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Mulching practices alter soil moisture, physico-chemical properties and pineapple (*Smooth cayenne*) yield

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Abstract
This field experiment was conducted in Chichu Kebele in the Dilla Zuria area from 2020 to 2023. The objective of the experiment was to determine the optimal mulching strategy for enhancing soil fertility and pineapple production by comparing three treatments (grass mulch, plastic mulch, and farmers' practices without any mulch) using a RCB (Randomized Complete Block) design. The study's findings showed that the treatments with plastic mulch had the greatest soil moisture content values (18.41%), while the treatments with no mulch had the lowest values (11.39%). Compared to mulched treatments, pineapple planted without mulch had the greatest bulk density values (1.43 g/cm^3). Total nitrogen and organic carbon has increase by 34 and 25%, respectively due to plastic mulching. However, total nitrogen and organic carbon has increase by 43 and 37.5%, respectively due to grass mulching. Fruit length was larger by 42.7 and 33.2%, respectively due to plastic and grass mulch compared to the control. However, fruit girth was wider by 54.1 and 43.8%, respectively due to plastic and grass mulches compared to the control. The pineapple with the most fruit yield (71.39 t/ha), fruit length (17.4 cm), fruit girth (46.67 cm), and sucker number (15 pieces) was obtained using plastic mulching. However, pineapple grown without mulch had the lowest yield ever noted. Plastic mulch outperformed farmers' practices and grass mulching in terms of conserving soil moisture, which increased yield and yield characteristics. For the baseline, the marginal rate of return generated by the plastic and grass mulch treatments was 118.5 and 93.65%, respectively. Thus, the study's best recommendation for improving soils and achieving a high pineapple fruit yield is to grow pineapples using plastic mulch.

Keywords Bulk density · Erosion control · Pineapple · Plastic mulch · Yield

1 Introduction

Many tropical countries have distinctly dry and wet seasons [1]. During the dry season, ground vegetation usually becomes scarce and thin, leaving the soil uncovered. Conversely, when the rainfall arrives, large amounts of valuable topsoil can be washed away, leaving the land uneven with gullies and low fertility. Not only steep slopes but plain fields are also prone to soil erosion, and can be severely affected [2]. However, soil erosion would not be a problem as long as there is a permanent plant cover or sufficient input of organic material [3]. This has been demonstrated by [4, 5] who reported that mulching of pineapple plots was the most effective means of combating erosion.

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In Ethiopia's southern and southwestern regions, investors and smallholder farmers have grown pineapples for food, income, and medical purposes. It has also been used to process sugar, wine, vinegar, and animal feed. The leaves have been used to make clothing, ropes, fishing nets, and pulps. In 2012, Ethiopia produced more than 8400 tons of pineapples. In 2022, pineapple production was 237% higher than in prior years [6]. Wondifraw et al. [7] Found a national average output of 45 tons/ha, which was much lower than the global average fruit yield of 67.5 tons/ha [8]. This low yield was partly due to the low fertility status of the soil, which resulted from depletion by subsequent crops, the lack of improved pineapple production and management technologies for diverse environments, the longer maturity, the poor marketing system, the presence of diseases and insect pests, and the lack of improved post-harvest handling technologies [9].

Mulching has several other essential applications, including reducing soil water loss, enriching soil fauna, and improving soil properties and nutrient cycling in the soil. It also reduces the pH of the soil, which improves nutrient availability [10]. Mulching is one of the soil amendment techniques that act of covering the soil with mulches such as bark, woodchips, leaves, dead grasses, plastic, and other materials to retain soil moisture by preventing water evaporation, especially in the summer season, to keep soil temperature cooler, to suppress weed growth and for decorative purposes [11]. Other authors reported that soil amendments enhanced soil moisture and other soil properties in the tropics, and improved biomass yield of the crop than the control (no soil amendments application) [12, 13]. Moreover, mulching reduces soil deterioration by limiting runoff and soil loss, and it increases soil water availability by reducing evaporation, managing soil temperature, or reducing crop irrigation requirements [14].

According to [15], mulching reduces the erosive power of the raindrops by keeping the soil covered, increases crop yield mainly due to the improvement of soil microclimate, enhancement of soil life, structure and fertility, conserves soil moisture, reduces weed growth, prevents damage of solar radiation and rainfall, and reduce the need for frequent tillage. Mulching of pineapple fields with black polythene followed by thatch grass/saw-dust gave better yield and quality, and suppressed weed growth [16]. Mulching the base of the pineapple plant with weeds that are cut through hand weeding or intercrop cultivation helps in weed control, water conservation, and improvement of soil nutrient status [17]. Other reported benefits of mulching include its positive role in climate change adaptation and enhancement of organic agriculture, which are both vital to improving the health and quality of life of human beings on Earth [18].

The Dilla Zuria district of the Gedeo zone is characterized by high rainfall and traditional farming systems that aggravate soil erosion [19]. The pineapple farms of Dilla Zuria district are exposed to this problem. In addition, there was a practice of producing pineapple crops in the upslope areas, these situations aggravated soil erosion and resulted in soil moisture and fertility decline, leading to pineapple yield reduction. Given the benefits of mulching reported by numerous authors [10–12, 14], the mulching practice was hypothesized to improve the soil conditions and pineapple productivity in Dilla Zuria district where the mulching practice was not used commonly for pineapple production in the past. Farmers of the area were simply planting the pineapple without applying any cover to the soil due to which they failed to notice mulching advantages including enhanced soil fertility, controlled soil erosion, suppressed weed, improved soil moisture levels, and increased fruit yield. Therefore, pineapple planting methods with different options of mulching have to be developed for Dilla Zuria of Southern Ethiopia for appropriate soil–water conservation, soil fertility enhancement, and increased productivity of pineapple. Thus this study was conducted with the main objective of identifying the best options of mulching for pineapple production and soil fertility enhancement.

2 Methodology

2.1 Description of the study area

The study was conducted at Chichu kebele which is one of 17 kebeles of Dilla Zuria district. The district is geographically located on 6° 25′ to 6° 41′ latitude and 38° 28′ to 38° 00′ longitude. It is found 385 km away from Addis Ababa, the capital city of Ethiopia. The district is located 1501 to 3000 m above sea level. The study area map including the elevation data is shown in Fig. 1. According to Gedeo Zone Plan and Development annual statistical data (2021), the total coverage of the area is 120 square kilometers. The soils of Dilla zuria district are originated from basalt rocks, and had deep red-dish to brown clayey to clay loam texture classified as Haplic Luvisols and Chromic Vertisols [20]. The topography of the district is categorized into level, mountainous, and medium sloppy areas. The agroecology of the district could be grouped into midland (woinadega), highland (dega), and lowland (Kolla) with black, red, and blue colored soil. The total population of the woreda is 129,747 composed of 65,129 and 64,618 men and women population, respectively. The area is covered by coffee, chat, fruit trees, farmlands, and other perennials. The average annual and monthly rainfall is 1253 mm and

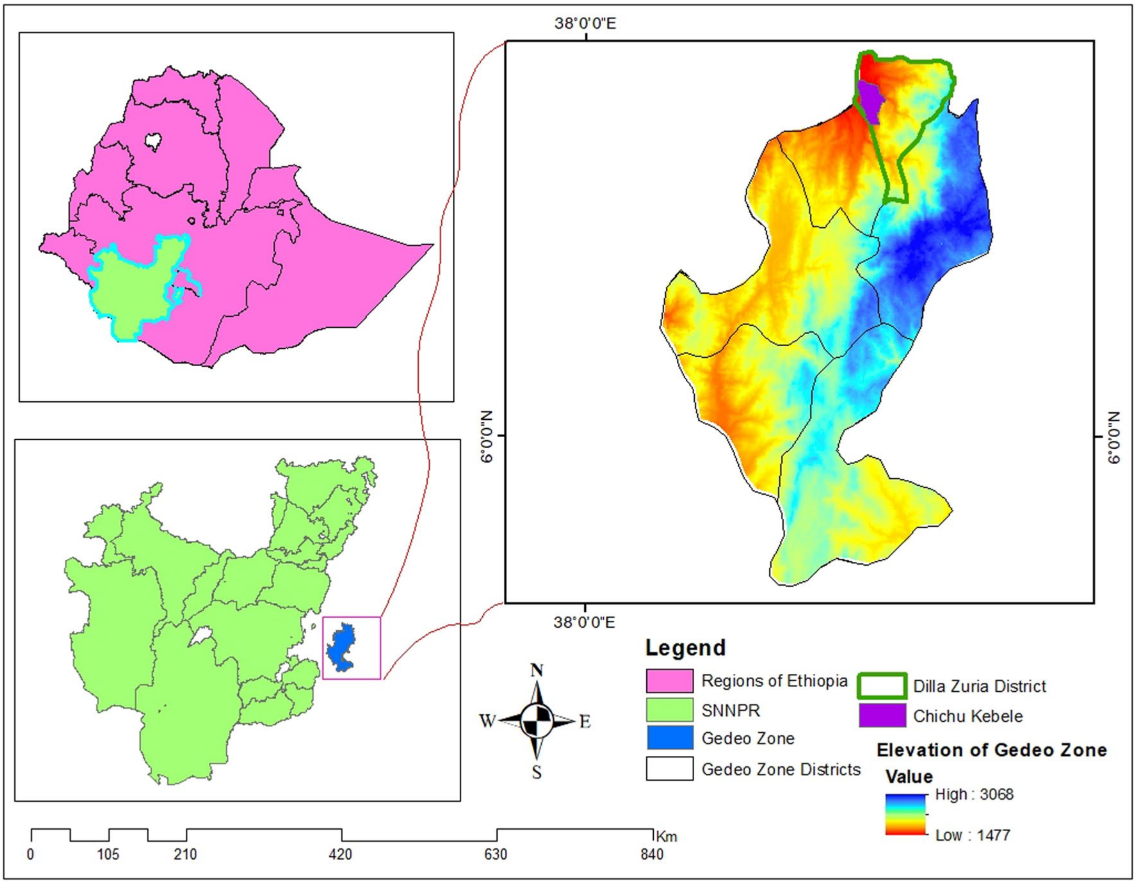

Fig. 1 Map of the study area

104.4 mm respectively. Whereas, the monthly average minimum and maximum temperature are 12.37 and 27.7 degrees Celsius respectively as shown in Fig. 2.

2.2 Field management

The pineapple suckers were planted on March, 2020 during the start of rainy season. The fertilizer was applied following [21], 138 kg/ha of P_2O_5 and 276 kg/ha N were side dressed in circles around the base of each plant in equal four splits at three months interval. Weeding was done thrice every year in February, June and August every year. Ridging was prepared by bringing the topsoil together after ploughing by oxen to provide needed nutrients and support to the plant. Harvesting was done for each sucker in a plot following the color change of the ripening fruit. The yield per plot was added up until the final harvest for collective analysis.

Fig. 2 Average monthly rainfall and temperature of the study area

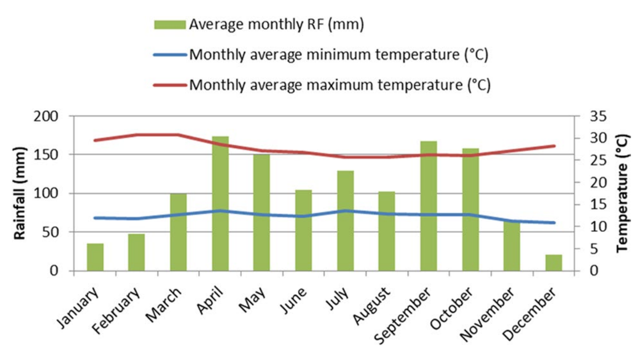

Table 1 Experiential treatments of the study

No.	Treatments	Characteristics
1	Planting of pineapple with plastic surface mulch between rows	Black polyethylene plastic having 70 micron thickness used for covering the rhizosphere of the experimental plot
2	Planting of pineapple with grass surface mulch between rows	Aerial part of local grasses such as *Setaria Sphacelata Sericea (Setaria)* dried in the sun for 8 days
3	Control (farmers' practices)	Without any mulching material on the soil surface of experimental plot

Plastic mulch and grass mulch were placed at the top of the ridge and planting holes were made based on plant spacing (40 cm)

Fig. 3 **a** Planting system and field view of the experiment. **b** Plastic mulch established on the experimental field in the Chichu area

2.3 Experimental procedure

The experiment was conducted within 3 years (2020 to 2023). In the 1st year, site selection, before the trial soil sample collection, pineapple seedling preparation, and experimental establishment were undertaken. The collected soils were used for analysis of organic carbon and soil particle size distribution. The soil moisture and bulk density data were collected every three months interval after the rainfall event. In the second and third years, data on sucker number, fruit characteristics, and yield were collected at each one-month interval for five rounds and summed up for statistical analysis. After the trial, the soil samples were also collected to evaluate the impacts of treatments on soil properties.

2.4 Research design

The experiment was laid out using three treatments (Table 1) and five replications in a Randomized Complete Block Design (RCBD). The pineapple was planted using a row planting system as shown in Fig. 3. Each experimental plot has two pineapple rows. The length of the plot was 4 m. The inter-row and intra-row spacing were 1 m and 0.4 m, respectively. Within each row, 10 seedlings were planted.

2.5 Statistical data analysis

The data set was checked for normality (Shapiro–Wilk test, $P > 0.05$) and homogeneity of variance (Chi-square Test, $P > 0.05$) before Analysis of Variance (ANOVA). The R software package was used to execute ANOVA. The one-way ANOVA was performed to test the impacts of mulching on soil parameters, pineapple yield, and sucker growth. Post-hoc tests for multiple comparisons were performed using Least Significant Differences (LSD test, $P < 0.05$) to compare means among measured parameters. The level of significance was defined at $P < 0.05$ for all statistical analyses.

2.6 Determining soil moisture content and yield of pineapple

The soils were collected at each three-month interval after rainfall events; to evaluate the soil moisture content of the treatments by using a core sampler. Wet soil weight was measured at the field using a sensitive balance. To measure dry weight, the collected soil was oven-dried at 105 °C for 24 h. The following formula was used for calculating the soil moisture content [22].

$$SMC = \frac{Ww - wd}{wd} * 100$$

where SMC is the soil moisture content dry base (%), Ww is the weight of the wet soil (g), W_d is the weight of the dry soil (g).

Representative soil composites were taken before and after the trial from 20 cm depth using augur to value the impacts of selected mulching practices on soil parameters. Each composite soil sample was subjected to physicochemical analysis. United States Department of Agriculture (USDA) soil texture classification method was used to classify soil texture. Collected soils were analyzed at the Hawassa Agricultural Research Center (HARC) soil and plant analysis laboratory.

The data on the number of pineapple suckers and fruit yield were collected every other month until October, 2023. The fruit yield was harvested from all populations of the plot (10 seedlings) and weighed using a digital balance at the field. The sucker numbers were counted manually and averaged for analysis. The rate of change of observed soil moisture, sucker number, and pineapple yield parameters against the control treatment was computed following [20].

$$\%\ change = \left(\frac{Treatment\ A - control\ treatment)}{Treatment\ A}\right) * 100$$

Treatment A refers to either plastic or grass mulch used in the experiment.

2.7 Cost–benefit analysis

Cost benefit analysis was done using partial budget analysis following [23]. After writing the treatments rank based on the cost, The MRR (%) was calculated using the formula;

$$\text{MRR}(\%\ ) = \left(\frac{net\ benefit\ trt\ ii - net\ benefit\ trt\ i}{cost\ trt\ ii - cost\ trt\ i}\right) * 100$$

where *trt ii* represents the treatment ranked before *trt i* based on the cost.

3 Result and discussion

3.1 Selected soil properties of the soil before and after the experiment

Variations in soil property values were recorded before and after the trial as shown in Table 2. Based on soil laboratory analysis results; the values of soil pH, organic carbon (OC), organic matter (OM), total nitrogen (TN), Cation exchange capacity (CEC), and phosphorus (P) showed a variation due to planting of pineapple using mulching system. This implies mulching improved soil properties. The values of pH, OC, OM, TN, CEC, and P were increased due to the application of grass and plastic mulches to the pineapple production system. This result agrees with [16], states mulching application in pineapple production system practice improved soil chemical properties. The result is also similar with [24], who states organic carbon, organic matter, total nitrogen, and phosphorus status of the soil were amended due to application of soil management practices. The percent of sand content couldn't show a variation due to the application of grass and plastic mulches. The percent of clay content increased from 59 to 63% due to the application of plastic mulch, but grass mulch influences clay content as shown in the table below. The higher values of organic carbon, CEC, and phosphorus due to plastic mulches compared to grass mulches were due to a significant reduction of moisture loss and greater

Table 2 Means of soil physicochemical properties before and after the experiment at the Chichu site

Soil physicochemical properties	Treatments			Change in soil properties due to mulch application		
	GM	PM	Control	% change to GM	%change to PM	%change to control
pH						
Initial	4.78	4.78	4.78			
After the trial	4.95	4.76	4.83	3.56	−0.42	1.05
OC (%)						
Initial	1.79	1.79	1.79			
After the trial	2.56	2.4	1.74	43.02	34.08	−2.80
OM (%)						
Initial	3.09	3.09	3.09			
After the trial	4.41	4.14	3.01	42.72	33.98	−2.59
TN (%)						
Initial	0.16	0.16	0.16			
After the trial	0.22	0.2	0.16	37.5	25	0
CEC (meq/100 g soil)						
Initial	29.6	29.6	29.6			
After the trial	38.2	34.7	29.4	29.05	17.23	−0.68
P (mg/kg soil)						
Initial	6.63	6.63	6.63			
After the trial	11.5	9.6	6.8	73.45	44.80	2.56
Soil texture						
%sand						
Initial	20.67	20.67	20.67			
After the trial	22	22	26	6.43	6.43	25.79
% clay						
Initial	61.67	61.67	61.67			
After the trial	63	63	63	2.16	2.157	2.16
% silt						
Initial	17.67	17.67	17.67			
After the trial	15	15	11	−15.11	−15.11	−37.75

GM Grass mulch, *PM* Plastic mulch, *pH* soil pH, *OC* organic carbon, *OM* organic matter, *TN* total nitrogen, *CEC* cation exchange capacity, *P* phosphorus

decomposition of previously medium-rated organic carbon in the clay soil of the study area (Table 2), which in turn arises from higher moisture and regulation of temperature occurring in plastic mulched plots [25].

3.2 Soil moisture, bulk density, and pineapple yield at selected mulching methods

According to the analysis of variance (ANOVA), variation in values of SMC, BD, fruit yield, FL, and FG was observed between treatments as shown in the table.

3.2.1 Soil moisture and bulk density

Statistically significant variation of soil content was observed between treatments at $P < 0.05$ (Table 3). Significantly higher soil moisture (18.41%) was conserved in treatment mulched with plastic whereas the lower soil moisture (11.39%) was recorded in the pineapple planted without any mulch (control). This might be due to the limited evaporation rate in surfaces covered by plastic. Plastic mulching protects soil from solar radiation, and its resistance to water flow has reduced soil evaporation. Mulches also lessen the impact of rainfall and splash, avoiding soil compaction, and surface run-off, and boosting water infiltration. All of these factors were combined to increase soil moisture content and decrease moisture depletion [26]. The current finding is in line with [10, 16, 26, 27], who indicated that black polythene conserved

Table 3 Mean squares of SMC, BD, and yield components of pineapple

Source	DF	SMC	BD	FW	FY	FL	FG	Sucker number
Replication	4	3.02 ns	1.64E−04 ns	3722963 ns	23.27 ns	2.81 ns	35.16 ns	10.2 ns
Treatment	2	252.4***	5.16E−03*	1.21E+08***	755.43***	172.3	1974.9	409.2
Error	8	7.96	3.14E−04	1,401,561	8.76	2.71	9.76	6.02

DF degree of freedom, *SMC* soil moisture content, *BD* bulk density, *FW* fruit weight, *FY* Fruit yield, *FL* fruit length, *FG* fruit girth

*** = highly significant variation; * = depicts significant variation

significantly higher moisture compared to organic mulching or farmers' practices in pineapple production systems across the world.

There was a significant variation of bulk density value among treatments, the higher bulk density values were recorded from farmer's practice (pineapple planted without any mulch). A similar study by [16] also depicts that the bulk density of soil was higher in a pineapple production field with no mulch than mulched fields. This study indicated that soil moisture and bulk density are inversely correlated. This is also in agreement with [28], who stated that soil water content and bulk density were negatively correlated.

3.2.2 Pineapple yield and yield components

The significantly highest fruit yield of 71.39 t/ha, fruit length of 17.4 cm, fruit girth of 46.67 cm, and sucker number of 15 pieces were recorded on the planting of pineapple using plastic mulch. But, the lowest fruit yield of 55.2 t/ha, fruit length of 9.98 cm, fruit girth of 21.44 cm, and sucker number of 4 pieces were observed from pineapple planted without any mulch (farmers practice) as shown in Table 4. Higher yield attributes and yield values under plastic mulch mulching could be attributed to better moisture availability throughout the dry period. Plastic mulch proved superior to alternative treatment and farmers' practices in terms of soil moisture conservation resulting in a corresponding increase in yield characteristics and yield. The picture of pineapple harvested during 3rd round harvest is shown in Fig. 4.

This finding was in agreement with the study outcome of [16] who indicated production of higher yield and yield parameters of pineapple in a pineapple production system mulched with black polythene than mulched with organic materials and zero mulching. The current result also agreed with the findings of [29] that planting pineapple through applying mulches produced significantly higher yield and yield attributes than plots without mulch in the Dale and Aleta chuko area of Sidama. According to [26], plastic mulching increases topsoil temperature in cool spring, promoting plant growth; during hot summer, straw mulching can moderate soil temperature, preventing the topsoil from reaching temperatures that inhibit plant growth.

3.3 Cost–benefit analyses

Economic analysis was conducted using a partial budget analysis [23]. Results showed that the marginal rate of return (MRR) of treatments was 93.7 and 118.5% for baseline (Table 5). This means farmers would benefit 93.7 and 118.5 cents for every one Ethiopian Birr (ETB) invested in pineapple production using grass and pineapple mulching practices, respectively.

4 Summary and conclusion

The pineapple-producing farms in the Dilla Zuria district are characterized by high rainfall and inefficient farming methods, which might worsen soil erosion. In addition, there was a practice of cultivating pineapple crops in regions with an upward slope, which made soil erosion worse and decreased soil fertility and moisture levels. This also decreased pineapple productivity in the district. The enhanced pineapple yields obtained through mulching could be attributed to enhanced soil fertility, managed soil erosion, inhibited weed growth, raised soil moisture content, and boosted fruit production. Pineapple was being planted by farmers in the study area without any mulch or cover. As a result, there was a decreased danger of soil erosion, reduced soil moisture, and a decrease in pineapple fruit production. This resulted in the facilitated soil erosion risk, less soil moisture content, and a decline in pineapple fruit yield. Therefore, the purpose

Table 4 Mean percentage of soil moisture, sucker number, and pineapple yield

Treatments	SMC (%)	% change	BD (g/cm^3)	% change	FW (g)	% change	FY (t/ha)	% change	FL (cm)	% change	FG (cm)	% change	Sucker per plant	% change
Planting of pineapple with plastic surface mulch	18.4a	61.6	1.36b	−5.1	28557a	22.2	71.4a	22.2	17.4a	42.7	46.7a	54.1	15.0a	73.3
Planting of pineapple with grass surface mulch	14.2b	19.8	1.37b	−4.4	25467b	12.8	63.7b	12.8	14.9b	33.2	38.1b	43.8	8.0b	50.0
Control (farmers practice)	11.4c	0.0	1.43a	0.0	22210c	0.0	55.5c	0.0	10.0c	0.0	21.4c	0.0	4.0c	0.0
CV (%)	19.2		1.3		4.7		4.7		11.7		8.8		26.7	

Means represented with the same letter are not significantly different; but means shown with different letters are significantly different at $p<0.05$

SMC soil moisture content, *BD* bulk density, *FW* fruit weight, *FY* Fruit yield, *FL* fruit length, *FG* fruit girth

Fig. 4 Pineapple harvested at Chichu Farmers Training Center (FTC)

Table 5 Partial budget analysis of the selected mulching methods for pineapple production

Variables	Treatments		
	Planting pineapple without any mulch	Planting of pineapple using grass mulch	Planting of pineapple using plastic mulch
Average fruit yield (g/plot)	22,210	25,467	28,557
Adjusted yield (t/ha)	55.53	63.67	71.39
Gross field benefits (ETB/ha)	1,665,900	1,910,100	2,141,700
Cost of labor (ETB/ha)	7200	10,080	12,200
Cost of weeding (ETB/ha)	1800	1500	500
Cost of seedling (ETB/ha)	500	500	500
Cost of black polythene plastic	0	0	800
The total cost varies	9500	12,080	14,000
Net benefit (ETB/ha)	1,656,400	1,898,020	2,125,500
MRR (%)		93.65	118.5

Assumptions, 1 seedling = 50ETB, 4X1m black polythene plastic = 200ETB, 1 kg pineapple fruit = 30ETB, 60 ETB = 1$

of this study was to determine the optimal mulching strategy for enhancing soil fertility and pineapple output. Three treatments were evaluated in this study: planting pineapples with plastic mulch, planting pineapples with grass mulch, and planting pineapples without any mulch (control). Each treatment was evaluated five times. The results showed that the treatment with plastic mulch had the highest soil moisture content value (18.41%), whereas the pineapple plant in the control group had the lowest value (11.39%). In a similar vein, pineapple planted with plastic mulching technique produced the greatest fruit output (71.39 t/ha), with fruits measuring 17.4 cm in length, 46.67 cm in girth, and 15 pieces of suckers. However, pineapple plants that produced no fruit were shown to have the lowest yield. The maximum bulk density was 1.43 (g/cm^3). The bulk density value of 1.43 (g/cm^3) was highest in pineapple planted without mulch than mulched treatments.

Applying mulches to the pineapple production system raised the soil's pH, organic carbon (OC), organic matter (OM), total nitrogen (TN), cation exchange capacity (CEC), and phosphorus (P). However, the percentage of texture did not alter due to mulching treatment. For the baseline, the marginal rate of return (%) generated by mulching with plastic and grass was 118.5 and 93.7%, respectively. Planting plastic mulching is therefore the greatest alternative for pineapple production systems in the study area and other regions of the world with similar soil texture, slope, and agroecologies. So, farmers and other stakeholders of the study area and other similar regions will practically implement this technique.

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Author contributions Mr. ZAK has made significant contributions to designing the experiment, soil samples, and fruit yield data collection, analysis, and interpretation; Mr. EAG has contributed to designing the experiment, soil samples, and fruit yield data collection; Dr. ABD and Dr. DMB have made a considerable contribution in designing the experiment, commenting and suggesting ideas in the manuscript preparation; Mr. TTW has made a significant contribution in soils samples collection and its analysis in soil Laboratory. Finally, all authors read and approved the final manuscript for publication.

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Data availability The datasets used and analyzed during the study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All authors agreed and approved the manuscript for publication in the journal of discover Sustainability.

Competing interests The authors declare that they have no competing interests.

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