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Research Article

Conservation Tillage for Soil and Water Conservation and Maize Yield in Kafa Zone Ethiopia

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Abstract

Background and Objective: Conservation tillage including strip tillage, two times tillage and zero tillage plays a great role in soil erosion reduction and soil moisture improvement which could lead to an increase in the yield of the crop. The study was conducted to determine the effects of tillage practices on grain yield and yield of maize, soil moisture and soil loss under a slope of 15-20% farmland. **Materials and Methods:** The experiment was carried out during the 2017 and 2018 years on Nitisols in Kafa Zone Southwestern Ethiopia. Four tillage methods conventional tillage (CT), strip tillage (ST), reduced tillage (RT) and no tillage (NT) were evaluated in randomized block design with three replications. **Results:** From the combined analysis of 2 years, there is no significant differences ($p>0.05$) in 100 seed weight, biomass and grain yield. The highest grain yield was found in conventional tillage ($4561.33 \text{ kg ha}^{-1}$) and the lowest in no-tillage ($3994.41 \text{ kg ha}^{-1}$) in the year 2017 while the highest yield was found in reduced tillage ($4843.00 \text{ kg ha}^{-1}$) and the lowest yield in strip tillage ($3188.66 \text{ kg ha}^{-1}$) in the year 2018. It was found that no tillage could save 34% of soil loss relative to conventional due to reduction in soil disturbance in no tillage. The moisture content was not significantly different in all treatments at the planting stage, flowering stage and harvesting stage. **Conclusion:** Overall, the economic analysis indicated that reduced tillage practice, next to no-tillage is economically beneficial than conventional. Generally, NT and RT can be recommendable to the area since they get higher economic net benefit than CT and reduce soil erosion. However, when tillage experiments are done, it is important to consider a compromise between short term and long-term benefits for farmers than direct recommendations.

Key words: Tillage methods, soil loss, grain yield, soil moisture, the net benefit, conventional tillage, biomass weight

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Agriculture in Ethiopia is mainly dependent on green water (rain-fed) than blue water (irrigation from rivers)¹. Also, over 95% of the annual gross total agricultural output is generated from smallholder farmers with an average farm size ranging from 0.5-2 ha². This indicates that the efficient use of the available green water is crucial for enhancing the agricultural productivity of smallholder farmers. Conservation tillage could be an option to conserve moisture and increase agricultural productivity.

Conservation agriculture has significant potential to improve rainfall-use efficiency through increased water infiltration and decreased evaporation from the soil surface, with associated decreases in runoff and soil erosion³. As one component of conservation agriculture, a reduced tillage system has a great role to control soil erosion, reducing surface sealing of soils, increasing infiltration of water into the soil, reducing runoff from the soil surface, slowing the breakdown of organic matter in the soil, reduce the formation of hardpan layers in soils, provide a better soil environment for crop growth and slow down the overland flow. Reduced tillage practice reduces erosion by saving runoff on a farm and prevents loss of soil material from farmland. Moreover, it is labour-saving and increases soil organic matter. No-tillage (slot planting), mulch tillage, strip tillage, ridge-till, minimum tillage, cover cropping and contour farming are types of conservation tillage systems⁴. The conventional tillage in the tropics resulted in a decline in soil fertility, which is closely correlated to the reduction of soil use^{5,6}. This is primarily due to soil erosion and the loss of organic matter associated with conventional tillage practices⁷ which leave the soil bare and unprotected in times of heavy rainfall, wind and heat⁸. However, the need to produce more food for an increasing population with decreasing soil and water resources caused a shift to minimum tillage in several parts of the world⁹. Soil disturbance through conventional tillage has been reported as, among others, a cause of land degradation through increased soil structure destruction and organic matter depletion¹⁰. Tillage practices are site explicit and depend on yield, soil type and the atmosphere¹¹. Tillage affects physico-chemical properties of soils including organic matter, which may affect plant development and yield¹²⁻¹⁴. Site-specific tillage practices may influence the development and yield of maize because of various soil conditions made. Thus, zero-tillage was born out of a necessity to combat soil degradation and has been widely adopted by farmers at different scales¹⁵. The impact of reduced tillage practice on soil erosion control by saving runoff and preventing loss of soils from farmlands

has not been studied except the role of tillage methods on soil moisture. Thus, this study focused on determining the effect of different tillage practices on maize grain yield and yield components, soil moisture content and soil loss under 15-20% slope in Gimbo Woreda, Kafa Zone.

MATERIALS AND METHODS

Description of the study area: The study was conducted in Shomba Sheka Kebele, Gimbo Woreda, Kafa Zone, Southern Nations Nationalities and People's Region between main cropping season (April-October) of 2017 and 2018. It is found within the Southwestern Plateau of Ethiopia and 450 and 725 km far from Addis Ababa and Hawassa, respectively. The area lies within 07°24'05.79"N latitude and 36°20'04.812"E longitude. The altitude of the study area is 1438 m.a.s.l. The topography is characterized by slopping and rugged areas having dominant Nitisol¹⁶.

Rainfall and temperature characteristics of the area: The area experiences one long rainy season, lasting from March/April-October (Fig. 1). The mean annual rainfall ranges from 1710-1892 mm. Over 85% of the total annual rainfall, with mean monthly values in the range of 125-250 mm occurs in the 8 months-long rainy seasons. The mean temperature ranges from 18.1-19.4°C¹⁷ (Fig. 2).

Treatments and experimental research design: The experiment was conducted for two consecutive (2017-2018) cropping seasons under rainfed conditions at midland agroecology to investigate the effect of different tillage practices on maize grain yield and yield components, soil moisture content and soil loss under 15-20% slope. Three farmers fields were selected based on similarity of soil type and slope. The experiment was established using a randomized. The plot size of 10×10 m was used. Four treatments: No-tillage, strip tillage, reduced tillage and conventional tillage /farmers' practice were evaluated. No-Tillage refers to disturbing soil only for placing seed and fertilizers, strip-tillage refers to tilling of only the strip that will be used as seedbeds 25 cm deep ploughed and the strip between the tilled rows are left under no-till, reduced tillage refers to tilling soil two round (more disturbance than strip tillage) and finally, conventional tillage refers to farmers practice commonly known to be three times ploughing. Plot size was 10×10 m, spacing between plots was 50 cm while the spacing between rows and plants was 75 and 25 cm, respectively. About 100 kg ha⁻¹ DAP and 50 kg ha⁻¹ urea (half

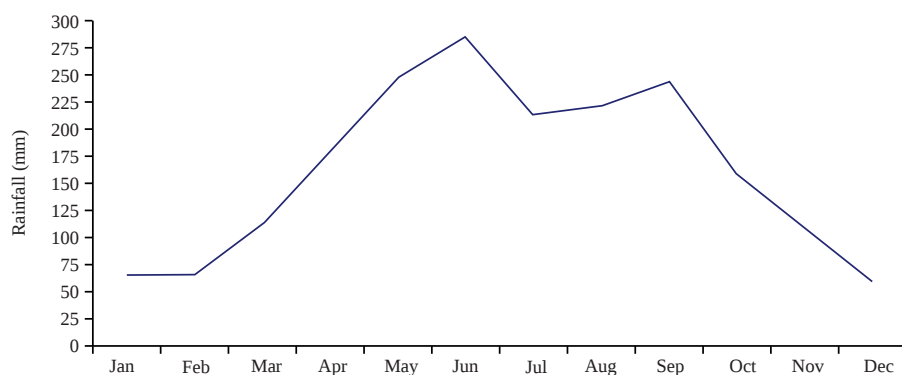


Fig. 1: Mean monthly rainfall of the area

Source: Wushwush rainfall station

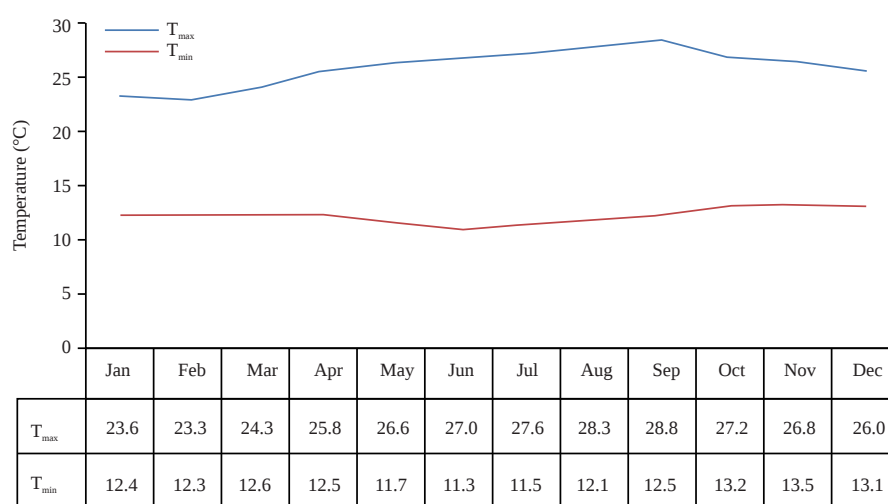


Fig. 2: Mean monthly temperature

Source: Wushwush rainfall station

split) was applied at planting and the other 50 kg ha⁻¹ urea (half split) was applied after 45 days of planting. Before sowing maize, weeds on the plot of no-tillage and strip-tillage practices were managed by application of 3 L ha⁻¹ herbicide (Glyph sate). High yielding maize variety BH540 was selected based on agro-ecology in the study area.

Data collection

Soil loss data: A catch pit having a dimension of 10 m×1 m×0.05 m was established at each plot to gather data on soil loss. During the entire growing period, sediment deposited in the catch pit was collected every week. Collected sediment was air-dried, weighed and summed up to total soil loss per plot per maize growing season. Soil moisture (soil water content) was also analyzed using gravimetric methods.

Maize grain yield and yield components: The gross plot size of 10×10 m was established and the net plot size of 8×8 m was used to collect grain yield and yield components (plant

height, biomass weight, weight of 100 seed and cob weight). The data on net plot size was interpolated to a hectare basis. Seed weight was determined by taking a random sample of hundred seeds and adjusting them to 12.5% moisture content. Total biomass yield was measured from the five middle rows when the plant reached harvest maturity.

Data analysis: Analysis of variance for all the agronomic and moisture data was performed using the GLM procedure of SAS Statistical Software Version 9.1¹⁸. Effects were considered significant in all statistical calculations if the $p \leq 0.05$. Means were separated using Fisher's Least Significant Difference (LSD) test. Economic analysis was done using partial budget analyses¹⁹. For a treatment to be considered a worthwhile option to farmers, the Minimum Acceptable Rate of Return (MARR) should be 100%, which is suggested to be realistic. This will enable to make farmer recommendations from marginal analysis.

RESULTS AND DISCUSSION

Effects of tillage on yield and yield components: A significant difference between treatments in plant height was observed (Table 1). The highest plant height was recorded in conventional tillage whereas the lowest plant height was recorded in zero tillage (Table 1). Although the yield difference was not significant between treatments, the highest grain yield was recorded in conventional tillage ($4561.33 \text{ kg ha}^{-1}$) compared to the other three treatments. Our results agree with the findings of²⁰ those who studied the effect of different tillage practices on Physical Properties of clay loam soil under Oats in Mexico where conventional tillage had got 13% higher yield than no-tillage.

The results demonstrated similar trends in the second year though variations were obtained on plant height, biomass and grain yield (Table 2). The yield difference was not significant between reduced tillage and conventional tillage however the highest grain yield was recorded in reduced tillage (4843 kg ha^{-1}) than others and the lowest in strip tillage practice ($3188.66 \text{ kg ha}^{-1}$). This finding was similar to the previous studies²¹ who applied the tillage practice on clay loam soil in Iran. According to Busari *et al.*²², a similar result was reported as conservation tillage practices have the potential for improving root penetration, minimizing erosion, enhancing water infiltration and overall yield.

The combined analysis result (Table 3) of two years showed that treatments are not significantly different for 100 seed weight, biomass and grain yield. However, conventional tillage gave a better result in terms of grain yield and biomass. The result agrees with the finding of Orfanou *et al.*²³ that conventional tillage had slightly better yield results than conservation tillage. The finding of Adugna²⁴ supports the current finding in such a way that maize grain yield under conventional tillage is higher than minimum tillage. However, the finding of Buah *et al.*²⁵ disagrees with the current result that minimum tillage overweight conventional tillage by a 68% increase of yield.

Effect of tillage on soil moisture: A significant difference in soil moisture content was not observed among treatments (Fig. 3). However, irrespective of tillage practices, higher moisture content was recorded at the flowering stage (Fig. 3). The non-existence of significant difference in moisture conservation can be due to sufficient moisture with less evaporation for growing the maize between March to September up to harvest (Fig. 2 and 3). In addition, due to the cover effect of maize during the growing season, the evaporation power is reduced resulting in less exposure of

conventional tillage plot for evaporation. Since the soil type of the study area is clay sandy loam, it may be the second reason for the problem of less yield and not significantly different moisture in treatments. Similarly, the same reason may be raised for high yield in conventional till (clayey soils need more disturbance for aeration and water flow).

Effect of tillage on soil loss: The results indicated that no-tillage contributed to the significant reduction of soil loss compared to conventional tillage in both years (Table 4). On average, no-tillage reduced soil loss by 34%, indicating that reducing soil disturbance is crucial to reducing soil loss. However, soil disturbance or conventional tillage contributed to the increase in maize yield. Thus, trade-off analyses are crucial to better agricultural productivity and natural resource management.

An economic evaluation of tillage methods: Farming practices like tillage experiments effectiveness should be evaluated in terms of short term advantages and long-term effects like reducing soil erosion, the addition of organic matter to the soil, stabilizing soil structure and porosity. However, for this study, the method of partial budget analysis which only focuses on grain yield and biomass values is considered. However, the long term advantage (value) of conservation tillage which adds value to the next cropping season than conventional is not considered due to the limitation of assumption under partial budget analysis (Table 5). Therefore it should be considered that conservation tillage has a non-valuated benefit.

The result of the economic analysis indicates that NT and RT methods are economically important as compared to strip and conventional tillage (Table 5). Because of the higher cost of investment ST and CT are out dominated by NT and RT and then removed from recommendation. However, if the preference is considered, the marginal analysis shows that farmers who can invest an additional cost of 1350 birr in RT than NT can get an additional benefit 2002 birr indicating 48% more benefit in RT than NT practice.

The marginal rate of return indicates what farmers can expect to gain on average in return for their investment when they decide to change from one practice (NT) to another (RT). In this study, adopting RT implies a 148% rate of return. As the analysis in this study is based on only four experiments in two years, the conclusions will likely be used to select promising treatments for further study, rather than for immediate farmer recommendations. From the result of economic analysis, it is observed that conventional tillage has less value than reduced tillage or minimum tillage. Farmers should be aware of

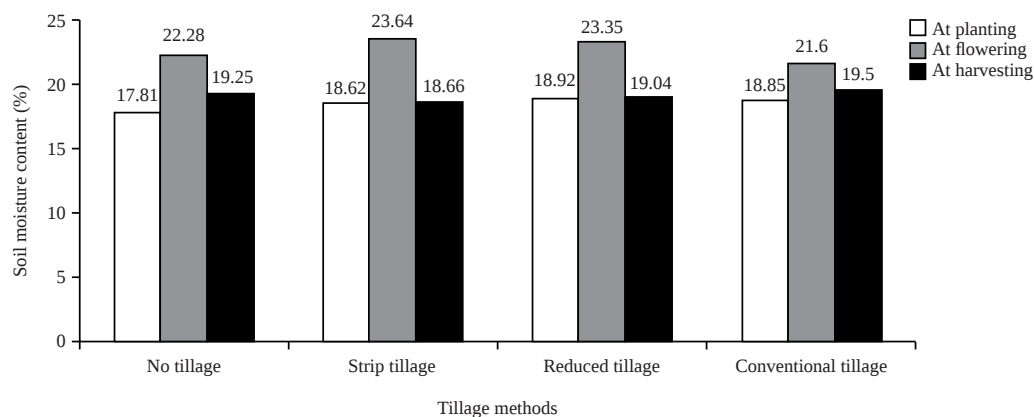


Fig. 3: Effect of tillage method on average soil moisture content

Table 1: Effects of different tillage practices on maize yield and yield components at first year

Treatments	Plant height (cm)	Cob weight (kg)	100 seed weight (gm)	Biomass weight (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
No tillage	208.40 ^c	0.26 ^a	41.51 ^a	966 ^a	3994.41 ^a
Strip tillage	217.53 ^{bc}	0.30 ^a	36.94 ^a	1166 ^a	4377.60 ^a
Reduced tillage	232.60 ^{ab}	0.30 ^a	42.10 ^a	1100 ^a	4098.46 ^a
Conventional tillage	239.33 ^a	0.31 ^a	40.06 ^a	1233 ^a	4561.33 ^a
Mean	224.46	0.29	40.15	1116	4257.95
CV (%)	3.78	16.53	8.18	25.89	11.93
LSD 0.05	15.46	0.08	5.97	526	924.81

Values with the same letters at superscript are not significantly different

Table 2: Effects of different tillage method on maize yield and yield components at second year

Treatments	Plant height (cm)	Cob weight (kg)	100 seed weight (gm)	Biomass weight (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
No tillage	204.73 ^b	0.28 ^a	40.40 ^a	1603 ^{ab}	3426.93 ^{ab}
Strip tillage	208.26 ^{ab}	0.29 ^a	38.73 ^a	1351 ^b	3188.66 ^b
Reduced tillage	226.26 ^a	0.35 ^a	41.80 ^a	2053 ^a	4843.00 ^a
Conventional tillage	229.60 ^a	0.32 ^a	42.53 ^a	2071 ^a	4594.66 ^{ab}
Mean	217.21	0.31	40.86	177	4013.31
CV (%)	5.4	11.65	8.24	19.46	19.77
LSD 0.05	21.36	0.06	6.12	626	1443.88

Values with the same letters at superscript are not significantly different

Table 3: Combined analysis result of two years for the effect of different tillage methods on maize grain yield and yield components

Treatments	Plant height (cm)	Cob weight (kg)	100 seed weight (gm)	Biomass weight (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
No tillage	206.56 ^b	0.27 ^b	40.95 ^a	1284 ^a	3710.67 ^a
Strip tillage	212.89 ^b	0.29 ^{ab}	37.83 ^a	1258 ^a	3783.13 ^a
Reduced tillage	229.43 ^a	0.32 ^a	41.95 ^a	1576 ^a	4470.73 ^a
Conventional tillage	234.46 ^a	0.31 ^{ab}	41.29 ^a	1652 ^a	4577.99 ^a
Mean	220.83	0.3	40.5	1442	4135.63
CV (%)	2.37	6.59	4.8	29.19	11.2
LSD 0.05	12.83	0.04	4.76	1030	1134.17

Values with the same letters at superscript are not significantly different

Table 4: Effect of different tillage practices on soil loss at the end of maize growing season

Treatments	One year		Two year		Two year average	
	Amount of soil loss (t ha ⁻¹)	Reduced soil loss relative to CT (%)	Amount of soil loss (t ha ⁻¹)	Reduced soil loss relative to CT (%)	Amount of soil loss (t ha ⁻¹)	Reduced soil loss relative to CT (%)
NT	2.83	54.9	14.4	27.7	8.6	34
ST	4.19	33.3	16.6	16.5	10.4	20
RT	5.12	18.5	17.3	13.1	11.2	14
CT	6.28	-	19.9	-	13.1	-

NT: No tillage, ST: Strip tillage, RT: Reduced tillage and CT: Conventional tillage

Table 5: Partial budget analysis for different tillage methods for a two-year average yield

	NT	ST	RT	CT
Average yield (kg ha ⁻¹)	3710.67	3783.13	4470.73	4577.99
Adjusted yield (kg ha ⁻¹)	3339.6	3404.82	4023.66	4120.19
Gross benefit (ETB ha ⁻¹)	16364.04	16683.62	19715.93	20188.93
Cost of herbicide (ETB ha ⁻¹)	750	750	0	0
Cost of labor to apply (ETB ha ⁻¹)	300	300	0	0
Cost of ploughing (ETB ha ⁻¹)	0	1200	2400	3600
Total cost (ETB ha ⁻¹)	1050	2250	2400	3600
Net benefit (ETB ha ⁻¹)	15314.04	14433.6D	17315.9	16588.9D
	15314.04	Not economic	17315.9	Not economic
Marginal cost from NT-RT	2400-1050 = 1350			
Marginal net benefit from NT-RT	17315.9-15314.04 = 2002			
Marginal rate of return from NT-RT	(2002 ÷ 1350) × 100 = 148%			

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, ST: Strip tillage, RT: Reduced tillage and CT: Conventional tillage

selecting economically viable and environmentally sound practices of farming. Although the yield in NT and RT practices are not significantly different from the conventional, simple economic evaluation showed better benefit from NT or RT practice. In addition, NT has a role in reducing erosion from slope land, protecting soil structure stability as well as conservation of moisture for the next season. From the farmers' perspective, the NT and RT are recommended for the areas, as farmers prefer practices with higher economic benefits. Studies that include trade off analysis are required to strengthen the findings of this research.

CONCLUSION

The results support that adopting CT can boost the yield and yield component of maize under clay loam soil but it has a less economic net benefit to farmers in short term. In addition, CT aggravates soil erosion than RT and NT practices. Since soils with clay properties cannot pass air and water, they require conventional tillage or deep ploughing. No-tillage and reduced tillage provide higher economic benefits though they did not support increased maize yield due to limited aeration for root penetration. On the contrary, the NT and RT support reducing soil loss compared to CT. Such practice should be performed with the attention so that soil property should be properly aerated to transfer water and air through it while sustaining maize yield for a future period.

SIGNIFICANCE STATEMENT

It was already known that modification of soil surface by tillage has an important contribution to increasing infiltration simultaneously increasing soil moisture distribution at the crop root system. Conventional tillage that is locally practised in the area aggravates soil erosion by making soil clots to fine

particles downslope. Previous studies in the study area, have reported the positive effect of minimum tillage on soil moisture improvement and crop yield. Minimum tillage methods, such as zero tillage, strip tillage and two times tillage have been applied to reduce soil disturbance and addition of organic matter to soil as well as reduce the cost of production. However, little attention was given to its role in controlling soil erosion from slope land. This study will help the researcher to uncover the importance of reduced tillage in soil erosion control from slope land that many researchers didn't work towards. The study also discovers the role of reduced tillage that can be beneficial for the farming community producing maize crops from slope land.

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