Evaluation of Conservation Tillage Methods for Soil Moisture Conservation and Maize Grain Yield in Low Moisture Areas of SNNPR, Ethiopia

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Abstract
Conservation tillage is a promising tillage practice for enhancing soil moisture conservation. The objective of the study is to evaluate conservation tillage methods on soil moisture and maize grain yield in Silte and Gurage zone of Ethiopia. No tillage, one-time tillage, two times tillage, and conventional tillage methods were evaluated. The treatments were laid out in randomized complete block design with three replications for three consecutive years (2018–2020). Besides soil moisture data, selected physical and chemical soil properties were collected. Economic analysis was also computed for each tillage method to select cost effective conservation tillage methods. The result reveals, conservation tillage methods had better soil infiltration and soil moisture content relative to conventional tillage. There was no significant difference between treatments in soil organic carbon, total nitrogen, and phosphorus in the top 10 cm in the Mareko site. However, except for phosphorus, significant differences \( p < 0.05 \) between treatments in soil organic carbon and nitrogen were detected in the 10–20 cm depth. The maize yield and yield components are significantly affected by treatments at the Mareko site and not significant at Mito. The results support that conservation tillage tested in this study could contribute to the improvement of soil properties and maize yield in study sites.

Keywords Conservation tillage · Marginal rate of return · Infiltration rate · Soil moisture conservation · Maize yield

Introduction
Land degradation in the form of soil erosion is the major environmental problem, which affects half of Ethiopia’s agricultural land ha\(^{-1}\) year\(^{-1}\) and results in a soil loss rate of 35 to 42 t year\(^{-1}\) and a monetary value of US$1 to 2 billion [6]. The removal of top fertile soil affects the productivity of agricultural lands and livelihood, casing ecosystems degradation, and loss of associated ecosystem services [12]. Also, for thousands of years, Ethiopian farmers have been practicing conventional or excessive soil tillage using animal traction [10] primarily to create a favorable environment to plant growth [15], control weeds, conserve moisture, and increase soil warming [28]. However, this practice with little or no ground cover with poor land management enhances soil erosion and land degradation [34]. The practice can also create hardpans in the subsoil, which can be detrimental to root proliferation below the plow layers [11].

The problem of soil erosion is also severe in southern Ethiopia. The report of Bekele et al. [4] shows that the average soil loss rate from the entire agricultural land estimated was 4.27 tons per hectare per year.

The problem is also severe in the Silte and Gurage zones of the southern region. The report of Bekele and Gemi [3] reported the average annual soil loss rate from agricultural land from Dijo watershed central rift valley basin of Ethiopia as 2.2 tons per hectare per year. Similarly, the report of SZFNDRD [27] and Survey [26] shows that flooding as the result of intensive rainfall seriously affected agricultural land and displaced many farmers from their resilience. Additionally, farmers in the study area plow the soil at shallow depth and remove all crop residues for livestock feed after harvest. Such improper practices with low soil moisture due to the...
erratic distribution of rainfall result from a significant negative impact on soil properties and crop grain yield.

The advantage of conservation tillage is diverse as it reduces soil erosion and conserves soil moisture [19]. Understanding the impacts of the tillage systems on soil hydraulic properties is necessary to conserve and manage soil water under different soil types, management scenarios, and climates [20]. This system could affect the ability of the soil to absorb and retain water, depending on the level of soil disturbance. Reduced tillage practice reduces erosion by saving runoff on the farm, preventing loss of soil material from farmlands, saving labor, increasing soil organic matter, and creating conditions that save susceptible soils from compaction or crusting [16]. These practices increase aggregate stability and soil resistance to raindrop impact and decrease water-dispersible clay [25].

This calls to practice conservation tillage to maintain crop residues for the sustainability of crop production. Therefore, the study has been focused to evaluate conservation tillage methods on soil moisture conservation, soil infiltration rate, soil properties, and maize grain yield. We hypothesized that the infiltration, soil moisture, and soil properties, resulting from long-term conservation tillage methods, could affect the yield of maize throughout the growing season in low moisture areas of Silte and Guraghe zones of SNNPR, Ethiopia.

Materials and Methods

Description of the Study Area This study was conducted in two districts: Mareko and Mito, located at Gurage and Mareko zones, respectively. The study was carried out for three consecutive years (i.e., from 2018 to 2020) (Fig. 1).

The soil type of the study site in Mito is predominantly Eutric Cambisols whereas the soil type in Mareko is Luvic Phaeozems [8]. The soil properties of the study sites such as bulk density (Bd), pH, organic carbon (OC), organic matter

Fig. 1 Location map of the study area
(OM), total nitrogen (TN), available phosphorus (Av. P), and soil texture are summarized in Table 1. According to the nutrient rating by Landon (1991), the study areas display low nutrient composition. The monthly rainfall distribution in the area ranges from 0 to 440 mm and most of the rain falls in July and August.

**Experimental Design**

Experimental plots were established in the farmer’s training center of the two districts. The experimental sites possess a slope ranging from 0 to 3%. Randomized complete block design (RCBD) with three replications was used to establish the treatments. A sketch diagram of experimental design was highlighted (Fig. 2). The treatments were (a) no tillage with herbicide (soil is disturbed only for placing seed and fertilizers), (b) reduced tillage (one-time tillage), (c) reduced tillage (two times), and (d) conventional tillage (three-time tillage). In each replication or block, four plots having a size of 5 m * 8 m size were established. A spacing of 2 m between plots was used while 1.5 m between replications, 0.8 m between rows, and 0.3 m between plants were used. Maize (Damot variety) was planted in May each year at a rate of 25 kg ha⁻¹. Two seeds were planted per hole and thinned to one seedling 2 weeks after planting. Based on the soil fertility map developed by NPS and NPSB fertilizers are the deficient fertilizers type in the study areas. Accordingly, in Mito woreda, all plots received the site recommended 121 kg ha⁻¹ NPS and 2 qt ha⁻¹ urea fertilizer, whereas 122 kg ha⁻¹ NPSB and 1 qt ha⁻¹ urea for Mareko woreda were used. One-third N and a full dose of P applied during planting and two-thirds of N top dressed. The weed under no-till practice was managed by application of 3–5 l/ha Glyphosate chemical herbicide and applied 15 days before sowing maize during April. The weeds in reduced tillage were managed by removing the weeds periodically from above the ground without disturbing the soil.

| Site  | Depth (cm) | BD (g/cm³) | pH  | %OC | %OM | %TN | P  | SD | CL | SLT | Textural class |
|-------|------------|------------|-----|-----|-----|-----|----|----|----|----|----------------|
| Mito  | 0–10       | 1.713      | 5.32| 1.15| 1.983| 0.099| 15.5| 40 | 45 | 15 | Sand clay      |
|       | 10–20      | 1.753      | 5.28| 1.05| 1.810| 0.091| 12.8| 42 | 40 | 18 | Sand clay      |
| Mareko| 10–20      | 1.699      | 5.2 | 1.17| 2.017| 0.101| 13.6| 43 | 46 | 11 | Sand clay      |
|       | 0–10       | 1.016      | 5.5 | 1.6 | 2.756| 0.138| 19  | 36 | 45 | 19 | Clay           |

SD, sand; CL, clay; SLT, silt; BD(g/cm³), bulk density.

**Fig. 2** A sketch diagram of experimental design
Soil Sampling and Laboratory Analysis

Before and after the experiment, a depth-wise soil sample was collected for physical and chemical properties. After the experiment, five soil samples one from each plot corner and one from the center of the plot were collected and composited for selected physical and chemical soil properties. Before the laboratory analysis, the collected sample was sieved and air-dried. The soil pH was determined by a 1:2.5 soil: water ratio using a pH meter as described by Van Reeuwijk [33]. The soil organic carbon (SOC) concentration was determined by Walkley and Black and rapid titration method as described in [22]. TN was determined by the modified Kjeldahl methods as modified by [22]. The Av. P content was determined using the Bray II extraction method.

Soil bulk density in the 0–10 cm and 10–20 cm soil depths was determined using a 753.6 cm³ volume of a core sampler. The soil contained in the core was dried at 105 °C for 48 h and weighed. Bulk density was calculated from the oven-dried mass of soil contained in the core volume.

Data Collection

Before experimentation, baseline data on farmer’s residue management, numbers of tillage frequency used by farmers (conventional tillage as control), and areas with similar farming systems and slopes were selected on both locations.

Soil Data  Soil samples before and after experimentation per site were collected for BD, OM, PH, Av. P, CEC, and TN, and organic carbon from 0 to 10 cm and 10 to 20 cm soil depth.

Soil Moisture Content Determination  For soil moisture analysis, soil samples were collected before planting, at each month after planting and harvesting from inside of every furrow from the top 0–10 cm soil depth. During sampling for moisture analysis, the date of the sampling was at 3 to 5 days after rain; if the rainfall interval allows, it is recommended to sample at 5 days after rainfall. The moisture content was determined by using the gravimetric method [21].

\[
SMC = \frac{(W_w - W_d)}{W_d} \times 100\%
\]

where \(MC\) = moisture content in (%), \(W_w\) = weight of wet soil (g), and \(W_d\) = weight of dry soil (g).

Soil Infiltration Rate

The soil infiltrations were measured using double-ring infiltrometer for 2 h using standard infiltration time (0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115). A double infiltrometer ring is pushed into the soil and water is poured into the ring, and the rate at which the water soaks into the soil is measured. Before the experiment, baseline infiltration data from each site were collected. After the experiment, the infiltration was also measured from each treatment. One block was randomly selected, and the rate of infiltration was measured from each treatment and compared with the site initial rate of infiltration and Horton’s infiltration curve.

Crop Data  Maize plant height, biomass, and grain yield were collected as parameters. Five plants per plot were randomly selected and the average plant height was reported for each treatment. For the biomass and grain yield data, two border rows were omitted and the rest of the rows were harvested from each plot and converted to a hectare basis.

Economic Analysis  Economic analysis was done using the partial budget and marginal analysis. The average market price (birr kg⁻¹) for maize was collected from the Mareko site. A short survey was conducted to know the market price of maize. Based on the survey data, the average market price for 1 kg maize was 8 Ethiopian birr. The cost of plowing, herbicide, and labor to apply the herbicide were considered. For a treatment to be considered a worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% [5], which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis.

Data Analysis

Analysis of variance (ANOVA) using SAS window 9.0 and least significant difference (LSD) were used to compare the treatment means at a 5% significance level. Before overall data analysis, a normality test was computed for each parameter using a histogram.

Results and Discussion

Effect of Conservation Tillage Methods on Soil Infiltration

The infiltration rate before the experiment for Mareko and Mito sites is 11.2 mm h⁻¹ and 10.1 mm h⁻¹, respectively. The results of infiltration after crop harvest under
no till, one-time till, two times till, and conventional till in a sandy clay soil texture in Mareko site were 17 mm h⁻¹, 15.8 mm h⁻¹, 21.9 mm h⁻¹, and 14 mm h⁻¹, respectively. Similarly, the infiltration rates after crop harvest under no till, one-time till, two times till, and conventional till in Mito site were 20.8 mm⁻¹, 25 mm⁻¹, 17.9 mm h⁻¹, and 14.4 mm h⁻¹, respectively. Conservation tillage methods have relatively better soil infiltration than conventional tillage methods (Fig. 3). In the Mareko site, two times tillage had 56%, no tillage 21%, and one-time tillage 12.9% higher soil infiltration rate compared to the infiltration rate in conventional tillage. Similar trends have been observed at the Mito site where no tillage had 44.4%, one-time tillage 73.6%, and two times tillage 24.3% higher infiltration rate compared to the infiltration rate in conventional tillage. In both testing locations, the rate of infiltration increased compared to the baseline condition and after crop harvest in the third year. The differences in soil infiltrations on conservation tillage after crop harvest could be due to the residue management in each year which contributed to higher soil infiltrations. The current soil infiltration rate falls within the range of the Horton infiltration curve. Fabrizzi et al. [7] confirmed that conventional tillage practices based on moldboard plowing and preparing fine seedbeds with residue removed or buried have resulted in poor soil fertility and degraded soil structure as indicated by soil surface sealing, low mesoporosity (pores of diameter), unstable soil aggregates, and low soil organic matter content, all of which affect water infiltration and soil water retention. Wang et al. [31] also reported that conservation tillage could delay runoff by 12–16 min in heavy rainfall events and improve final infiltration rate by 60.9% in comparison with conventional moldboard plowing in Shanxi province. This enhances soil aeration, infiltration rate, and water holding capacity of the soil. Ahaneku and Dada [2] discovered conservation tillage methods enhance soil aeration, infiltration rate, and water holding capacity which encourages root penetration, nutrient uptake, and vigorous growth of crops through reduced penetration resistance of the soil to plant root and farm implement. The report from Melkassa agricultural research center showed that the water infiltration measurement during 2015 and 2016 for conservation agriculture plots established on silt loam of Andosols in 2010 was about 15% higher as compared to conventional practice [18].

Table 2  Maize germination percentage (2019)

| Treatments                        | Germination % |
|-----------------------------------|---------------|
|                                   | Mito | Mareko |
| No tillage with Glyphosate        | 79.8b | 58.2b  |
| One-time tillage                  | 85.9ab | 81.8a  |
| Two times tillage                 | 88.8a  | 79.5a  |
| Conventional tillage              | 93.8a  | 58.7b  |
| Mean                              | 87.1  | 69.5   |
| CV (%)                            | 5.2   | 4.9    |
| LSD (5%)                          | 9.0   | 6.8    |

Means with the different letters are statistically different at 5% level.

Fig. 3  Soil infiltration rate (mm h⁻¹) in Mareko and Mito sites
A significant difference ($p < 0.05$) between treatments in germination rate was observed (Tables 2, 3, and 4). The germination percentage shows increasing trends across the years in both locations. The 2 years combined analysis result shows significant ($p < 0.05$) germination percentage was observed between no tillage with one-time and two times at the Mito site. However, the crop germination percentage was significantly different between two-time tillage and conventional tillage in this site. At the Mareko site, statistically significant ($p < 0.05$) crop germination percentage was observed between no tillage and conventional tillage.

**Effects on Soil Physical and Chemical Properties**

Significant differences were not observed among the treatments in bulk density (Table 5). However, the bulk density of conservation tillage methods at both soil depth recorded lower compared to the conventional tillage methods, which shows a relatively sufficient amount of residue cover in the soil, which contributed to the surface soil being loose and porous to store and retain more moisture at both locations after crop harvest (Figs. 4, 5, and 6). A reduced bulk density leads to an increase in porosity and enables the plant to establish more easily. The soil bulk density increases as soil depth increases.

Similarly, significant differences between treatments in soil moisture were not detected. Higher soil moisture contents were observed at the maize development stage in both locations (Figs. 4, 5, and 6). In both locations after crop harvest, the moisture content in the soil under conservation tillage is better relative to conventional tillage methods (third-year cropping season). If the comparison is required with conservation tillage methods, at Mareko site, no till has 30%, one-time tillage has 14%, and two-time tillage has 8% soil moisture advantage over conventional tillage methods, whereas at the Mito site, NT has 41.4%, one-time tillage has 57%, and two-time tillage has 46.6% soil moisture advantage over conventional tillage methods, which shows the ability of conservation tillage methods in conserving soil moisture.

Studies (e.g., [30]) reported that conservation agriculture plots had significantly higher water infiltration than conventional for two seasons in Zimbabwe (49% and 45% higher) and Zambia (57% and 87% higher) under sandy soil (Zimbabwe) and finer-textured soil (Zambia). Temesgen et al.

**Table 3** Maize germination percentage (2020)

| Treatments                  | Germination (%) | Mareko | Mito |
|-----------------------------|-----------------|--------|------|
| No tillage with Glyphosate  | $66^b$          |        | $91.3$|
| One-time tillage            | $74^{ab}$       |        | $93.3$|
| Two times tillage           | $83^a$          |        | $91.3$|
| Conventional tillage        | $80.7^a$        |        | $90.0$|
| Mean                        | $75.9$          |        | $91.5$|
| CV (%)                      | $8.4$           |        | $4.8$ |
| LSD (5%)                    | $12.8$          |        | NS   |

Means with the different letters are statistically different at 5% level

**Table 4** The combined result of maize germination percentage (2019–2020)

| Treatments                  | Germination (%) | Mareko | Mito |
|-----------------------------|-----------------|--------|------|
| No tillage with Glyphosate  | $63.2^c$        | $84.3^b$|
| One-time tillage            | $78.6^{ab}$     | $89.7^{ab}$|
| Two times tillage           | $85.2^a$        | $89.7^a$|
| Conventional tillage        | $71.9^{bc}$     | $92.0^a$|
| Mean                        | $74.7$          | $88.9$ |
| CV (%)                      | $12.9$          | $6.5$  |
| LSD (5%)                    | $11.70$         | $7.04$ |

Means with the different letters are statistically different at 5% level

**Effect of Conservation Tillage Methods on Crop Germination**

A significant difference ($p < 0.05$) between treatments in germination rate was observed (Tables 2, 3, and 4). The germination percentage shows increasing trends across the years in both locations. The 2 years combined analysis result shows significant ($p < 0.05$) germination percentage was observed between no tillage with one-time and two times at the Mito site. However, the crop germination percentage was significantly different between two-time tillage and conventional tillage in this site. At the Mareko site, statistically significant ($p < 0.05$) crop germination percentage was observed between no tillage and conventional tillage.

**Table 5** Soil chemical properties after maize harvest at Mareko woreda

| Treatments                  | Soil properties at different soil depths | Bulk density (g/cm$^3$) |
|-----------------------------|-----------------------------------------|------------------------|
|                             | 0–10 cm | 10–20 cm | 0–10 cm | 10–20 cm |
|                             | %OC   | %TN | P (ppm) | %OC | %TN | P (ppm) | %OC | %TN | P (ppm) |
| No tillage                  | 1.88 | 0.14 | 22.04 | 2.06$^a$ | 0.18$^a$ | 19.53 | 0.61 | 0.64 |
| One-time tillage            | 1.75 | 0.16 | 20.91 | 1.58$^b$ | 0.14$^b$ | 19.40 | 0.60 | 0.65 |
| Two time tillage            | 1.76 | 0.15 | 21.32 | 1.32$^a$ | 0.11$^b$ | 19.77 | 0.61 | 0.65 |
| Conventional tillage        | 1.65 | 0.15 | 20.98 | 1.34$^b$ | 0.12$^a$ | 21.55 | 0.65 | 0.68 |
| Mean                        | 1.76 | 0.15 | 21.30 | 1.57 | 0.14 | 20.06 | 0.61 | 0.65 |
| CV (%)                      | 24.5 | 24.7 | 6.48 | 12.7 | 12.6 | 11.5 | 1.5 | 2.2 |
| LSD (5%)                    | NS   | NS | NS | 0.40 | 0.03 | NS | NS | NS |

Means with the same letter are not statistically different at 5% level; NS, means not significant
reported as conservation tillage ensures more moisture storage, reduces surface runoff, and benefits the crop in arid and semi-arid areas by reducing drought risk and increasing grain yield. Similarly, Schlesinger [23] reported the impacts of conservation agriculture on crop yield, soil and water productivity, and management of weeds and pests. Higher water infiltration on conservation tillage improved the soil moisture under these practices. Thierfelder and Wall [30] reported that higher water infiltration on conservation tillage leads to higher plant-available soil moisture that generally enables crops to overcome in-season dry spells and reduce the risk of crop failure. Soil water content on sandy loam and loam soils in the top of 0–30 cm soil layer reported from Melkassa Agricultural Research Center and Wolenchity (Olanchiti) research sub-station was high in conservation agriculture than under conventional tillage during the main growing season [32] (Fig. 7).

Results revealed that in the 0–10 cm depth, there was no significant difference in soil organic carbon, total N, and phosphorus ($p > 0.05$) at both sites (Tables 5 and 6). However, significant differences between treatments in soil properties were observed in the Mareko site in the 10–20 cm depth (Table 5). At both sites, total N, soil organic carbon, and phosphorus contents in conservation tillage were higher than conventional practices, though the results were not statistically significant (Tables 5 and 6). The higher percent of soil organic carbon in conservation tillage could be attributed to the decomposition of crop residue including roots. Lal [17] reported a significantly higher SOC in soil with no tillage. According to Abbas et al. [1], the lowest value of SOC and N in conventional tillage could be due to the inversion of top soil during plowing.
Effects on Maize Yield and Yield Components

At Mito, there were no significant differences ($p > 0.05$) between treatments in plant height, biomass, and grain yield of maize. However, the grain yield of all treatments showed increasing trends. Maximum maize grain yield was obtained from two times tillage methods in three consecutive years cropping season. The non-significant difference between the treatments could be attributed to the lack of rainfall in the area. In the case of Mareko, all the yield and yield components are significantly affected by the conservation tillage methods in three consecutive years. However, maximum maize grain yield (5158.3 kg/ha; 4333.3 kg/ha) was recorded from two times tillage
methods in second- and third-year cropping seasons, respectively (Tables 7 and 8).

Low maize yield in both locations was recorded in the first year which is attributed to lack of rainfall during the grain filling stage. Conversely, the yield of maize particularly at the Mareko site in the third year was reduced due to high rainfall distribution in the area (Table 9). Comparatively, maize grain yield in conservation tillage methods is better than conventional tillage methods which could be due to high soil infiltration rate (Fig. 2) and soil moisture content. On average, 13% and 6% increased maize grain yield obtained from two times and one-time tillage respectively compared to conventional approach which could be attributed to more water retention due to high infiltration rate of the soil as providing a better environment for root growth. The yield for no tillage is reduced significantly ($p < 0.05$) relative to others in the third-year combined analysis at the Mareko site. However, the yield of conservation tillage is similar to the conventional tillage methods at the Mito site.

Shapiro et al. [24] discovered no-tillage corn and sorghum produced lower yields than conventionally tilled corn and sorghum. University of Idaho [14] discovered that the

| Treatments         | Soil properties at different soil depths |
|--------------------|------------------------------------------|
|                    | 0–10 cm | 10–20 cm |
|                    | %OC   | %TN | P (ppm) | %OC | %TN | P (ppm) |
| No tillage         | 0.99  | 0.09 | 22.40   | 0.66 | 0.08 | 20.19   |
| One-time tillage   | 1.65  | 0.14 | 19.89   | 1.01 | 0.09 | 19.99   |
| Two times tillage  | 1.17  | 0.10 | 21.0    | 0.83 | 0.07 | 21.15   |
| Conventional tillage | 1.05 | 0.09 | 18.89   | 1.02 | 0.09 | 22.88   |
| Mean               | 1.21  | 0.11 | 20.6    | 0.88 | 0.08 | 21.1    |

| Treatments         | Study sites |
|--------------------|-------------|
|                    | Mito woreda | Mareko woreda |
|                    | Ph (m) | Biomass (kg/ha) | Yield (kg/ha) | Ph (m) | Biomass (kg/ha) | Yield (kg/ha) |
| No tillage         | 2.2    | 8375.0          | 2941.7         | 2.2    | 8750            | 2466.7         |
| One-time tillage   | 2.6    | 8708.3          | 3100.0         | 2.4    | 13583           | 3258.3         |
| Two times tillage  | 2.6    | 8791.7          | 3375.0         | 2.4    | 14542           | 3691.7         |
| Conventional tillage | 2.5   | 8083.3          | 2766.7         | 2.7    | 15875           | 4183.3         |
| Mean               | 2.5    | 8489.6          | 3045.8         | 2.4    | 13,187.5        | 3400.0         |
| CV (%)             | 6.2    | 10.6            | 18.7           | 4.8    | 12.2            | 12.1           |
| LSD (5%)           | NS     | NS              | NS             | 0.23   | 3217.4          | 820.2          |

Means with the same letter are not statistically different at 5% level.

| Treatments         | Locations |
|--------------------|-----------|
|                    | Mareko woreda | Mito woreda |
|                    | Ph (m) | Biomass (kg/ha) | Yield (kg/ha) | Ph (m) | Biomass (kg/ha) | Yield (kg/ha) |
| No tillage         | 2.5    | 7075.0$^b$       | 2758.3$^c$    | 2.7    | 9979.2          | 4345.8         |
| One-time tillage   | 2.6    | 13,333.3$^a$     | 5033.3$^a$    | 2.7    | 10,958.3        | 5000.0         |
| Two times tillage  | 2.6    | 12,416.7$^a$     | 5158.3$^a$    | 2.7    | 12,316.7        | 5512.5         |
| Conventional tillage | 2.4   | 9083.3$^b$       | 3645.8$^b$    | 2.8    | 10,437.5        | 4541.7         |
| Mean               | 2.5    | 10,477.1         | 4148.9         | 2.7    | 10,922.9        | 4850           |
| CV (%)             | 6.6    | 11.7             | 7.6            | 1.5    | 9.4             | 11.4           |
| LSD (5%)           | NS     | 2442.1           | 634.77         | NS     | NS              | NS             |

Means with the same letter are not statistically different at 5% level.
practices of no tillage are associated with higher chemical costs and reduced yields due to increased disease, weed, and insect pressure. However, the crop residue under no tillage has the benefit of reduced soil erosion, increased soil organic carbon, conservation of soil moisture, and cooler soils during the heat of summer [13]. In general, the yield differences under no tillage, reduced, and conventional tillage are affected by factors such as location, soil texture, and rainfall. Fowler and Rockstrom [9] reported conversion from conventional tillage to conservation agriculture resulted in major improvements in yield and water productivity in parts of semi-arid to dry sub-humid East Africa, with a doubling of yields in good years due to increased capture of rainwater (Table 10).

### Financial Feasibility of Treatments

Since the grain yield of maize for 3 years in Mito is not significant, economic analysis was computed only for the Mareko site. In our study, the marginal rate of return of the change from no tillage to one-time tillage is 252.5%, well above the 100% minimum MRR [5]. Due to the higher cost of investment, both two times tillage and conventional tillage methods are out dominated by one-time tillage and no tillage and excluded from the recommendation. From the marginal analysis result (Table 11), farmers who can invest an additional cost of 3,132 birrs in one-time tillage than no tillage can get an additional benefit of 7,907.76 birrs indicating 52% more benefit in one-time tillage than no-tillage practice. Regardless of the economy, it is better to ensure soil sustainability. No tillage and one-time tillage at different soil depths could substantially improve soil organic carbon and total nitrogen (Table 5). They are also economically feasible tillage methods. Even though two times tillage are economically out dominated from the treatments, it maintains greater than 30% residue in the soil as no tillage and one-time tillage throughout the cropping season, which enabled the treatment to improve soil moisture and infiltration (Fig. 2).

### Conclusion and Recommendation

The results support that the conservation tillage method tested in this study could contribute to the improvement of soil properties and maize yield. Most of the tested technologies were also economically feasible. Therefore, for the Mareko case, for example, farmers use either no tillage or one-time tillage depending on their initial investment capital. For the Mito case, since the differences in soil moisture, soil properties, and maize yield between the treatments are statistically not different, farmers can select either of the conservation or conventional tillage methods to maximize the yield of maize. Further, studies are required, for example, to detect the effects of conservation tillage on soil erosion and water balance.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s41101-022-00129-0.

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| Treatment             | Locations                  | Mareko woreda |
|-----------------------|----------------------------|---------------|
|                       | Ph(m) | Biomass (kg/ha) | Yield (kg/ha) | Ph(m) | Biomass (kg/ha) | Yield (kg/ha) |
| No tillage            | 2.20  | 9342.4          | 5091.1        | 2.1   | 4800           | 2458.3        |
| One-time tillage      | 2.19  | 10,253.9        | 5423.2        | 2.1   | 6292           | 3208.3        |
| Two times tillage     | 2.31  | 10,807.3        | 6556.0        | 2.3   | 8792           | 4333.3        |
| Conventional tillage  | 2.21  | 10,351.6        | 5820.3        | 2.3   | 7750           | 3875.0        |
| Means                 | 2.20  | 10,188.8        | 5722.7        | 2.2   | 6908.3         | 3468.8        |
| CV (%)                | 7     | 9.8             | 16.2          | 11    | 23.6           | 26.1          |
| LSD (5%)              | NS    | NS              | NS            | NS    | 3262.8         | 1806.6        |

Means with the same letter are not statistically different at 5% level
Table 11  Partial budget analysis for different tillage methods for the three-year average yield

| Treatments     | NT  | 1TT | 2TT  | CT  |
|----------------|-----|-----|------|-----|
| Average yield (kg/ha) | 2612.5 | 4145.8 | 4425 | 3914.6 |
| Adjusted yield (kg/ha)  | 2351.25 | 3731.22 | 3982.5 | 3523.14 |
| Gross benefit (ETB/ha)  | 18,810 | 29,849.76 | 31,860 | 28,185.12 |
| Cost of herbicide (ETB/ha) | 735 | 0 | 0 | 0 |
| Cost of labor to apply (ETB/ha) | 300 | 0 | 0 | 0 |
| Cost of plowing (ETB/ha) | 0 | 4167 | 8333 | 12,500 |
| Total cost (ETB/ha) | 1035 | 4167 | 8333 | 12,500 |
| Net benefit (ETB/ha) | 17,775 | 25,682.76 | 23527D | 15,685.12D |
| Marginal cost from NT to 1TT | 4167 – 1035 = 3132 |
| Marginal net benefit from NT to 1TT | 25,682.76 – 17,775 = 7907.76 |
| Marginal rate of return from NT to 1TT | (7907.76 / 3132) * 100 = 252.5% |

D = when put in increasing order of total cost, any treatment that has net benefits that are less than or equal to those of treatment with lower costs is dominated, and therefore, it is eliminated from further consideration.

NT, no tillage; 1TT, one-time tillage; 2TT, two times tillage; CT, conventional tillage.

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