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Research Article

Effectiveness of Soil Moisture Conservation Practices in Enhancing the Productivity of Sorghum Under Rainfed Cropping System in Semiarid Climate Type of Babile District, Eastern Ethiopia

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To grasp how soil moisture conservation techniques can lessen the effects of dry spells in moisture-stressed areas, we carried out a field experiment using a randomized complete block design (RCBD). The study took place in the Babile district over the 2021 and 2022 cropping seasons, involving six treatments across three replications. Each plot measured 4.2 by 5.4 m. The treatments were (A) Zai pit, (B) closed end Tied ridge, (C) flatbed (control) with sorghum, (D) Zai pit with legume cover cropping, (E) closed end Tied ridge with legume cover cropping, and (F) flatbed with legume cover cropping. We analyzed grain yield variance (analysis of variance [ANOVA]) and accumulated rainfall amounts throughout the experiment. Our results indicated that rainfall during the cropping seasons was 410 mm over 35 days in 2021 and 213 mm over 18 days in 2022. The grain yield from the Tied ridge moisture conservation practice was recorded at 6.85 t/ha in 2021 and 5.72 t/ha in 2022 at the Babile site, compared to yields of 4.75 t/ha in 2021 and 2.99 t/ha in 2022. When comparing the Zai pit with legume cover cropping (4.44 t/ha) to those without (4.25 t/ha), no significant differences were found. However, the mean grain yield from Zai pit practices was notably lower than that from the Tied ridge practices but higher than both variations of flatbed farming practices. Across the combined sites and seasons, the average sorghum grain yields were 5.07 t/ha for Tied ridge with cover cropping, 4.65 t/ha for Tied ridge without cover cropping, 3.65 t/ha for Zai pit with legume cover cropping, 3.52 t/ha for Zai pits without legume cover cropping, 3.12 t/ha for flatbed with legume cover cropping, and 3.07 t/ha for flatbed without legume cover cropping (control). The treatment effects on grain yield showed a highly significant variation ($p < 0.05$), with Tied ridge practices yielding 2 t/ha more than control treatments. The use of legume covers cropping did not significantly alter the sorghum grain yield across all treatments. Nonetheless, Tied ridge treatments with legume cover cropping consistently produced higher grain yields compared to other practices at both experimental sites. In summary, our findings are valuable for assessing effective Tied ridge moisture conservation practices for enhancing crop production, underscoring the importance of raising awareness about these practices as a viable strategy to counteract the adverse impacts of dry spells.

Keywords: climate variability; in situ moisture conservation practices; rainfed cropping system; soil moisture and sorghum grain yield

1. Introduction

In semiarid regions, rainfall can be quite unpredictable and insufficient, posing a significant risk to crop production [1]. The occurrence of prolonged dry spells can lead to diminished soil water content and ultimately crop failure, presenting a serious challenge for smallholder farmers [2]. Furthermore, climate change and variability are expected to exacerbate these issues in the future, with prolonged dry spell frequency and drought becoming more prevalent [3]. In Ethiopia, widespread drought and extended dry spells significantly impact the crop production system [4]. Poor soil management, reduced soil fertility, and inadequate measures to conserve soil moisture have all contributed to declining crop yields in semiarid areas [5]. The combination of low seasonal rainfall, high soil moisture stress, unproductive soils, and increased land degradation has been linked to low crop productivity in these regions [6].

In order to address climate variability challenges and mitigate soil-related moisture constraints affecting crop production in semiarid regions, farmers and researchers have implemented various soil and water conservation practices, as evidenced by scientific research [7–9]. One potential approach involves increasing soil moisture and enhancing rainwater infiltration through the implementation of rainwater harvesting practices, thereby improving crop water productivity [9, 10]. Additionally, the essential replenishment of nutrients, adoption of soil water conservation practices, and integrated use of manure and inorganic fertilizer are crucial for enhancing soil productivity in drought-prone semiarid areas [11–14]. Water harvesting practices have significantly contributed to enhancing rainfed agriculture's sustainability and reliability by making more efficient use of rainwater [15]. Furthermore, the utilization of suitable soil moisture conservation practices has been shown to increase rainfall use efficiency and mitigate the impacts of intraseasonal dry spells [15–17]. Various studies have also explored alternative practices to address soil water deficiency challenges and boost crop yield in semiarid regions [6, 9, 10, 18].

Several soil moisture conservation practices have been identified and utilized in dry land areas. Some of these practices include Tied ridge, Zai pits, semicircular bunds, half-moons, contour bunds, eyebrow terraces, and Negarim [6]. Additionally, it has been reported that strip cropping, mixed cropping, intercropping, fallowing, mulching, contour plowing, crop rotation, preservation of tillage, and agroforestry are significant agronomic soil and water conservation practices in Ethiopia [19]. Furthermore, a study conducted in southern Ethiopia indicated that in situ rainwater harvesting techniques such as Targa, Tie ridge, and Zai pit have played a crucial role in enhancing soil water storage, improving crop yields, and adapting to dry spells during growing seasons [20].

The Zai pit, a soil moisture conservation technique utilized by farmers in Burkina Faso, aims to replenish soil moisture, enhance soil fertility, and ultimately improve crop production [21]. This approach is particularly valuable in mitigating the adverse effects of frequent dry spells in semiarid regions, as the water captured in the Zai pit helps to alleviate their impact [22]. Additionally, Zai pit practices contribute to water preservation, soil erosion control, and the retention of rainfall and surface runoff water, subsequently safeguarding seeds and organic matter against erosion and conserving essential nutrients [21]. Furthermore, the combination of Zai pit soil moisture conservation methods with legume cover cropping systems has been shown to triple sorghum yield in rainfed systems in South Africa compared to the control group [21]. Similarly, soil water conservation strategies, such as enhanced soil fertility with the addition of organic manure, improved crop varieties, and optimized crop management practices, serve as essential measures in addressing the challenges posed by climate variability and change, ultimately leading to increased grain yield in water-stressed farming regions [23]. Thus, the combination of water harvesting practices and soil fertility enhancements presents a promising approach for optimizing crop productivity in dryland areas [16].

The study was carried out in Babile district, a semiarid region in the eastern Hararghe zone of Ethiopia. This area has been adversely affected by climate change-induced drought, irregular seasonal rainfall, and rising temperatures [24, 25]. According to the annual report from the Central Statistical Agency of Ethiopia (CSA) [26], the primary crops grown in the Babile district of eastern Hararghe zone are rainfed agricultural crops, including sorghum, maize, and groundnut. Sorghum and maize in the Eastern Harerge zone contributed 28.11%, 26.55% of the grain crop area, and 31.18% and 29.67% of the production of the zone, respectively [27]. The annual total sorghum production in Ethiopia is approximately 3.95 million tons, with an average yield of 2.18 t/ha nationwide while 1.6 t/ha in Babile district. Considerably, it is lower than the potential yield of 3 to 5 t/ha under rainfed dry land agriculture production [28–30]. Mainly, sorghum productivity in eastern Ethiopia has stagnated at less than 0.5 t/ha, significantly below the countrywide average productivity level [31]. The main reasons for this low productivity were identified in a study [32], which highlighted several factors such as unspecified planting density, unfavorable rainfall patterns, soil infertility, low yield potential of available varieties, poor crop management, inadequate soil moisture conservation practices, fertility management, and droughts.

In order to reduce the impacts of climatic challenges and soil-related constraints, this study utilized the early maturing, drought-resistant Teshale sorghum variety, and easily feasible and applicable soil moisture conservation practices (closed end Tied ridge, Zai pit, and flatbed) were implemented, both with and without legume cover cropping system. Sorghum is known for its drought tolerance and ability to withstand various stresses such as heat, drought, and flood [33]. It is widely cultivated in the semiarid regions of eastern Ethiopia under rainfed condition [31]. However, despite that it is widely adapted to semiarid regions, sorghum can still fail in some years due to high seasonal rainfall variability [1]. Therefore, this study aimed to assess the effectiveness of three types of soil moisture conservation practices, with and without a legume cover cropping system, on sorghum productivity in the semiarid parts of Babile district during the 2021 and 2022 cropping seasons at both research station and farmer center.

2. Materials and Methods

2.1. Experimental Site Characteristics. The field experiment for this study took place in eastern Hararghe zone, Babile district, known locally as Babile research site, and on a farmer's field at Tuula Kebele for the 2021 and 2022 cropping seasons. Babile research site is situated at 9.219°N, 42.322°E, about 1633 m above sea level, while Tuula Kebele Farm site is located at 9.205°N, 42.323°E, about 1619 m above sea level, in Babile

Table 1: Description of applied treatments during the cropping seasons.

Code	Detail descriptions of the experimental procedure
A	In planting the Zai pit, we utilized the Teshale sorghum variety with a pit size of 60 cm width, 60 cm length, and a depth of 25–30 cm. The planting rate applied was seven seeds per pit
B	In Tied ridge, *Teshale* sorghum variety was planted in 10 rows with a closed furrow of 45 cm in length and 30 cm wide with a planting rate of three seeds of sorghum per closed furrow
C	Flatbed, *Teshale* sorghum variety was planted in a row planting pattern with ten rows having 60 cm spacing and 14 seeds per row with planting space of about 32 cm were applied
D	Zai pit + legume cover crop, Teshale sorghum variety was planted in 60 cm width and 60 cm length and depth of 25–30 cm with a planting rate of seven seeds of sorghum and four seeds of haricot bean applied per Zai pit
E	In Tied ridge + legume cover crop, Teshale sorghum variety was planted in closed furrow Tied ridge with a 45-cm-length and 30-cm-wide planting pattern. Each closed furrow contained three seeds of sorghum and two seeds of haricot bean. This method was applied to 10 rows
F	Flatbed + legume cover crop, Teshale sorghum variety was carefully planted in a surface area of 10 rows with 60 cm spacing between them. The planting rate was 14 seeds per row, with a planting space of 32 cm. Additionally, eight haricot bean seeds were planted per row with a planting space of 60 cm

district, eastern Ethiopia. The climate in this area is semiarid, with a growing period ranging from 75 to 120 days [34]. The district experiences bimodal rainfall patterns, with the *Belg* season from March to May, the *Kiremt* season from June to September, with highly erratic nature, and a dry season called *Bega* from October to February [34]. The average annual rainfall is 731 mm, with 294.4 mm during March to May and 324.1 mm from June to September [30]. Additionally, the soil in the research sites is reddish brown gravelly sandy loam with sandy clay loam texture (18% clay, 6% silt, and 79% sand), near neutral in reaction (pH = 6.6), 0.04 mS/cm electrical conductivity (EC), and 0.56% organic carbon [35]. The study area heavily relies on rainfed agriculture carried out by smallholder subsistence farmers [30].

3. Experimental Design and Crop Management

The experiment was carried out over two cropping seasons in 2021 and 2022 at two distinct locations, Haramaya University's Babile Research Station and Tuula Kebele farmer's field, with land slopes of 1% and 5% respectively. The study was implemented on previously cultivated soil, following a randomized complete block design (RCBD) with three replications. Treatments included (A) Zai pit + sorghum, (B) closed end Tied ridge + sorghum, (C) flatbed (control) + sorghum, (D) Zai pit + sorghum + legume cover cropping, (E) closed end Tied ridge + sorghum + legume cover cropping, and (F) flatbed + sorghum + legume cover cropping, as detailed in Table 1. The treatments have been selected by taking into account the local agroclimate characteristics, the socioeconomic conditions of the farmers, the cost of the techniques, and easy applicability of those farming practices in the study area. The experimental units were randomly assigned treatments, ensuring each treatment occurred equally often within each block. Factors such as treatment, seasons, locations, and blocks were the main considerations, while subfactors included the interaction of seasons with treatment, seasons with location, and treatment with location. The total area of the land for the experiment was 30.1 m × 19 m (571.9 m^2) at each site, and the plot size was 4.2 m × 5.4 m (22.68 m^2), with a buffer zone of 0.7 m spacing and 0.7 m between each plot. To minimize edge effects, guard rows were used, and ditches of 0.3 m deep and 0.3 m wide were constructed around the field to divert runoff from adjacent farms.

During the land preparations for flatbed and Tied ridge practices, plowings were conducted at a depth of 20 cm to initially prepare the field. This was followed by hand plowing at a depth of 10 cm to further refine the seedbed. Zai pit preparation was carried out at a depth of 25–30 cm, with each pit measuring 60 cm in length and 60 cm in width as per the specifications outlined in sources Motis, D'Aiuto, and Lingbeek, Sawadogo, and Getare, Mucheru-Muna, and Ndung'u [21, 36, 37] for dryland crop production. The manual preparation of the holes took place in April, during the small rainy season. Following the creation of Zai pits, each pit was filled with a mixture of cattle manure and topsoil in a 1:3 ratio. A space of 20–25 cm depth was intentionally left above the manure–soil mix to allow for water accumulation, as detailed in Motis, D'Aiuto, and Lingbeek [21]. Consequently, water stored in the Zai pits served to delay the onset of severe moisture stress, providing a buffer against damage due to water deficits during dry periods, in line with findings from Nyamadzawo et al. [38]. The seeding space and depth adhered to specified treatments, with the Zai pit plot treatments all receiving an equal seed rate, as indicated in Table 1. The seed depth for all treatments was consistently 30 mm.

In our experiment, we ensured that an equal amount of fertilizer and cattle manure was applied at the same rate to all treatments, as mandated by the Zai pit treatment. The combined use of both inorganic fertilizers and organic manures has been proven to boost grain yield [12] and is more beneficial than solely relying on Zai pit for sustainable agriculture [39]. The organic fertilizer application was taken a dry cattle manure at a rate of 9.5 t/ha based on recommendation of Zougmoré, Jalloh, and Tioro [22], equivalent to 0.35 kg of cattle manure per Zai pit or 7 kg/plot, and testing its laboratory analysis of composition was 0.6% N, 0.3% P, and 0.5% K (Table 2). Additionally, following the guideline from Mahdi, Pichai, and

Table 2: Sorghum crop management practices in both cropping seasons.

Cropping seasons	Planting date and depth	Planting density (pl/m^2)	Applied cattle manure content (%)	Fertilization rate (kg/ha)	Harvest date
2021	July 13, 30 mm	7	0.6 N, 0.3 P, and 0.5 K	41 N, 20 P	November 28
2022	July 10, 30 mm	7	0.6 N, 0.3 P, and 0.5 K	41 N, 20 P	November 14

Note: In both cropping seasons, 9500 kg/ha of manure, 100 kg/ha of DAP, and 50 kg/ha of urea fertilizers were used.

Savitree [31] for sorghum crop production in eastern Ethiopia, we uniformly applied 50 kg/ha of urea and 100 kg/ha of DAP to all plots. Throughout our fieldwork, we meticulously recorded daily rainfall, sowing date, seed planting rate, harvesting date, and the weight of sorghum grain yield in t/ha. Furthermore, we carefully separated the sorghum grain heads from the stover, dried them for 2 weeks postharvesting, and hand-threshed them. Subsequently, we utilized a moisture meter, as suggested by Kimaru-Muchai et al. [40], to determine the moisture content of the grains and adjusted the grain weights to 12.5% moisture content.

3.1. Soil Sampling. Soil organic matter plays a crucial role in enhancing soil fertility and maintaining soil moisture content, which is essential for promoting healthy root growth in crops. To begin our assessment, we collected soil samples in a zigzag pattern from the entire experimental field before any land preparation activities took place, focusing on the 0–20 cm depth. Disturbed samples were obtained from nine points within each experimental field using an auger, allowing us to analyze soil texture (sand, silt, and clay percentages), total organic matter, total nitrogen, available phosphorus and potassium, cation exchange capacity (CEC), soil EC, and pH levels. Furthermore, we made use of a core sampler to gather soil samples for analyzing bulk density (BD), field capacity, and permanent wilting point prior to commencing the experiment. Throughout the plant growth and development stages, gravimetric soil water content was evaluated at 7-day intervals. Soil cores were collected from each plot at the experimental sites to measure the wet weight, and subsequently, these samples were oven-dried at 105°C for 24 h to determine the dry weights.

3.2. Gravimetric Soil Water Content. The gravimetric soil water content (represented as θ_g) denotes the mass of water per mass of dry soil, as described in Bilskie [41]. This was determined by initially weighing a soil sample (M_{wet}) and then proceeding to dry the sample in an oven at 105°C to eliminate the water, followed by weighing the dried soil (M_{dry}). The water content was subsequently calculated using Equation (1):

$$\theta_g = \frac{M_{water}}{M_{soil}} \times 100 = \left(\frac{M_{wet} - M_{dry}}{M_{dry}}\right) \times 100, \qquad (1)$$

where θ_g is the gravimetric soil water content in percent and M_{wet} and M_{dry} are the mass of wet and dry soil sample. The gravimetric soil water content was recorded at both sites within 7-day interval during the experimental seasons.

3.3. Soil Sample Preparation and Analysis. After carefully collecting the soil samples, the disturbed soil was crushed into small crumbs and thoroughly mixed. The composite soil was then separated into subsamples and labeled, and any foreign materials were removed. Afterward, it was air-dried, ground using a mortar and pestle, and sieved through a 2-mm sieve. For the determination of organic matter and total N, subsamples were ground to soil and passed through a 0.5-mm sieve. The sieved soil was then stored in a clean plastic container for subsequent analysis. The texture of the soil was determined using the Bouyoucos hydrometer method as outlined in Day [42], while the soil BD was determined using the core sampling method based on Al-Shammary et al. [43]. The volume of the core sampler used for soil sample collection was 98 cm^3. Furthermore, the soil water content at field capacity (1/3 bar) and permanent wilting point (15 bar) was determined using a pressure plate apparatus based on Kirkham [44]. The total soil sample porosity was estimated from the values of BD and particle density (PD) based on Bilskie [41], with the latter assumed to have the generally used average value of 2.65 g/cm^3 (Equation (2)):

$$\text{Total porosity}\ (\%) = \left(1 - \frac{BD}{PD}\right) \times 100. \qquad (2)$$

The soil pH was determined by creating a suspension of 1:2.5 soils/water ratio and using a glass electrode connected to a digital pH meter. The organic carbon content was determined following the method outlined in Nelson and Sommers [45], and the percentage of organic matter was calculated by multiplying the organic carbon percentage by a factor of 1.724. Total nitrogen was determined using the Kjeldahl method as described in Jackson [46]. Available phosphorus was determined using the Olsen method with extraction involving 0.5 M $NaHCO_3$ [46]. Soil CEC was determined by saturating with ammonium acetate as per Summer and Miller [47]. The EC of the soil sample was measured based on Rayment and Higginson [48] by taking a soil sample, creating a saturated paste with deionized water, extracting a 1:2.5 soil-to-water ratio, and then measuring the EC of the extracted solution.

3.4. Seasonal Cumulative Rainfall Analysis. The study area's rainfall performance was analyzed for the experimental seasons from July to October. We assessed the dekadel (10 days) rainfall amount and the number of rainy days within 10 days before sowing and 10-day interval after sowing. We compared the cumulative rainfall of the 2021 and 2022 experimental seasons to evaluate the rainfall performance. The calculation was based on the daily rainfall data from July to October during the

Table 3: Dekadel rainfall distribution during cropping seasons.

Items	10 DBS	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS	110 DAS	Total
2021 RF	17.8	44.4	14.7	44.0	8.8	45.6	66.2	61.7	16.2	89.9	0.0	0.0	410
2021 NRD	2.0	4.0	1.0	5.0	2.0	5.0	4.0	5.0	3.0	4.0	0.0	0.0	35
2022 RF	12.7	0.0	18.9	20.3	7.7	50.6	46.4	32.2	17.5	0.0	6.6	0.0	213
2022 NRD	1.0	0.0	1.0	1.0	1.0	4.0	4.0	1.0	4.0	0.0	1.0	0.0	18

Note: Total is the period from July to October, dekadal amount of rainfall, and number of rainy days before sowing and days after sowing.
Abbreviations: DAS, days after sowing; DBS, days before sowing; NRD, number of rainy days in number; RF, rainfall (mm).

cropping seasons of sorghum crop. The accumulated rainfall represents the total amount of rainfall in millimeters (mm):

$$C_i = \sum_{i}^{n} N_i, \tag{3}$$

where C_i is the cumulative rainfall time series in millimeters (mm) at a given period, N_i is the daily recorded rainfall in millimeters (mm), and n is number of days of observations.

3.5. Relationship of Sorghum Grain Yield and Soil Water Content. To assess the correlation between crop yield and soil water storage at the study sites, we calculated the correlation coefficient based on Klugh [49]. For the entire growing season, we used the Pearson product–moment correlation coefficient to understand the relationship between sorghum grain yield and soil water content, as shown in Equation (4):

$$r = \frac{\sum_1^n \left(Xi - \overline{X}\right) \times \sum_1^n \left(Yi - \overline{Y}\right)}{\sqrt{\sum_1^n \left(Xi - \overline{X}\right)^2} \times \sqrt{\sum_1^n \left(Yi - \overline{Y}\right)^2}}, \tag{4}$$

where r is the correlation between soil water content and sorghum grain yield; Y is the sorghum grain yield obtained from each plot, and X is the gravimetric soil water content recorded at each plot over the entire observation time period, while $\overline{X}$ and $\overline{Y}$ are the average of soil moisture content and sorghum grain yield obtained from each plot.

3.6. Statistical Data Analysis (Analysis of Variance [ANOVA]). Statistical analysis involved in testing the weight of grain yield, and gravimetric soil moisture content variation among different treatments was conducted using ANOVA in Fisher's ANOVA technique at a 5% probability level. The comparison was made using the LSD test method based on McLean, Sanders, and Stroup [50]. Interpretations were made on each level of the interaction factor when significant treatment interaction existed. Additionally, for the combined use of different seasons and locations, an analysis of pooled variance of data was performed using R software version 4.2 based on Moore and Dixon [51]. The possible additive linear model for an experiment repeated over treatment, block, years, locations, and interactions as factors was calculated based on Moore and Dixon [51] by Equation (5). Further, the additive linear model for an experiment repeated over years by combined seasons of weight of grain yield was analyzed by Equation (6), and only treatment effect on soil moisture content within a single season was analyzed by Equation (7):

$$Y_{ijkl} = \mu + T_i + B_j + Y_k + L_l + TY_{ik} + YL_{kl} + TL_{il} + YLT_{kli} + \varepsilon_{ijkl}, \tag{5}$$

$$Y_{ijk} = \mu + T_i + B_j + Y_k + YT_{ik} + \varepsilon_{ijk}, \tag{6}$$

$$Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}, \tag{7}$$

where Y_{ijkl} is the response measured on the ijklth experimental unit (plot), μ is the overall mean Y_i is the effect of the k^{th} year, L_l is the effect of the l^{th} location, YL_{kl} is the interaction effect of the k^{th} level of Y with the l^{th} level of L, Bj is the effect of the j^{th} block, T_i is the effect of the i^{th} treatment, YT_{ki} is the interaction effect of the k^{th} level of Y with the i^{th} level of T, LT_{li} is the interaction effect of the l^{th} level of L with the i^{th} level of T, YLT_{kli} is the interaction effect of the k^{th} level of Y with the l^{th} level of L and the i^{th} level of T, and ε_{ijkl} is experimental error, NID $(0,\delta^2)$.

4. Results and Discussion

4.1. Seasonal Rainfall Distribution During Experimental Seasons. The study area's rainfall performance during the 2021 and 2022 cropping seasons is presented in Table 3. The results indicate that the total rainfall during the sorghum growing period was 410 mm over 35 days in the first cropping season (2021) and 213 mm over 18 days in the second cropping season (2022) (Table 3). In contrast, the long-term average total rainfall during the growing period from July to October was 319 mm [33]. This suggests that the 2022 cropping season experienced lower seasonal rainfall compared to the long-term average and 2021 copping season. Additionally, the number of rainy days during the first cropping season (2021) was higher than in the second cropping season (2022) (Table 3). As a result, the grain yield obtained in the 2021 copping season was more than in 2022 cropping season.

During the 2021 and 2022 cropping seasons, it was observed that the 2022 cropping season experienced considerably drier conditions compared to the 2021 season (Figure 1). Furthermore, both cropping seasons exhibited high variability in rainfall, with a significant occurrence of dry spells, particularly during the 2022 growing season (Figure 1). These findings are consistent with the findings reported by Hadebe et al. [1] and Kimaru-Muchai et al. [40], indicating that seasonal rainfall in semiarid regions is characterized by high variability, poor distribution, and low amounts.

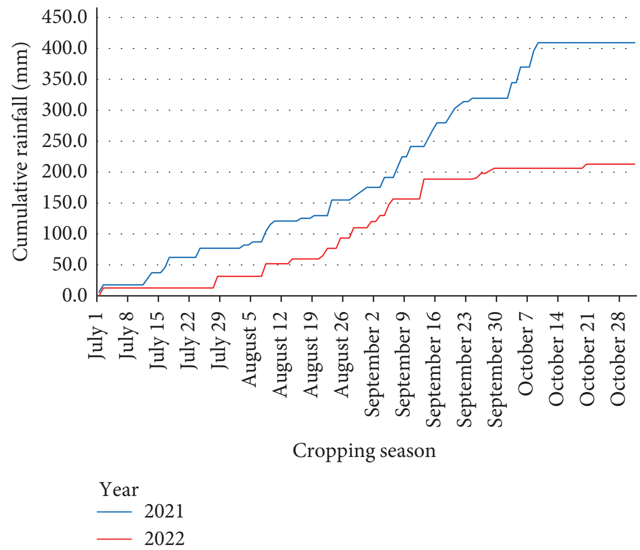


Figure 1: Comparison of rainfall distribution during the experimental seasons.

Table 4: Soil physical properties of laboratory result at experimental sites of 0–20 depth.

Sites	Sand (%)	Clay (%)	Silt (%)	BD	Po	SOM (%)	FC (%)	PWP (%)	Texture
Tuula	76	20	4	1.76	34	1.73	12.72	3.52	Sandy clay loam
Babile	85	9	6	1.80	32	1.56	11.50	4.02	Loamy sand

Note: Composite soil sample taken 0–20 cm depth.
Abbreviations: BD, bulk density in g/cm^3; FC, field capacity; Po, porosity of the soil sample in %; PWP, permanent wilting point of the soil; SOM, soil organic matter.

4.2. Soil Physical and Chemical Properties. The soil at the Tuula experimental site consisted of 76% sand and 20% clay, while at the Babile site, it was 85% sand and 9% clay (Table 4). According to the USDA soil texture classification [52], the soil textures were identified as sandy clay loam and loamy sand, respectively. Additionally, prior to the experiment, the organic matter content in the 0–20-cm soil depth at both sites was measured at 1.73% and 1.56% (Table 4), indicating a low organic matter content based on the rating in Tadese [53]. This low organic matter content affects soil water holding capacity and aeration. To address this issue, compost, manure from off-farm sources, and legume application practices were suggested [54, 55]. The gravimetric soil water content at field capacity for both sites was approximately 12.72% for Tuula and 11.5% for Babile, with permanent wilting points of 3.52% and 4%, respectively (Table 4). The BD of soil samples at the Tuula and Babile sites was recorded as 1.76 and 1.8 g/cm^3, indicating compacted soil (Table 4).

In Table 4, the depth of the surface topsoil (0–20 cm) is presented, showing a soil pH of 6.6 and 6.3 (1:2.5 soil:water ratio extract) at the Tuula and Babile experimental sites, indicating a neutral pH based on Jones [56]. The CEC for the topsoil at both sites is rated as 11.5 and 8.5, suggesting a low CEC due to sand dark textural properties [57]. This indicates the soil's limited ability to hold positively charged ions, affecting soil structure stability, nutrient availability, and its reaction to fertilizers [58]. The total nitrogen contents at both experimental sites are 0.092 and 0.062, indicating a very low rating based on Jones [56]. Soil with low total nitrogen content can lead to soil fertility degeneration, while an excess can cause soil hardening, leading to plant burnout and shriveling leaves [59]. The potassium content of the topsoil at both sites is reported as 0.449 and 0.348, indicating a medium potassium content based on Roy et al. [60].

According to Olsen [61], the available P ratings are 10.23 (upper boundary of medium rating) and 7.72 (medium content) for Tuula and Babile sites, respectively (Table 5). The EC of soil samples at both sites is 0.7 and 0.69 dS/m (1:2.5 soil: water ratio extract), indicating low EC, which can lead to soil aggregation and structural collapse due to limited water and air movement through the soil [62]. Soil with low total nitrogen, low organic matter, and low EC can harden and limit drainage, but this can be improved through tillage and the application of compost, manure, and legume cover cropping [54, 55]. After the experiment, there was an improvement in soil NPK nutrient content, as seen in Table 5. This includes an increase in total nitrogen from 0.092 to 0.12, potassium content from 0.449 to 0.82, and available phosphorus from 10.23 to 11.6 at the Tuula site (Table 5). Similarly, at the Babile site, total nitrogen increased from 0.062 to 0.08%, potassium content from 0.348 to 0.61 cmol (+) kg^{-1}), and available phosphorus from 7.72 to 10.1 mg/kg (Table 5).

4.3. Gravimetric Soil Water Content. The soil water content measured at Babile research site over a 7-day interval from the 30th to 90th of days after sowing during the cropping season

Table 5: Soil chemical properties of laboratory result at experimental sites of 0–20 cm depth.

Sites	Before conducting the experiment						After conducting experiment		
	CEC (cmol (+) kg^{-1})	TN (%)	K (cmol (+) kg^{-1})	Av. P (mg/kg)	pH (H_2O)	EC (H_2O)	TN (%)	K (cmol (+) kg^{-1})	Av. P (mg/kg)
Tuula	11.5	0.092	0.449	10.23	6.74	0.70	0.12	0.82	11.6
Babile	8.5	0.062	0.348	7.72	6.6	0.69	0.08	0.61	10.1

Note: Composite at 0–20 cm soil depth, and a 1 to 2.5 soil-to-water ratio is used for pH and EC analysis.
Abbreviations: Av. P, available phosphorus; CEC, cation exchange capacity in centimole per kg (cmol (+) kg^{-1}); EC, electrical conductivity in deci Siemens per meter (dS/m); K, potassium in the soil in cmol (+) kg^{-1}; pH, soil pH; TN, total nitrogen.

Table 6: Mean separation of gravimetric soil water content in percent at Babile site 2021 season.

Trt	37 DAS	Trt	51 DAS	Trt	58 DAS	Trt	65 DAS	Trt	79 DAS	Trt	85 DAS
E	24.9^{a}	D	35.3^{a}	D	35.6^{a}	E	33.3^{a}	E	23.6^{a}	E	35.1^{a}
D	23.6^{a}	E	35.3^{a}	E	34.8^{a}	D	33.0^{a}	D	$23.3^{a,b}$	A	$33.6^{a,b}$
A	23.3^{a}	A	33.0^{a}	A	31.8^{a}	A	$29.3^{a,b}$	A	21.4^{b}	D	$33.5^{a,b}$
B	$21.8^{a,b}$	B	$30.0^{a,b}$	B	$30.4^{a,b}$	B	$29.3^{a,b}$	B	21.4^{b}	B	$30.0^{b,c}$
F	$17.6^{b,c}$	F	$26.4^{b,c}$	F	25.2^{b}	F	$23.0^{b,c}$	F	19.2^{c}	F	$26.2^{c,d}$
C	16.1^{c}	C	23.7^{c}	C	24.6^{b}	C	21.0^{c}	C	18.8^{c}	C	23.8^{d}
$LSD_{(0.05)}$	5.13	—	5.5	—	5.8	—	6.4	—	1.98	—	4.3
CV (%)	13.3	—	9.8	—	10.5	—	12.4	—	5.12	—	7.8
p-Value	0.016	—	0.003	—	0.006	—	0.006	—	0.001	—	0.0007

Note: Letters A to F are treatments (Trt), A is Zai pit, B is Tied ridge, C is flatbed, D is Zai with legume, E is Tied ridge with legume, and F is flatbed with legume, DAS is days after sowing, treatments with the same letters of superscript have no significant difference at 5% level, CV is coefficient of variation of gravimetric soil water content in %.

Table 7: Mean separation of gravimetric soil water content in percent at Babile site for the 2022 season.

Trt	45 DAS	Trt	59 DAS	Trt	73 DAS	Trt	80 DAS	Trt	87 DAS
E	28.2^{a}	E	32.6^{a}	E	27.6^{a}	E	22.9^{a}	E	20.4^{a}
D	27.5^{a}	D	32.5^{a}	D	$25.8^{a,b}$	D	20.9^{a}	B	$18.3^{a,b}$
A	26.3^{a}	B	31.7^{a}	B	$23.8^{a,b,c}$	B	$19.7^{a,b}$	D	$16.9^{a,b}$
B	$23.7^{a,b}$	A	$28.3^{a,b}$	A	$21.2^{b,c,d}$	A	$16.5^{b,c}$	A	15.7^{b}
F	19.8^{b}	F	$24.0^{b,c}$	F	$19.5^{c,d}$	F	$15.7^{c,d}$	F	11.6^{c}
C	19.6^{b}	C	23.1^{c}	C	16.5^{d}	C	12.2^{d}	C	11.4^{c}
$LSD_{(0.05)}$	5.7	—	4.3	—	5.43	—	3.81	—	3.86
CV (%)	10.7	—	8.3	—	13.3	—	11.62	—	13.5
p-Value	0.005		0.001		0.009		0.001		0.002

Note: Letters A to F are treatments (Trt), A is Zai pit, B is Tied ridge, C is flatbed, D is Zai with legume, E is Tied ridge with legume, and F is flatbed with legume, DAS is days after sowing, treatments with the same letters of superscript have no significant difference at 5% level, CV is coefficient of variation of gravimetric soil water content in percent.

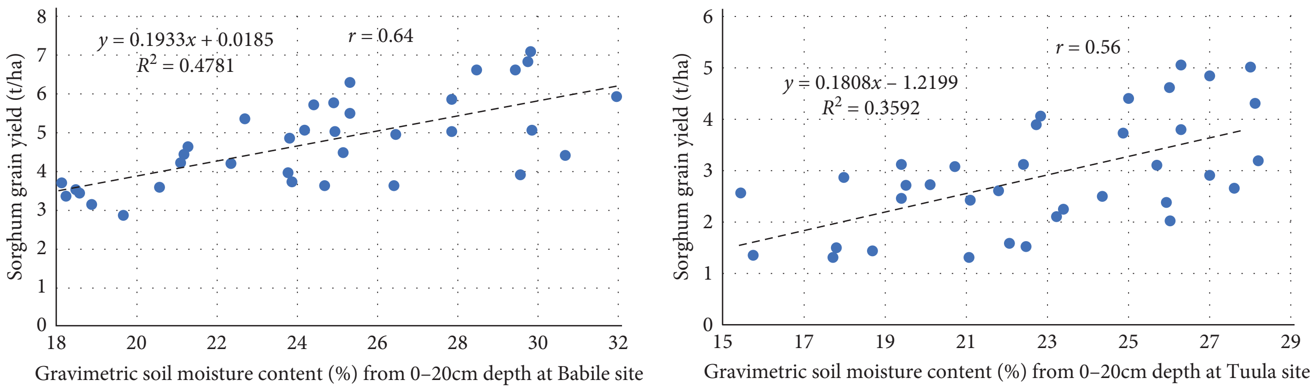
showed significantly higher levels in Tied ridge soil moisture conservation compared to flatbed control in most observations (Tables 6 and 7). Similarly, at the Tuula experimental site, the gravimetric soil water content was notably higher in Tied ridge compared to flatbed control (Table 8). Results indicate that different soil water conservation practices had a significant impact on the soil water content at both experimental sites (Tables 5 –8). Therefore, the application of Tie ridge and Zai pit with legume cover cropping practices proved to be highly effective in retaining the highest possible gravimetric soil water content throughout the seasons, in comparison to the flatbed treatment (Tables 5 –7). These findings are consistent with a previous study by Naba et al. [20], which showed that soil moisture content during dry spell periods was significantly higher in Targa and Tie ridges than in the control (flatbed) practice.

The correlation between sorghum grain yields in both combined seasons obtained from each treatment and gravimetric soil water content at 0–20 cm depth at each plot shows a significantly positive relationship with gravimetric soil moisture content with line fit ($p < 0.001$; $R^2 = 0.49$ (Figure 2a) and $R^2 = 0.36$ (Figure 2b)) at Babile and Tuula farm site, respectively. Similarly, the study reported by Barrett-Lennard et al. [63] revealed a significant correlation between barley grain yield and gravimetric water content at 0–20 cm depth ($p < 0.001$; $R^2 = 0.40$), emphasizing the strong relationship between grain yield and gravimetric moisture content.

Table 8: Mean separation of gravimetric soil water content in (%) at Tuula site of both seasons.

Trt	44 DAS in 2021	Trt	79 DAS in 2021	Trt	86 DAS in 2021	Trt	45 DAS in 2022	Trt	59 DAS in 2022	Trt	80 DAS in 2022	Trt	87 DAS in 2022
D	21.7^{a}	E	20.9^{a}	E	35.5^{a}	E	24.9^{a}	E	31.53^{a}	E	18.5^{a}	E	18.0^{a}
A	21.4^{a}	D	$18.5^{a,b}$	D	34.0^{a}	D	24.8^{a}	D	31.51^{a}	A	$16.8^{a,b}$	B	15.3^{b}
E	20.5^{a}	B	$16.6^{b,c}$	A	33.9^{a}	A	$23.7^{a,b}$	A	30.6^{a}	F	$15.4^{b,c}$	D	15.0^{b}
F	$18.5^{a,b}$	A	$15.3^{b,c}$	B	$31.9^{a,b}$	B	$19.3^{b,c}$	F	$29.2^{a,b}$	D	$14.3^{b,c}$	A	14.9^{b}
B	$18.2^{a,b}$	C	14.5^{c}	F	$28.1^{b,c}$	F	18.2^{c}	B	$28.6^{a,b}$	B	13.9^{c}	F	$13.5^{b,c}$
C	16.3^{b}	F	13.4^{c}	C	24.8^{c}	C	15.5^{c}	C	23.0^{b}	C	11.3^{d}	C	12.9^{c}
$LSD_{(0.05)}$	3.99	—	3.52	—	5.1	—	4.4	—	6.99	—	2.65	—	1.92
CV	11.3	—	11.7	—	8.9	—	11.5	—	13.2	—	9.7	—	7.1
p-Value	0.004	—	0.001	—	0.024	—	0.003	—	0.007	—	0.001	—	0.002

Note: Letters A to F are treatments (Trt), A is Zai pit, B is Tied ridge, C is flatbed, D is Zai with legume, E is Tied ridge with legume, and F is flatbed with legume, DAS is days after sowing, treatments with the same letters of superscript have no significant difference at 5% level, CV is coefficient of variation of gravimetric soil water content in percent.



(a) (b)

FIGURE 2: (a, b) Relation between grain yield and gravimetric soil water (%) at 0–20 cm depth.

TABLE 9: Analysis of variance (ANOVA) of grain yield in t/ha with combined site and seasons.

Causes of variation	DF	Sum of square	Mean of square	*F* value	Pr (>*F*)
Treatment (T)	5	40.9	8.18	27.4	0.0001***
Block (B)	2	0.84	0.42	1.41	0.255
Year (Y)	1	22.88	22.88	76.5	0.0001***
Location (L)	1	63.11	63.11	211.1	0.0001***
T × L	5	1.81	0.36	1.21	0.319
Y × L	1	2.59	2.59	8.66	0.0051**
T × Y	5	1.53	0.31	1.02	0.42
T × Y × L	5	0.50	0.10	0.337	0.889
Residuals	46	13.75	0.30	—	—

Note: Significant codes are 0, "***"; 0.001, "**"; 0.01, "*"; 0.05, "."; 0.1, "1".

5. Sorghum Grain Yield Variation

The grain yield performance at different treatments, sites, and seasons indicates that the treatment, season, and location had highly significant effects on the variation of sorghum grain yield ($p < 0.05$) (Table 9). The interaction of season with location also had significant variation of sorghum grain in the study area ($p < 0.05$) (Table 9). Comparing sorghum grain yield mean variations obtained from Babile research site with combined seasons, there was a significant higher in Tie ridge with legume cover cropping (6.28 t/ha), followed by Tied ridge without legume cover cropping (5.67 t/ha), compared to control (flatbed) (3.88 t/ha) practices (Table 10).

Upon comparing the Zai pit with legume cover (4.44 t/ha) and without legume cover cropping (4.25 t/ha), no significant mean variation was observed. However, the mean grain yield obtained from Zai pit practice variation is significantly lower than the yield obtained from the Tied ridge practice. Notably, the rainfall distribution during 2021 was better in amount and had lower dry spells than the 2022 cropping season (Figure 2), and moisture content variation among the treatment was observed in Babile site (Tables 6–8), resulting in higher grain yield observed at Babile than Tuula site (Table 10). However, the rainfall is low, and the Tied ridge practice sustained the occurrence of that dry spell and obtained more yield, but the control (flatbed) practices have great variation with yield obtained at different seasons (Table 10).

Furthermore, the combined sites and seasons yielded an average of 5.07, 4.65, 3.65, 3.52, 3.12, and 3.07 t/ha for sorghum grain yield from Tie ridge with cover cropping, Tie ridge without cover cropping, Zai pit with cover cropping, Zai pits without cover cropping, flatbed with cover cropping, and flatbed without cover cropping (control), respectively (Table 10). Therefore, the study showed that there was a significant impact of seasonal rainfall variability (Figure 2) on sorghum grain yield and significant soil moisture content variation among treatment in seasons and site (Tables 6–8). The study's results indicate that the grain yield of sorghum in this research falls within the potential rainfed productivity range of 3 to 5 t/ha, as reported by FAOSTAT2017 [28], and exceeds the average sorghum grain yield level in Ethiopia, which is estimated at about 2.18 t/ha in countrywide while 1.6 t/ha in Babille district under rainfed dry land agriculture [29, 30]. But the maximum yield obtained in combined seasons and sites at Tied ridge practices was 5.07 t/ha, while the lowest yield from flatbed practices was 3.07 t/ha (Table 10). These figures reflect increases of 68% and 47%, respectively, compared to prior studies of 1.6 t/ha [30]. Thus, these treatments prove to be the most effective strategies for enhancing sorghum grain yields, particularly in areas significantly impacted by dry spells. Such methods are vital for

Table 10: Sorghum grain yield in (t/ha) mean separation of combined seasons and sites.

Trts	Babile in 2021	Babile in 2022		Combined S at Babile		Tuula in 2021		Tuula in 2022		Combined S of Tuula		Combined sites and seasons	
	GY	Tr	GY	Tr	GY	Tr	GY	Tr	GY	Tr	GY	Tr	GY
E	6.85^{a}	E	5.72^{a}	E	6.28^{a}	E	4.75^{a}	E	2.99^{a}	E	3.87^{a}	E	5.07^{a}
B	6.22^{a}	B	5.15^{a}	B	5.68^{a}	B	$4.51^{a,b}$	B	2.72^{a}	B	3.62^{a}	B	4.65^{a}
A	4.84^{b}	D	4.22^{b}	D	4.44^{b}	D	$3.65^{b,c}$	D	2.06^{b}	D	2.85^{b}	D	3.65^{b}
D	4.66^{b}	A	$3.68^{b,c}$	A	4.25^{b}	A	$3.54^{b,c}$	A	$2.01^{b,c}$	A	$2.78^{b,c}$	A	$3.52^{b,c}$
C	4.41^{b}	F	$3.55^{b,c}$	C	3.88^{b}	C	2.81^{c}	C	$1.75^{b,c}$	F	$2.28^{c,d}$	F	3.12^{c}
F	4.29^{b}	C	3.47^{c}	F	3.83^{b}	F	2.73^{c}	F	1.41^{c}	C	2.07^{d}	C	3.07^{c}
CV%	12.8	—	9.0	—	11.8	—	16.2	—	11.9	—	16.2	—	14.2
$LSD_{(0.05)}$	1.2	—	0.71	—	0.68	—	1.08	—	0.45	—	0.56	—	0.45
p-Value	0.01	—	0.001	—	0.001	—	0.008	—	0.001	—	0.001	—	0.001

Note: Letters A to F are treatments (Trts), A is Zai pit, B is Tied ridge, C is flatbed, D is Zai with legume, E is Tied ridge with legume, and F is flatbed with legume, S is season, CV is coefficient of variation of soil water content in %, treatments with the same letters of superscript have no significant difference at 5% level of significance.

improving crop productivity in drought-prone and semiarid regions that experience severe dry spell effects [13, 17].

Notably, Tied ridge with legume cover cropping practices consistently showed higher yields. Pairwise comparison and statistical grouping of mean grain yields revealed no significant difference in grain yield due to the legume cover cropping treatments, but there was mean variation among Tied ridge, Zai pit, and flatbed (control) treatments in combined season and site (Table 10). There was also a yield improvement for planting sorghum with legume cover cropping treatment (Table 10). In South Africa, Zai pit soil moisture conservation practices with legume cover cropping system increased sorghum grain yield in rainfed systems by threefold compared to Zai without legume cover cropping [21]. The flatbed (control) treatment in this study exhibited lower yields compared to the other treatments considered. This is attributed to its low ability to retain soil moisture over the entire seasons (Tables 6–8), with soil moisture content being significantly correlated with grain yield (Figure 2). The results indicate that more moisture conserved in Tied ridge has resulted in better sorghum grain yield than the flatbed (control) treatment, which aligns with previous findings reporting the beneficial impact of in situ soil moisture conservation practices in Tied ridge over control (flatbed) treatment, as reported by Mamo et al. and Mahdi et al. [4, 31].

Additionally, a study by Gebrekidan [64] indicated that Tied ridge sorghum planting is more advantageous than flatbed for moisture conservation and applied nutrient management, achieving maximum sorghum grain yield. In southern Ethiopia, a study by Naba et al. [20] uncovered that traditional rainwater harvesting techniques like Targa, Tie ridge, and Zai pit resulted in a substantial increase in grain yield through soil moisture conservation in Targa. Similarly, research by Kimaru-Muchai et al. [40] in the drier regions of upper eastern Kenya found that combining Zai pits are small planting pits that can be used to improve soil fertility, while Tithonia is a green manure that's high in nutrients. As a result, the study suggests utilizing Tie ridge with manure and inorganic fertilizer to maximize sorghum grain yield. This recommendation aligns with previous research by Zingore et al., Baptista et al., and Mekuriaw et al. [11–13, 17], which indicated that combining water harvesting practices and soil fertility amendments in dryland areas has a promising potential for increasing crop productivity by enhancing soil water infiltration.

6. Conclusion

In the recent study, the effectiveness of various soil moisture conservation practices (Tied ridge, Zai pit, and flatbed) was examined by RCBD, both with and without a legume cover cropping system, for the 2021 and 2022 cropping seasons. ANOVAs for moisture content among treatment and rainfall distribution were analyzed. ANOVA revealed that treatments and seasonal and location variation significantly affected the variation in sorghum grain yield. It was found that the dry spell's impact on sorghum grain yield was mitigated when using Tied ridge at both experimental sites compared to the other practices. Notably, the rainfall distribution during 2021 was better in amount and had lower dry spells than the 2022 cropping season, and moisture content variation among the treatment was observed in Babile site, resulting in higher grain yield observed in 2021 and at Babile than Tuula site. Therefore, the study showed a significant impact of seasonal rainfall variability on sorghum grain yield and significant soil moisture content variation among treatment in seasons and site.

Upon analysis at both experimental sites, it was determined that the grain yield obtained from Tied ridge with and without legume cover cropping treatments did not show statistical significance. Notably, the practice of Tied ridge soil moisture conservation displayed the most promising results for sorghum grain yield production. Consequently, the combined utilization of Tied ridge soil moisture conservation practices proved to be more effective in enhancing grain yield, especially under erratic seasonal rainfall patterns and lower rainfall amounts in arid and semiarid moisture-stressed regions of the study area. Therefore, it is recommended to widely used Tied ridge practice application in the future to improve sorghum grain yield in rainfed farming systems in the study areas well as in semiaid regions.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation based on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Abdisa Alemu Tolossa took overall responsibility for all aspects of the research process, including design, data collection, compilation, entry, analysis, interpretation of results, editing, and manuscript writing. Diriba Korecha Dadi, Lemma Wogi Mirkena, Zelalem Bekeko Erena, and Feyera Merga Liben were supervising, providing edits, and enhancing the quality of the manuscript during the write-up.

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