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# Effect of Organic Manure on Sorghum (*Sorghum bicolor*) Yield, Runoff and Soil Loss at Tahitay-Adiabo District, Tigray, Ethiopia

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

A field experiment was carried out in Tahitay Adiabo district, Tigray, Ethiopia to study the impact of organic manure on soil erosion, runoff, and sorghum yield during the cropping seasons of 2019 and 2020. The experiment utilized a randomized complete block design (RCBD) with tri replicates. The treatments included control, compost, animal manure, compost with mulch, animal manure with mulch, and recommended NP fertilizer. Each plot measured 6m x 4m and was situated on a 4% sloped terrain. The findings indicated significant differences (P<0.01) among the treatments in terms of their influence on runoff volume, soil erosion, and sorghum yield. The application of compost with mulch and animal manure with mulch was particularly effective in reducing soil erosion and runoff

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compared to treatments using inorganic fertilizer and manure without mulch. Moreover, the control, animal manure, and inorganic fertilizer (NP-fertilizer) treatments exhibited high levels of soil loss and runoff volume, highlighting the effectiveness of compost with mulch and animal manure with mulch in mitigating soil erosion and runoff under the prevailing slope and rainfall conditions of the study area.

*Keywords: Organic matter; run-off; soil loss; sorghum yield; agricultural farming; soil fertility.*

## 1. INTRODUCTION

Maintaining soil productivity is a key challenge in agricultural farming. Crops are often rotated between fields to utilize the most fertile soils for multiple years without the need for fertilizers. However, this practice is unsustainable in meeting the growing demands of an increasing population. Tropical soils face issues such as low fertility and erosion, which lead to a decline in nutrient levels. Soil erosion ranks as the second most significant environmental concern after population growth and poses a threat to agriculture in Africa and other regions [1]. This issue is particularly critical in developing countries like Ethiopia, where the majority of the population relies on agriculture. The Ethiopian Highlands, encompassing 46% of the total land area and more than 95% of cultivated land, are among the most degraded areas in Africa [2]. The rapid soil erosion in this region worsens the decline in soil fertility by depleting organic carbon and essential nutrients for plants. Consequently, this negatively impacts both household and national food security, as well as the ongoing development endeavors in the country. Research indicates that sediment-related nutrient losses have surpassed acceptable levels in Ethiopian agricultural systems [3-8]. While significant efforts have been made to combat large-scale soil erosion, the focus has predominantly been on mechanical soil and water conservation methods in agricultural lands. Limited attention has been given to issues like soil organic matter depletion, soil fertility reduction, and physical and organic soil degradation [9]. As a result, the desired outcomes have not been achieved, leaving the ultimate solution intricate and elusive.

The Tigray highlands function as a grain production hub, generating significant amounts of straw annually. Additionally, the plateau supports a large livestock population. However, crop residues and organic fertilizers are primarily utilized for domestic needs, limiting their potential for enhancing soil quality within the agricultural framework. It is uncommon practice for farmers to burn crop residues for weed and disease control. The region's soils are predominantly silt loam, characterized by poor structure and low water retention capacity. With minimal vegetation cover between harvest periods, these soils are prone to topsoil erosion during the rainy season. Notably, there is a lack of comprehensive research on the impact of organic fertilizers and crop residues on runoff, soil erosion, and sorghum yield in this specific agro-climatic setting. Consequently, this study aims to investigate the effects of organic fertilizers on soil erosion and runoff, analyze the relationship between rainfall, runoff, and sediment loss under organic fertilizer management, and evaluate sorghum productivity under existing conditions.

## 2. METHODS AND MATERIALS

### 2.1 Study Area Description

The study took place in the Tahitai-Adiabo district in northwestern Tigray, Ethiopia. The study site is located at 37.78$^0$E and 14.4$^0$N, with an elevation of 1035 meters above sea level. The soil at the site is silt loam, comprising 26% sand, 61% silt, and 13% clay. The long-term precipitation (1986-2016) ranged from 623 to 850 mm, with an average of 780 mm per year with a coefficient of variation of 23%. The region experiences a bimodal rainfall pattern, with peaks in July and August. Seasonal precipitation during the experimental period ranges from 430 to 750 mm. The average annual maximum and minimum temperatures are 30°C and 15°C, respectively. The topography consists of gently undulating plains with an average gradient of 4%. Crop cultivation in the area is mainly cereal-based, with sorghum being the most widely cultivated crop, followed by maize.

### 2.2 Experimental Design and Procedure

Eighteen test plots for drainage were set up, each measuring 6 meters in length and 4 meters in width. Metal sheets enclosed each plot; buried 15 cm deep and extending 20 cm above the ground surface along the edges (refer to Fig. 2).

The design of the collection containers featured a multi-slot divider, selected based on FAO's recommendations [10,11]. To prevent direct seepage of sedimentation and evaporation losses, lids were placed on the collection vessels. Rainfall during the experimental season was measured daily using a non-recording rain gauge.

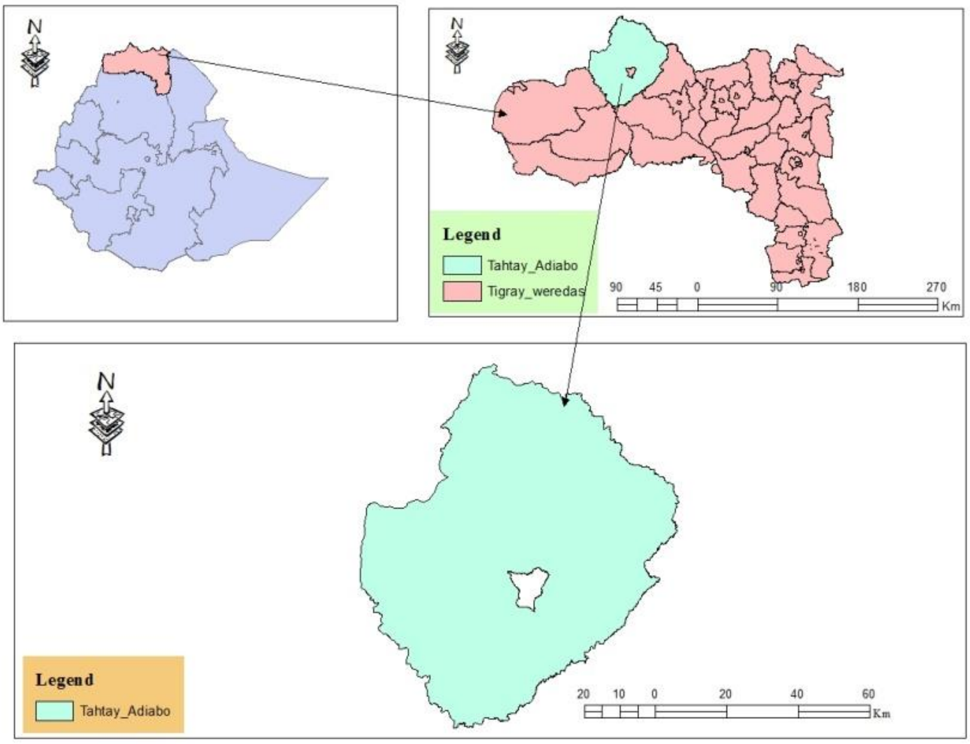


**Fig. 1. Study area map**


**Fig. 2. Field experimental layout**

The research included six different treatments: control, compost, compost + mulch, animal manure, animal manure + mulch, and recommended inorganic fertilizer (NP). The study followed a randomized complete block design with three replications. Agronomic practices like tillage, planting timing and method, seeding rate, and weed control were carried out based on local practices and conditions. Sorghum was chosen as the test crop because of its high yield and widespread cultivation in the area. The selected cultivar was planted on June 18, 2019, and June 21, 2020, at a seeding rate of 15 kg per hectare as per local recommendations. The plants were spaced 30 cm apart. Inorganic fertilizer treatments included urea and di-ammonium phosphate (DAP) mixed into the soil at planting in a fixed rate of 30 kg/ha of nitrogen (N) and 10 kg/ha of phosphorus (P). All other management practices were consistently applied to each plot following local guidelines. Manure from cattle and small ruminants was obtained from local farmers, air-dried, combined, and spread on the experimental plots. The compost was made using the appropriate method and was ready before the planting season. Organic manure and compost were spread at a rate of 20 tons per hectare one month before sowing, based on the plot size. During the application of organic fertilizers (animal manure and compost), efforts were made to ensure even distribution across the entire surface. Prior to sowing, further mixing was done to a depth of about 20 cm in the soil.

## 2.3 Soil Sampling

Sampling lines were crossed diagonally to collect bulk soil samples from the test sites. As the depth of sorghum roots typically ranges from 20-25 cm, the soil sampling depth was set at 0-20 cm. Soil sampling was done using an Augur before the start of the experiment and immediately after harvest. The samples were then taken to the laboratory for physical and chemical analysis following standard procedures. Particle size distribution was determined using the hydrometer method [12], and soil pH was measured potentiometrically in a supernatant suspension with a soil-to-water ratio of 1:2.5 [13]. Soil organic carbon content was assessed using the potassium dichromate wet combustion method [14], while soil available phosphorus content was determined through the sodium bicarbonate extraction method [15]. Soil total nitrogen content was evaluated using the wet oxidation method based on the Kjeldahl method [16], and exchangeable potassium levels were measured using a flame photometer [17].

**Table 1. Soil properties of the experimental site before planting**

| Soil Parameters | Sampling Depth (0-20cm) |
|---|---|
| Sand (%) | 28 |
| Clay (%) | 46 |
| Silt (%) | 26 |
| Textural Class | Clay |
| pH | 6.73 |
| Organic matter (%) | 1.06 |
| Total nitrogen (%) | 0.05 |
| Av. Phosphorus (ppm) | 3.08 |
| EC (mmh) | 0.36 |

## 2.4 Runoff and Sediment Loss

The collection tanks were used to measure the daily runoff volume from each plot following rainstorms. After each rainstorm, the depth of runoff collected in the tanks was measured right away using a measuring ruler placed inside the tank. To ensure uniform sediment distribution throughout the water depth, the tank contents were vigorously stirred with a wooden stick. Following stirring, a 1-liter measuring container was submerged below the water surface in the tanks, and a 1-liter sample of the water-sediment mixture was taken from each tank and placed into a pre-cleaned 1-liter bottle. When the first tank overflowed, the discharge from the second tank was multiplied by 3 to calculate the total overflow volume from the first tank. Sediment samples were placed in beakers and allowed to settle for 72 hours. The clear water was then carefully decanted, and the weight of wet sediment per liter of runoff was measured, air-dried, and stored for further analysis. The sediment samples were sent to the Shire Soil Laboratory. Furthermore, 2-5g of wet sediment was oven-dried at 105°C for 24 hours to calculate the moisture correction factor (mcf). The concentration of dry sediment per liter of runoff was then determinedas:

$$Sc=Mw / Mcf \tag{1}$$

Where: Sc is the Sediment concentration (g/L); Mw is the mass of wet sediment (g/L); mcf is the moisture correction factor given as: mcf = (100 + Mc)/100; where, Mc is the moisture content of sediment (%). The product of the sediment concentration and the total runoff per plot per day was used to determine the daily sediment loss as:

$$SL=(Sc*Ro) / 100 \quad (2)$$

## 2.5 Data Analysis

The study examined how treatments impacted runoff, soil loss, and sorghum yield by analyzing the data with an analysis of variance (ANOVA) and using the general linear model (GLM) method in the Gen STAT statistical analysis software. Treatment means were separated using Duncan's multiple range tests with a 5% probability.

# 3. RESULTS AND DISCUSSION

## 3.1 Runoff Volume

A significant decrease in runoff was observed in organic treatments compared to the control and inorganic fertilizer treatments, with the exception of animal manure. Treatments involving compost, compost + mulch, and animal manure + mulch exhibited notably lower runoff depths than other treatments. Specifically, the application of compost with mulch resulted in the highest reduction in runoff (515.8 $M3ha^{-1}$) among the treatments. In contrast, the control treatment had the highest runoff (1050.7 $M3ha^{-1}$), followed by the inorganic fertilizer treatment (872.1 $M3ha^{-1}$). However, treatments involving manure did not show a significant reduction in runoff, possibly due to the additional time required for manure to impact the soil's physical and chemical properties.

Compared to the control, runoff reductions were 50.91%, 50.1%, and 39.82% for compost + mulch, compost, and animal manure + mulch, respectively. Similar results have been obtained in other studies [18-20]. The significant decrease in runoff is attributed to improved infiltration from detention flow, where mulch materials disperse raindrop energy and prevent surface runoff, ultimately reducing storm water runoff. The study also demonstrated that applying animal manure without surface covering or mulching is much less effective in reducing runoff compared to compost application. No statistically significant reduction in runoff was observed with animal manure application compared to control and inorganic (NP) treatments, suggesting that the benefits of animal manure in runoff reduction may not be evident in short-term trials [21]. This impact is seen as a ripple effect on subsequent crops, as indicated in various publications. Surface application of manure has been linked to increased runoff, with one report showing that manure treatments resulted in 8% more runoff than controls in the first year of application [22].

## 3.2 Soil Loss

Analysis of variance indicated that compost, mulch, and compost had a significant impact on soil loss ($p \leq 0.01$). Table 2 displays the average soil loss for each treatment. Treatments involving compost, compost + mulch, and animal manure + mulch were notably more effective in reducing soil loss compared to other treatments in the study. However, it was observed that animal manure showed no significant difference from the control and inorganic (NP) treatments. The substantial decrease in soil loss with compost and compost + mulch aligns with previous findings that reported a decline in soil erosion with straw mulch applications [23]. Soil erosion primarily occurs due to raindrop impact, runoff erosive force, and sediment transport by raindrops, and surface runoff [24,25]. The coverage and roughness of the soil surface play a crucial role in mitigating the impact of raindrops and reducing soil loss. The overall outcomes indicate that compost and surface mulch not only diminish surface runoff but also shield the soil surface, thereby decreasing soil shedding caused by raindrops, lowering runoff erodibility, creating more infiltration opportunities, and capturing sediment carried by surface runoff. As illustrated in Table 2, compost, compost + mulch, and animal manure with mulch significantly decreased soil loss and sediment concentration in runoff water. The reduction in soil loss compared to the control group was 78.28%, 91.14%, and 90.8%, respectively. Soil loss in plots treated with animal manure and inorganic fertilizer did not significantly differ from the control, largely due to higher runoff (Table 2) and the extended period needed for organic matter in animal manure to integrate into the soil and impact soil properties. Furthermore, the utilization of dairy manure did not lead to a remarkable reduction in soil loss, as indicated in previous studies [22].

**Table 2. Runoff and sediment yield**

| Treatments | Runoff Volume ($M^3ha^{-1}$) | Sediment Loss($Tonha^{-1}$) |
|---|---|---|
| Control | 1050.7$^b$ | 17.50$^c$ |
| Compost | 523.5$^a$ | 3.80$^b$ |
| Animal manure | 821.54$^b$ | 15.9$^c$ |
| Compost + mulch | 515.8$^a$ | 1.55$^a$ |
| Animal manure + mulch | 632.3$^a$ | 1.61$^a$ |
| Recommended NP Fertilizer | 872.1$^b$ | 16.50$^c$ |
| Mean | 735.9 | 9.48 |
| LSD | 117.6 | 2.12 |
| CV (%) | 32.1 | 17.6 |
| P-value | 0.001 | 0.001 |

**Table 3. Grain and above ground biomass yield**

| Treatments | Grain Yield ($Qha^{-1}$) | Biomass Yield ($kgha^{-1}$ ) |
|---|---|---|
| Control | 10.34$^c$ | 2410$^c$ |
| Compost | 24.4$^a$ | 3851$^{bc}$ |
| Animal manure | 18.5$^b$ | 4183$^{ab}$ |
| Compost + mulch | 28.8$^a$ | 4753$^{ab}$ |
| Animal manure + mulch | 23.6$^a$ | 5555$^a$ |
| Recommended NP Fertilizer | 15.6$^b$ | 4968$^{ab}$ |
| Mean | 20.20 | 4287 |
| LSD | 5.4 | 526.8 |
| CV (%) | 20.1 | 19 |
| P-value | 0.001 | 0.01 |

### 3.3 Sorghum Yield

The study results displayed in Table 3 revealed that grain yield was influenced by various treatments. The treatment that included compost with mulch showed the highest grain yield at 2880 kg $ha^{-1}$, followed by compost alone at 2440 kg $ha^{-1}$, with statistically significant differences. This highlights the importance of meeting nutrient requirements to achieve optimal grain yield. Compost enhances nitrogen and phosphorus availability for plants, leading to improved sorghum grain yield. These outcomes align with previous research indicating that organic fertilizer application increases grain yield [26]. Additionally, the use of organic fertilizer significantly enhanced sorghum growth and grain yield by improving soil physical and chemical properties [27]. Apart from the direct impact of nutrients released by chicken manure on growth and yield, the increased porosity and moisture content can enhance root growth and nutrient uptake. Proper timing and dosage of fertilizer application play a crucial role in meeting crop demands and offer substantial opportunities for yield enhancement [28,29].

## 4. CONCLUSION

In the study area's current soil and agro-climatic conditions, the use of compost with mulch and animal manure with mulch notably decreased sediment concentrations and soil losses. However, it was noted that using animal manure without mulch led to soil losses similar to those in the control treatment and inorganic fertilizer application. Grain yields were impacted by both compost and animal manure applications. The research concludes that compost and mulched compost enhance soil fertility and boost sorghum yields. The use of animal manure did not provide any advantages compared to the control treatment. Therefore, it is recommended to utilize compost with mulch and animal manure with mulch as resources for sustainable sorghum production and soil erosion management in the area.

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## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that no generative AI technologies such as large-scale language models (e.g. ChatGPT, COPILOT) or text-to-image generators were used in writing or editing the manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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