frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 06 September 2024
DOI 10.3389/fsufs.2024.1455206

Impact of mulching treatments on growth, yields, and economics of common bean (*Phaseolus vulgaris* L.) in Eastern Tanzania

Ahamed Mwarabu Ramadhani[1]*, Eliakira Kisetu Nassary[1], Filbert B. Rwehumbiza[1], Boniface H. J. Massawe[1] and Susan Nchimbi-Msolla[2]

[1]Department of Soil and Geological Sciences, Sokoine University of Agriculture, College of Agriculture, Morogoro, Tanzania, [2]Department of Crop Science and Horticulture, Sokoine University of Agriculture, College of Agriculture, Morogoro, Tanzania

EDITED BY
Surendra K. Dara,
Oregon State University, United States

REVIEWED BY
Oli Bachie,
University of California Agriculture and Natural Resources, United States
Aurelio Scavo,
University of Messina, Italy

*CORRESPONDENCE
Ahamed Mwarabu Ramadhani
mwarabua@gmail.com

RECEIVED 27 June 2024
ACCEPTED 12 August 2024
PUBLISHED 06 September 2024

CITATION
Ramadhani AM, Nassary EK, Rwehumbiza FB, Massawe BHJ and Nchimbi-Msolla S (2024) Impact of mulching treatments on growth, yields, and economics of common bean (*Phaseolus vulgaris* L.) in Eastern Tanzania. *Front. Sustain. Food Syst.* 8:1455206. doi: 10.3389/fsufs.2024.1455206

Mulching is a widely used agricultural practice that can significantly affect crop growth, yield, and economic outcomes, particularly in regions with varying climatic conditions. The present study evaluated the influence of various mulching practices on the growth, yield, and economic viability of common bean (*Phaseolus vulgaris* L.) cultivation in Tanzania. The study was conducted across three sites in the eastern agro-ecological zone of Tanzania: Kipera (E4 200–1000 m.a.s.l.), Mgeta (E14 500–000 m.a.s.l.), and Ndole (E2 500–1200 m.a.s.l.). Four mulching treatments—polythene mulch, synthetic biodegradable mulch, rice husk mulch, and a control group—were applied to assess their effects on plant growth and yield components. Results revealed significant variations in growth parameters and yield components across sites. Notably, polythene mulch and synthetic biodegradable mulch consistently outperformed the other treatments. Polythene mulch resulted in an average plant height of 68.37 cm, followed closely by synthetic biodegradable mulch at 68.26 cm, both significantly ($p < 0.05$) taller than rice husk mulch (62.79 cm) and the control (57.74 cm). Canopy coverage was highest with polythene mulch at 61.7%, followed by synthetic biodegradable mulch at 60.5%. Grain yields did not differ significantly between synthetic biodegradable mulch (2.64 t ha^{-1}) and polythene mulch (2.67 t ha^{-1}). Economic analysis indicated that synthetic biodegradable mulch offers promising marginal returns (MR: Tshs. 3,787,450 or USD 1,469) and a benefit-cost ratio (BCR) of 1.91, compared to polythene mulch (MR: Tshs. 4,114,050 or USD 1,595, BCR: 2.06). These findings suggest that synthetic biodegradable mulch is a sustainable and economically viable option for enhancing common bean production across diverse agro-ecological settings in Tanzania.

KEYWORDS

mulching practices, Phaseolus bean performance, economic analysis, sustainable food production, agro-ecological systems

1 Introduction

Global production of common beans (*Phaseolus vulgaris* L.) varies widely, with significant contributions from Latin America, Asia, North America, and especially East Sub-Saharan Africa (Uebersax et al., 2023). Leading producers include Brazil, India, Mexico, China, and the United States, with Brazil accounting for approximately 11–12% of world production (Uebersax et al., 2023). In East Sub-Saharan Africa, countries such as Kenya, Tanzania, Uganda, Rwanda, and Ethiopia are prominent producers, although average yields in this region are typically lower (0.5–0.8 t/ha) due to limited access to improved seed varieties, fertilizers, and modern farming techniques (Nkhata et al., 2021). Despite these challenges, beans remain crucial for nutrition and are a cash crop supporting farmers' economies. Global bean production has increased from 16.6 million tons (Mt) in 1988–1990 to 29.3 Mt in 2015–2017, driven by increases in both cultivation areas and yields (Deresa, 2018). The Americas and Asia are the most important producing regions, with South America alone producing 30% of the global common bean supply (Heuze et al., 2019). The top five producers of dry beans during 2013–2017 were India, Myanmar, Brazil, the United States, and Mexico, followed by China and several African countries (FAOSTAT, 2019).

Beans are nutritionally rich, providing protein, dietary fiber, and essential minerals such as iron, magnesium, potassium, zinc, phosphorus, and calcium (Huertas et al., 2023). They are crucial for populations with limited access to animal proteins, helping to combat malnutrition and support overall health (Rodríguez et al., 2021). Beans support muscle growth, digestion, blood health, cardiovascular health, immune function, bone health, and prenatal development (Mullins and Arjmandi, 2021). High consumption rates are found in Central and South America, the Caribbean, East Africa, and parts of Asia (Bhat et al., 2022). Globally, 12–18% of annual bean production is traded internationally, with China, Myanmar, and the United States being major exporters and India and the European Union being the largest importers (Meng et al., 2022; FAOSTAT, 2019).

Common beans are a crucial global food legume, with 27.5 million metric tons cultivated across 34.8 million hectares in 2020 (Pathania et al., 2014; Uebersax et al., 2023). In Tanzania, common bean consumption and commercial use surpass those of other pulses, with over 75% of rural households relying on beans for daily subsistence (Ndimbo et al., 2022; Birachi et al., 2020; Kilima and Bolle, 2020). Beans provide 35% protein and 340 calories per 100 g, making them a vital food source for health and nutrition (Didinger et al., 2022). Bean production provides benefits that support systems sustainability, including short growth duration with immediate dietary return and low carbon footprint, which facilitates crop diversification and its integration as a cover crop (Uebersax et al., 2023). Compared to cereal grains, legumes have reduced the requirement for water and nitrogen through their symbiotic relationship with N-fixing diazotrophs, thus increasing leaf nitrogen content and directly mitigating leaf water losses (Adams et al., 2018).

Despite being widely cultivated in diverse agro-ecologies, and its importance in Tanzania, common bean yields have consistently lagged, ranging from 0.5 to 1.0 t ha^{-1}, compared to the potential of 1.5–3.5 t ha^{-1} achievable with high-yielding varieties under optimal growth conditions (Nassary et al., 2020). The low productivity is related to several factors, including degradation of soil physical properties, agronomic practices, and management factors (poor soil fertility and moisture stress, along with the impact of climate change; Beebe et al., 2013; Namugwanya et al., 2014; Ndimbo et al., 2022). The use of mulches has been reported to improve soil, microclimate, and management conditions in agriculture, thus improving crop productivity (Mola Ida et al., 2019; Cozzolino et al., 2020; Di Mola et al., 2021). Mulches prevent water loss by minimizing evaporation, controlling weeds, modulating soil temperature, and enhancing the aesthetic appeal of an area (Mhlanga et al., 2021; Abbate et al., 2023). Applying mulch, particularly organic mulch, is more beneficial for agricultural soil due to its decomposing in an optimal environment (Mola Ida et al., 2019). The effectiveness of mulch depends on factors such as the type of material, application method, and environmental conditions. While mulching provides many benefits, it is important to choose the right mulch and apply it properly to avoid negative impacts like soil and environment pollution, transmission of disease, and insect pests, as well as weed seeds (Du et al., 2022; Girsang et al., 2023). The use of synthetic biodegradable mulch is increasing in agriculture; it emerges as an alternative option to commonly used polythene mulches that, contribute to environmental pollution (Nelson et al., 2020; Menossi et al., 2021). Synthetic biodegradable mulches are designed to break down into natural components over time, leaving minimal harmful residues behind and reducing the environmental impact of polythene mulches (Serrano-Ruiz et al., 2021; Madin et al., 2024).

Synthetic biodegradable mulch is made from different polymers and compositions of polysaccharides such as cellulose and starch, designed to biodegrade *in situ*, into agricultural soil (Chapman, 2018; Mola Ida et al., 2019). The use of synthetic biodegradable mulch may entail environmental potential for agricultural systems that deserve short- and long-term exploration (Serrano-Ruiz et al., 2021). Synthetic biodegradable mulch influences soil temperature, which affects physical, chemical, and biological processes such as evapotranspiration, nutrient uptake by plants, seed germination, seedling emergence, and decomposition of organic matter by microbes (Di Mola et al., 2021). Unlike polyethylene mulch, which needs to be removed once applied as mulching, synthetic biodegradable mulch degrades naturally through microbial activity in the soil. Its degradation depends on factors such as particle size, moisture, and temperature changes (Sintim et al., 2019). In Tanzania, synthetic biodegradable mulch is used by large agricultural companies, research institutes, and major farmers, particularly for horticultural crops (Massawe et al., 2023). However, its use in the country is limited due to a lack of awareness, and its performance in crops such as common beans and its degradability rate are rarely documented in Tanzania (Menossi et al., 2021; Somanathan et al., 2022). This study focused on the potential of synthetic biodegradable mulch on the performance of common bean crops in a field environment through comparison with polythene mulch and rice husk as locally organic mulch and control (without mulch) in three agro-ecological zones

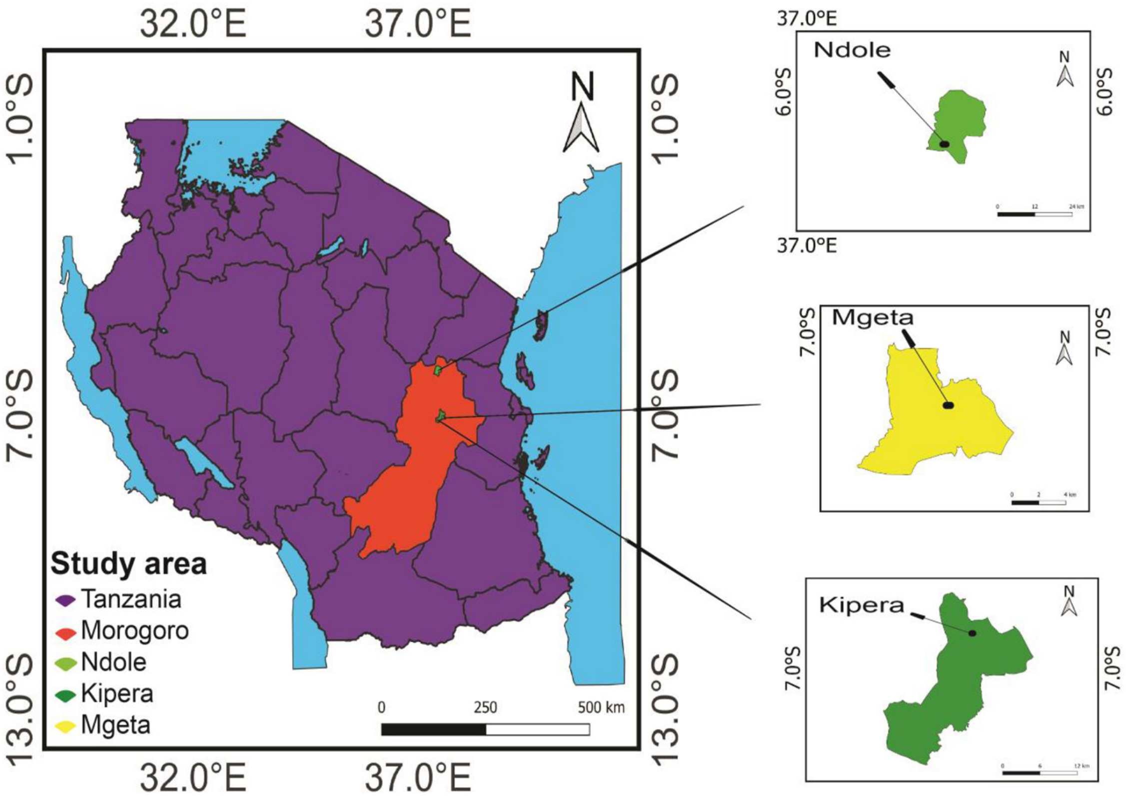

FIGURE 1
Map of Tanzania and Morogoro region showing areas of the study sites.

within major Eastern Plateaux and Mountain Blocks zones of Tanzania.

2 Materials and methods

2.1 Description of study sites

The study was conducted in three villages, which are located in three different agro-ecological zones within the major Eastern Plateaux and Mountain Blocks zones of Tanzania (Figure 1). The villages were Kipera, Ndole, and Mgeta, all in Mvomero district, Morogoro region. Kipera village is in an agro-ecological zone coded E4, which is characterized by rainfall between 800 and 1,000 mm per year, altitude ranging from 200 m to 1,000 m above sea level, temperature of 19–31°C, and soil is moderately deep to deep, or reddish sandy clays to clays. Ndole village is located in an agro-ecological zone coded E2, characterized by an altitude of 500 to 1,200 m rainfall, ranging from 800 to 1,000 mm, temperature 15–30°C, and soil is moderately deep to deep, dark reddish brown, yellowish red or red sandy clay loams and sandy clays with weak or moderate structure and Mgeta is located in agro-ecological zone coded E14, which is characterized by altitude of 500 to 2,000 m. Rainfall between 1,000 and 1,200 mm, temperature 10–25°C, and soil is deep yellowish or reddish sandy clays to clays with moderate to strong structure (MAFSC, 2014).

2.2 Experimental design, layout, and treatments

The experiment was laid out in a randomized complete block design (RCBD) to minimize variability and ensure reliable results. Four farmers' fields in a village (site) formed replicated blocks, with each farmer having four plots where three mulch treatments and a control were randomized. Thus, each village (site) had 16 experimental plots, each measuring 4 m by 2.8 m, giving a total area of 11.2 m^2 per plot. The spacing between plots was 0.5 m, with a 1 m alley between blocks. The total area demarcated was 19.5 m in length and 4.8 m in width. The treatments included Novamont medium-cycle synthetic biodegradable mulch made from renewable resources, such as plant materials like corn-starch-based polymers, which decompose naturally over time. The mulch was black in color, with a thickness of 15 μm and a width of 1.2 m, suitable for several crops with an average life cycle of 4–6 months. The material complies with the OK biodegradable soil certification, the European standard EN17033, and international environmental impact standards (European standards UNI EN 13432:2002, UNI EN 14995:2007; and American standard ASTM 6400:04).

Additionally, black low-density polyethylene (LDPE) mulch with a thickness of 25 μm and a width of 1.2 m, which is a standard thickness suitable for general crop production and commercially available, was applied to the plots. Holes of 2.6 cm^2 were then manually perforated in each film for seed sowing. Rice husk, sourced locally from Kipera and Dumila villages, was applied in a layer ∼2.5 cm thick and spread evenly over the soil surface immediately after sowing.

Common bean seeds (Uyole 18 variety), commonly grown by farmers in the study area, were sown on the 2nd, 7th, and 8th of June 2023 at Kipera, Mgeta, and Ndole, respectively. One seed was sown per hole with a spacing of 0.4 m between rows and 0.1 m between plants within a row, following a germination test. Sowing was done on the same day for all plots at each site, including the control plot. The soil was tilled to a depth of 20 cm to ensure a fine tilth suitable for seed sowing. The total duration of the crop cycle from sowing to harvest was ∼4 months. Harvesting was carried out manually on the 12th and 16th of September for Kipera and Ndole, respectively, and on the 4th of October for Mgeta in 2023. A fertilizer application of 50 kg/ha NPK (23:10:5) with MgO_2 and Zn_3 was made 1 week after germination, with no additional fertilization during the crop cycle. Pest control was achieved through two applications of a broad-spectrum insecticide (Imidacloprid 200 g/L and Chlorpyrifos 480 g/L) at 4 and 8 weeks after sowing, respectively. Weeds were controlled manually two times during the crop cycle, at 3 and 6 weeks after sowing, in control and rice husk treatments.

2.3 Data collection

2.3.1 Growth and yield parameters

Side rows and the plants in the first two holes at the edges of each inner row were excluded from data collection. Plant growth parameters, such as the number of leaves per plant, plant height, number of branches per plant, and ground coverage, were collected at 7-day intervals. A quadrat frame of 1 m^2 was used to measure ground coverage by bean plants. In each plot, 18 plants were randomly selected and tagged with blue string for growth parameter data collection. Yield components measured from these same bean plants included the number of pods per plant and the number of seeds per pod. Bean plants from the six inner rows were harvested at maturity, with an actual harvest area of 3.8 × 2 m (7.6 m^2). One square meter of bean plant samples at maturity was harvested from two locations within each plot. Plant components were separated and dried in an oven at 70°C for 48 h, and the samples were then weighed to calculate total biomass (t/ha). Grain yield (t/ha) and 100-seed weight were measured from the bean plants harvested from the six inner rows.

2.3.2 Soil parameters, surface temperature, and rainfall soil moisture and temperature

A composite soil sample was taken from each plot in each farmer's field, totaling 48 disturbed samples, using an auger, mats, and sampling bags for the analysis of organic carbon using the Walkley-Black method, pH, and electrical conductivity using the electrode method. Additionally, 48 undisturbed soil samples were collected using a core and core sampler for the determination of bulk density (Motsara and Roy, 2008). Soil moisture and soil temperature were measured weekly during the experiment using a Quick Draw moisture probe tensiometer (Model 2900F1) and a glass thermometer, respectively (Figure 2). Climate data (temperature and rainfall) were also collected daily using a thermometer and a rain gauge installed at each site.

2.3.3 Economic analysis

Economic benefits data collected included input costs (seeds and mulches), labor costs (for land preparation, sowing seeds, mulching application, irrigation, insect control, and harvesting), and the market price of dry grains of the respective common bean varieties at harvest. The profitability of synthetic biodegradable mulch, rice husk, and polythene mulches was calculated using the gross benefit (GB), which was determined as the average adjusted grain yield (kg/ha) multiplied by the dry grain yield price received by farmers for the sale of the crop per kg. Total variable cost (TVC) was calculated as the sum of all production costs incurred on the farm. Net benefit (NB) or marginal return (MR) was calculated by subtracting total variable costs from the GB. The marginal rate of return (MRR) was calculated as the ratio of the differences between the net benefits of successive treatments (mulching) to the difference between the total variable costs of successive treatments. The market price was considered stable across mulch materials, and the mulches used did not alter the harvest time of common bean crops (Shaaban and Kisetu, 2014; Marí et al., 2018). Furthermore, the marginal rate of return from each mulch type compared to no mulch was computed as described by Shaaban and Kisetu (2014).

2.4 Statistical data analysis

In assessing the variability of the mean measured parameters (growth, yield, soil temperature, and soil moisture) in common beans, a split-plot design for the analysis of variance (ANOVA) was performed. The experimental sites (Ndole, Kipera, and Mgeta) and mulching materials (no mulch, synthetic biodegradable mulch, polythene mulch, and rice husk) were the factors in the ANOVA. The sites were considered whole plots, and the mulching materials were considered sub-plots. Replicate farmers were treated as random effects. Significant treatment means were compared using the least significant difference (LSD) at a 5% threshold with Tukey's *post-hoc* multiple comparisons. In-depth analysis was conducted using the Shapiro–Wilk test for normality and Bartlett's test for homogeneity of variances for the effects of mulching materials on the number of branches per plant since the ANOVA output showed statistically insignificant ($p = 0.288$). The reported data represent the means of each measurement. The factors effect model is shown in Equation 1.

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \quad (1)$$

where Y_{ij} is the observed assessed parameter in the ijth factors; μ is the overall (grand) mean of the assessed parameter; α_i and β_j are the main effects of the factors sites and mulches, respectively; $(\alpha\beta)_{ij}$ is the two-way interactions between the factors sites and mulches; ε_{ij} is the random error associated with the observation of the assessed parameter in the ijth factors. Mean climatic data (surface temperature and

FIGURE 2
Growth performance of common bean, **(a)** early stage of common bean in synthetic biodegradable mulch, **(b)** common bean in rice husk mulch, **(c)** common bean starting flowering, and **(d)** quick draw moisture probe tensiometer in measuring soil moisture.

rainfall) were subjected to GenStat 15th edition software, and Tukey's *post-hoc* test at a 5% threshold was used to compare significant means across three contrasting agro-ecological zones (sites). Furthermore, differences in economic profitability of synthetic biodegradable mulch against control, rice husk, and plastic mulches were compared using the least significant difference (LSD) at the 5% threshold by Tukey's *post-hoc* multiple comparison.

3 Results

3.1 Influence of mulches on growth

The effects of mulches on various growth components of common bean plants, such as plant height, number of branches per plant, number of leaves per plant, and ground coverage, were evaluated across three distinct sites: Kipera, Mgeta, and Ndole. The findings of the study revealed remarkable consistency in the effects of the mulches on these growth parameters of common bean plants across diverse environmental conditions.

The tallest common bean plant height was observed at the Kipera site (70.8 cm), and the shortest height was observed at the Mgeta site (58.7 cm). The height of the plant in Kipera was significant ($p = 0.029$) compared to that of Ndole as well as that of the Mgeta site. The average height in Ndole was higher than that of Mgeta and was slightly significant. The results indicated that site conditions influenced the growth height of the common bean. In mulching practices, the tallest bean plant height was recorded in polythene mulch, followed by synthetic biodegradable mulch, although they were not significant (Table 1). Rice husk resulted in a slightly shorter bean plant height, while the control had the shortest common bean plant height. Bean plant height recorded from polythene mulch and synthetic biodegradable mulch was significant compared to that of rice husk and control treatment, and rice husk common bean plant height showed significance compared to that of the control treatment. The interaction effect in the plots treated with polyethylene mulch was observed to produce the tallest common bean plants across all three sites, followed

TABLE 1 Growth performance of common bean as influenced by the main effects of sites and mulching practices.

Factors and levels	Plant height (cm)	Number of branches/plant	Number of leaves/plant	Canopy cover (%)
Sites				
Kipera	70.8[a]	2.6[a]	5.9[a]	72.7[a]
Mgeta	58.7[c]	1.5[b]	3.2[b]	48.6[b]
Ndole	63.4[bc]	1.5[b]	3.7[b]	50.9[b]
LSD (0.05)	8.1	0.800	0.6	6.335
CV (%)	7.3	24.9	8.5	6.4
p-value	0.029	0.027	<0.001	<0.001
Practices				
PE	68.37[a]	1.9[a]	4.6[a]	61.7[a]
SBM	68.26[a]	1.9[a]	4.4[a]	60.5[a]
Rh	62.79[b]	1.8[a]	4.2[ab]	57.2[b]
Control	57.74[c]	1.8[a]	3.8[b]	50.3[c]
LSD (0.05)	2.6	0.201	0.4	1.580
CV (%)	2	19.2	4.8	5.6
p-value	<0.001	0.288	0.002	<0.001

PE, polythene mulch; SBM, synthetic biodegradable mulch; Rh, rice husk; LSD, least significance difference; CV, coefficient of variation. Means along the same column and category of comparison bearing different letter(s) differ significantly. The main effect of mulching materials on the number of branches per plant: the Shapiro–Wilk test for normality, $W = 0.707$ ($p < 0.001$); Bartlett's test for homogeneity of variances, $\chi^2 = 0.8$ with 3 degrees of freedom ($p = 0.849$).

by synthetic biodegradable mulch, while the control treatment consistently resulted in the shortest plants across all sites (Figure 3).

The number of branches in the common bean plant was observed to be statistically higher at the Kipera site compared to Ndole and Mgeta. In mulching practices, there were no significant differences ($p = 0.288$) in the number of branches per plant in all treatments. Polythene mulch and synthetic biodegradable mulch indicated a higher number of branches compared to rice husk and control treatments. The mean interaction effects were observed to be higher at the Kipera site in the plots treated with polyethylene mulch and synthetic biodegradable mulch. Conversely, at the Mgeta and Ndole sites, no significant differences were observed in the mean number of branches among the different treatments, as all treatments had the same mean number of branches. The Shapiro–Wilk test for normality ($W = 0.707$, $p < 0.001$) indicated that the data on the number of branches per plant significantly deviated from a normal distribution. The lack of normal distribution suggests potential outliers, skewness, or other forms of non-normality that could affect the interpretation of results. On the other hand, Bartlett's test for homogeneity of variances ($\chi^2 = 0.8$, df $= 3$, $p = 0.849$) suggested that the variances across different mulching materials on the number of branches per plant were homogeneous. This means that despite the non-normal distribution of the data, the assumption of equal variances holds, which is favorable for certain analyses that require this condition.

The effect of mulching on the number of leaves of common bean plants indicated that the Kipera site was observed to have a significantly ($p = 0.027$) higher number of leaves compared to Ndole and Mgeta. However, Mgeta showed fewer leaves per bean plant. The highest number of leaves per plant was observed in plots treated with polythene mulch, followed by those treated with synthetic biodegradable mulch, rice husk, and control (without mulch). The plot treated with polythene mulch and synthetic biodegradable mulch resulted in a significantly higher leaf number of bean plants compared to rice husk and the control treatment. The plots treated with rice husk and the control treatment were not statistically significant. The plots treated with polyethylene mulch in Kipera and Mgeta sites exhibited higher average interaction effects on the number of leaves per common bean plant, whereas synthetic biodegradable mulch tended to have these effects in Ndole. The control (without mulch) consistently resulted in fewer mean number of leaves across all sites.

The effect of mulching on ground coverage by common bean plants was observed to be higher at Kipera sites, followed by Ndole sites, and low at Mgeta sites. Ground coverage recorded a significant difference ($p < 0.001$) at Kipera sites compared to Mgeta and Ndole, while Ndole and Mgeta showed no significant difference in ground coverage. Mulching practices with polythene resulted in higher canopy cover, followed by synthetic biodegradable mulch and rice husk, and the control was observed with a low percentage of ground coverage. Plots treated with polythene and synthetic biodegradable mulch were not significant. However, there is a significant difference observed between rice husk and control. Rice husk also showed a significant difference with the control treatment in ground coverage. The ground coverage was observed to have higher interaction effects across all three sites in the plots treated with polyethylene and synthetic biodegradable mulch, and it remained low across all sites in the control treatment.

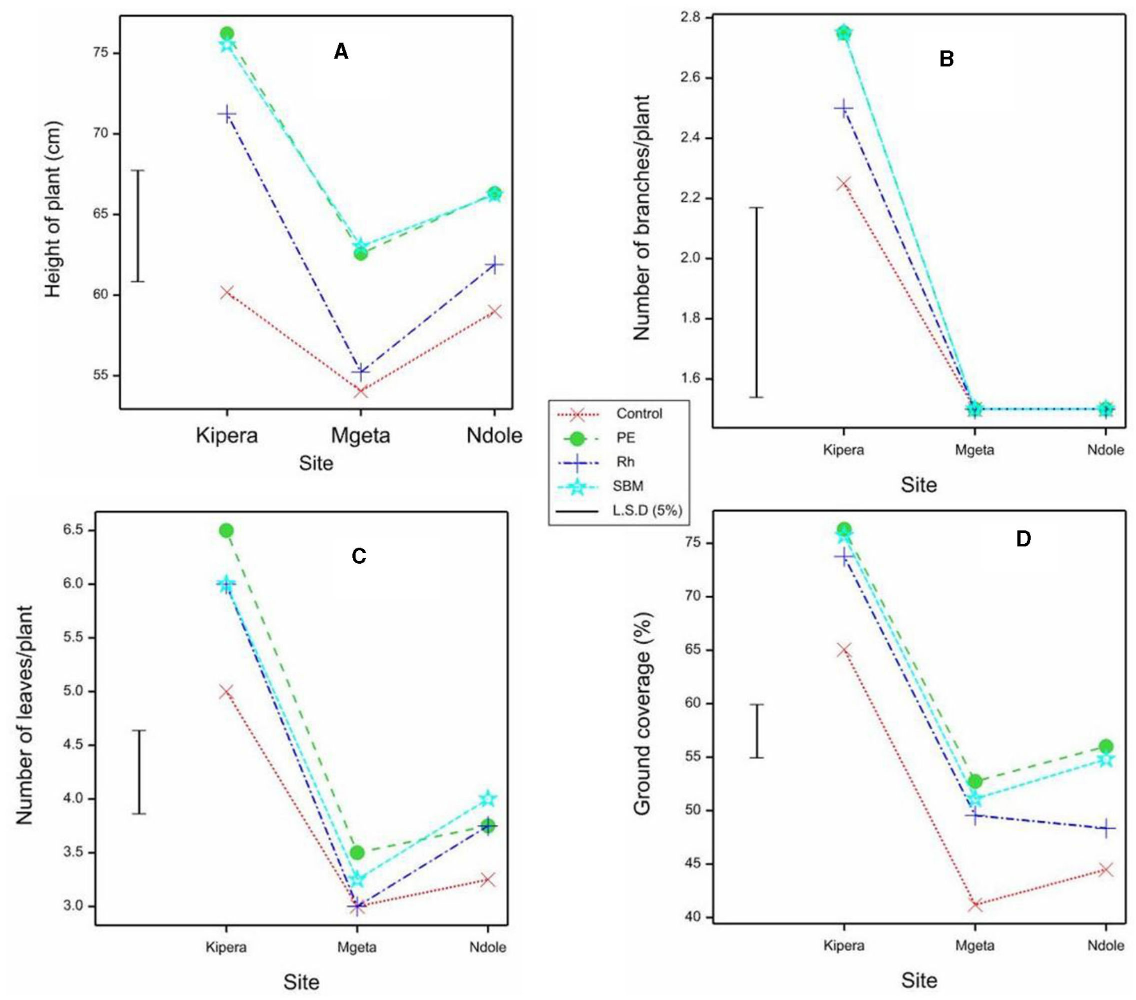

FIGURE 3
Interaction effects of sites and mulching practices on common bean growth components with LSD (5%), including **(A)** height of plants, **(B)** number of branches per plant, **(C)** number of leaves per plant, and **(D)** ground coverage (%) for different mulch in three sites.

3.2 Influence of mulches on yields of common bean

The effects of site variation on common bean yield components were observed, with no significant ($p > 0.05$) difference in the number of pods per plant, the number of seeds per pod, and 100-grain weight across the different sites. However, numerically, Kipera exhibited the highest average number of pods per plant, followed by Ndole and Mgeta. The number of seeds per pod in all sites displayed nearly similar average numbers, ranging from 3.06 to 3.63 seeds per pod. Additionally, the 100-seed weight showed slight average differences per 100 grains, ranging from 36.5 to 38.1 g. In terms of biomass yield, Ndole demonstrated the highest average biomass yield (7.1 t ha^{-1}), followed by Mgeta (6.7 t ha^{-1}) and finally Kipera (6.5 t ha^{-1}).

Significant ($p < 0.001$) differences were observed in the number of pods per plant among the various mulching practices. Specifically, statistical disparities were noted within the plots treated with polythene mulch, synthetic biodegradable mulch, and the control. Plants treated with polythene had the highest average number of pods per plant, followed by those treated with synthetic biodegradable mulch, and finally, the control or without mulch. The interaction effects of mulching on the number of pods per plant across all sites were examined, and results indicated that plots treated with polythene mulch exhibited higher mean numbers of pods per plant compared to the control (without mulch) across all sites. Similarly, synthetic biodegradable mulch showed a similar trend of the increased number of pods per plant compared to the control. The analysis revealed that at the Mgeta site, both polythene mulch and synthetic biodegradable mulch resulted in comparable numbers of pods per plant. However, at Kipera and Ndole sites, polythene mulch demonstrated a higher number of pods per plant compared to other mulches. Furthermore, significant ($p = 0.032$) differences were observed in the number of seeds per pod among the mulching practices, with polythene mulch showing the highest average number of seeds per pod, followed by synthetic biodegradable mulch, and rice husks. However, a slight difference was detected between polythene mulch and synthetic

TABLE 2 Yield performance of common bean as influenced by the main effects of sites and mulching practices.

Factors	Number of pods/plant	Number of seeds/pod	100 grain weight (g)	Biomass yield (t ha^{-1})	Grain yield (t ha^{-1})
Sites					
Kipera	7.25^{a}	3.63^{a}	37.7^{a}	6.5^{a}	2.48^{a}
Mgeta	6.68^{a}	3.06^{a}	36.7^{a}	6.7^{a}	2.28^{a}
Ndole	6.71^{a}	3.19^{a}	36.6^{a}	7.1^{a}	2.33^{a}
LSD (0.05)	1.76	0.69	1.72	0.51	0.56
CV (%)	14.8	12.2	2.7	4.4	13.7
p-value	0.684	0.196	0.276	0.084	0.675
Practices					
PE	7.50^{a}	3.58^{a}	38.1^{a}	7.5^{a}	2.67^{a}
SBM	7.25^{ab}	3.42^{ab}	38^{a}	7.2^{ab}	2.64^{a}
Rh	6.67^{bc}	3.17^{ab}	36.5^{b}	6.9^{b}	2.49^{a}
Control	6.08^{c}	3.00^{b}	35.4^{b}	5.4^{c}	1.65^{b}
LSD (0.05)	0.45	0.41	0.8	0.33	0.15
CV (%)	6.1	2.5	1.0	2.5	3.2
p-value	0.001	0.032	<0.001	<0.001	<0.001

PE, polythene mulch; SBM, synthetic biodegradable mulch; Rh, rice husk; LSD, least significance difference; CV, coefficient of variation. Means along the same column and category of comparison bearing different letter(s) differ significantly.

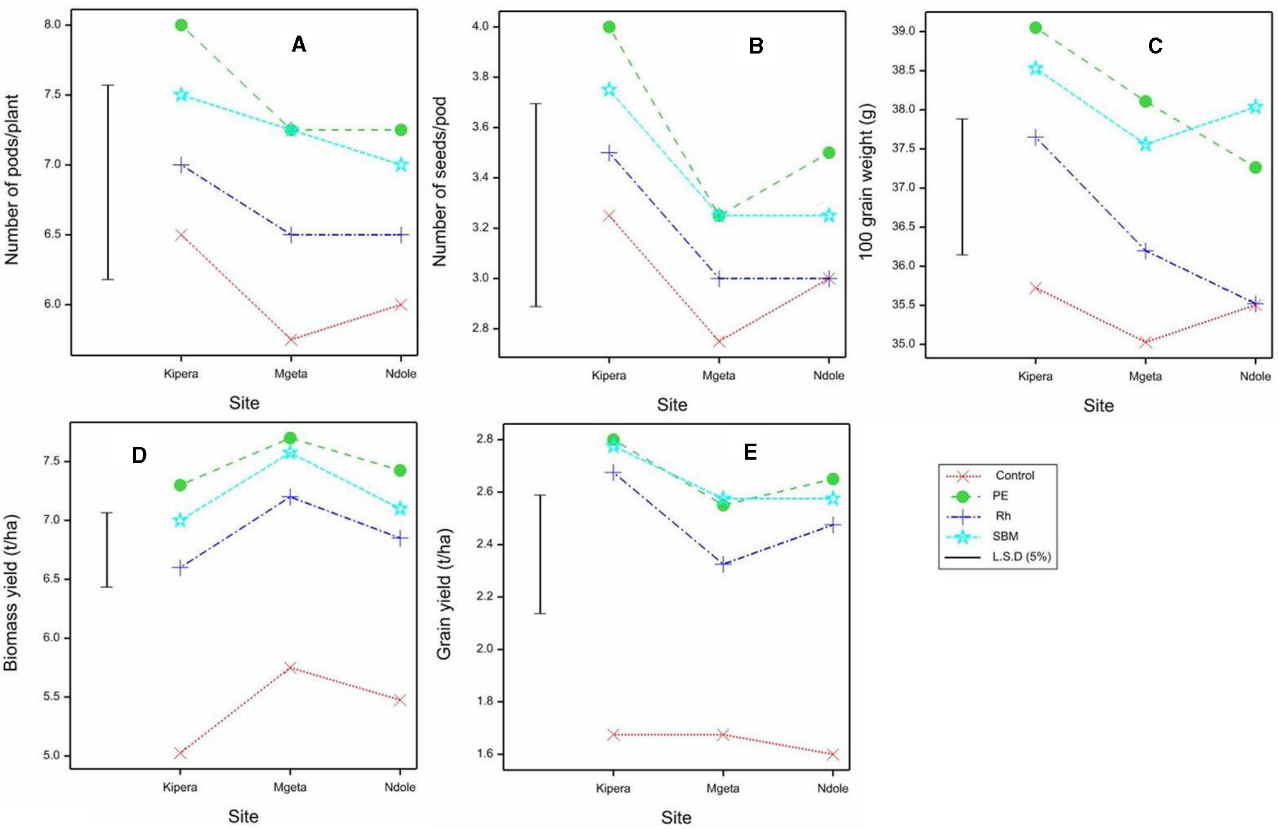

FIGURE 4
Interaction effects of sites and mulching practices on common bean yield components with L.S.D (5%), including **(A)** number of pods per plant, **(B)** number of seeds per pod, **(C)** 100 seeds grain weight, **(D)** biomass yield (t ha^{-1}), and **(E)** grain yield (t ha^{-1}) for different mulch in three sites.

TABLE 3 Soil temperature and moisture regimes in different mulch types across three experimental sites.

Factors	Soil temperature (°C)	Soil moisture (cent bars)
Sites		
Kipera	24.5[a]	49.52[a]
Mgeta	20.4[b]	46.08[a]
Ndole	22.2[c]	47.34[a]
LSD (0.05)	0.5	5.65
CV (%)	1.3	6.8
p-value	<0.001	0.38
Practices		
PE	23.2[a]	45.32[c]
SBM	23.1[a]	45.72[c]
Rh	21.9[b]	47.76[b]
Control	21.2[c]	51.78[a]
LSD (0.05)	0.37	0.59
CV (%)	1.1	3.7
p-value	<0.001	<0.001

PE, polythene mulch; SBM, synthetic biodegradable mulch; Rh, rice husk; LSD, least significance difference; CV, coefficient of variation. Means along the same column and category of comparison bearing different letter(s) differ significantly.

biodegradable mulches, but they were statistically different from the control (Table 2). Across all sites, polythene mulch generally had higher mean values of the interaction effects compared to the control. In contrast, synthetic biodegradable mulch and rice husk mulch demonstrated varying interaction effects of sites and mulch compared to the control (Figure 4B).

Plants grown in plots with polythene mulch showed the highest average weight per 100 grains (38.1 g), followed by those with synthetic biodegradable mulch (38.0 g), rice husks (36.5 g), and the control (35.4 g). Although synthetic biodegradable mulch and polythene mulch did not indicate significant ($p > 0.05$) differences between them, significant ($p < 0.001$) differences were observed with rice husk and control treatments in 100-grain weight among the mulching practices. Across all sites, the use of polyethylene mulch and synthetic biodegradable mulch generally resulted in a higher interaction effect in 100-seed grain weights compared to the control (Figure 4C). The effects of rice husk treatment varied across different sites, with some sites showing slight increases in 100-grain weight compared to the control. The Kipera site exhibited the highest mean 100-grain weights across all sites.

Regarding biomass yield components, plots treated with polythene mulch showed significantly ($p < 0.001$) higher values compared to rice husk and the control plot. Synthetic biodegradable mulch was observed to have a slightly different effect compared to polythene mulch; similarly, synthetic biodegradable mulch exhibited a statistically different effect compared to the control treatment, and a slight difference was observed with rice husk (Table 2). Biomass yield also differed significantly among the mulching practices ($p < 0.001$). The interaction effects indicated that polythene mulch yielded higher mean biomass across all sites, followed by synthetic biodegradable mulch and rice husk mulch, and the control had the least biomass interaction effects (Figure 2). The Mgeta site exhibited the highest biomass yield, ranging from 5.8 to 7.7 t ha^{-1} over other sites, and Kipera had the lowest biomass yield, ranging from 5.0 to 7.0 t ha^{-1}, different from other components.

Although grain yield varied slightly among sites, these differences were not significant ($p = 0.675$). There were significant ($p < 0.001$) differences in grain yield among the mulching practices. The results indicated that polythene mulch, synthetic biodegradable mulch, and rice husks had no statistical difference. However, there was a difference observed with the control. Grain yield showed that plots treated with polythene mulch resulted in the highest average grain yield (2.67 t ha^{-1}), followed by synthetic biodegradable mulch (2.64 t ha^{-1}), rice husks (2.49 t ha^{-1}), and the control had the least performance (1.65 t ha^{-1}) across the three sites. At the Kipera site, both polyethylene mulch and synthetic biodegradable mulch demonstrated the highest mean grain yield interaction, reaching 2.8 t ha^{-1}. In contrast, at the Ndole site, the control, which involved no mulch application, exhibited the lowest mean grain yield of 1.6 t ha^{-1}. Additionally, the highest grain yield of 2.58 t ha^{-1} was recorded at the Mgeta site in synthetic biodegradable mulch, followed by polythene mulch (2.55 t ha^{-1}) (Figure 4E).

3.3 Soil temperature and moisture regimes under mulching

Soil temperature varied significantly ($p < 0.001$) across different sites (Kipera, Mgeta, and Ndole). Kipera had the highest soil temperature (24.5°C), followed by Ndole (22.2°C), and Mgeta had the lowest temperature (20.4°C). The effects of mulching practices on soil temperature were observed significantly (Table 3). Polyethylene and synthetic biodegradable mulch showed nearly similar soil temperatures (23.2 and 23.1°C, respectively), which were higher than rice husk mulch (21.9°C) and the control (21.2°C). The differences between mulching practices were significant ($p < 0.001$). Kipera consistently exhibited the highest soil temperature interaction effect across all mulching practices, followed by Ndole, and then Mgeta (Figure 5A). The interaction between the site and mulching practice had varying effects on temperature regulation at each site.

Polyethylene mulch and synthetic biodegradable mulch resulted in the highest temperature interaction effects across all sites, followed by rice husk mulch, and the control treatment. The highest soil temperature was recorded with synthetic biodegradable mulch (25.2°C) at the Kipera site, while the lowest soil temperature was observed with the control treatment (19.4°C). Soil moisture content analysis showed no significant ($p = 0.38$) site differences. All sites exhibited relatively similar soil suction levels, with Kipera recording the highest soil suction content (49.52 Cent bars) and Mgeta the lowest (46.08 Cent bars). Mulching practices significantly influenced soil suction content (Table 3). The control exhibited the highest soil suction content (51.78 Cent bars), followed by rice husk mulch (47.76 Cent bars), synthetic

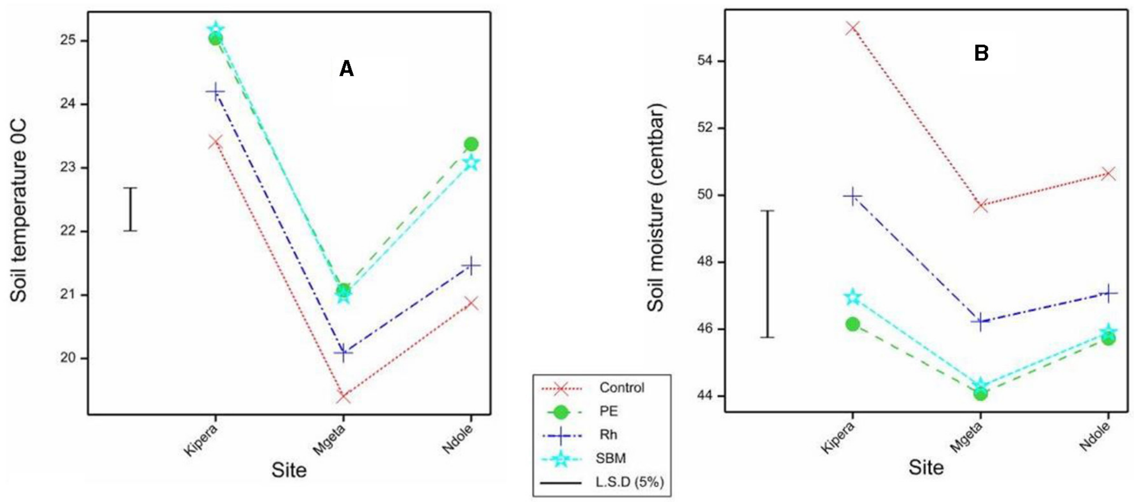

FIGURE 5
Interaction effects of soil temperature and moisture regimes **(A, B)** with LSD (5%) for different mulch in three sites.

TABLE 4 Soil characteristics of selected parameters across the sites.

Factors	pH_{H2O}	EC (dS m^{-1})	OC (%)	OM (%)	Bd (g cm^{-3})
Mgeta	5.5^{c}	0.22^{a}	1.40^{a}	2.41^{a}	1.37^{a}
Kipera	6.9^{a}	0.36^{a}	2.82^{a}	4.87^{a}	1.23^{a}
Ndole	6.3^{b}	0.19^{a}	2.09^{a}	3.61^{a}	1.38^{a}
LSD (0.05)	0.31	0.15	1.22	2.1	0.16
CV (%)	2.8	34.3	33.4	33.4	7
p-value	<0.001	0.062	0.075	0.075	0.098

pH_{H2O}, pH of water; EC, electrical conductivity; OC, organic carbon; OM, organic matter; Bd, bulk density, LSD, least significance difference; CV, coefficient of variation. Means along the same column and category of comparison bearing different letter(s) differ significantly.

biodegradable mulch (45.72 Cent bars), and polyethylene mulch (45.32 Cent bars). The differences in soil suction among mulching practices were significant ($p < 0.001$).

The interaction between the site and mulching practice influenced soil moisture differently at each site. Kipera generally exhibited higher soil suction levels across all mulching practices compared to Mgeta and Ndole. The highest suction was recorded in the control at the Kipera site (55 Cent bars). Mgeta and Ndole showed relatively similar soil suction levels, with Mgeta slightly lower than Ndole. The control resulted in the highest soil suction levels across all sites, while polyethylene mulch had the lowest soil suction, with the lowest soil suction (44 Cent bars) at Mgeta, followed by synthetic biodegradable mulch also at Mgeta (Figure 5B).

3.4 Soil characteristics of selected parameters

Soil characterization of selected parameters at the sites indicated that Kipera had pH, which was neutral to slightly acidic, low bulk density (indicating potentially better soil structure), and higher levels of organic carbon and organic matter. Mgeta had significantly more acidic soil compared to Kipera and Ndole, with no significant differences among the sites in other parameters (Table 4).

3.5 Temperature and rainfall across the three sites

Kipera and Ndole had similar surface temperatures, both significantly higher than Mgeta. The differences in temperature between the sites were statistically significant (Table 5). Rainfall measurements showed high variability, and the differences were not statistically significant across the three sites.

3.6 Economics of using mulching materials in common bean production

Synthetic biodegradable mulch had the highest total variable costs, followed by polythene mulch, rice husk mulch, and control. Gross benefits are higher for the plastic mulch, followed by the synthetic biodegradable mulch. Marginal returns, benefit–cost ratios, and marginal rates of return varied among the mulch practices, with each metric suggesting different levels of economic performance (Table 6). Polythene mulch had a higher marginal return, and synthetic biodegradable mulch was nearly close; the control was observed to have a low marginal return over all treatments. The benefit–cost ratio was observed to be higher in the control (2.96), followed by polythene mulch and synthetic biodegradable mulch recorded with a lower benefit–cost ratio than all other mulch types. Marginal rates of return were recorded higher in polythene mulch (1.38), synthetic biodegradable (1.21), and rice husk (1.19).

The data revealed that, among the mulching materials tested, polyethylene mulch resulted in the highest experimental yield of 2.67 tons per hectare, followed by synthetic biodegradable mulch with 2.64 tons per hectare, and rice husk with 2.49 tons per hectare (Table 7). The control had the lowest yield of 1.65 tons per hectare. Polythene mulch generated the highest income of Tshs. 8,001,000 per hectare, followed by synthetic biodegradable mulch with Tshs. 7,926,000 per hectare, rice husk mulch with Tshs. 7,476,000 per hectare, and the control plot yielded the lowest income of Tshs. 4,950,000 per hectare.

TABLE 5 Surface temperature and rainfall.

Factors	Surface temperature (°C)	Rainfall (mm)
Sites		
Kipera	24.4[a]	1.8[a]
Mgeta	21.6[b]	1.4[a]
Ndole	24.2[a]	0.5[a]
LSD (0.05)	0.62	1.76
CV (%)	10.3	573.1
p-value	<0.001	0.32

LSD, least significance difference; CV, coefficient of variation. Means along the same column and category of comparison bearing different letter(s) differ significantly.

4 Discussion

The use of synthetic biodegradable mulch and polythene for most growth components proved to be better compared to rice husk mulch and control or without mulch except in the number of branches per plant. Site conditions were found to affect the growth parameters of common bean plants, including height, number of branches per plant, number of leaves per plant, and ground coverage. The location had a significant effect on plant height, with the Kipera site showing greater height than the Ndole and Mgeta sites. These differences suggested that local environmental factors, such as microclimate, could affect agricultural practices. Kipera is a low-land area; therefore, microclimate is different from Ndole's middle altitude and Mgeta, which is a high-altitude area. The study by Achenef et al. (2021) also observed the effects of location on the growth of the common bean, Kipera. Superior height performance could be attributed to more favorable conditions like better soil quality, optimal moisture levels, and favorable temperature ranges, and it was supported by Haleke Besaye and Galgaye (2022). Mulching practices on bean plant height across the three

TABLE 6 Partial budget Tanzanian shillings (Tshs) analysis of the economic performance of common bean production under mulch practices.

Production cost	Control plot*	Rice husk mulch plot	Plastic mulch plot	SBM mulch plot
1. Variable cost				
Land preparation	1,100,000.00	1,100,000.00	1,100,000.00	1,100,000.00
Sowing	175,000.00	175,000.00	185,000.00	185,000.00
Seed	189,000.00	189,000.00	189,000.00	189,000.00
Weeding	210,000.00	70,000.00		
Mulch		1,886,000.00	1,721,250.00	2,460,750.00
Laying of mulch		375,000.00	205,000.00	205,000.00
Remove of mulch			487,000.00	
Total variable cost (TVC)	1,674,000.00	3,795,000.00	3,887,250.00	4,139,750.00
2. Gross benefit (GB)	1,650.2kg @3,000 = 4,950,600.00	2,492.3 kg @3,000 = 7,476,900.00	2,667 kg @3,000 = 8,001,000.00	2,642. 4 kg @3,000 = 7,927,200.00
3. Marginal return (MR) = GB/TVC	3,276,600.00	3,681,900.00	4,114,050.00	3,787,450.00
4. Benefit–cost ratio (BCR= GB/TVC)	2.96	1.97	2.06	1.91
5. Marginal rate of return (MRR) = GB with mulch – GB without mulch and TVC with mulch – TVC without mulch	1.19	1.38	1.21	

*The exchange rate was Tshs. 2,609.3/= per USD 1 based on Bank of Tanzania (BOT) rates of 26 June 2024.

TABLE 7 Experimental yield (t ha^{-1}), and total income obtained for mulching and no mulch materials in common bean performance estimated in t/ha and income obtained.

Mulching materials	Yield (t ha^{-1})	Yield (kg ha^{-1})	Price (Tshs ha^{-1})	Income (Tshs ha^{-1})
PE	2.667[a]	2,667	3,000	8,001,000.00
SBM	2.642[ab]	2,642	3,000	7,926,000.00
Rh	2.492[b]	2,492	3,000	7,476,000.00
Control	1.650[c]	1,650	3,000	4,950,000.00
LSD (0.05)	0.152	–	–	–
CV (%)	3.2	–	–	–
p-value	<0.001	–	–	–

PE, polythene mulch; SBM, synthetic biodegradable mulch; Rh, rice husk; LSD, least significance difference; CV, coefficient of variation. The exchange rate was Tshs. 2,609.3/= per USD 1 based on Bank of Tanzania (BOT) rates of 26 June 2024.

sites, polythene, and synthetic biodegradable mulch had higher performance compared to rice husk and control. The differences in plant height under different mulching practices highlighted the importance of mulch type in optimizing plant growth; the use of polythene mulch and synthetic biodegradable mulch provided the best results in terms of plant height, and this could be due to their effectiveness in moisture retention, temperature regulation, and weed suppression. These factors contribute to an improved microenvironment for the bean plants and promote better growth. Demo and Asefa Bogale (2024) reported that the use of mulch as a soil cover improves the microenvironment, resulting in better growth and performance of crops. Soil characterization of selected parameters revealed that Kipera had superior soil quality. The pH was neutral to slightly acidic, which is optimal for many crops. Additionally, Kipera had the highest levels of organic carbon and organic matter, indicating a richer nutrient profile. The bulk density was the lowest among the sites, suggesting a better soil structure that supports plant growth and yield, as revealed by USDA-NRCS (2008). High bulk density is an indicator of low soil porosity and soil compaction, which may cause restrictions to root growth and poor movement of air and water through the soil. Therefore, it revealed that for common bean production consideration of sites and type of mulching was important, polythene and synthetic biodegradable mulches were particularly effective, likely due to their superior moisture retention and thermal properties as observed by Gheshm and Brown (2020) and Lu et al. (2020). However, synthetic biodegradable mulch could be more effective due to its degradability in the environment and have less environmental impact (Kasirajan and Ngouajio, 2012).

In number of branches per plant, the Kipera site had significantly more branches compared to other sites. It was supported by de Mejía et al. (2003), suggesting that the number of branches is a more variable trait within each site, which could be due to microclimate and soil condition of an area. Mulching practice showed no significant difference in the number of branches, similar results obtained by Kamal et al. (2010). This implied that bean branching is less influenced by the type of mulch and more by other factors. In the number of leaves per plant, Kipera had a significantly higher number of leaves compared to other sites; this revealed that the site influences the number of leaves per plant, and this could be due to climatic factors such as temperature, light intensity that influenced the number of leaves per plant. Liu et al. (2020) observed that climatic factors significantly influence the final leaf numbers of crops. Mulching practices of polythene mulch and synthetic biodegradable mulch resulted in more leaves compared to the control, where rice husk is intermediate. Synthetic biodegradable mulch and polythene had a higher number of leaves, which was observed to be significant to control; this indicated that these mulching are effective in enhancing plant and leaf number, likely due to their better moisture retention, temperature regulation, weed suppression, and reducing competition of resources, making the crop healthier. Yin et al. (2019) and Iqbal et al. (2020) reported similar results that application of mulch showed effective use of the resource by crop through reduction of competitors.

Kipera showed the highest canopy cover, significantly greater than Mgeta and Ndole; the effects could be due to the difference in microclimate of these three sites. In mulching practices, synthetic biodegradable mulch and polythene had a greater percentage of ground coverage compared to rice husk and control, and they indicated a statistical difference. The greater percentage of ground coverage in synthetic biodegradable mulch could be enhanced by their efficiency in modulating microclimate and increasing the effective use of resources by crops, which resulted in the promotion of growth. Similarly, Iriany et al. (2021) and Soylu and Kizildeniz (2024) reported that this mulch improves soil nutrient status and nitrogen usage effectiveness, promoting plant growth and yield. Synthetic biodegradable mulch could be highly beneficial for enhancing plant growth and its ability to degrade in agricultural soil.

The results provided valuable insights into the effectiveness of specific agricultural practices and environmental conditions on bean productivity. Notably, the common bean yield parameters showed no significant variation across the three sites. The finding suggests that yield components in common beans across the eastern agro-ecological zone are independent of altitudinal differences, indicating uniform growing conditions across these sites. This contrasts with the study conducted by Nassary et al. (2020), which reported significant variations in yield components due to altitudinal differences. The impact of mulching practices on yield parameters was significant across most metrics, as reflected in the number of pods per plant, number of seeds per plant, 100-grain weight, plant biomass, and grain yield. Both polythene and synthetic biodegradable mulch showed the highest yield parameters, indicating their effectiveness in enhancing bean growth and productivity. Polythene and synthetic biodegradable mulch led to the highest number of pods per plant, significantly enhancing pod formation compared to the control. Additionally, the number of seeds per pod was significantly higher with these mulches, suggesting that they improve conditions for seed development. These results imply that polythene and synthetic biodegradable mulch both enhance the growth and yield of beans by maintaining soil moisture and temperature, reducing weed competition, and improving nutrient availability, which makes them particularly effective mulching options for maximizing bean productivity. Li et al. (2016) and Serrano-Ruiz et al. (2021) reported similar scenarios on how this mulching enhances the productivity of vegetable crops, wheat, and maize yield.

In terms of 100-grain weight, both synthetic biodegradable mulch and polythene mulch resulted in higher 100-grain weights, reflecting improved grain quality and size. These practices likely enhance soil moisture retention, temperature regulation, and weed suppression, which contribute to better plant health and higher yields. Similar findings were highlighted by Ngouajio et al. (2008) and Cozzolino et al. (2023), who reported that biodegradable mulching improved yield and quality in melon production. Synthetic biodegradable mulch produces biomass yields nearly as high as those observed with polythene mulch. This is likely due to better overall plant growth supported by optimal moisture and efficient use of nutrients by crops. Similar results were obtained for other crops, such as strawberries, maize, and tomatoes (Costa et al., 2014; Deng et al., 2019; Sekara et al., 2019). The grain yield of common beans was significantly higher with synthetic biodegradable mulch and polythene mulch compared to the control. These mulches were particularly effective in enhancing grain yield parameters, including pod formation, seed development, grain weight, biomass yield, and overall grain yield. This suggests that adopting mulching practices, especially using polythene or synthetic biodegradable mulch, can substantially improve common bean productivity. Similar results were reported by other researchers (Shan et al., 2022; Samphire et al., 2023; Massawe et al., 2023). However, polythene is reported to have several environmental impacts, so synthetic biodegradable mulch can be a suitable alternative to polyethylene due to fewer effects upon the completion of its degradability in agricultural soil (Chah et al., 2022; de Sadeleer and Woodhouse, 2024).

Kipera recorded the highest soil temperature among the three sites. The differences between sites were significant, indicating that site-specific factors such as local climate, soil type, and vegetation cover influenced soil temperature. Polythene and synthetic biodegradable mulch treatments had similar and the highest soil temperatures, significantly different from rice husk and control treatments. This suggests that mulching, particularly with polythene and synthetic biodegradable materials, effectively increases soil temperature, and this could be due to its effectiveness in absorbing sunlight and worms in the soil. This finding is consistent with the studies by Zhang et al. (2022) and Snyder et al. (2015). In terms of moisture, there was variability among the sites. The control (no mulch) had the highest soil suction level, while polythene had the lowest suction. These differences are significant, demonstrating that mulching practices affect soil moisture retention, with polythene and synthetic biodegradable mulch being more effective. Lower suction or tension indicates moist soil, whereas higher suction indicates drier soil. These mulches provide a barrier that reduces heat loss from the soil, helping to maintain warmer soil temperatures, which can enhance root development, especially in cooler climates. Additionally, by preventing rapid drying of the soil surface, they promote more uniform moisture distribution in the root zone, enhancing plant growth and yield. Similar effects of synthetic biodegradable mulch and polythene mulch were reported by other previous studies (Schonbeck, 2012; Menossi et al., 2021). The surface temperature was significantly higher in Kipera and Ndole compared to Mgeta, implying that location-specific temperature variations could affect the growth and yield of crops differently in these areas. Although rainfall was not significantly different across the three sites, it showed high variability.

In terms of cost efficiency, the control plot had the lowest total variable cost but yielded the lowest gross benefit. Among the mulch practices, synthetic biodegradable mulch had the highest total variable cost. Polythene mulch had the highest marginal rate of return, followed by synthetic biodegradable mulch. While the control plot is the most cost-efficient in terms of benefit–cost ratio, the polythene mulch was observed to be the most profitable and had the highest marginal return, followed by synthetic biodegradable mulch. The data demonstrated that mulching significantly enhances both the yield and income of common bean production compared to no mulch. To maximize yield and income for common bean, polythene mulch might offer the best balance between cost and return, with synthetic biodegradable mulch as a nearly close; despite its higher initial investment cost, the mulch can potentially pay off. Studies by Marí et al. (2018) and Madrid et al. (2022) also revealed that polythene mulch is more economically viable than synthetic biodegradable mulch.

The degradability of synthetic biodegradable mulch is influenced by several abiotic and biotic factors. Abiotic factors include temperature, moisture, UV radiation, and mechanical stress. Miles et al. (2017) observed similar findings, noting that these factors, along with wind, play a crucial role in causing mechanical abrasion. Biotic factors, such as microorganisms (bacteria, fungi, and actinomycetes), enzymatic activity, plant root interactions, soil invertebrates, and the diversity of microbial communities, also play crucial roles in biodegradability. For instance, Fontanazza et al. (2021) reported that the bacterium *Pseudomonas putida* was responsible for the biodegradation of synthetic biodegradable mulch in agricultural soils. Due to its degradability in soil, synthetic biodegradable mulch has reduced environmental implications compared to polythene. This makes it the most promising alternative for non-degradable plastic mulching, as revealed by Soylu and Kizildeniz (2024).

5 Conclusion and recommendations

Mulching has been identified as a viable solution to improve soil conditions and enhance crop productivity. The three-site experiment indicated that both synthetic biodegradable mulch and polythene mulch showed superior performance. However, there were no significant differences between these two types of mulch for most growth and yield parameters. Economic analysis revealed that polythene mulch provided the highest marginal return, closely followed by synthetic biodegradable mulch, making them both economically viable options for common bean production. This indicates that synthetic biodegradable mulch is a viable alternative to polythene mulch. Additionally, environmental conditions at different sites played a crucial role in growth and yield parameters, likely due to more favorable microclimatic conditions.

The adoption of synthetic biodegradable mulch is crucial, given its comparable performance to polyethylene mulch and its environmental benefits. Despite the higher initial cost, the use of polyethylene and synthetic biodegradable mulches resulted in higher yields and economic returns. Synthetic biodegradable mulch offers a sustainable alternative, reducing plastic waste and degradation issues associated with polyethylene mulch. Promoting the use of synthetic biodegradable mulches among Tanzanian farmers, particularly smallholders who rely heavily on common bean cultivation, is highly important. The promotion can be facilitated through government subsidies, awareness campaigns, and training programs to highlight the benefits and proper application techniques. Implementing site-specific management practices that consider local environmental conditions has shown the highest improvement in the growth and yield of common beans; therefore, farmers should consider local environmental conditions when selecting mulching practices to maximize benefits. Policymakers and agricultural extension services should align and support farmers in adopting these practices, especially the use of synthetic biodegradable mulch, which is environmentally friendly, through setting policies that, in implementation, would reduce the investment cost through subsidies or financial assistance. Long-term research into the effects of synthetic biodegradable mulch on crop performance and its economic impact across different crop types and environmental conditions is recommended to fully establish the long-term benefits and potential drawbacks. Integrated agronomic practices, such as combining mulching with optimal irrigation, fertilization, and pest management, can further enhance common bean productivity. Farmers should be trained and encouraged to adopt an integrated approach to sustainable agriculture.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AR: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. BM: Supervision, Writing – review & editing. EN: Supervision, Writing – review & editing. FR: Supervision, Writing – review & editing. SN-M: Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The authors acknowledge material and financial support from the FoodLAND project. FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802). The views and opinions expressed in this publication are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission. We thank all the FoodLAND partners and field staff for their support when doing this research.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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