Comparative evaluation of conservation agriculture and other management practices to improve the productivity of Vertisols in the Amhara region

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Abstract

The vast potential of Vertisols in the study area is underutilized due to excess soil water content. Conservation agriculture integrated with Vertisols drainage have a pronounced positive role to improve crop yield under high rainfall areas. This study aimed to evaluate the effects of conservation agriculture (CA) and Vertisols drainage on the productivity of sorghum and sesame. The study was conducted in Metema experimental station and it has three replications with six treatments of a permanent raised bed with minimum tillage (PRB+MT), permanent raised bed with minimum tillage and mulch (PRB+MT+M), broad bed furrow (BBF), flatbed with minimum tillage and mulch (Flat+MT+M), flatbed with minimum tillage (Flat+MT) and control. Melkam and Abassina varieties were used for sorghum and sesame respectively while the recommended agronomic practices were applied equally to all treatments. The results showed that the highest sorghum and sesame grain yields were obtained from plots treated with PRB+MT+M and BBF respectively. These excess soil water drainage techniques were able to improve the yield of sesame by 46.20 % and sorghum in the range of 20-39.74 %. On the other hand, the lowest grain yield and relatively highest soil moisture (43.87%) were observed at the plots

contents were significantly different between treatments, while the lowest mean soil moisture content (38.69 %) was obtained at BBF. Therefore, Vertisols-dominated fields should be treated with PRB with minimum soil disturbance and BBF to enhance sorghum and sesame production, respectively. Indeed, soil nutrients were not improved significantly within three years of experiments. Hence, to identify the most efficient Vertisols management technique that helps to improve soil quality long-term Vertisols management is required.

Keywords: Drainage; Sesame; Soil Moisture; Sorghum; Waterlogging

Introduction

Vertisols have crucial importance for improving and sustaining food production in Ethiopia (Wubie, 2015). The advantages of Vertisols are their good chemical fertility and occurrence in extensive flatland making it easy for reclamation and mechanical cultivation. However, they are not easy to cultivate due to their poor internal drainage and waterlogging during the wet season and are hard to cultivate during the dry season (Debele & Deressa, 2016; Rutherford, 2008; Wubie, 2015). In Ethiopia, the tremendous potential of Vertisols for crop production is severely constrained because of excessive soil water leading to yield reduction (Gebrehiwot, 2018). The problem of Vertisols is believed to be emanated from the intensity of seedbed preparation and the grazing practices in wet conditions. These practices are supposed to cause compaction and pan formation that hinder hydrological conductivity and create perched water on the surface which usually leads to waterlogging.

Likewise, the study area mostly situated as a flatland with the vast potential of Vertisols is underutilized because of excess soil water and conventional tillage. The above-mentioned challenges could be tackled through conservation agriculture (CA). CA includes minimum soil disturbance, permanent soil cover, and crop rotation to increase productivity by improving soil quality (Busari *et al*., 2015; Rusinamhodzi et al., 2011). In the study area, sorghum, cotton, and sesame have been produced for a long time conventionally with limited farm inputs. To maximize crop production there have been Vertisol management practices and technologies developed by research institutions in Ethiopia. Of the technologies so far released for the extension system, the popular BBF, camber bed maker, raised bed system and some other known traditional methods are some to mention.

The research conducted by Latham, Ahn, and Elliott (1987) showed that preparing broad beds and furrows (BBF) and raised beds (RB) with shallow ditches in between them on Vertisol, increased the grain and straw yields of the crops dramatically. However, there are few success stories in the adoption of Vertisol management technologies by small-scale farmers due to the lack of compatibility of the technologies with the farmers' socio-economic conditions (Debele & Deressa, 2016). Therefore, it is high time to test and amend alternatives to existing various technologies and other experiences from around the world for their effectiveness and ease of use by the farmers.

Hence, the amendments of excess soil water drainage techniques and CA with stable retention are required to improve Vertisols' productivity. CA reduces the energy (fuel for machines and calories for humans and animals) and time required. There is also greater production of biomass in a system with cover crops and zero or reduced tillage compared to conventional tillage. In this way, organic matter can be built up in the soil, which has a great influence on the activity and the population of the micro-organisms. It is believed that such kinds of research should receive high priority because of the vast underutilized potential of Vertisols for crop production. Therefore, the objective of this study is to evaluate the effectiveness of CA and drainage techniques on the productivity of major crops in the northwestern lowlands.

Materials and methods

The study was conducted at Metema experimental station in the northwestern lowlands of the Amhara region in Ethiopia, which is geographically located between 12º 17' 31" to 13º 5' 40" N latitude and 36º 0' 15" to 36º 46' 30" E longitude (Figure 1). The experiment was conducted in 2017, 2018 and 2019 cropping seasons with sorghum-sesame-sorghum rotation. The test crop varieties were Melkam for sorghum and Abasina for sesame. The recommended fertilization for sorghum (100 NPS kg/ha and 150 kg/ha urea) and sesame (65 kg/ha urea) were applied. The experiment, which has six treatments, was laid out in a randomized complete block design (RCBD) with three replications and a 5m length by 4m width plot size. The spacings between plots and blocks were 1.5m and 1.8m respectively.

The spacing between plants and rows for sorghum was 15 and 75cm respectively whereas, the spacing between plants and rows for sesame were 10 and 40cm respectively. Different drainage techniques and flatbeds with stable retention and minimum soil disturbance were compared with local practice. Among the drainage methods, a permanently raised bed (PRB) and broad bed furrow (BBF) were used to drain excess water. Approximately 30 % of crop residue was left at harvest on permanently raised beds and flatbeds with minimum soil disturbance.

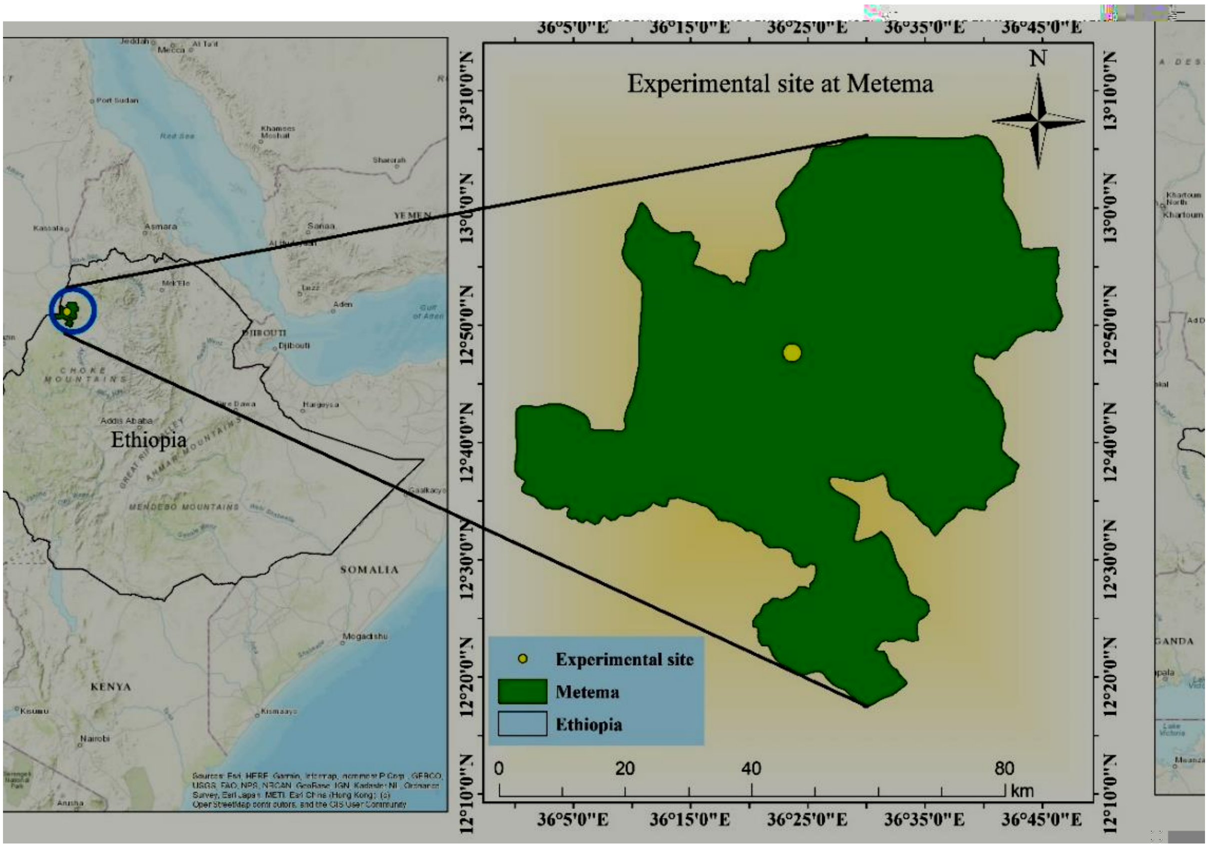

Figure 1. Location of the study area

Soil samples were collected from a depth of 0-20 cm to determine the physicochemical properties of the soil. Whereas, the soil moisture data were collected within two weeks intervals throughout the growing season. Soil moisture content was determined using the gravimetric method by measuring initial weight and oven-dried weight at 105^{0}C for 24 hours and is defined as the ratio of the mass of water-held soil to the dried soil (Klute, *et al.*, 1986). Finally, the biological and soil data were analyzed using SAS software and an excel spreadsheet while the means were compared using mean separation by LSD.

Result and discussion

The results in (Figure 2) showed that the soil moisture contents were significantly different among treatments where the lowest soil moisture result was obtained at BBF as compared to the other treatments. It could be because of the timely and orderly removal of excess water using BBF to improve the growing conditions of the crop. Excess water drainage helps to minimize the soil water content in the root zones of the plant and thereby crop yield is enhanced significantly. Similarly, Debele and Deressa (2016), reported as BBF performed best in both excess rain and dry spells. It may be due to the provision of effective drainage during excess rains and it serves as in-situ moisture conservation during dry spells (Ertiban *et* *al*., 2017; Verma *et al*., 2017). Whereas, the highest soil water contents were recorded from local practice and flatbeds without stable retention that was supposed to cause compaction and excess soil water under high rainfall conditions.

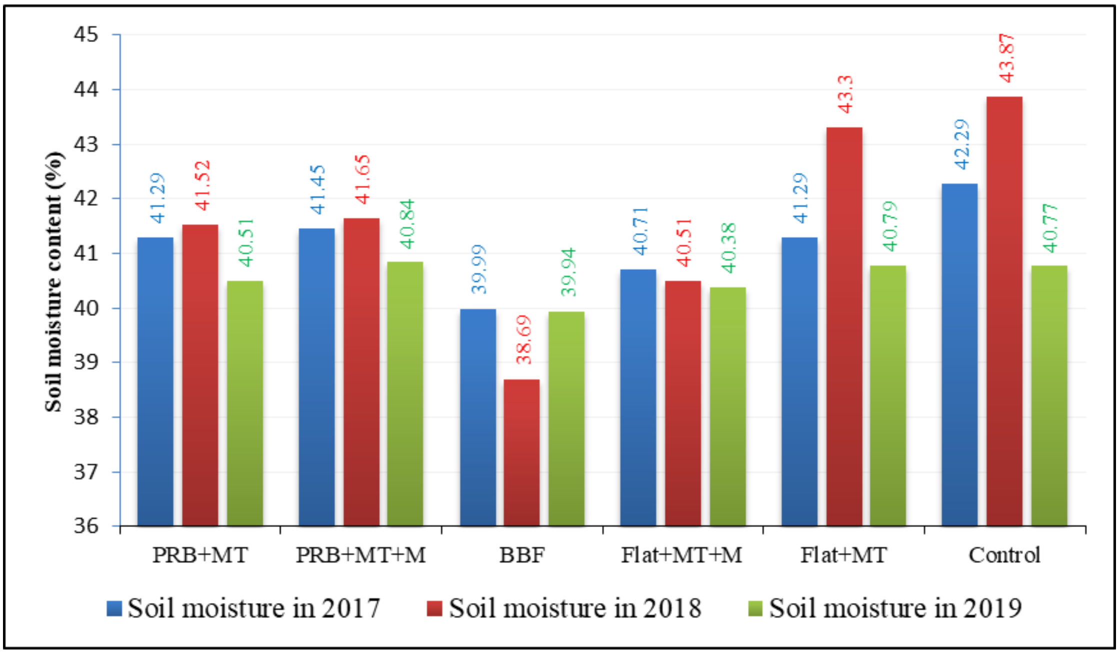

Figure 2. The mean growing season soil water contents for the experimental years

In this research, the soil's physical and chemical properties were not significantly varied among treatments except bulk density and organic carbon in the 2018 and 2019 experimental years respectively. The results of organic carbon and bulk density were numerically improved compared with the results of the initial year (2017). Generally, in this study, the treatment variation on soil nutrients was not consistent across the experimental years. Several scholars argued that nutrients and crop yield improvement could be enhanced by long-term Vertisols management using CA practices (Pathak *et al*., 2011). This may require longer-term and more data monitoring to identify the effectiveness of CA on soil quality improvement.

Table 1. Soil physical and chemical properties

Years	Treatments	pH (H2O)	Available P /ppm	O.C %	CEC (cmol/kg)	Ex. K (cmol (+)/kg)	Bulk density (g/cm^3)
	Initial	6.940	2.830	1.200	79.850	0.400	1.32
2017	PRB+MT	7.040	6.716	1.799	62.188	0.342	1.23
	PRB+MT+M	6.980	5.264	1.717	65.741	0.383	1.26
	BBF	6.750	8.168	1.759	65.398	0.356	1.25
	Flat+MT+M	7.240	5.324	1.636	62.916	0.342	1.32
	Flat +MT	7.040	5.506	1.718	63.044	0.315	1.34
	control	6.700	6.111	1.677	61.118	0.342	1.33
2018	PRB+MT	7.170	3.254	1.294	78.873	0.571	1.12^{b}
	PRB+MT+M	7.133	2.868	1.363	78.338	0.516	1.16^{ab}
	BBF	7.127	3.132	1.475	78.317	0.526	1.17^{ab}
	Flat+MT+M	7.303	3.254	1.349	81.313	0.621	1.19^{ab}
	Flat +MT	6.943	1.649	1.363	77.732	0.511	1.26^{a}
	control	6.860	3.030	1.391	80.828	0.516	1.29^{a}
2019	PRB+MT	6.740	2.347	1.373^{ab}	72.060	0.437	1.03
	PRB+MT+M	6.823	3.417	1.280^{bc}	71.067	0.453	1.02
	BBF	6.820	1.953	1.223^{c}	70.463	0.440	1.14
	Flat+MT+M	6.880	1.593	1.250^{c}	69.937	0.443	1.07
	Flat +MT	7.073	2.010	1.213^{c}	68.787	0.400	1.03
	control	7.097	1.650	1.393^{a}	70.157	0.387	1.10

The CA practice, i.e., the combination of the permanent raised bed, minimum tillage and stable retention, PRB+MT+M resulted in the significantly highest sorghum grain yield similarly in 2017 and 2019 (Table 2). Sorghum grain yield was improved by 20 to 39.74% as a result of CA compared with conventional practice in 2017 and 2019 respectively. This yield improvement could be related to timely removals of excess water, minimum soil disturbance and crop residue retention. Whereas, the reasons that caused the lowest grain yield obtained from the local practice, were supposed to be compaction and excess soil water resulting in restricted air and water movements in the root zones of Vertisols (Abera, Beshir, & Liben, 2020; Liben et al., 2018).

Table 2. Yield and yield components of sorghum for 2017 and 2019 experimental years

Treatments	Plant Height (cm)		Head length (cm)		Biomass (ton/ha)		Grain yield (ton/ha)	
	2017	2019	2017	2019	2017	2019	2017	2019
PRB+MT	183.33[a]	190.66	31.90[a]	27.03	24.19[a]	23.70[a]	5.42[ab]	4.51[ab]
PRB+MT+M	184.10[a]	192.33	29.67[ab]	26.73	27.13[a]	23.90[a]	5.62[a]	5.29[a]
BBF	173.70[a]	190.67	30.40[ab]	26.97	26.69[a]	20.13[b]	5.06[bc]	4.23[bc]
Flat+MT+M	177.73[a]	191.33	28.47[bc]	25.77	24.27[a]	23.40[ab]	4.88[c]	5.13[ab]
Flat +MT	161.90[b]	192.66	27.40[cd]	27.43	19.63[b]	23.43[ab]	4.76[c]	4.91[abc]
control	172.73[ab]	196.33	26.90[d]	28.00	18.38[b]	22.77[ab]	3.95[d]	4.16[c]
CV (%)	3.59	2.9	4.39	6.70	8.52	8.41	9.84	10.86
LSD(0.05)	11.46	10.16	2.35	3.29	3.55	3.5	0.44	0.93

** Note: PRB+MT is a permanent raised bed with minimum tillage, PRB+MT+M is a permanent raised bed with minimum tillage and mulch, BBF is broad bed furrow, Flat+MT+M is flatbed with minimum tillage and mulch, Flat+MT is flatbed with minimum tillage, BM is biomass, GY is grain yield.*

Sorghum provides optimum grain yield under deep, fertile, and well-drained soils and is relatively drought tolerant than soil with excess water. In drainage problematic soils, it is obvious that soil water status stays above field capacity after effective rainfall (Ertiban *et al*., 2017). The plant parameter result showed that the highest plant height and head length were obtained in 2017 from CA treatments compared with the flat and control beds. Similarly, the biomass yield in the two experimental years was significantly different between treatments while the highest biomass (27.13 t/ha) was recorded in PRB+MT+M. The results showed that the yield parameters are attributed to grain yield as explained in (Table 2). Generally, the highest grain yield of sorghum in CA plots was supported by the results of plant height, head length and biomass (Table 2).

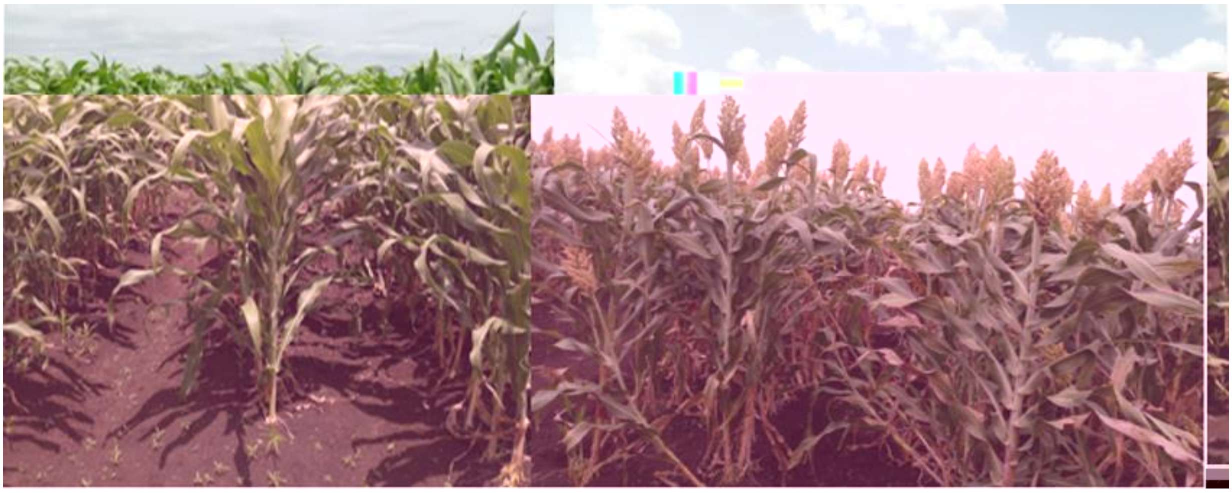

Figure 2. Field performances of sorghum at different growing stages

Table 3 revealed that the grain yield, biomass, bearing zone height, and the number of branches of sesame were significantly higher because of BBF than sesame yields produced by other treatments. The results confirmed that excess water drainage through BBF improved sesame productivity by 46.20% compared with local practice while the recommended agronomic practices and variety were the same for all treatments. Similarly, Sarkar *et al*. (2016) found that 51.67-58.24% sesame yield losses were observed due to 36 hours of waterlogging and suggested removing the standing water from the field as early as possible to avoid drastic yield loss from excess soil water. Aslam et al. (2015), also reported as maximum grain yield was obtained from beds (843 kg ha^{-1}) followed by ridge planting (811 kg ha^{-1}) than the conventional method (349 kg ha^{-1}). Whereas, Agegnehu and Sinebo (2012), found that BBF and ridge and furrow (RF) increased the chickpea yield by an average of 45% over the flatbed.

Table 3. Yield and yield-related components of sesame (2018)

Treatments	Bearing zone height (cm)	Number of branches	Biomass (ton ha^{-1})	GY (kg ha^{-1})
PRB+MT	65.53^{ab}	4.23^{bc}	5.63^{ab}	1044.31^{b}
PRB+MT+M	64.07^{abc}	4.27^{b}	5.7^{ab}	1014.35^{b}
BBF	71.87^{a}	4.97^{a}	6.59^{a}	1138.52^{a}
Flat +MT + M	52.20^{d}	4.17b^{cd}	5.48^{ab}	823.73^{c}
Flat +MT	55.13^{cd}	3.87^{d}	4.81^{bc}	825.35^{c}
Control	56.80b^{cd}	3.90^{cd}	3.35^{c}	778.77^{c}
CV (%)	8.25	4.46	17.98	7.95
LSD (0.05)	9.14	0.35	1.72	84.38

Meanwhile, the lowest sesame grain yield was obtained from local practices and flatbeds compared with other treatments that may be related to excess soil water content. Sesame is considered a drought-tolerant oil crop and is typically susceptible to harmful effects of waterlogging that is detrimental to crop survival and grain yield (Dossa *et al*., 2019; Sarkar *et al*., 2016; Terefe et al., 2012). A few hours of waterlogging (lasting over 36 hours) are detrimental to crop growth, yield, and survival (Dossa *et al*., 2019). According to Sharaby and Butovchenko (2019), the ideal soil for sesame cultivation is characterized by good drainage, is well-ventilated, and is highly fertile to maximize crop yield.

Figure 3. Field performance of sesame at different growth stages

Generally, most plant parameters and grain yields for sorghum and sesame were significantly highest from PRB+MT+M and BBF respectively. PRB+MT+M and BBF allow the water to drain away from the plant root zone and help to reduce the adverse effects of excess soil water. That is why the highest grain yield was obtained at the lowest soil moisture content resulting in timely removals of excess water from the root zone. The results of this study showed that excess soil water drainage has a positive impact on yield and yield-related parameters of sorghum and sesame. However, the soil's physical and chemical properties were not significantly improved. Hence, a long-term study of conservation agriculture is needed to identify the effectiveness of the technologies on soil quality improvement.

Conclusion

The study aimed to evaluate the effectiveness of various drainage techniques integrated with conservation agriculture. It was conducted for the last three years (2017-2019) as a rotation of sorghum-sesame-sorghum. The results of this study showed that sorghum production was significantly varied between treatments while the highest yield was obtained from PRB+MT+M. Based on the results of two experimental years the grain yield of sorghum was improved by 20 to 39.74% compared with local practice. On the other hand, sesame production was enhanced by 46.20 % as a result of surface water drainage using BBF technology while the recommended agronomic practices and variety were the same for all treatments. Meanwhile, the highest grain yield (1138.52 kg ha^{-1}) and the lowest mean value of soil moisture (38.69 %) were obtained at BBF than other treatments. Whereas, the lowest grain yield (778.77 kg ha^{-1}) and relatively highest soil moisture (43.87%) were observed at the farmers' practice. The negative relationship between grain yield and soil moisture confirmed that surface drainage has a significant positive impact on crop production enhancement under high rainfall conditions. However, the soil properties were not improved significantly among treatments which may be due to the short duration. Generally, to enhance sorghum and sesame production preparation of raised beds with minimum soil disturbance and broad bed furrow should be considered accordingly. Furthermore, to identify the most efficient Vertisols management technique that helps to improve soil quality, long-term Vertisols management is required.

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