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A Combined Ridging and Cover Crop Tillage System for Sustainable Coffee Plantation in Kenya

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Abstract: The introduction of ridge tillage and beans as a cover crop was investigated as a means of management for mitigating soil erosion and increasing the physical functionalities of soil. In a completely randomized design, four treatments were applied to twelve plots, three with ridges introduced (T1), three with beans as the cover crop (T2), three with cover crops combined with ridges (T3), and another three as controls without intervention (T4). Four physical properties were monitored, i.e., soil moisture content, bulk density, infiltration rate, and aggregate stability. Data were collected from two seasons with beans as the cover crop, with each season lasting three months. The results showed that T3 resulted in the highest soil moisture content at $34.87 \pm 6.78\%$, followed by T2 and T1 with $34.20 \pm 0.65\%$ and $32.65 \pm 1.71\%$, respectively, while T4 had the minimum value of $28.28 \pm 5.30\%$. The bulk density of the soil was found to be lowest at T2 and T3, both having a value of 0.92 g cm^{-3} with standard deviations of ± 0.03 and ± 0.11 , respectively. This was followed by T1 with $0.98 \pm 0.05 \text{ g cm}^{-3}$ while T4 had the highest bulk density of $1.17 \pm 0.13 \text{ g cm}^{-3}$. A similar trend was observed for both the basic infiltration rate and aggregate stability, except that, in terms of the latter, T1 was ranking second after T3, with 64.07% of water stable aggregates greater than 0.25 mm diameter. The interventions introduced in coffee plantations had significant effects on the bulk density and infiltration rate; however, there was no significant difference in the moisture content and aggregate stability. Further investigation is needed to quantify the environmental effects of these interventions, e.g., greenhouse gas emissions and yields.

Keywords: aggregate stability; cover crop; ridging; soil quality; coffee plantation



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1. Introduction

Coffee is grown in at least seven of Kenya's eight provinces, making it a popular and important crop [1,2]. Coffee has long been one of the leading strategic cash crops contributing to Kenya's economic growth. In 2019, Kenya had approximately 28 million hectares of agricultural land [3], out of which, coffee occupied about 119,000 hectares, with about 204 million coffee trees. Approximately 6,000,000 people are directly and indirectly employed in the sector, and about 70% of Kenya's coffee is produced by small farmers. An estimated 800,000 producers, mostly smallholders, are involved in growing coffee [4], employing roughly 5 million people, or 30% of Kenya's agricultural workforce, at different stages of the production chain. More than 800,000 rural households' economic status and means of subsistence are directly impacted by this. Additionally, it is significant in the agricultural gross domestic product (GDP) of the nation, accounting for approximately 10% of the total agricultural exports [5,6]. Yet, due to a number of problems, e.g., soil erosion, climate change, low profits from smallholding plantations, and high cost of production, Kenya's coffee-planted area has declined by 30% in recent years [7].

Despite the great importance of coffee to the Kenyan economy, it has not been possible to have sustainable production due to various challenges cited in this paper. Due to the degradation of soils, production has been declining, leading to losses for most of the farmers, forcing them to either seek other revenue sources or diversify by intercropping with other crops, mostly fruits. There is also the problem of soil erosion occurring in the farms, leading to the loss of fertile top soil. This does not only increase the need for more fertilizer application but also lowers the net income of the farmer. Reversing the declining trend of coffee plantation, which is both a pillar for Kenya's economy and a backbone supporting smallholders, requires combined approaches of intervention, e.g., pests and disease control, consolidation of land fragmentation, stabilizing of coffee prize fluctuations, curtailing soil and water erosion, and improving the functionalities of the soil etc. [8,9]. Among the identified intervention tasks, an urgent need exists for a combined strategy to prevent soil and water erosion, increase soil fertility, and improve soil functionality and outputs. This can be achieved by minimizing management practices that negate soil fertility such as the excessive use of herbicides, compaction of soil, and depletion of the top soil layer.

Developing or finding principles for sustainable orchard farming can be undertaken by resorting to conservation agriculture (CA) principles. CA, with its three pillars (no till, soil cover, crop rotation), has evolved into a number of principles and practices in the last decades. Examples of these practices include ridge tillage [10,11], cover crops [12], straw mulching [12], contour tillage [13,14], basin tillage [15,16], strategic tillage [17], sub-soiling [18], etc. The selection of each practice or combination of individual ones has been proved to be site-specific and the impacts of the interventions were found to be influenced by not only the local farming system, but also the soil condition, climate, and the geology.

By lowering production costs, preserving soil quality, lowering labor input costs for herbicide and weeding, and lowering emissions of greenhouse gases, conservation agriculture (CA) has been promoted for the sustainability of agricultural productivity and the environment [19,20]. Preservation farming has likewise been found to further develop the total solidness of soil that upgrades nutrient maintenance and lessens soil disintegration, subsequently adding to soil fertility and promoting air permeability, water infiltration, and nutrient cycling [21,22]. One of the engineering methods used to control runoff on steep slopes is ridge tillage, which prepares a seedbed higher than the average land surface of the field. It has been proposed as a superior option in contrast to zero tillage, as it upgrades soil fertility, further enhances management, lessens water and wind erosion [23], it can also allow for planting of more than one crop, promotes proper root development, and advances pest controlling [24,25]. These benefits can be tapped into when correctly incorporated into coffee farming which suffers from frequent soil erosion since most of the farms are on steep slopes.

Poor land management, including land use without the installation of appropriate erosion control measures and the export of nutrients from farms, is directly linked to the depletion of soil resources because most coffee farms are located on steep slopes that are prone to runoff. Using herbicides to control weeds between rows for an extended period of time not only increases production costs but also lowers environmental quality [26]. Washing away top soil by frequent runoff has led not only to the depletion of nutrients from the farms but also to the high and frequent use of inorganic fertilizers in the production of coffee. This raises the cost of production and also leads to water pollution downstream by phosphorus coupled with the release of greenhouse gases such as N_2O and CO_2 to the atmosphere [27]. Therefore, the traditional approach of shifting cultivation, applying mineral fertilizers and/or manure in inadequate amounts, and incorporating grain legumes into cropping systems is insufficient to meet these challenges. To deal with this problem in coffee farms, new farming techniques need to be explored and studied for adoption by local farmers. The ties that exist between social problems and soils are the engine behind the recently developed concept of soil security. This is centered on issues such as food security,

sustainability, climate change, carbon sequestration, emissions of greenhouse gases, and degradation caused by erosion and the loss of organic matter and nutrients [28,29].

A number of interventions have been used to help reduce soil degradation with varying levels of success. Most farmers use improved practices such as compost manure application, mulching, intercropping, and row planting [30]. Because of the hilly terrain and steep slopes in the Cherara area, most farmers are using terraces to prevent the loss of soil due to surface runoff; this has not been very successful due to the labor demand in coming up with the terraces. A lack of appropriate machinery to mechanize the operations has largely affected the adoption of these technologies. The steep slopes are less workable with machines without modifications on either the machinery or the terrain. The introduction of ridging into the coffee farms will allow the planting of the crops on relatively flat beds that would allow for some level of mechanization. This study was carried out to evaluate the effects of the use of leguminous cover crops (common beans) and ridging singly and in combination on the physical properties of the soil. The common bean was chosen because it is one of the most popular crops in the area, and most farmers would readily adopt it for their farming operations. It is a staple food in Kenyan communities, used in dishes such as “githeri” and stews [31]. Additionally, it has good vegetative characteristics that make it a good cover crop. These interventions were introduced into already established coffee plantations for ease of data collection and to form a basis for more focused future work into the implementation of the chosen strategy.

This study assumes that the introduction of cover crop and ridge conservation tillage practices will increase the soil organic matter (SOM) within the coffee farms and also reduce compaction. This increase in the SOM is assumed to have a direct influence on the porosity and, thus, on the water holding capacity. This change in the water holding capacity would in turn affect related water hydraulic processes through the soil moisture. In most instances, changes in soil moisture affect lateral runoff and leaching, and affect the infiltration rate. Soil moisture affects crop growth and yield since it determines how much water is accessible to plants. The presence of cover crops above the soil increases soil moisture by facilitating water infiltration. Additionally, surface cover captures some of the precipitation, reducing the amount of water reaching the soil’s surface and reducing soil evaporation, thereby reducing wasteful water losses to the atmosphere. Overall, we made an assumption that the data obtained on the physical properties of the soil were solely affected by the interventions under this study, neglecting the changes that would occur due to natural processes since the work was not performed in a controlled environment. For this study, the following hypotheses were proposed: 1. Introducing combined ridge tillage and cover crops to coffee plantations can increase the soil moisture content (MC), reduce the bulk density (BD), increase the infiltration rate (IR), and increase aggregate stability. 2. By using cover crops or ridge tillage as intervention methods in coffee plantations, the physical properties of the soil will improve, whereas the fields without intervention will have poor soil properties because of a lack of soil cover or changes to slope gradients. As such, this study’s main objective was to determine how the physical properties of the soil (MC, BD, IR, and AS) change when ridge tillage and cover crops are combined, or when cover crops or ridge tillage are introduced individually to be able to propose an intervention for the long-term study and adoption in coffee plantations in Kenya.

2. Materials and Methods

2.1. Description of the Study Area

The study area is found in Kericho County, Kipkelion constituency, which is majorly rural (Figure 1). It is a few miles south of the Equator with hilly terrain and high elevation (around 8000 feet, or 2500 m, above sea level). It has a cool and wet climate with a peak rainfall in April. In an area of approximately 400 square miles (1000 square kilometers), there are approximately 300,000 people living in small farms and villages that cultivate coffee as a cash crop and maize and other crops for subsistence. The fact that many of the communities are quite remote and can only be reached via miles of winding mud

roads has contributed to the region's low level of mechanization. In coming up with this study, 12 fields were chosen out of 30 fields so as to represent the growing area within the constituency. For each field, each treatment was applied once and replicated on three fields. Therefore, the number of fields equaled the experimental plots (4×3).

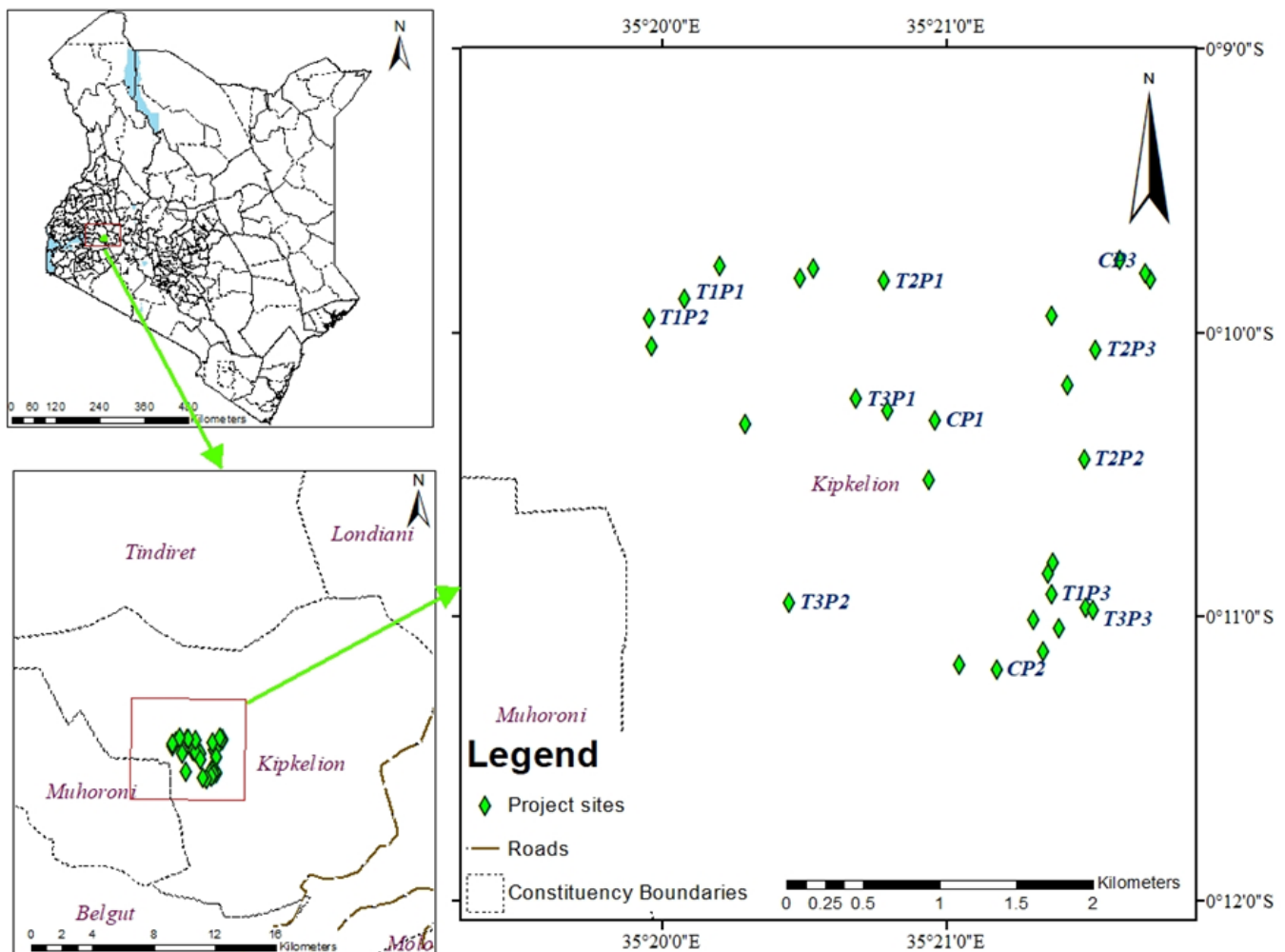


Figure 1. Project locations in Kenyan map showing coffee growing areas.

2.2. Soil Types, pH, and Fertility

The study area is mainly composed of brown loamy sand soils on a hilly terrain. The slope has scattered vegetation cover due to intensive farming of maize and coffee plantations. Some key soil chemical parameters were noted from data on a report by the national accelerated agricultural inputs access program, in collaboration with the Kenya Agricultural Research Institute and the Department of Kenya Soil Survey, on soil suitability evaluation for maize production in Kenya. Although the primary focus of this study is to determine the effects of cover crops and ridging on the physical characteristics of the soil to assist farmers in selecting the appropriate interventions. The pH of the soil in the plots varied from moderately acidic (6.42) to strongly acidic (4.82). The level of total organic carbon (TOC) in the soil ranged from moderate (1.55% TOC) to high (6.74% TOC). Preliminary studies of the soils were also conducted to determine the soil type and some physical properties of the soil before interventions were applied and data for

this preliminary investigation are given in Table 1. A soil particle distribution test was performed by mechanical sieve analysis and the soil type was determined on a soil textural triangle. Bulk density was obtained by gravimetric method and soils for the same collected using a standard core ring. Particle density was calculated from the following relationship:

Table 1. General physical characteristic statuses of the plots before interventions.

Factor	Value
Sand (%)	71
Silt (%)	18
Clay (%)	11
Textural class	Loamy sand
Bulk density (g cm ⁻³)	1.17 ± 0.05
Particle Density (g cm ⁻³)	2.62 ± 0.18
Total porosity (%)	55.3 ± 1.2
Moisture content at field capacity (%)	35.0 ± 2.5

Errors in the data in Table 1 represent standard deviations.

The particle density of a soil = dry mass (g) of soil/volume of soil particles.

$$d_p = \frac{W_{ds}}{V_s} \quad (1)$$

where d_p is particle density; W_{ds} is oven-dry weight of soil; V_s is volume of solids

Using the determined bulk density and particle density, percentage soil porosity was obtained using the relationship:

$$\%P = 100\% - \left(\frac{BD}{d_p} \times 100 \right) \quad (2)$$

2.3. Experimental Design

The study used a completely randomized experimental design (CRD). As indicated in the study area map, 4 treatments were randomly assigned to plots and replicated 3 times for a total of 12 plots. The treatments were ridge tillage, cover crops, ridge tillage combined with cover crops, and control. Each treatment was designed to have a homogenous collection area within each plot. In order to achieve this, all activities within the plots, other than the treatments, were kept the same. Plot selection was also performed in order to ensure a similar slope and soil type. In our case, the control plots chosen were to be as close to the treatment parcels as possible, with a similar slope. They had no ridges introduced nor were cover crops planted, while weed control was achieved by hand cultivation with hoes. The control captures the results that would have occurred if the interventions had not been implemented. In this way, any differences in outcomes between treatment groups and comparison groups can be attributed to the program or policy.

The 12 plots were selected from already established coffee plantations planted with old coffee Arabica and treatments applied as follows: Treatment 1 (T-1): ridges were introduced at a spacing of 6 m since the recommended spacing for Arabica coffee is 3 m × 1 m, so double spacing was performed. Treatment 2 (T-2): the ground was covered with beans crop which was allowed to grow up to maturity stage before data were collected (Figure 2). Treatment 3 (T-3): combination of cover crops and terracing. Three other plots were used as control with no intervention applied to them (T-4). As part of the evaluation of the performance of the treatments, data were collected during two bean seasons in the months of March and July and averaged. Daily precipitation and temperature of the area during the time of data collection are presented in Figures 3 and 4.



Figure 2. Coffee intercropped with common beans.

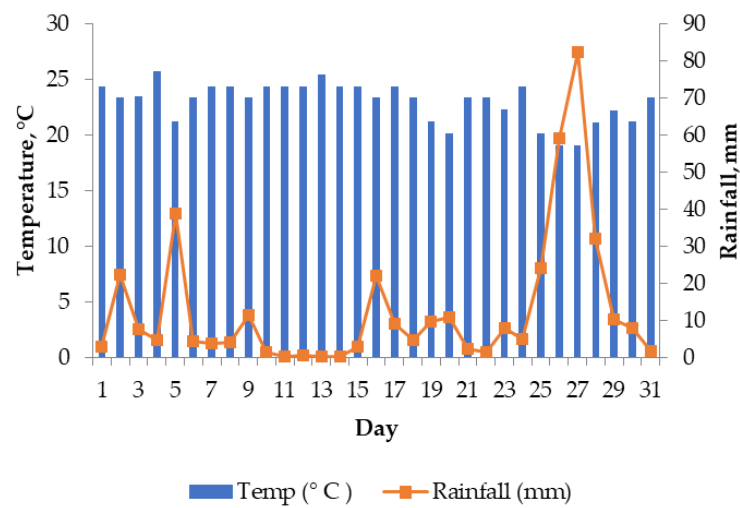


Figure 3. Daily mean temperature and rainfall data for the month of March, 2021.

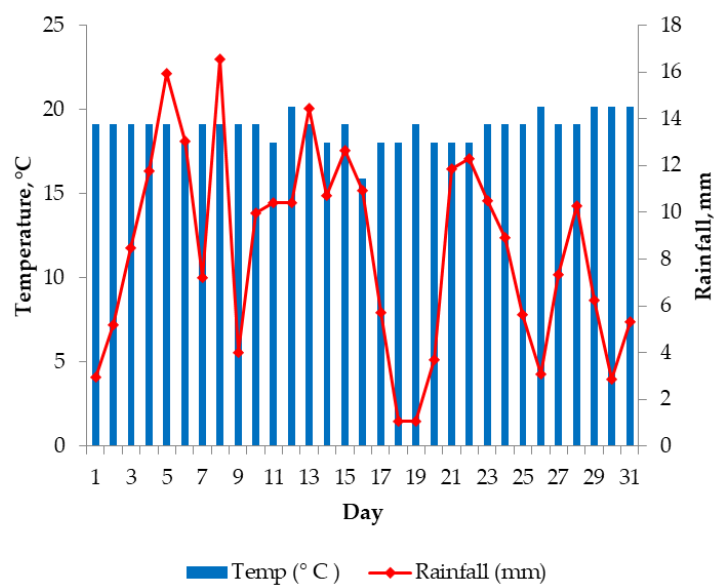


Figure 4. Daily mean temperature and rainfall data for the month of July, 2021.

2.4. Sampling and Field Tests

Samples of soil were taken from the fields following a “W” pattern to ensure samples represented the fields sampled. A total of five samples were collected from each plot in order to determine the properties that were studied. This corresponded to the number of edges of the “W” pattern that was used in the data process. Samples for bulk density were collected using a core ring and kept undisturbed for laboratory analysis. Water infiltration into the soil was measured using a double ring infiltration method. Double-ring infiltrometers were used where a small ring was first installed, centered inside a larger ring. The diameters of the rings were 30.48 cm for the inner ring and 60.96 cm for the outer ring. By keeping the sides of the infiltrometer rings vertical, care was taken to avoid any soil disturbance resulting from excessive hitting force or trampling over the surface of the land [32]

Soil samples collected for the determination of bulk density, moisture content were then taken to the soil laboratory within the Department of Agricultural Engineering, Egerton University. Soil for aggregate stability was collected carefully from the top soil after the removal of loose debris using a spade as shown on Figure 5. In the field, soil was sieved through a 25-mm sieve before being placed in a paper bag and placed inside a separate container to prevent crushing. Soil samples were dried in the lab on a wire table with good ventilation. An amount of 70 g of dry aggregate samples was used with two sieves in a stack (1.0 and 0.25 mm) to measure the wet-aggregate stability. For complete wetting and saturation of aggregates by capillary action, these sieves were lowered into a basin containing water to a level of wetting the base of the upper sieve. The aggregates were then sieved for 2 min, while time readings were conducted using a stopwatch, and hand lifting the sieves with a stroke length of 27 mm and a frequency of 30 strokes per minute according to the procedure described by Wander and Bollero [33]. Each sieve’s retained soil was dried, transferred to a container, and weighed. Percentage of water stable aggregates were calculated and recorded according to the formula:

$$\text{water stable Aggregates (\% of soil > 0.25 mm)} = \frac{(\text{weight of dry aggregates} - \text{sand})}{(\text{weight of dry soil} - \text{sand})} \times 100 \quad (3)$$



Figure 5. Soil sample collection for aggregate stability analysis.

2.5. Statistical Data Analysis

Statistical analyses were performed using MS Excel version 2013. Comparisons were conducted between ridge tillage, cover crops, combined cover crops with ridge tillage, and control on their effects on the physical properties of the soil. The data were analyzed using analysis of variance (ANOVA) and honestly significant difference (HSD) using Tukey’s model with a significance level (α) of 0.05.

3. Results and Discussion

3.1. Quantitative Soil Physical Analysis

In the fields, quantitative measurements were carried out to determine the infiltration capacity (mm/min) of the soils using double ring infiltrometers. The bulk density, moisture content, and aggregate stability were evaluated from undisturbed soil samples transferred to the laboratory for analysis. The results were as shown in Table 2 and further discussed in subsequent sections.

Table 2. Effect of treatments on physical properties.

Id	Moisture Content (%)	Bulk Density (g/cc)	Basic Infiltration Rate (mm/min.)	Aggregate Stability (%)
T1	32.65 ± 1.71 ^a	0.98 ± 0.05 ^a	0.70 ± 0.10 ^a	64.07 ± 7.68 ^a
T2	34.20 ± 0.65 ^a	0.92 ± 0.03 ^{a,b}	0.80 ± 0.10 ^a	62.43 ± 3.53 ^a
T3	34.87 ± 6.78 ^a	0.92 ± 0.11 ^{a,b}	0.80 ± 0.15 ^{a,b}	68.73 ± 4.94 ^a
TC	28.28 ± 5.31 ^a	1.17 ± 0.13 ^{a,c}	0.50 ± 0.10 ^{a,c}	58.00 ± 1.40 ^a

Errors in the data represent standard deviations from the mean of data set, same letters per column indicate insignificant difference between treatments while different letters in a column show significant difference.

3.2. Effects of Treatments on Soil Moisture Content

Using the data from Table 2, it shows that there existed variations in the soil moisture content over the test period based on the various interventions. The results show that ridge tillage mixed with the cover crop (CR) had the highest moisture retention followed by the cover crop (CC) and the fields where no intervention was applied had the least moisture retention. Treatments affected the soil moisture content measured and averaged over the span of the investigation. CR treatment had the highest average of moisture content at 34.87%. This was almost equal to the CC treatment which had 34.20%. RT had 32.65% of moisture content but was still better than the average obtained in the fields where no intervention was taken. It implies that the use of cover crops and ridge tillage has a positive influence on the amount of moisture in the soil. However, analysis of variance (ANOVA) at a 95% level of confidence ($p = 0.05$) resulted in no significant difference between the treatments (Table 3). Generally, the high value of the moisture content in CR could be due to the fact that the cover crop shades the surface of the soil and prevents evapotranspiration and direct evaporation of water from the soil's surface. The ridges also help to act as a storage of water in the soil [34,35]. The ridges are also important in preventing runoff [36] which allows for more water to infiltrate into the soil. According to Clark [37], there are a number of ways cover crops can increase soil moisture: encouraging the growth of mycorrhizal fungi on crop roots, providing surface residue, and creating root channels for use by subsequent crops all contribute to improving rainfall infiltration and the soil's capacity to hold water. Further, Blanco-Canqui, Shaver [32] state that cover crops reduce compaction in the soil, enhance the structural and hydraulic properties of the soil, regulate the temperature of the soil, enhance the microbial properties, recycle nutrients, and eliminate weeds. Similarly, Lungu [38], in their study on the effect of ridging and mulching on soil moisture, found that ridging and mulching greatly improved the amount of moisture retained in the soil, which agrees with the high level of moisture found in our study when ridging and cover crops are used together.

There are a few reasons that might make sense for why utilizing ridging and cover crops may increment the soil's moisture and lessen the production loss brought about due to prolonged dry spells. One explanation is that ridges and cover crops assist with further developing precipitation penetration through an expanded number of macrospores, due to the cover crops' roots and from the expanded action of earthworms and furthermore diminished speed of rain floods [34]. Because cover crop residue on the surface of the soil reduces evaporation, rain that has penetrated the soil is more likely to remain in the root zone. In addition to reducing moisture loss and crop stress, that residue can help soil microbes function more effectively by keeping the soil cooler [35]. As organic matter

increases and the structure of the soil aggregates improve, improving the health of the soil may eventually result in an increase in the soil's capacity to hold moisture. Nonetheless, even temporarily, cover crops can kindle mycorrhizal organisms, and those organisms can help poorly developed crop roots due to drought to better access moisture and nutrients.

Table 3. One-factor ANOVA for effect of treatment on moisture content ($p = 0.05$).

Source of Variation	SS	df	MS	F	<i>p</i> -Value	F Crit
Between Groups	82.046	3	27.349	1.394	0.314	4.066
Within Groups	156.974	8	19.622			
Total	239.020	11				

3.3. Effects of Treatments on Soil Bulk Density

The effects of different interventions on the soil bulk density were also evaluated and the results showed that the use of cover crops, and combined cover crops with ridge tillage had the lowest bulk density at 0.92 g cm^{-3} , while the fields with no intervention had the highest bulk density at 1.17 g cm^{-3} . These results show that the use of a cover crop or its combination with ridges can reduce soil compaction in the coffee plantations and thereby lead to increased water infiltration into the soil [39]. This would in effect reduce the amount of runoff down into the rivers, will lead to less pollution of water, and also reduce the loss of nutrients from the fields. The bulk density (BD) was decreased by 16.1, 21.6, and 26.1% in ridge tillage (RT), cover crop (CC), and combination of cover crops with ridge tillage (CR), respectively, compared to no intervention. CC and CR had similar results for the bulk density while RT had a higher BD. Analysis of variance (ANOVA) at a 95% level of confidence ($p = 0.05$) showed a significant difference between treatments (Table 4).

Table 4. One-factor ANOVA for effect of treatment on bulk density ($p = 0.05$).

Source of Variation	SS	df	MS	F	<i>p</i> -Value	F Crit
Between Groups	0.128	3	0.043	5.377	0.025	4.066
Within Groups	0.063	8	0.008			
Total	0.191	11				

When practiced without cover crops, the bulk density under ridge tillage tended to be high with a low moisture content almost close to the no intervention scenario. According to Haruna, S.I., et al. [40], CCs play a significant role in modifying the soil bulk density when included in crop rotation cycles. The bulk density of soil is affected by several mechanisms due to CCs. The mass per unit volume of CC residues is typically lower than that of soil minerals. Due to this, the ratio of the mass to volume of soil decreases with a greater residue content. In addition, living CCs have roots that penetrate the soil. These plant roots leave behind biopores that increase soil porosity and reduce soil mass/volume ratios.

Further post-hoc analysis, using the Tukey technique, revealed that CC and CR had significant differences with the control ($p = 0.05$) as shown on Table 5. There was, however, no significant difference between RT, CC, and CR. RT, however, did not have a significant difference with the control. Under various tillage techniques, changes in the soil bulk density can be a good indicator of the physical health of the soil and water retention capacity [41]. A similar result was reported by Salem et. al. [42]. According to Breland T. A. [43], in their study on the use of the effects of clover and ryegrass catch crops on the soil structure, they found a reduced bulk density and increased pore volume in the soil. The bulk density of the soil is a key indicator of the soil's quality since it determines the pore spaces within a volume of soil. Root growth and activity in cover crops can be linked to the reduction in the bulk density observed in the two treatments where the cover crop is involved [40,44]. Roots together with ridges also increase the resistance of top soils to concentrated surface erosions, hence, encouraging microbial activity [45].

Table 5. Tukey results for pairwise comparison of treatments on bulk density.

Treatments Pair	Tukey HSD Q Statistic	Tukey HSD <i>p</i> -Value	Tukey HSD Inference
A vs. B	1.232	0.802	insignificant
A vs. C	1.232	0.802	insignificant
A vs. D	3.669	0.118	insignificant
B vs. C	0.000	0.900	insignificant
B vs. D	4.901	0.0346	* <i>p</i> < 0.05
C vs. D	4.901	0.0346	* <i>p</i> < 0.05

A—ridge tillage, B—cover crop, C—combined ridge tillage and cover crop, D—control, * significant difference at *p* = 0.05.

3.4. Effects of Treatments on Water Infiltration Rate

The infiltration rates for the different interventions were evaluated and the results showed that using cover crops alone and the combination of ridge tillage together with cover crops gave the highest basic infiltration rate at 0.80 mm/min followed by ridging and no intervention at 0.70 and 0.5 mm/min, respectively, as shown on Table 2. Analysis of variance at a 95% confidence level showed a significant difference between the treatments, presented in Table 6. However, upon performing a post-hoc Tukey analysis, it revealed that only CR was significantly different compared to the control, as indicated in Table 7. There was no significant difference between the treatments themselves. Considering the loamy sand soils which have been reported to have a basic infiltration rate of 0.36 mm/min in gentle slope fields [46,47], the results show infiltration rates above the basic rate which is a good indicator for reducing surface runoff. Surface sealing, the prevalence of cracks and open pores, or the development of crusts and an impermeable layer are all examples of surface conditions of the soil that can play a significant role in determining whether or not infiltration will even take place [48,49]. The bulk density of fields with treatments 2 and 3 (T2 and T3) were the lowest and exhibited higher infiltration rates, as shown in Table 2. Further, the higher values could be attributed to the larger pores created by the coffee plant roots and microbial quality [50–52].

Table 6. One-factor ANOVA for effect of treatment on infiltration rate (*p* = 0.05).

Source of Variation	SS	df	MS	F	<i>p</i> -Value	F Crit
Between Groups	0.343	3	0.114	8.56	0.007	4.066
Within Groups	0.107	8	0.013			
Total	0.449	11				

Table 7. Tukey results for pairwise comparison of treatments on infiltration rate.

Treatments Pair	Tukey HSD Q Statistic	Tukey HSD <i>p</i> -Value	Tukey HSD Inference
A vs. B	1.500	0.705	insignificant
A vs. C	4.000	0.085	insignificant
A vs. D	3.000	0.225	insignificant
B vs. C	2.500	0.354	insignificant
B vs. D	4.500	0.051	insignificant
C vs. D	7.000	0.004	** <i>p</i> < 0.05

** significance difference at *p* = 0.01.

3.5. Effects of Treatments on Soil Aggregate Stability

The evaluation of the effects of these treatments on the aggregate stability of the soil results showed that the fields without any intervention had the lowest percentage, at 58%, while the use of ridging together with cover crops was highest, at 68.73%. Scaled over similar-textured soils, a soil aggregate stability below 25 percent is considered poor physical

quality, 30 to 50 percent is considered low to medium physical quality, and 50 to 75 percent is considered medium to good physical quality and above 80 percent is considered excellent physical quality. This indicates that the tillage practices under investigation have an impact on the capacity of these soil aggregates to withstand crumbling under the disruptive effects of water or wind erosion [53,54]. Since this test was conducted through wet sieving, it implies that the use of cover crops and ridging techniques increases the ability of the soil to resist the impact of raindrops and water erosion [55,56]. Analysis of variance showed no significant difference in the effects of the applied treatments with the control.

Generally, the results showed that cover crops in combination with ridge tillage practices had a significant influence on the physical properties of the soil compared to the fields where no intervention was applied. Further, this combination had better results compared to scenarios where they were used singly. This is in agreement with the results by He, G., Wang and Bowles Timothy M. [57,58], who found a significant result in the effect of cover crops on the physical properties of the soil. The applied treatments had a significant impact on the bulk density of the soil and infiltration as determined by analysis of variance, and there was a significant difference between the interventions. As a result, we reject the null hypothesis that a coffee plantation's physical properties of the soil are unaffected by cover cropping and ridge tillage. Therefore, it is also true that the physical properties of the soil in coffee plantations are influenced by the use of cover crops and ridge tillage. When compared to fields in which no intervention was made, the findings of our study demonstrate that, in terms of the properties of the soil that were tested, ridge tillage and the application of cover crops have a positive impact on the quality of the soil because they result in an increased moisture content, decreased bulk density, increased infiltration rate, and a higher percentage of aggregate stability of the soil.

4. Conclusions

The results of ridge tillage, cover crops, and combined ridge tillage and cover crop treatments showed differences in the response of the moisture content of the soil, bulk density, infiltration rate, and aggregate stability. Soils under combined cover crop with ridge tillage and cover crop alone practices showed a significant difference in the effect on the bulk density when compared with the control. When practiced independently, soils under either ridge tillage or cover crop systems had intermediate values of moisture content, bulk density, infiltration rate, and aggregate stability of wet soil. A cover crop–ridge tillage system practiced together performed significantly better on the bulk density and infiltration rate. According to our findings, practices involving short-term cover crops–ridge tillage, if introduced to a farming system, may maintain soil moisture while simultaneously increasing soil aggregation and the proportion of soil pores. With or without ridge tillage, cover cropping tends to increase the moisture content, decrease the bulk density, and increase the infiltration rate. It appears to be especially effective when combined with ridge tillage to improve the aggregate stability. The results showed that when we consider soils that need a low infiltration rate, especially where water is added through irrigation, then no intervention could be better as compared to other treatments. We discovered that cover crops and ridging systems altered the aggregate stability values, indicating an improvement in the soil's structure. These results show that the treatments had a significant effect on the bulk density and infiltration rate but no significant difference in the response on the moisture content and aggregate stability. As a result of these studies, we have validated our hypotheses that ridge tillage with cover crops, or ridge tillage alone, or cover crops alone, in the short-term, can increase the soil's moisture content (MC), reduce the bulk density (BD), increase infiltration (IR), and improve the aggregate stability in a field without treatment. As a result, ridge tillage and cover crops can be combined for the purpose of mitigating the soil erosion challenges on Kenyan coffee plantations. The implications of these interventions' long-term effects on the physical properties of the soil may be further explored in future studies with larger sample sizes and a wider range of soils and climates over longer periods.

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