Evaluation of Conservation Agriculture for Sustainable Sorghum Production in the Lowland Area of North Shewa, Central Ethiopia

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Abstract

In Ethiopia, 85% of the land surface is prone to soil erosion. Furthermore, complete crop residue removal at harvest, livestock overgrazing in the aftermath, frequent tillage, drought, and poor use of technology and practices are the main causes of dryland agricultural degradation. As important technology conservation agriculture has been revealed to be a sustainable way to intensify crop production and sustain rural livelihoods. The experiment was carried out in a rain-fed field using a permanent fixed site for 3 years (2017–2019) at Efratana gidim wereda, in order to evaluate the effect of CA for sustainable production of sorghum. Four treatments were evaluated: (1) No-tillage (NT) that is the preparation of slot for drilling of seed at sowing, (2) Conventional tillage (Mockus) which is three tillage operations and removal of crop residues, (3) No-tillage with residue retention (NT+R) which is 30% residue retention on the filed during harvest and (4) Conventional tillage and residue incorporation (CT+R) that was similar to conventional tillage except 30% residue incorporated during tillage. The result of the combined analysis of the two sorghum production years confirmed that the conventional tillage with 30% residue retention could marginally give a statistically greater (p<0.05) yield. Even though it is not statistically different (P<0.05), the yield of mung bean was also numerically higher in no-tillage with 30% stubble retention. The crop yield analysis confirmed that the conventional tillage with 30% residue incorporation could give 3.94 % and 27.49% sorghum and mung bean yield advantage respectively compared to the conventional tillage. The soil analysis implied that no-tillage with 30% residue retention could improve all soil physical and chemical properties. The no-tillage with 30% residue retention could improve exchangeable potassium, available phosphorous, soil organic carbon, and soil nitrogen with 2.3%, 4%, 4%, and 13.1% respectively when compared to conventional tillage. The total nitrogen also improved with 12% in conventional tillage with 30% residue incorporation. The soil was improved in no-tillage with residue retention but the crop yield was statistically dominated by conventional tillage and residue incorporation so, it is better to conduct the experiment for a long season in the appropriate site.

Keywords: *No-tillage, Residue, Rainfed, Mung bean*

Introduction

Land degradation is directly linked to climate-related hazards and food poverty in Ethiopia, where roughly 85 percent of the land surface is prone to moderate to severe soil degradation and erosion(Taddese, 2001). Furthermore, comprehensive crop residue removal at harvest, livestock overgrazing in the aftermath, frequent tillage, drought, and poor use of technology and practices are the main causes of dryland agricultural degradation in Ethiopia*(Assefa et al.*, 2015).

As an important technology conservation agriculture showed potential benefits for both high rainfall areas and low rainfall areas (Mkoga, Tumbo, Kihupi, & Semoka, 2010).Conservation agriculture (CA) has been revealed to be a sustainable way to intensify crop production and sustain rural livelihoods in several African countries. Conservation agriculture is mainly used to keep the soil covered (>30% residue), to have minimal soil disturbance, and to mix and rotate crops as well (Ashburner, Friedrich, & Benites, 2002). Usually, the retention of 30% surface cover by residues characterizes the lower limit of

surface raises the organic matter content of the soil, improving fertility, reducing the amount of CO_2 that is produced as a result of residue burning, and protects the soil from erosion. Different research result state that the major reasons for the increase in yields are better moisture availability, improved soil fertility, and better root growth as a result of conservation tillage application (Temesgen, Rockstrom, Savenije, Hoogmoed, & Alemu, 2008).

Further, crop residues also conserve water by reducing runoff and evaporation which is paramount for economic crop production in the drylands of semi-arid tropics. Tillage takes valuable time that could be used for other useful farming activities or employment.

To improve the productivity of the sorghum the farmer disturbs their land 3-5 times per season by tillage for growing sorghum with a continuous mono-cropping system under rainfed farming system. The area is also familiar to free grazing in cropland after harvesting of the main crop; this causes erosion, compaction, low infiltration, low organic matter content, low fertility, and finally low productive performance. Sorghum is the most important cereal crop in the low land areas of North Shewa due to its high nutritional value

,tolerance to moisture stress and productivity habit on a marginal land with low soil fertility(Prasad & Staggenborg, 2009). The time required for tillage can also delay the timely planting of crops, with subsequent reductions in yield potential (Hobbs & Gupta, 2003). Similarly in the study area; due to delays in plantation and the shortage of rainfall at the end of summer the crop mostly faces moisture stress and finally it lost productivity. So, this study was carried out to evaluate the effects of conservation agriculture for sustainable sorghum production in rainfed farming area.

Materials and Methods

Description of the Study Area

The field experiment was conducted in Efratna gidim wereda at Yimlowa farmers training center from 2017 to 2019 during main cropping seasons (July to September). The capital of Efratna gidim, Ataye is located 290 kilometers from Addis Abeba at the northeastern part of the country between 10^0 ^{0}
m.a.s.l. Efratana Gidim is bordered on the south by Kewet, on the southwest by Menz Mam Midir, on the west by Menz Gera Midir, on the north by Antsokiyana Gemza, and on the east by the Oromia Zone. The area has an average annual rainfall of 1085 mm and annual mean minimum and maximum temperatures of 15.18°C and 32.95°C, respectively. Sorghum and Teff are the major cereal crops grown in Efratana gidim. Ploughing frequency in Efratana Gidim depends on crop type, usually three times for Mung bean; three to five times for sorghum (Sorghum bicolor L.) and four to six times for teff (Eragrostis tef). Repeated ploughing is expected to use as control of weeds and aeration of soil particles. The time of ploughing depends on the availability of oxen, type of crop, and rainfall.

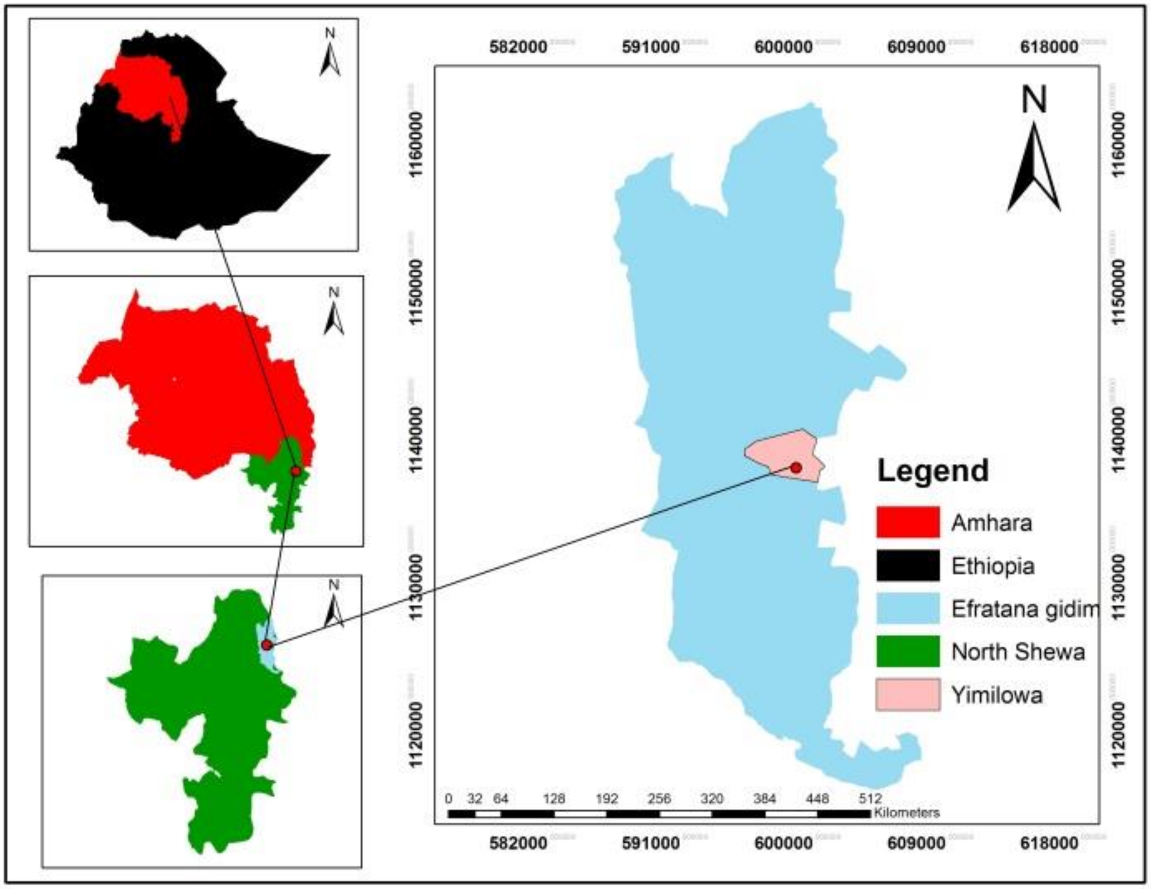

Figure1. Location map of the study area

Experimental Procedures: The experimental layout was a randomized complete block design (RCBD) with three replications. The plot size was 4.5m by 8m with a slope gradient of 3%. Sorghum seeds were sown after enough moisture was existed in the soil mostly at the start of July at Efratana gidim. Seeds were sown by hand drilling, seeds with 25 cm intra-row and 75 cm inter-row spacing. For rotation after growing sorghum in the second production season (year) Mung bean seeds were sown at the end of July with a 25 kgha-1 seed rate. Plants were hand weeded and cultivated once a year because of the rain-fed character of the area.

Treatments and Experimental Design: Two field operational management practices (No-tillage and conventional tillage) were used as treatments. No-tillage; No-tillage with 30% residue retention; conventional tillage with 30% residue incorporation; conventional tillage (control) were the treatments that were used for this experiment. No-tillage in this experiment means only sowing of the crop with a small slot prepared by hoeing material.

Residue retention in this experiment means retaining 30% of the stalk by cutting at 30% height of the crop during harvesting. Residue incorporation in this experiment means incorporating 30% stalk during the first plowing. Conventional tillage in this experiment means that the local practice applied by sorghum cultivars which means 3-5 times plowing of farmland.

Data Collection: The crop data such as plant height (cm), head height (cm), number of pods per plant were recorded from 10 randomly taken plants and the averages were calculated. The yield of sorghum and Mung bean (kg) were recorded and adjusted with 12.5% and 10% seed moisture content respectively. The grain yields of both crops were converted to ton per hectare (ton/ha). Soil samples before sowing of the test crop and after harvesting of the test crop were collected for the analysis of selected soil chemical properties. Bulk density and soil moisture content data were also analyzed at different times of experimentation.

Data Analysis: ANOVA was used to test for statistical differences in crop parameters between the management treatments. All the data were subjected to analysis of variance using R software version 3.6.1 to determine treatment effects. Wherever the difference among treatment means was compared using the Fisher's least significant difference test at 5% ($P<0.05$) level of significance.

Results and Discussion

Effects of Conservation Agriculture on Yield and Yield Components

In the first year of experimentation (2017/18) there was no significance difference between the treatments (NT, NT+R, CT+R and CT) related to yield parameter. This agrees with the previous researches reported no yield benefit of Conservation agriculture over conventional tillage in the initial year (Thierfelder, Mombeyarara, Mango, & Rusinamhodzi, 2013). Research carried out for three seasons by; Naab, Mahama, Yahaya, & Prasad, (2017) reported no significant difference between Conservation agriculture and Conventional tillage in maize grain yield. The 2019/20 and the combined crop parameters were significantly lower in no-tillage and no-tillage with residue retention compared to conventional tillage and conventional tillage with 30% residue incorporation as shown (Table 1). This may be due to the high weed infestation that occurred in the no-tillage treatments. Greater weed densities in no-till treatments were found throughout the whole season. In this research no-tillage treatments result in lower sorghum yields when compared to the conventional tillage and conventional tillage with residue incorporation. Since our research was a three-years trial, it is necessary to develop optimal weed control options for no-tillage practices. We also observed that there was immediate growing of tillers around the nodes of the stubble of sorghum especially in the no-tillage with residue retention. This is the result of the rainfall immediately after harvest and the irrigation scheme in the above side of the experimental site. Due to this, the retained crop residues could not be dried and decomposed within short time. This finally leads to need more time for decomposition residue.

Table1. Effects of different farming practices on grain, biomass, and plant height of sorghum in 2017/8 and 2019/20 cropping seasons

	The combined result of 2017/8 &2019/20			2019/20 cropping season			2017/8 cropping season		
Treatment	Grain yield (kgha-1)	Biomass (kgha-1)	Plant height	Grain yield (kgha-1)	Biomass (kgha-1)	Plant height	Grain yield (kgha-1)	Biomass (kgha-1)	Plant height
NT	3968.8c	17042bc	192.6	4201.4b	17812.5b	182.4	3736.1	16271.5	202.7ab
CT	4441.7ab	19416.2a	196.1	5288.9a	22559.7a	195.4	3594.4	16272.6	196.7b
NT+R	4083bc	15521.1c	195.3	4213.9b	16857.6b	183.6	3952.1	14184.6	207a
CT+R	4616.7a	18556.2ab	197.9	5483.3a	23572.9a	193.6	3750	13539.4	202.2ab
Mean	4277.5	17633.8	195.5	4796.9	20200.7	188.7	3758.2	15067	202.2
CV(%)	7.8	7.94	4.5	4.63	3.82	4.75	5.64	9.13	2.31
LSD(0.05)	444.1	1733.9	ns	444	1541.7	ns	ns	ns	9.36

As we can look in (**Table 2**) the result of Mung bean revealed that there was no statistical variation generated between treatments in all parameters (grain yield, straw yield; plant height, and pod length). Even though it was not statistically significant ($P<0.05$) the experimental result implies the conventional tillage with residue incorporation could result in numerically better grain and straw yield. The vegetative performance of the Mung bean was also better in conventional tillage with residue incorporation than the other treatments.

Table 2. Effects of farming systems on grain, straw, and vegetative parameters of Mung bean in 2018/9 cropping seasons

Treatments	Grain yield (kgha-1)	Straw yield (kgha-1)	Plant height(cm)	Pod length (cm)
NT	740.2	2016	50.6	10.9
CT	1002.2	2111.7	55.2	10.8
NT+R	1024	2018	54.6	11
CT+R	1277.8	2563.4	56.6	11.1
CV (%)	20.2	37.8	7.4	7.4
LSD (0.05)	ns	ns	ns	ns

Effects of Conservation Agriculture on Soil Physio-Chemical Properties

From the result (Table 3), we can conclude that no-tillage with residue retention could preferably improve all soil chemical properties. Even though the result of electrical conductivity (E.C ds/m) was dropped under a similar range that is normal and free from salinity problems, higher EC potential observed under the no-tillage and residue retention treatment. This result comes from CA practice, which have the ability to adjust the EC of the soil by increasing the EC of the soil that is initially high and decreasing that is initially high(Husson et al., 2018). The exchangeable potassium increased with 2.3% in no-tillage and residue retention compared to the conventional tillage. Similarly, the other studies revealed that the level of extractable K increases at the soil surface with no-tillage as tillage intensity decrease and residue retention increase (Govaerts, Sayre, Lichter, Dendooven, & Deckers, 2007; Ismail, Blevins, & Frye, 1994). The soil available P was improved by 4% on the treatments having residue retention than the control. This is due to the large phosphorus addition from the decomposition of residues retained on the surface since the available P generally has a direct relation with the surface placement of crop residues that leads to the accumulation of SOC and microbial biomass near the surface. Moreover, the shallower incorporation of crop residues and fertilizer P as well as small P losses due to water erosion under conservation agriculture leads to higher P contents in the surface soil.

(Piegholdt, Geisseler, Koch, & Ludwig, 2013) also reported a 15% higher total P content in the topsoil (0-5 cm) of Zero tillage plots as compared to conventional tillage due to larger P addition from the decomposition of residues retained on the soil surface.

SOC is also improved by 4% which was being the keystone to soil quality as reported to an important indicator of agricultural sustainability. The loss of SOC can be minimized through long-term adoption of conservation agricultural practices that reduce its oxidation by causing less mixing of the soil. Another reason for the accumulation of SOC under no-tillage with residue retention is expected to be the presence of crop residue which protects the soil from erosion. Similar studies on comparative analysis of SOC under different medium and long term studies revealed that Zero tillage accounted for higher SOC in the tune of 3.86-31.0% over conventional tillage (Balota, Colozzi Filho, Andrade, & Dick, 2004; Govaerts et al., 2009). Many researchers also suggested that to achieve the beneficial effect of Zero tillage in terms of higher SOC, its long-term implementation is essential. Usually, a SOC change is directly proportional to the amount of crop residues returned to the soil.

The available soil nitrogen was improved by 13.1% in no-tillage with residue retention compared to the conventional tillage. Comparably soil nitrogen was increased by 12% in conventional tillage with residue incorporation compared to the conventional tillage. The improvement of soil nitrogen has a direct relation with the availability of retained and incorporated residue(Dou, Wright, & Hons, 2008). This implied that the retention and incorporation of crop residues could improve soil nitrogen and reducing nutrient loss through acting as protective layers and facilitating microbial activities in the soil. Solar heat and rainfall are the main causes of nutrient loss through volatilization and erosion so the incorporated and retained residue could also minimize the impacts of those events.

Table 3. The effects of conservation agriculture on soil chemical properties

Treatment	E.C (dS/m)	Exchangeable k(cmol(+)/kg of soil	PH (1:2.5)	Available. P (ppm)	SOC (%)	SOM (%)	Total N (%)
NT	0.106	3.316	7.3	32.2	1.836	3.167	0.149
CT	0.119	3.378	7.2	34.8	1.822	3.143	0.149
NT+R	0.142	3.456	7.2	36.2	1.895	3.269	0.168
CT+R	0.117	3.384	7.2	34.8	1.828	3.154	0.166

During the experimentation, there was no shortage of rainfall or moisture in the study area. Due to this, we could not catch the effects of conservation agriculture on moisture as visually on the crop stands and crop yield similarly. However, based on the soil sample analysis we could see that no-tillage with residue retention (NT+R) and conventional tillage with residue incorporation (CT+R) can hold better moisture than the remaining farming systems as shown (Figure 2). Zero tillage systems that maintain residue retention over soil surface resulted in a significant change in soil physical environment, especially in upper few centimeters of the soil (20 cm).

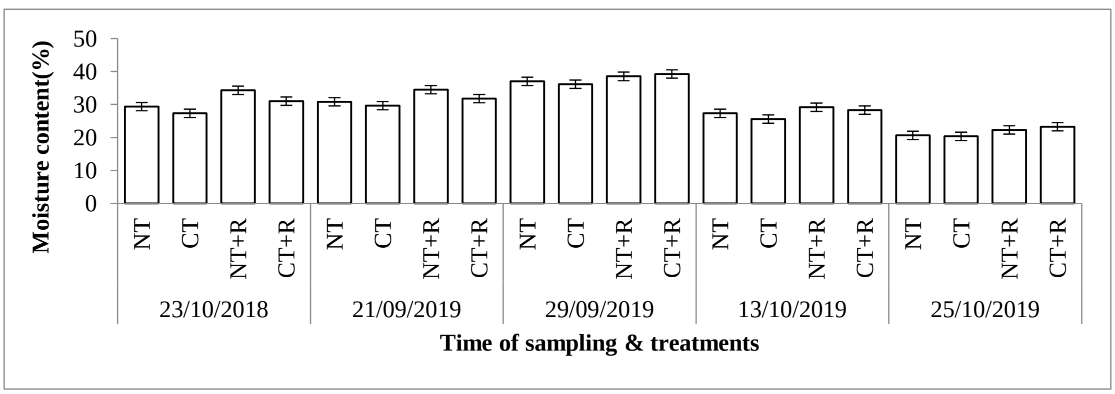

Figure 2. Effects of different farming systems on soil moisture content in different sampling time.

The result of the analysis of bulk density (g/cm^3) is stated that conventional tillage with residue incorporation (CT+R) could minimize surface compaction and bulk density than other treatments to a small extent. This is expected to be the fact that the incorporated crop residue can amend the soil organic carbon. The beneficial effect of CA in terms of better soil quality is reflected through improvement in physical soil properties like lower bulk density(Kay & VandenBygaart, 2002), higher aggregate stability, enhanced water holding capacity, and better soil structure and this is in agreement with (Yadav et al., 2017). Reduction in intensity of tillage operations through the adoption of CA practices would be expected to result in a progressive reduction in soil compaction over time (Kay & VandenBygaart, 2002). The higher SOC and differential chemical composition of crop residues and root biomass bring out differential addition of SOC that may also lead to a difference in soil Bulk density.

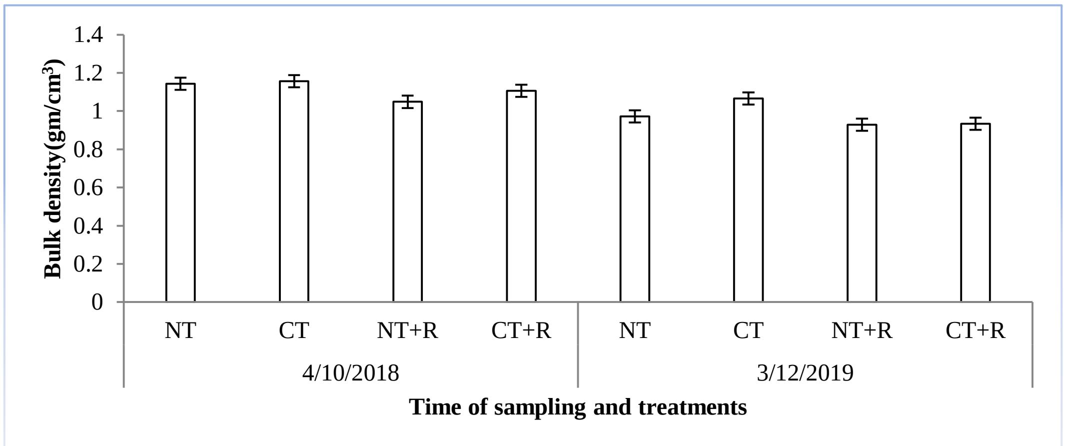

Figure 3. The effects of different tillage system on soil bulk density (g/cm^3)

Conclusion

This research found that conventional tillage with 30% crop residue retention can boost sorghum and mung bean grain and straw yields. In the sorghum growing seasons studied, conventional tillage with 30% residue retention resulted in a statistically significant (P0.05) increase in yield. The results of the soil properties experiment demonstrated that no-tillage with 30% residue retention improved all physical and chemical qualities more than the other treatments. Some soil characteristics, particularly exchangeable potassium and total nitrogen, could be improved by conventional tillage with 30% residue incorporation. The aggregate stability, mulching impact, and hydrological benefits of stubble all contribute to the enhancement. Crop yield, on the other hand, differed depending on treatment and crop type. In lowland areas, weed control should be given special care while cultivating any crop with no-tillage systems. In addition to the high weed density, the retained stubble re-grows many tillers around the nodes, causing plant nutrients to be scrambled all through the offseason. In general, the results of this experiment demonstrate that conservation agricultural experiments have a good influence; nonetheless, it is preferable to conduct conservation agricultural experiments in a larger plot over a longer period of time to validate their benefit.

References

Ashburner, J., Friedrich, T., & Benites, J. (2002). Opportunities and constraints for conservation agriculture in Africa. LEISA-LEUSDEN-, 18, 13-14.

Assefa, W., Niguse, H., Teklay, A., Kiros, M., Adhena, M., & Tsehaye, B. (2015). Evaluation of conservation farming: implications for food security and climate change mitigation options in the moisture deficit areas of south Tigray, Ethiopia. American-Eurasian Journal of Scientific Research, 10(3), 134-140.

Balota, E. L., Colozzi Filho, A., Andrade, D. S., & Dick, R. P. (2004). Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol. Soil and Tillage Research, 77(2), 137-145.

and plant analysis, 39(5-6), 667-679.

Govaerts, B., Sayre, K., Lichter, K., Dendooven, L., & Deckers, J. (2007). Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. Plant and Soil, 291(1), 39-54.

Govaerts, B., Sayre, K. D., Goudeseune, B., De Corte, P., Lichter, K., Dendooven, L., & Deckers, J. (2009). Conservation agriculture as a sustainable option for the central Mexican highlands. Soil and Tillage Research, 103(2), 222-230.

Hobbs, P. R., & Gupta, R. K. (200

Rice

Systems: Issues and Impacts, 65, 149-171.

Husson, O., Brunet, A., Babre, D., Charpentier, H., Durand, M., & Sarthou, J.-P. (2018). Conservation agriculture systems alter the electrical characteristics (Eh, pH and EC) of four soil types in France. Soil and Tillage Research, 176, 57-68.

and continuous corn yields. Soil Science Society of America Journal, 58(1), 193-198.

Kay, B., & VandenBygaart, A. (2002). Conservation tillage and depth stratification of porosity and soil organic matter. Soil and Tillage Research, 66(2), 107-118.

Mkoga, Z., Tumbo, S., Kihupi, N., & Semoka, J. (2010). Extrapolating effects of conservation tillage on yield, soil moisture and dry spell mitigation using simulation modelling. Physics and Chemistry of the Earth, Parts A/B/C, 35(13-14), 686-698.

Mockus, V. (1964). National engineering handbook. US Soil Conservation Service: Washington, DC, USA, 4.

Naab, J. B., Mahama, G. Y., Yahaya, I., & Prasad, P. (2017). Conservation agriculture improves soil quality, crop yield, and incomes of smallholder farmers in North Western Ghana. Frontiers in plant science, 8, 996.

the distribution of phosphorus fractions of loess soils in Germany. Journal of Plant Nutrition and Soil Science, 176(2), 217-226.

Prasad, P. V., & Staggenborg, S. A. (2009). Growth and production of sorghum and millets. Soils, plant growth and crop production, 2.

Taddese, G. (2001). Land degradation: a challenge to Ethiopia. Environmental management, 27(6), 815-824.

Temesgen, M., Rockstrom, J., Savenije, H., Hoogmoed, W., & Alemu, D. (2008). Determinants of tillage frequency among smallholder farmers in two semi-arid areas in Ethiopia. Physics and chemistry of the earth, parts A/B/C, 33(1-2), 183-191.

Thierfelder, C., Mombeyarara, T., Mango, N., & Rusinamhodzi, L. (2013). Integration of conservation agriculture in smallholder farming systems of southern Africa: identification of key entry points. International Journal of Agricultural Sustainability, 11(4), 317-330. doi:10.1080/14735903.2013.764222

Yadav, M., Parihar, C., Kumar, R., Yadav, R., Jat, S., Singh, A., . . . Meena, V. (2017). Conservation Agriculture and Soil Quality An Overview. Int. J. Curr. Microbiol. Appl. Sci, 6, 1-28.