revealed that N fertilization via urea only resulted in a decline in soil exchangeable K. This suggests that the crop K nutrition requirement was fulfilled by the indigenous soil supply. Such unbalanced fertilizer applications cause gradual nutrient mining in the crop fields [44], which in turn can lead to the depletion of K. The findings from this study are consistent with those of [14], who found that sole N fertilization derived from urea reduced soil K by up to 24% from its initial level. On the other hand, applying cattle manure to the soil caused a little rise in soil K, suggesting that the manure restored the soil K, which ultimately had a residual effect on the soil. A meta-analysis report by [45] indicated that the application of manure considerably increased soil K by 19.1% when compared with inorganic fertilizers. Studies have indicated that the addition of nitrogen (N) to soils through both inorganic and organic fertilizer sources, along with proper fertilizer management, may cause soils to gradually accumulate nutrients [19,29]. If weather and other agronomic conditions remain consistent, this could result in higher crop yields.

4.2. Agronomic Benefits of N Fertilization

The findings of this study revealed that the tested N fertilization rates and application strategies had significant and positive effects on maize plant growth and yield in both cropping seasons and sites relative to the control treatment. The highest level of inorganic N (75 kg ha^{-1}) derived from urea alone gave the best crop stand and maize yields across the sites and seasons. Nitrogen is a crucial nutrient element required by maize plants in greater quantity than any other nutrient [46]. It is a component of amino acids, which serve as the building blocks for plant proteins and enzymes and is a necessary macronutrient for plant activity. Additionally, N is a part of the chlorophyll molecule, which gives the plant the ability to use photosynthesis to absorb solar energy, thus promoting plant growth and crop yield [47]. When N fertilization strategies were compared, sole urea applications at the recommended rate gave the highest values for yield and yield components in the 2021 growing season compared to cattle manure alone or in combination with urea. Inorganic fertilizers are considered the most effective due to their solubility behavior and are readily available to plants immediately after their application [48].

In contrast, in the 2023 cropping season, N fertilization with cattle manure alone or in combination produced comparable yields to those in the treatments that received urea alone. This could be due to the accumulation of soil organic matter over the two consecutive seasons, which resulted in improved soil quality, ultimately improving the crop yield. Manure has been shown to improve the physical characteristics of the soil, such as structure, aeration, water retention, soil tilt, bulk density, enhancing soil microbial activities, and supplying both macro- and micronutrients, in contrast to mineral fertilizer, which supplies specific plant nutrients [19,20,36,39]. Furthermore, the yield reduction observed in the 2023 cropping season upon the application of urea alone can be explained by the low rainfall amount and poor distribution during the cropping season (Figure 1). Research has shown that higher and better rainfall distribution during vegetative growth has a significant and positive influence on N uptake by plants and the partitioning of more assimilates to leaves, resulting in large leaf sizes [49].

4.3. Economic Benefits of N Fertilization

The results from the NB and BCR have demonstrated that it is more beneficial to use urea at a rate of 75 kg N ha^{-1}. Nonetheless, promising NB and BCR can also be obtained by N fertilizer at 50 kg ha^{-1} using either urea alone or in combination with cattle manure. The BCR of using sole manure or a combination of manure and urea increased in the second cropping season. The increase in BCR observed in the second growing season is attributed to the increase in maize grain yield, which ultimately increased the bulkiness of the produce, thus giving farmers a higher return on investment. This implies that considering the scarcity of animal manure and the high prices of mineral fertilizers, an integrated approach to N fertilization for maize production in the study area can be the most effective strategy to increase crop yield while simultaneously enhancing soil quality. Consistently, the BCR of sole urea utilization at recommended (50 kg N ha^{-1}) or highest (75 kg N ha^{-1}) rates were higher than that of cattle manure alone or in combination at the same N application rates. The bulkiness of cattle manure, thus the high labor cost to apply, which added up to a high cost of production, can account for the low BCR seen in this study. A similar observation was also reported by [50], where the utilization cost of cattle manure in banana production in the same study area was higher than that of mineral fertilizers. One ton of cattle manure in the study area costs about USD 30. Since the quality of cattle manure in the study area is very low due to poor handling, a huge amount of manure is required to meet crop nutrient demand, thus increasing the production cost. The benefits of using manure are often determined by the quality of the manure and the reactivity of the soil [32]. While the use of manure alone has not proven beneficial for this study, it has been reported that the long-term application of manure in agricultural lands improves crop production in the same way that mineral fertilizers do, but it improves soil health more effectively [19,36]. Combining manure with mineral fertilizer may be the best alternative for increasing crop yields and household income in a sustainable manner, as smallholder farmers in the area may find it difficult to obtain enough manure for optimal crop fertilization.

5. Conclusions

In this study, we assessed the potential of using cattle manure and urea as sources of N fertilizer for optimizing maize production in Hai District, located on the southeast slope of Mount Kilimanjaro, central–northern Tanzania. All tested N fertilizer sources and application strategies significantly increased maize grain and stover yield throughout the two cropping seasons. The treatment that received the highest N rate derived from urea alone gave the highest grain yield across the sites and seasons. However, the economic analysis showed no significant differences between the treatments that received the highest N rate and the treatments that received a combination of cattle manure and urea at the recommended rate (50% each) for the second cropping season. Furthermore, the soil qualities of the area were significantly improved by the use of cattle manure during the two succeeding cropping seasons. This implies that adopting the technology of supplementing inorganic and organic fertilizers that are produced within farmsteads could enhance soil quality and crop productivity in a sustainable way.

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