2. Comparative Evaluation of Conservation Agriculture and Other Management Practices to Improve Productivity of Vertisols

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Abstract

Vertisols are dark-colored clays that develop cracks when expanding and contracting with changes in moisture content. In the highlands of Ethiopia, tillage methods and frequency affect drainage, soil erosion, moisture conservation, weeding, and harvesting of crops. Five tillage methods namely broad bed and furrows (BBF); permanently raised bed with no-tillage (PRB+NT); permanently raised bed with no-tillage and 30% stubble retention (PRB+NT+M); Flatbed with no-tillage (Flat+NT) and a flatbed with no-tillage and 30% stubble retention (Flat+NT+M) were evaluated for their effects on the productivity of vertisol. The study was conducted in Moretna Jiru wereda, Enewari for seven years (2015 to 2022) in the central highland of Ethiopia. In this study, the soil indicaters such as moisture content, bulk density, organic carbon, PH, available Phosphorous, extractable Potassium, electrical conductivity, and total Nitrogen, and productivity indicators namely the plant height; grain yield, and straw yields were measured. The result indicated, Flat+NT+M and Flat+NT significantly increased the grain yield of wheat by 13.4% and 11.2% respectively as compared to BBF for the experimental years 2015/16 and 2017/18. However, in experimental years 2019/20 and 2021/22 the wheat yield was high on BBF compared to other conservation agriculture practices. On the other hand, BBF gave the highest grain yield of Faba bean as compared to the conservation agriculture practices. A soil property data implies that PRB+NT+M, Flat +NT, and Flat+NT+M could improve the total N, soil PH, Organic C, moisture holding capacity, and extractable Potassium. Economically, Flat+NT was the most profitable practice with 1147.6% marginal rate of return (MRR). Based on the agronomic, economic, and soil property results, the best combinations of crop and land preparation methods were: Flat+NT and Flat+NT+M for wheat production in dry years. Effective drainage method like BBF has an advantage for better production of Faba bean on Vertisols.

Keywords: BBF, flat bed; no tillage; Moretna Jiru; Enewari; permanently raised, stubble

Introduction

Vertisols are dark-colored clays that develop cracks when expanding and contracting with changes in moisture content(Wubie, 2015). It is the fourth most important soil in Ethiopia in terms of area coverage, constituting 7.6 million ha in the central highlands(Jutzi and Mesfin, 1987). Vertisols is a very fertile soil and it can be productive enough if properly managed. The problem of vertisols is believed to be emanated from the intensity of seedbed preparation (frequent plowing even during the muddy time) and the grazing practices in wet conditions. Frequent tillage and delayed planting not only substantially reduce the growing period and crop productivity, but also exacerbate soil erosion, which is already among the devastating environmental problems of the Ethiopian highlands(Astatke *et al.*, 2002). The higher tillage frequency increases the loss of soil organic matter because of the mixing of the soil and crop residues, disruption of aggregates, and increased aeration (Doran and Smith, 2015). The soils remain bare during the peak rain season with occasional tillage operations enduring vulnerability to soil erosion. These practices are also supposed to cause compaction and pan formation that hinder hydrological conductivity and create perched water on the surface which is usually seen in water logging. Even after repeated cultivations, the seedbed is rough. These lead to the deterioration of the physical, chemical, and biological quality of the soil over the long term, and vertisols are no exception.

As a solution for mentioned problems experiences from countries like India and Australia shows that proper knowledge and management of vertisols have resulted in increased yields. Hence the proper management applications of the technology for Vertisols are believed to increase productivity and food security levels in Ethiopia. Among the options surface drainage method, known as broad bed and furrow (BBF) constructed by broad bed maker (BBM), which was developed at ICRISAT in India(El-Swaify *et al.,* 1985) and other known traditional methods (like Shuribie in North Shewa) are some of the experiences that can be mentioned. Several authors reported increased yields of some crops grown on vertisols due to the use of the BBF as compared to the flat seedbeds (Astatke, Mohamed Saleem and El Wakeel, 1995; Haque, Lupwayi and Luyindula, 1996). Despite the yield advantage it is better to test and amend alternatives on existing various technologies and other experiences from around the world for their economic effectiveness; draining excess water; environmentally friendly and ease of use by the farmers.

Therefore, this study aimed to evaluate the effectiveness of integration of conservation agriculture with different land management practices for the improvement of productivity of Vertisols and to introduce cheap and environmentally friendly methods of land management for Vertisols.

Materials and Methods

Description of the Study Area: The study was conducted at Moretna Jiru woreda North Shewa, Ethiopia. Enewari is situated at 39°9.5'E longitudes and 9°53'N latitudes and 198 km Northeast of the capital city Addis Ababa (Figure 1). The altitude of the experimental site is 2664m. Ithas a unimodal type of rainfall distribution with a mean annual rainfall of 1142.1mm, while the minimum and maximum temperatures are 9.43°C and 21.14°C, respectively. June, July, and August receive large shares of the annual rainfall. Moretna Jiru woreda is dominantly covered with heavy clay soil (pellic Vertisols) and extremely constrained by water logging problems. The dominant land use of the wereda is seasonal crops; those are wheat (Tritium aestivum L.), tef (Eragrostis tef), lentil (Lens culinaries Medik) and Faba bean (Vicia faba) while the marginal lands along the roadsides, gully bottoms, and flood plains are the major grazing ground.

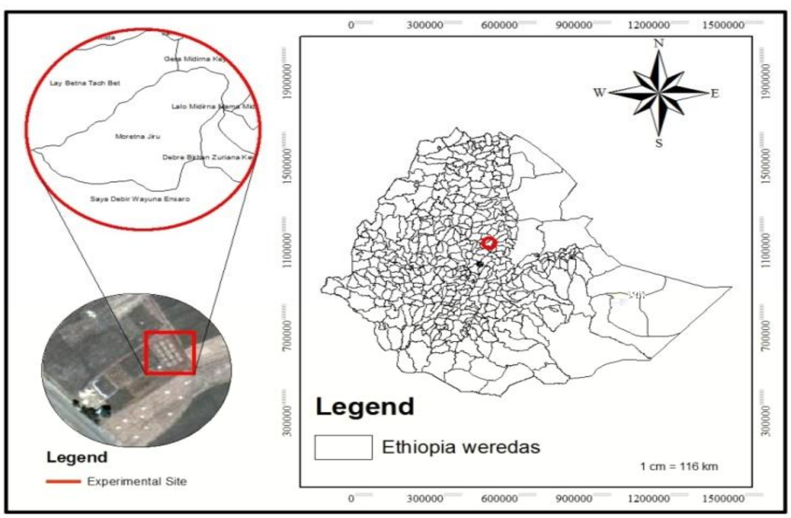

Figure 1. The location map of the experimental site

Experimental Procedures and Treatment Description: The experimental layout was a randomized complete block design with three replications, and the plot size was 4m by 4.8m. The total area of the experimental area was 18m by 30m. The tillage plowing was done with a hand-made digging hoe. The first plowing is started in mid-April based on the availability of moisture for all experimental years for BBF treatment. Seeds were sown by hand drilling seed 20cm between row spacing for wheat and the rotation after wheat grown in the second production season Faba bean seed was sown with 10cm between plants and 40cm between row spacing. The variety of the test crop were used Menzie and Lalo for Bread wheat (and Faba bean ( ) respectively. The seed rate of the test crop was 131.25 Kgha^{-1} for wheat (and with 10 cm spacing between plants for faba bean ( ). The fertilizer rate used for this experiment was 275Kgha^{-1} urea and 272.36 Kgha^{-1} NPS for wheat (and 121 Kgha^{-1} NPS for faba bean ( ).

The evaluated tillage practices were described as:

- **a.** *Broad bed and furrows (BBF):* Broad beds and furrows were constructed by the broad bed maker (BBM), which is an oxen-drawn traditional wooden plow, modified for the construction of raised beds and furrows. With an effective bed width of 80 cm and 40 cm of bed furrows, it is intended to facilitate surface drainage through the furrows between the beds so that the crops grow on the beds. This practice was introduced in the study area formerly and due to this the broad bed and furrows are the control treatment of this experiment.
- **b.** *Permanently raised bed with no-tillage (PRB+NT):* These beds were prepared with a 1.2 m bed width and 40 cm furrow at the start of the experiment. After the beginning of the experiment, plots were kept intact fallow until they were perforated in small slots for sowing. The seeds were drilled and covered by a single tillage operation using the local peg for both testing crops wheat and faba bean. The practice was aimed at minimizing pre-sowing soil disturbance, reducing oxidation of SOM, and maintaining some surface cover to reduce soil erosion. The treatments were kept permanent while two crops: wheat (*Tritium aestivum* L.), faba bean were rotated following their traditional sequence. In this treatment, the bed and furrow were permanently untouched for draining the excess water from the field. All the cultural practices other than the treatments were implemented according to the recommendation for the respective crops.
- **c.** *Permanently raised bed with no-tillage and 30% stubble retention (PRB+NT+M):* This treatment was kept similar to a permanently raised bed with no-tillage (PRB+NT) except for 30% stubble retained in the field. The stubble retention in this experiment was performed by cutting the test crop at 30% height during harvesting.

d. *Flatbed with no-tillage (Flat +NT):* This treatment kept the field flat and not tilled over all periods of the season. The test crops were grown by perforating small slots. The seeds were drilled and covered by a single tillage operation using the local peg for both testing crops (Faba bean & wheat). This practice was aimed at minimizing pre-sowing soil disturbance, reducing oxidation of SOM, and maintaining some surface cover to reduce soil erosion. All the cultural practices other than the treatments were implemented according to the recommendation for the respective crops. The flat land untouched in this treatment was proposed as an agent for aggregate stability and biological tillage through developing favorable conditions for micro-organisms.

e. *Flatbed with no-tillage and 30% stubble retention (Flat+NT+M):* This treatment was kept similar to the flatbed with no tillage except 30% stubble retained in the field at the time of harvesting. The stubble retention in this experiment was performed by cutting the test crop at 30% height during harvesting.

Data Collection and Analysis: Composite soil samples before sowing and after harvesting of test crops were collected from each plot at 0 to 20 cm depths for physic-chemical property analysis. Soil core samples were collected at 0 to 30 cm depths for BD measurement (Blake and Hartge, 1986; Arshad, Lowery and Grossman, 1996).Correspondingly, auger sampling was made to determine gravimetric moisture content(Lowery *et al.,* 2015). Grain yield and other agronomic data having a response to crop yield were collected for each experimental year. Labor and other economic data were also collected.

The collected data were subjected to analysis of variance using R software version 4.1.3 to determine treatment effects. Wherever the difference among treatment means was compared using Fisher's least significant difference test at 5% (P=0.05).

Selection of treatments for further experimentation and for developing farmer recommendations partial budget analysis was done by following the CIMMIT manual (CIMMYT, 1988).

Results and Discussion

Effect of Conservation Agriculture on Yield and Yield Component of Wheat: The agronomic and yield-related impacts of conservation agriculture during wheat production years shown in Table 1, Flat+NT and Flat+NT+M gave marginally higher wheat yields for the first two experimental years 2015/16 and 2017/18. During these experimental years, there was no rainfall in October and November showed in Figure 2. As a result, conservation agriculture, (Flat+NT and Flat+NT+M) was more advantageous compared to farmer's practice. Because of conservation agriculture conserve more soil moisture compared to farmer practices. Taking all specific practices as an overall effect, conservation agriculture significantly increased wheat crop yield by 4.37%-13.4% as compared to the conventional farming system (BBF). There were statistical differences in specific effect sizes among the conservation agriculture practices ($P < 0.05$). Flat +NT +M and Flat +NT gave statistically highest wheat grain yield than other treatments, they have 13.47% and 11.2% yield advantage compared to conventional tillage (BBF) respectively. This was in line with the study reported by (Erkossa, Stahr and Gaiser, 2006), who stated that the BBF significantly decreased the grain yield of wheat by 35% in some parts of Ethiopian highlands. Similar to our result, among the conservation agriculture methods applied in China, straw retention showed a significant positive effect on crop yield. Another study found by(De Vita *et al.*, 2007; Li *et al.*, 2010), reported significantly higher wheat yield under straw retention than under conventional tillage only in dry years.

However, the wheat yield for the next two experimental years 2019/20 and 2021/22 become lower in Flat+NT and Flat+NT+M compared to PRB+NT+M, PRB+NT, and BBF as shown in Table 1. The rainfall in those cropping seasons was high compared to the previous experimental year as shown in Figure 2. There was no moisture deficiency up to the harvesting time. In that case, farmer practice (BBF) was more advantageous compared to conservation agriculture. According to field observation, there was a water logging problem on Flat +NT+M and Flat+NT as compared to BBF, PRB+NT, and PRB+NT+M. Taking all specific practices as an overall effect, conservation agriculture practices lowered wheat crop yield by 1.9% to 19.3% as compared to the conventional farming system (BBF). This was disagreeing with the study reported by (Erkossa, Stahr and Gaiser, 2006) BBF significantly decreased the grain yield of wheat by 35% in some parts of Ethiopian highlands. Another study was found by (De Vita *et al.*, 2007; Li *et al.*, 2010), who reported significantly higher wheat yield under straw retention than under conventional tillage only in dry years.

Table 1. Effects of conservation agriculture practices on wheat yield

Treatments	2015/16		2017/18		2019/20		2021/22	
	GY*	ST	GY	ST	GY	ST	GY	ST
BBF	5245.4ab	8000.9ab	4500b	7541.7	3743.1a	5861.1a	4566	5854.2a
PRB+NT	5007.8b	7518.7bc	5240a	8171.9	3519.5ab	4617.2c	4593.8	5480.5a
PRB+NT+M	5130.2b	7247.6c	5040.7ab	8341.2	3304.7bc	5317b	4566.4	4132.8b
Flat+NT	5420.1a	8344.5a	5416.7a	8891.7	3203.1bc	4250c	4479.2	6208.3a
Flat+NT+M	5520.8a	7985.6ab	5537.5a	9271.7	3020.8c	4732.1c	3849	3833.3b
CV (%)	2.9	4.3	6.9	8.4	6	5.3	7.8	9.7
LSD (0.05)	286.9	627.8	664.9	ns	379.6	503.2	ns	927

**GY: grain and SY: straw in Kgha-1 and PH: plant height (cm)*

Figure 2. The distribution of rainfall during the growing seasons of the experiment

Effect of Conservation Agriculture on Yield and Yield Component of Faba Bean: The agronomic and yield-related impacts of conservation agriculture during Faba bean production years shown in Table 2 revealed that there was statistically lower Faba bean grain yield in all conservation agriculture practices compared to farmer practices. Even though it was not significant at ($p<0.05$), the growth parameter (plant height) was high in BBF. In the study area for three experimental years, there was 372.2mm, 385.8mm, 75.9mm, and 29.1mm average rain in July, August,

Th75.9mm

September, and October respectively. This might influence the performance of Faba bean in mulched treatments. Based on field observation in the experimental years' stubble retention is caused to excessively increasing soil moisture, this may lead to lower yield. In line with our study, BBF has 98% yield advantage over flatbed tillage system (Agegnehu G and Ghizaw A, 2004). In other scholars, stubble retention could also depress crop growth by nutrient immobilization in soil microbes and increase residue-borne diseases. Straw retention improves soil moisture conditions by improving soil structure and reduces soil water evaporation, thus benefiting crop growth under dry conditions; however, straw retention in areas with high rainfall may lower crop yield owing to water logging (Rusinamhodzi *et al.*, 2011).

Table 2. Effects of conservation agriculture on Fababean yield

	2016/17			2018/19			2020/21		
Treatment	GY*	ST	PH	GY	ST	PH	GY	ST	PH
BBF	3943.3	4063.7	101.8a	3158	2887.5	87a	2178.8a	1149.3	69.7a
PRB+NT	3541.7	3807.3	99.2a	2650.7	2427.7	77.8b	1505.2b	903.6	68.1a
PRB+NT+M	3828.1	4259.7	99.9a	2185.6	2915.8	76.5b	1466.1b	882.8	65.8a
Flat+NT	3507	3652.8	91.2b	2393.2	2447.9	72.9bc	1597.2b	1024.3	65.7a
Flat+NT+M	3763.9	4221.2	92.1b	1953.2	3192.7	69.7c	1927.1ab	871.5	57.2b
Mean	3716.8	4000.9	96.8	2468.1	2774.3	76.7	1734.9	966.3	65.3
CV (%)	4.6	7.5	3.04	18.6	14.1	4.59	15.8	16.7	5.1
LSD (0.05)	ns	ns	5.55	ns	ns	6.64	516.9	ns	6.3

**GY: grain and SY: straw in Kgha^{-1} and PH: plant height(cm)*

Effect of CA on Selected Soil Physiochemical Properties

Effect of Conservation Agriculture on Selected Soil Chemical Properties: As shown in Table 3, the soil result indicates that the available Phosphorus was improved on BBF and PRB+NT+M as compared to PRB+NT, Flat+NT, and Flat+NT+M. Soil available P content was increased by crop harvest possibly due to the residual effects of fertilizer applied for the test crop. Soil P increases reported in this study following crop fertilization agree with earlier findings (Ishaq, Ibrahim and Lal, 2002). The PH for all treatments ranged from 6.6 to 6.7. The pH range of 6.0 to 6.8 is ideal for most crops because it coincides with the optimum solubility of the most important plant nutrients. PRB+NT+M, Flat+NT, and Flat+NT+M resulted in a net increase of 0.64–1.27% in soil organic carbon content and organic matter over conventional tillage (BBF). In line with our study (Li *et al.*, 2020) indicates that no-tillage with residue retention and reduced tillage with residue retention increase soil organic carbon stock by 29% and 27% respectively compared to conventional tillage. Similarly (Bravo *et al.,* 2007; Meena *et al.,* 2015), reported that zero tillage resulted in a net increase of 16–27% in soil carbon content over conventional tillage. And also PRB+NT and PRB+NT+M could better conserve soil total Nitrogen (N %). PRB+NT and PRB+NT+M could also improve the total N by 0.64% and 3.18% as compared to the BBF. In this study, the result of electrical conductivity (E.C ds/m) was a similar range for all tillage treatments which is normal and free from salinity problems. Flat +NT+M and Flat +NT could improve exchangeable Potassium by 5.6% and 26.1% respectively compared to farmer practices. Similarly, other studies revealed that the level of extractable K increases at the soil surface with no tillage as tillage intensity decreases and residue retention increases(Ismail, Blevins and Frye, 1994; Govaerts *et al.,* 2007). The effect of conservation tillage on enhancing SOC sequestration has been reported by several researchers(Potter *et al.,* 1997; Post and Kwon, 2000; Lal, 2001, 2004). There was a significant ($P<0.001$) difference in mean pH, total mineral N, and percent organic and microbial biomass C contents obtained after harvest(Kutu, FR, 2012).

Table 3. Effect of conservation agriculture on selected surface soil (0-20 cm) chemical properties

Treatment	Available P(ppm)	E.C(ds/m)	K (cmol/Kg of soil)	PH (kcl)	SOC (%)	SOM (%)	Total N (%)
BBF	16.65	0.13	0.88	6.6	0.785	1.35	0.0785
PRB+NT	15.25	0.12	0.83	6.6	0.725	1.247	0.079
PRB+NT+M	16.4	0.12	0.86	6.6	0.79	1.359	0.081
Flat+NT	12.6	0.22	1.11	6.7	0.795	1.367	0.07
Flat+NT+M	13.25	0.11	0.93	6.7	0.795	1.367	0.076

Effect of Conservation Agriculture on Soil Moisture Content: During experimentation in the study area (for moisture samples taken years) there was no shortage of rainfall. Due to this, it was difficult to see the effect of conservation agriculture tillage practice on moisture as visually on crop yield. According to soil sample analysis, the three-year moisture data indicates conservation agriculture tillage practice shows some improvement in soil moisture compared to that of farmer practice. As shown in Figure 3, Flat+NT, Flat+NT+M, PRB+NT, and PRB+NT+M improve soil moisture by 3.4%, 6.9%, 3.4%, and 5.8% respectively as compared to that farmer practice. This might be important in moisture deficit years. In line with our studies, other scholars' studies show soil moisture content was improved with increased use of crop residues as a soil cover (Akilapa *et al.*, 2020).

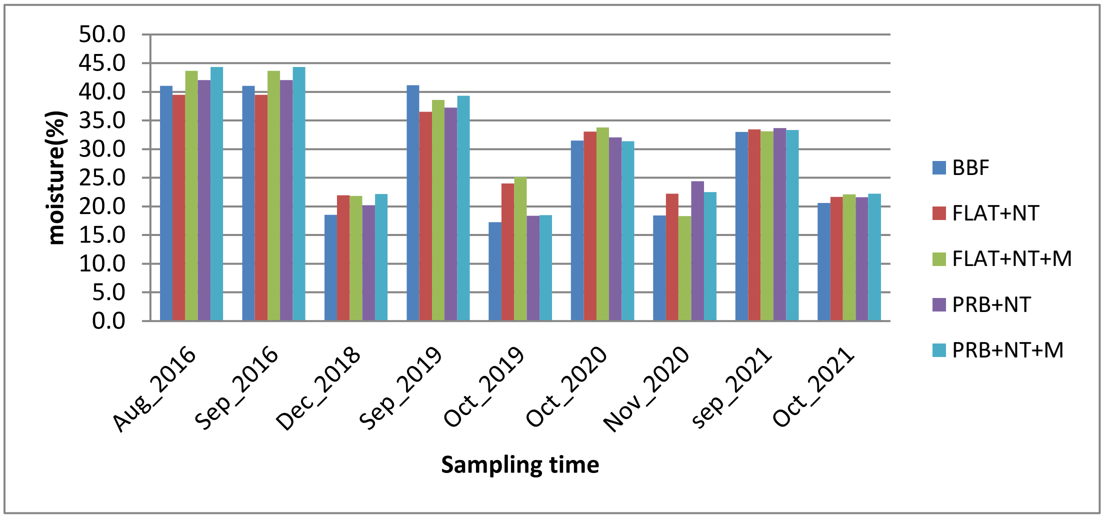

Figure 3. Effect of conservation agriculture on soil moisture content

Effect of Conservation Agriculture on Soil Bulk Density: As shown in Figure 4, the result of bulk density analysis (gcm^{-3}) indicates that conventional tillage practice could minimize surface compaction and bulk density to a small extent compared to conservation agriculture tillage treatments. In line with our study, other scholars (Bhattacharya *et al.*, 2020) indicate that the bulk density of surface soil (0-15cm) in conservation agriculture is 2% -3% greater than conventional tillage.

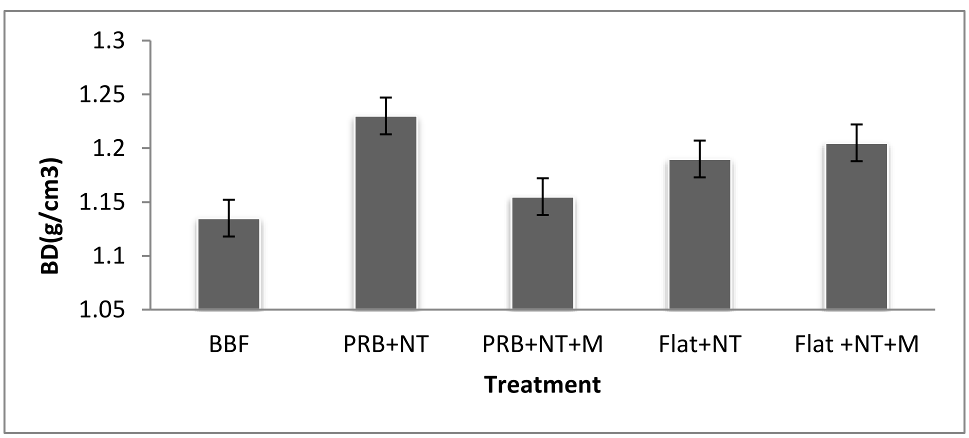

Figure 4. Effect of conservation agriculture on soil bulk density

The Economic Viability of Conservation Agriculture: Furthermore, this experimenthas not only seen the effect of conservation agriculture on crop yield and soil properties but also on the reduction of energy, labor, and inputs. As shown in Table 4, the result of the partial budget analysis Flat bed with no tillage could have maximum MRR (1147.6 %) and the Net benefit (64460.2 ETB) was also highest than the other treatments. This revealed that the Flat bed with no tillage treatment was economically feasible and the MRR could dominate the other treatments. Zero tillage offers farmers of a great opportunity to reduce energy inputs in crop production.

Table 4. The partial budget analysis of the experiment

Treatments	TVC ($ETBha^{-1}$)	Revenue ($ETBha^{-1}$)	Net benefit ($ETBha^{-1}$)	MC	MB	MRR (%)
PRB+NT+M	2800.9	62246.4	59445.5			
FLAT+NT+M	3339.1	65940.3	62601.2	538.2	3155.7	586.3
PRB+NT	4490.7	67888.2	63397.5	1151.6	796.4	69.2
FLAT+NT	4583.3	69043.5	64460.2	92.6	1062.7	1147.6
BBF	8257.2	70675.2	62418.0	3673.9	-2042.2	-55.6

Conclusion and Recommendation

Effects of conservation agriculture practices on crop yield were analyzed using seven-year field experimental data. The effect of land management practices on the growth parameter (plant height); grain yield and straw yield depend on the crop type and year. The statistically highest wheat grain yield was obtained from Flat+NT+M and Flat +NT for the experimental year 2015/16 and 2017/18 due to a small amount of rainfall rained during the cropping season but in the experimental year, 2019/20 and 2021/22 wheat yield high in BBF compared to Flat+NT+M and Flat+NT due to excess amount of rainfall rained on cropping season than the previous experimental year. The result of this study indicated conservation agriculture for wheat yield showed a positive result on Vertisols for dry years. But for normal years BBF gave high yield advantages compared to conservation agriculture practice. Additionally, BBF provided the statistically highest Faba bean yield and plant height. Flat+ NT+M and Flat+NT have a lower impact on the environment and can better preserve soil organic matter, soil organic carbon, and extractable Potassium and especially Flat+NT is a feasible and energy-saving strategy. The findings of this study led us to the conclusion that while conservation agricultural approaches were not preferable for the production of Faba beans, they would be more beneficial for the production of wheat during years with little rainfall. We found through a long-year trial that Flat+NT+M and Flat +NT were effective in many dimensions and that they should be employed widely.

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