Evaluation of conservation agriculture for soil loss, runoff, soil property and agronomic response in Yilmana Densa, Ethiopia

Tilashwork Chanie, Miseganaw Fentahun, Mulugeta Worku, Assefa Derebe, Asmare Wubet, Tadele Amare, Chernet Birrie

Adet agricultural research center, P.O.Box 08, Bahir Dar, Ethiopia

Corrospondance email: tilashworkchanie@gmail.com

Abstract

In Ethiopian highlands including the study area, the livelihoods of an increasing human population are dependent on tillage-based soil management for intensive crop production. This farming practice combined with the dynamic climate change leads to soil degradation. This degradation eventually leads to loss of soil and water, crop productivity, and deterioration of vital soil physicochemical properties. Moreover, farmers have to face challenges such as the consumption of much time, labor, energy, agrochemicals, and other production inputs required by intensive cropping. The objective of this study was to evaluate the effects of conservation agriculture (CA) on runoff, soil loss, soil properties and crop yield. To achieve the objective, five treatments as no-tillage combined with mulching and intercropping (NT + M + In), no-tillage combined with mulching and rotation (NT + M + R), conventional tillage combined with mulching and rotation (CT + M + R), potato production as farmers practice and conventional tillage (CT) were evaluated in simple plot design. The over-year effect of treatments on runoff and soil loss was compared using analysis of variance at a 95% level of confidence. The result verified that the significant difference among treatments in reducing runoff and soil loss is mainly due to minimum soil disturbance for the case of treatments combined with no-tillage and due to ridges for the case of potato plots as compared to local practices. There is also significant runoff reduction due to mulching as

+ M + R) have a significant effect on soil and water conservation with a runoff reduced by 73, 62, 56 and 38 % and soil loss reduced by 78, 68, 63, 27 % respectively as compared to the local practices or CT. Based on the result of the study no-tillage, ridges and mulching maximize the water and soil conservation effect of CA and should be recommended as important elements and be implemented widely. Consequently, these elements help to stabilize crop yields against weather extremes since often, CA increases average yields in the long term

Keywords: conservation agriculture, mulching, ridge

Introduction

The growth of human population and climate change cause the world's agricultural systems need to produce more food through intensified farming (Page et al., 2020; Struik and Kuyper, 2017). This agricultural practice leads to declining in the quality of basic natural resources particularly soil and water, which eventually lead to loss of crop productivity and environmental risk such as on-site and off-site effects on land and also on water bodies, (Blum, 2013; Kopittke et al., 2019; Issaka and Ashraf, 2017). Moreover, farmers have to face high costs for energy, labor, agrochemicals, and other production inputs required by intensive cropping.

This needs to adopt more sustainable and cost-effective agricultural practices by considering the relationship between natural resources and community lifestyle (Gomiero, 2016). Most of the above challenges could be tackled through conservation agriculture (CA) for all farmers and rural communities that depend on the agri-environment in the area such as Ethiopian highlands including Yilmana Densa (González-Sánchez et al., 2016). Araya et al. (2011) stated that CA aims to improve soil quality and crop yield whilst reducing runoff and soil erosion. Rusinamhodzi et al. (2011) also mentioned that CA includes important elements such as reduced tillage, permanent soil cover and crop rotations to optimise food supply through improving soil fertility and reducing soil loss and runoff. Due to mulching CA provides a protective blanket of leaves, stems and stalks. Consequently, it enhances soil productivity by improving its physicochemical properties through soil and water conservation and improving soil OM, the population of micro-organisms (which take over the function of traditional tillage such as loosening of the soil and mixing the soil components), humus formation (Fuhrer and Chervet, 2015; Shokati and Ahangar, 2014; Amini and Asoodar, 2015; Khursheed et al., 2019).

Moreover, CA saves energy such as fuel for machines and calories for humans and animals and time required for cultivation. For instance, Wijewardene (1979) found that no-tillage required 52 MJ of energy and 2.3 hours of labour per hectare whereas conventional tillage needed 235 MJ and 5.4 hours to cultivate the same area of land. Therefore, it is very crucial to test and amend alternatives to existing technologies for their effectiveness on soil and water conservation and ease of use by the farmers, i.e., to improve soil productivity in representative areas of the Amhara region.

Materials and methods

The study was conducted during 2016-2020 cropping seasons at Adet agricultural research center on the station and during 2018-2020 at Debre Mawi watershed in Yilmana Densa district of Amhara region which is one of the soil erosion-prone areas of the region. For this experiment, five treatments with a simple plot design were set. Although crop rotations were not used as a treatment, we used maize and faba bean crops as a rotation which has also the benefit to control pests and diseases by breaking their cycles. Besides, faba bean is a legume crop that can fertilize the soil when used for crop rotation. To achieve soil cover, 30% of the crop stand (residue) was retained after harvest.

From the total treatments implemented in the simple plot design, the first treatment was potato planting as a farmers' practice where the ridge and early land cover are expected as functioning as soil and water conservation practice as compared to faba bean and maize prlanting as a farmers' practice; the other four treatments were no-tillage (NT) combined with 30% stubble retention or mulching (M) and intercropping(In), NT combined with M and rotation (R), conventional tillage (CT) combined with M and R, and farmers practice (CT) as mentioned in Table 1. During this experiment, the management of land in CA included no tillage leaving crop stubbles in the field and zero grazing. Other agronomic practices and fertilizations were the same for all plots, and the crop rotation was cereal by legume (pulse crops), i. e., maize and fababea except for the potato plot. Potato has different fertilizer and agronomic practices requirements.

Table 42. Experimental design and treatments description

Treatment		Description
T_1:	Potato	Conventional tillage
T_2:	NT + M + In	No tillage + Mulching (30%) + Intercropping
T_3:	NT + M + R	No tillage + Mulching (30%) + Rotation
T_4:	CT + M + R	Conventional tillage + Mulching (30%) + Rotation
T_5:	CT	Farmers' practice (conventional tillage)

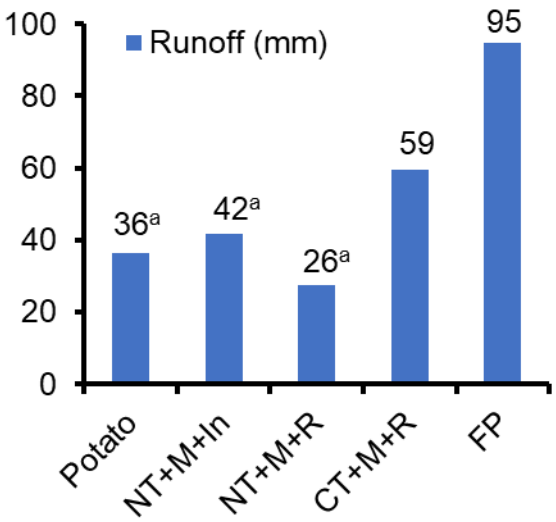
*****Plot size: **10** m x 10 m (Adet on station); 5 m x 22 m at Debre Mawi

*****Design: simple plot design

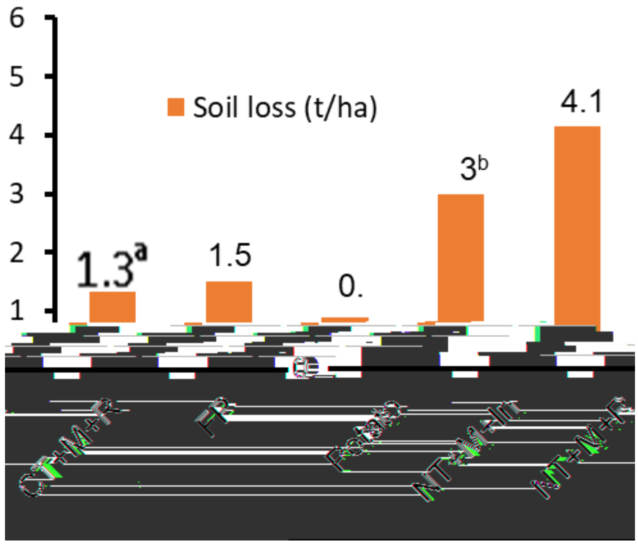
Regarding data collection, runoff and sediment were harvested using rectangular tanks which were installed at the end of each experimental plot; these data were recorded in every 24 hours of the day; then sediment data were oven-dried. Besides, crop agronomic data particularly grain yield (i.e., very important component of crop performance) and soil samples at 0-20cm soil depth (for pH, organic matter, bulk density and soil moisture analysis) were collected. Finally, the effects of treatments were compared, using analysis of variance and graphical presentation.

Results and discussion

The CA practices and conventional potato production were implemented for five and three cropping seasons at Adet on station and Debre Mawi watershed respectively. Except for the fixed potato plot, the other four plots were planted with maize and faba bean test crops in rotation. Runoff and soil loss showed responses to some treatments implemented during these years. It is confirmed that the first three treatments (Figure 1, 2) particularly treatments with no-tillage and potato plots are effective to reduce runoff and soil loss significantly as compared to farmers' practice. The conventional tillage combined with mulching and rotation is also better in runoff reduction than farmers' practice due to the mulching effect (Figure 1). Such effectiveness of CA on runoff and soil loss reduction is supported by different studies such as Ghosh et al. (2015) and Araya et al. (2011). This effect is primarily due to no-tillage that leaves the soil undisturbed (Khursheed et al., 2019; Seitz et al., 2019). It is also confirmed that mulching reduces runoff and soil loss by enhancing infiltration of rainfall with an efficient mulch application found to be 0.25–0.50 kg/m^2 (Adekalu, et al., 2007; Mannering and Meyer, 1963; Kavian, et al., 2020; Wang et al., 2021).



* CV (%): 38.6; LSD (5%): 26.9



* CV (%): 46.4; LSD (5%): 1.3

Figure 25. Effect of CA practices on 2016 to 2020 average runoff and soil loss at Adet on station

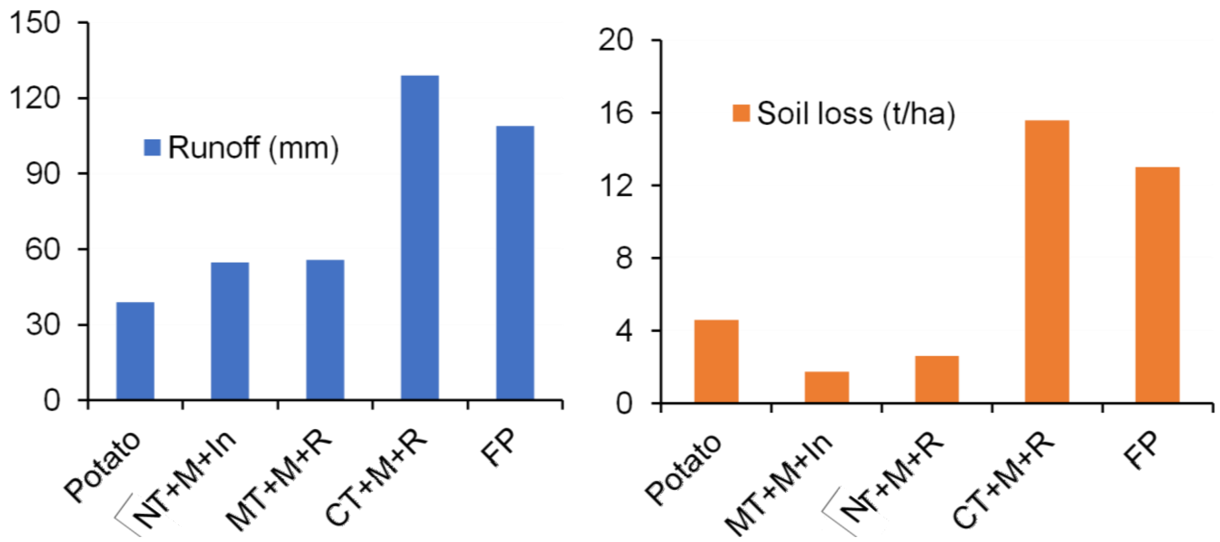


Figure 26. Effect of CA practices on 2018 to 2020 average runoff and soil loss at Debre Mawi watershed

Unlike runoff and soil loss, a significant difference was not observed in crop yield in this a short-term study. However, NT+M+R and CT+M+R show some maize and faba bean yield advantages as compared to farmers' practices. As compared to local practices, NT+M+R improves maize yield by 1.4 and 0.3 t/ha at Adet and Debre Mawi respectively (Figure 3-4 A) and faba bean yield by 0.6 ton/ha both at Adet and Debre Mawi (Figure 3-4 B). Whereas CT+M+R improves maize yield by 2 and 0.7 ton/ha at Adet and Debre Mawi respectively (Figure 3-4 A), and faba bean yield by 0.6 and 0.1 ton/ha at Adet and Debre Mawi (Figure 3-4 B). In this study, the farmer's practice was better than one of the CA practices (i.e., NT+M+IN) in maize and faba bean yield except in maize yield at Adet.

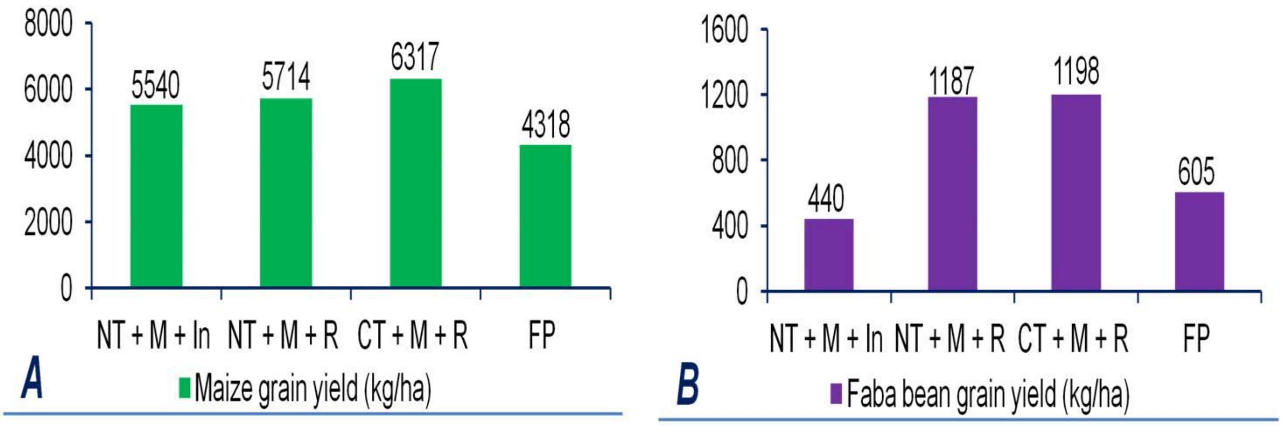


Figure 27. Average grain yield at Adet; A: Maize grain yield in kg/ha during 2017 and 2019; B: Faba bean during 2018 and 2020

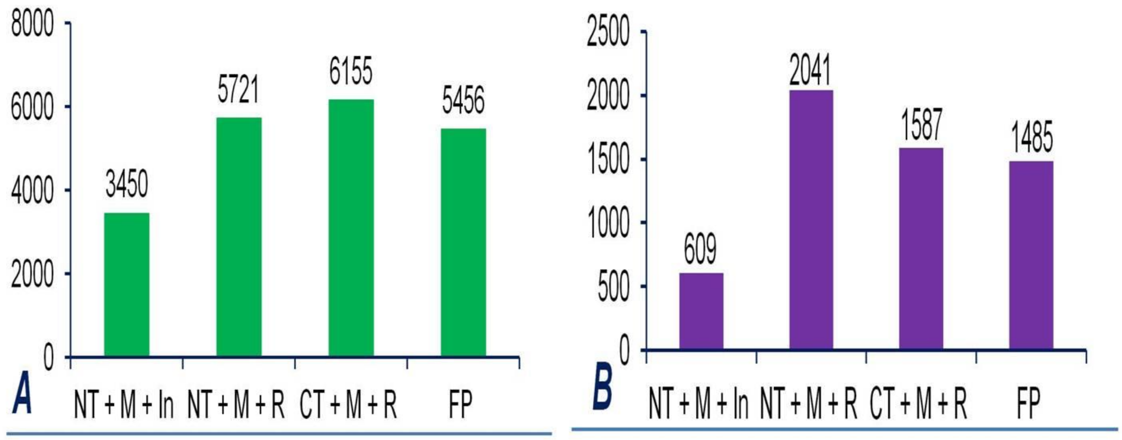


Figure 28. Average grain yield at Debre Mawi; A: Maize grain yield in kg/ha in 2019; B: Faba bean during 2018 and 2020

Similar to crop yield there was no significant difference in soil parameters including pH, organic matter (OM) and bulk density (Table 2).

Table 43. Soil chemical and physical properties (2018-2020 average values)

Treatment	**pH (Adet)**	**%OM (Adet)**	**Bulk density, g cm^{-3} (Adet)**
Potato	5.2	2.5	1.19
NT + M + In	5.5	3.0	1.30
NT + M + R	5.5	2.8	1.35
CT + M + R	5.4	2.6	1.27
FP	5.4	2.4	1.25
Treatment	pH (Debre Mawi)	%OM (Debre Mawi)	Bulk density, g cm^{-3} (Debre Mawi)
Potato	5.5	2.0	1.31
NT + M + In	5.5	2.0	1.27
NT + M + R	5.6	2.2	1.20
CT + M + R	5.6	2.0	1.27
CT	5.7	2.4	1.31

Conclusion and recommendation

This study confirms that conservation agriculture especially with an element of no-tillage is effective land management practice for a short period to reduce runoff and soil loss, in water-induced soil erosion-prone areas such as in Yilmana Densa district and other similar regions of the world. Rearding potato conventional farming treatment, the reasearch confirmed that in soil erosion-prone areas where potato, maize and faba bean are major crops, potato conventional production is preferable instead of maize ana faba bean conventional production to minimize runoff and soil loss. .Therefore these practices are recommended to be used by smallholder farmers to enhance soil and water conservation where soil erosion by water is severe. However, a long-term observation is important to determine the effect of other CA practices on soil properties and grain yield.

References

Adekalu, K. O., Olorunfemi, I. A. and J.A.Osunbitan,J. A. 2007. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. *Bioresource Technology*, 98, 4, pp. 912-917.

Amini, S. and Asoodar, M. A. 2015. Investigation the effect of conservation tillage on soil organic matter (SOM) and soil organic carbon (SOC) (the review). *New York science journal*, 8(3): 16-24.

Araya, T., Cornelis, W. M., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D., Sayre, K. D., Haile, M. and Deckers, J. 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use and Management, September 2011, 27, 404–414, doi: 10.1111/j.1475-2743.2011.00347.x.

Blum, W. E. H. 2013. Soil and land resources for agricultural production: General trends and future scenarios-A worldwide perspective. *International Soil and Water Conservation Research*, Vol.1, No.3, pp.1-14.

Fuhrer, J and Chervet, A. 2015. No-tillage: long-term benefits for yield stability in a more variable climate? *Procedia environmental sciences*, 29: 194 – 195.

Ghosh, B. N., Dogra, P., Sharma, N. K., Bhattacharyya, R. and Mishra, P. K. 2015. Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas. International *SoilandWater Conservation Research*, 3(2015)112–118.

Gomiero, T. 2016. Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. *Sustainability*, 8, 281; doi:10.3390/su8030281.

González-Sánchez, E. J., Kassam, A. Basch, G. Streit, B., Holgado-Cabrera, A. and Triviño-Tarradas, P. 2016. Conservation Agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe. *AIMS Agriculture and Food*, 1(4): 387-408, DOI: 10.3934/agrfood.2016.4.387.

Issaka, S. and Ashraf, M. A. 2017. Impact of soil erosion and degradation on water quality: a review. *Geology, Ecology, and Landscapes,* 1:1, 1-11, DOI:10.1080/24749508.2017.1301053.

Kavian, A., Kalehhouei, M., Gholami,L., Jafarian, Z., Mohammadi, M. and Rodrigo-Comino, J. 2020. The Use of Straw Mulches to Mitigate Soil Erosion under Di_erent Antecedent Soil Moistures. *Water* **2020**, 12, 2518; doi:10.3390/w12092518.

Khursheed, S., Simmons, C., Wani, S. A., Tahir Ali, T., Raina, S. K and Najar, G. R. 2019. Conservation tillage: impacts on soil physical conditions–an overview. *Adv Plants Agric Res.* 2019;9(2):342–346.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna. B. A. and Lombi, E. 2019. Soil and the intensification of agriculture for global food security. *Environment International*, 132 (2019) 10507.

Mannering, J. V. and Meyer, L.D. 1963. The Effects of Various Rates of Surface Mulch on Infiltration and Erosion. *Soil science society America journal*, 27, 1, 84-86.

Page, K. L., Dang, Y. P. and Dalal, R. C. 2020. The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Front. Sustain. Food Syst. 4:31.doi: 10.3389/fsufs.2020.00031*.

Rusinamhodzi, L., Corbeels, M., van Wijk, M. T., Rufino, M. C., Nyamangara, J. and Giller, K. E. 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy Sust. Developm*. DOI 10.1007/s13593-011-0040-2.

Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., van der Heijden, M. G. A. and Scholten, T. 2019. Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development* (2019) 39: 4. https://doi.org/10.1007/s13593-018-0545-z.

Shokati, B. and Ahangar, A. G. 2014. Effect of conservation tillage on soil fertility factors: A review. *International journal of biosciences*, 4(11):149-156.

Struik, P. C. and Kuyper, T. W. 2017. Sustainable intensification in agriculture: the richer shade of green. A review. Agron. *Sustain. Dev*., (2017) 37: 39. DOI 10.1007/s13593-017-0445-7.

Wang, B., Niu, J., Berndtsson, R., Zhang, L., Chen,X., Li, X. and Zhu, Z. 2021. Efficient organic mulch thickness for soil and water conservation in urban areas. www.nature.com/scientificreports.

Wijewardene, R. 1979. Systems and energy in tropical small holder farming. In Proc. Appropriate tillage workshop (pp. 73-86). Zaria, Nigeria: IAR.