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Effect of Conservation Tillage Practice on Chemical Properties and Productivity of Chickpea Double Crop in Central High Land Vertisol of Ethiopia

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Abstract: Conservation tillage is considered the best practice for crop production in a sustainable way. A three-year field experiment was examined to evaluate the conservation tillage effect on the productivity of chickpea (Cicer arietinum) double crops during the 2018-2020 main cropping seasons. A randomized complete block design with a split-plot arrangement with three replications was used. The main plots were improved variety and local variety. Subplots were zero tillage with mulching, zero tillage without mulching, minimum tillage with mulching, minimum tillage without mulching, farmer practice with mulching and farmer practice without mulching. Data was collected on plant height, number of pods per plant, number of seeds per pod, thousand seed weight, grain yield, biomass yield and harvest index. Data was subjected to the general analysis of variance using R software version 4.2. Mean separation was calculated using the least significant difference LSD at a 5% probability level. The results revealed that the main effect and interaction effect of varieties and tillage methods with mulching significantly ($P < 0.05$) influenced pod per plant, seed per pod, biological yield and grain yield. The average total nitrogen available phosphorous and organic carbon content of the soil were significantly influenced by the use of different tillage methods and mulching combinations, indicating that tillage system and organic mulching can contribute to yield and yield components. Therefore, it was concluded that the combined use of chickpea varieties and tillage methods with mulching not only increases the productivity of chickpeas but also can improve the fertility status of Vertisols.

Key words: Conservation tillage · Chickpea productivity · Mulching practice · Vertisol

INTRODUCTION

Chickpea is one of the major highland pulse crops commonly grown in the highland and semi-highland areas of Ethiopia mostly on vertisols. The crop is commonly cultivated using residual moisture as a rain-fed crop [1, 2]. According to FAOSTAT [3] report, chickpeas covered an area of 241,212 ha with the production of 515,642 tons and productivity of 2.14 tons per hectors. The growth and yield of chickpeas are directly influenced by water uptake and evapotranspiration [4, 5]. The inability to properly manage the limited moisture is as much a problem as is the limited resource [6]. In the highland of the country, chickpea is grown with residual moisture (after the harvest of the first crop grown in the main rainy season) without considering evaporative losses and negative consequences of conventional tillage practice that degrades soil bases. To increase the yield of chickpeas grown with residual moisture, identifying suitable tillage methods and other management practices like mulching which can reduce the upper soil temperature, conserve available soil moisture and improve soil organic matter is crucial [7].

Conservation tillage practice (no-tillage or minimum tillage with/without residue retention) has been extensively used to reduce the negative impacts of farming practices used in intensive tillage systems. Conservation tillage practices have many advantages in minimizing costs, increasing water use efficiency, improving soil properties and preserving soil carbon [8, 9] and have been adopted on more than 155 million hectares of farmland globally [10]. Minimum tillage benefits not only crop production, profitability and resource sustainability and reduces demands on labor and time

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[11], but also it facilitates the use of other improved crop management technologies [12]. The absence of soil disturbance and the availability of effective non-residual herbicides open the way for earlier sowing and can bring a strong positive effect on crop production [13].

The success of minimum tillage depends on where crops are sown immediately after the first rains of autumn using minimal soil disturbance to utilize and store rainfall, assisted by the retention of residue from previous crops [14]. Some scholars demonstrated better yield from wheat in rotation with chickpeas and lentils under no-tillage compared to conservation tillage [15, 16] and found successful results. Until recently, minimum tillage with mulching practice and early chickpea sowing has been little known or used by farmers in the highlands of Ethiopia where the production of the crop depends on rainfall. Thus, alternative land preparation methods, straw mulching and current farmer practices need to be compared with different chickpea varieties. Therefore, the objective of this paper was to evaluate the effect of different tillage methods with straw mulching on the yield of chickpea varieties in double cropping systems in highland vertisols areas of Ethiopia.

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted at the Ginchi sub-center in the central part of Ethiopia. Ginchi sub-center is located 75 km west of Addis Ababa on the way to Ambo. It is situated at 9°02'N latitude and 38°12'E longitude with an elevation of 2200 m above sea level and receives an average annual rainfall of 1095 mm, average relative humidity of 58.2% and average maximum and minimum air temperature of 24.6°C and 8.4°C respectively. The soil of the area is predominantly black clay Vertisol.

Experimental Design, Treatments and Field Management: Chickpeas were planted as a double crop (after the first crop, wheat had been fully matured and harvested). The treatments were laid out in a split-plot design where the chickpea varieties (Local and Mastewal or improved) were put on the main plot and the factorial combination of three tillage practices (zero tillage, minimum/strip tillage, farmers practice, or once tillage) and straw mulching (3 cm mulching thickness and no mulching) were put on subplot. The treatments were replicated three times. Tillage practices, strip tillage, here refers to disturbing only the portion of the soil that is to contain the seed row with 30 cm intervals using local *Maresha* without disturbing the space in between rows. A farmer’s practice is planting the second crop immediately after harvesting the first crop with only a single tillage covering the seed. The recommended nitrogen (15 kg N ha^{-1}) and phosphorous (20 kg P ha^{-1}) fertilizers were applied uniformly. The size of each main plot was 24 mx 4 m (96 m^2) and the size of each subplot was 4m x 4m (16 m^2). The spacing between main plots, subplots and blocks was 2 m, 0.5 m and 1 m respectively. The space between plants was 10 cm and between rows was 20 cm. The net plot size used for data collection and measurement was 12.4 m^2. Any other important agronomic practices like weeding were carried out uniformly for all the experimental units throughout the cropping season.

Data Collection and Measurement: When the crop reached the physiological maturity stage, by leaving the last two rows within each plot, all plants within the experimental unit were harvested at ground level. Ten plants from each plot (experimental unit) were selected randomly to determine the number of pods per plant and the number of seeds per pod. The pods were threshed manually and the number of seeds per pod was determined by manual count. The seeds harvested from the experimental units were then air-dried and weighed to determine the average grain yield (kg ha^{-1}). Total above-ground plant biomass (biological yield) obtained was dried up to lose the moisture content, for two weeks, in the open air and weighed. Then, the weight was converted into kg ha^{-1}.

Soil Sampling and Analysis: Soil samples were taken both before and after planting from the experimental site. Before planting, samples were randomly taken from five different spots in an X-pattern across each block at a depth of 0-30 cm to make one composite sample. After harvest, the samples were taken at 0-30 cm depth from each plot of the experimental site. The sample was air-dried and sieved through a 2 mm sieve. Soil texture determination was done by hydrometric method [17]. The pH of the soil was measured from the suspension of 1:2.5 (weight/ volume) soil-to-water ratio using a glass electrode attached to a digital pH meter [18]. Organic carbon content was determined using the wet digestion method [19]. Total Nitrogen content was determined by the Kjeldahl digestion [20]. Available Phosphorus was extracted using the Bray-II method [21]. The P extracted with this method was measured by spectrophotometer following the procedures described by Murphy and

Chapman [22]. Cation exchange capacity (CEC) and exchangeable bases were extracted by saturating the sample with 1N NH_4OAc. Cation exchange capacity was determined from the extract using the ammonium acetate method [23]. Calcium and magnesium were determined from the extract by using the atomic absorption spectrophotometer method while exchangeable potassium and sodium were determined using a flame photometer as described by Rowell [24].

Statistical Analysis: All data were subjected to statistical analysis of variance using a generalized linear model (GLM) in R statistical software version 4.1 [25]. The significance of the treatments was tested using the agricolae package of R [26]. The means were compared using the lsmean package of R [27] with the least significant difference (LSD) set at a 5% level of significance.

RESULTS AND DISCUSSION

Soil Physicochemical Properties of the Experimental Site Before Planting: The results of laboratory analysis for soil physical and chemical properties were presented in Table 1 for composited soil samples collected from (0-30 cm) before planting. The results indicated that soil texture was dominated by clay (65.80%) followed by silt (20.90%) and sand (13.30%). The dominance of clay in the experimental soil shows the opportunity of holding high exchangeable cations for crop growth. However, such characteristics of soil may be prone to either water logging or erosion unless properly managed [28]. The mean soil pH of the experimental site was 6.23. Based on the rating of Tekalign [29], the soil pH is rated as slightly acidic. FAO [30] reported that the preferable pH ranges for most crops and productive soils are between 4 and 8 range. Soil organic carbon and total nitrogen content were 0.11 and 1.45 percent which classified into the low range as suggested by Tekalign [31]. Soils that are tilled frequently like this site are usually low in organic carbon content because tilling decrease soil organic carbon content which adversely affects soil fertility unless organic source are added timely. Similarly; available phosphorus in soil was 10.47. It was found in the medium range as suggested by Cottenie [32]. The soil cation exchange capacity of the soil was (51.67 meq/100kg) which was classified into a very high range as rated by Landon [33]. This could be due to the dominance of the soil of the study area by the smectite mineral group which can bear high exchangeable cations.

Table 1: Average soil analytical results of the experimental site before planting

Parameters	Block -1	Block-2	Block-3	Mean
Clay (%)	65.8	64.9	65.7	65.47
Silt (%)	20.9	21.3	20.8	21.00
Sand (%)	13.3	13.8	13.5	13.53
pH (H_2O)	6.3	6.2	6.2	6.23
OC (%)	1.02	1.04	1.11	1.06
TN (%)	0.12	0.12	0.11	0.12
av. P (ppm)	10.5	9.85	11.07	10.47
CEC (meq/100kg)	52.64	49.12	53.25	51.67
Ca (meq/100kg)	34.29	35.13	34.18	34.53
K (meq/100kg)	1.32	1.21	1.35	1.29
Mg (meq/100kg)	14.87	13.43	14.06	14.12
Na (meq/100kg)	0.12	0.11	0.11	0.11

pH-Power of hydrogen; OC-Organic Carbon; TN-Total Nitrogen; av. P-Available Phosphorous; CEC-Cation Exchange capacity.

Effect of Tillage Methods with Mulching on Soil Chemical Properties after Harvest: Soil samples were taken from each plot after harvesting. Soil pH values, organic carbon (OC), total nitrogen (TN), available phosphorus (P) and exchangeable bases (Ca, Mg, K and N) were found to improve after harvest as indicated in Table 2 below. The result showed that soil pH was not statistically affected either by the main effect of varieties, tillage methods with mulches combination, or interaction of varieties of tillage methods and mulching combination. The average total nitrogen and organic carbon content of the soil were significantly influenced by the use of different tillage methods and mulching (Table 2). The highest total nitrogen (0.18%) and soil organic carbon (1.15 %) were obtained from the use of minimum tillage with mulch combination. Available P and exchangeable bases determined after harvesting were also found to improve although statistically non-significant. In general, the results indicate that integrated use of tillage methods and mulching with crop residue can result in significant improvement in the overall condition of the soil as well as the productivity of chickpeas.

Effect of Tillage Methods with Mulching on Yield and Yield Components of Chickpea: Analysis of variance indicated that the main effect of tillage with mulch as well as the interaction effect of varieties and tillage with mulch significantly ($P \leq 0.05$) influenced the number of pods per plant and seed per pod. However, the main effect of chickpea varieties did not significantly ($P \leq 0.05$) influence pod number per plant (Table 3) as well as seed number per pod (Table 4). The highest number of both pods per plant (44.07) and seeds per pod was respectively recorded from the combined application of Mastewal variety along with

Table 2: Mean soil analytical results after harvesting

Treatments	pH (H_2O)	TN (%)	OC (%)	Av. P (ppm)	K (meq/100g)	Mg (meq/100g)	Ca (meq/100g)	CEC (meq/100g)
ZT with mulch	6.36	0.17^{ab}	1.130^{ab}	11.70	1.43	16.70	32.87	54.31
ZT without mulch	6.42	0.15^{b}	1.10^{b}	11.48	1.36	16.37	31.95	54.41
MT with mulch	6.32	0.18^{a}	1.150^{a}	12.60	1.45	16.17	33.17	55.49
MT without mulch	6.38	0.16^{ab}	1.10^{b}	11.20	1.39	14.85	32.7	54.79
FP with mulch	6.40	0.16^{ab}	1.15^{a}	10.52	1.44	16.12	31.56	55.83
FP without mulch	6.42	0.15^{b}	1.10b	10.40	1.39	16.05	31.50	54.03
LSD (0.05)	NS	0.015	0.06	NS	NS	NS	NS	NS
CV (%)	1.2	7	4.3	8.3	6	6	4.5	2.9

Means in a column with different letters are significantly different at $p \leq 0.05$; ZT-Zero Tillage; MT-Minimum Tillage; FP - Farmer Practice; pH-Power of hydrogen; OC-Organic Carbon; TN-Total Nitrogen; av. P-Available Phosphorous; CEC-Cation Exchange capacity; LSD - Least Significant Difference; CV- Coefficient of Variation; NS-Non-Significant at $p \leq 0.05$.

Table 3: Interaction effect of tillage with mulching on the number of pods per plant

	Number of pods per plant	
Tillage with Mulching	Local	Mastewal
ZT and mulch	30.07^{cd}	32.13^{bcd}
ZT and without mulch	26.60^{d}	33.13^{bcd}
MT with mulch	35.33^{bc}	44.070^{a}
MZ without mulch	35.47^{bc}	33.87^{bcd}
FP with mulch	36.27^{bc}	38.40^{ab}
FP without mulch	30.70^{bcd}	28.67^{cd}
CV (%)	13.6	
LSD (0.05)	5.51	

Means in a column with different letters are significantly different at $p \leq 0.05$ZT - Zero tillage; MT - minimum tillage; FP - farmers practice; LSD - Least Significant Difference; CV- Coefficient of Variation.

Table 4: Interaction effect of tillage methods and mulching of seed per pods of chickpea

	Number of Seeds per pod	
Tillage with Mulching	Local	Mastewal
ZT and mulching	1.20^{b}	1.30b
ZT and without mulching	1.00^{b}	1.67^{a}
MT with mulching	1.67^{a}	2.00^{a}
MT without mulching	1.30^{b}	1.80^{a}
FP with mulching	1.67^{a}	2.00^{a}
FP without mulching	1.20b	1.30b
CV (%)	18	
LSD (0.05)	0.46	

Means in a column with different letters are significantly different at $p \leq 0.05$; ZT - Zero tillage; MT- Minimum Tillage; FP; Farmers Practice; LSD - Least Significant Difference; CV- Coefficient of Variation.

minimum tillage + wheat straw much and Mastewal variety + minimum tillage with straw much though statistically par with farmer practice with mulch when used with the same variety. The lowest value of both pods per plant (26.6) and number of seeds per pod (1.0) was obtained when local variety was used with zero tillage without mulch. The highest number of pods per plant obtained might be due to improvement in the overall condition of the soil and the availability of soil moisture as a result of mulching. In general, an improvement in the number of pods possessed by improved variety resulted from the moisture-utilizing capacity of the variety.

Results indicated that there exists a significant difference in the main effect of varieties and tillage method with mulch as well as between the interaction effect of varieties and tillage methods with mulch (Table 5). The highest biological yield (3158.10kgha^{-1}) was recorded from minimum tillage practice with mulch when used along with Mastewal variety while the minimum value (1623.81 kg ha^{-1}) was obtained from the plot that was treated with zero tillage with mulch and Mastewal variety. The improvement in biological yield under minimum tillage with mulch could be related to better moisture conserved by mulch and improvement in soil condition. Similarly, Simon *et al*. [34] reported that the soil tillage method can affect biological yield and other components of chickpeas as it influences most soil characteristics such as temperature, moisture distribution and soil density [35, 36]. Proper selection and implementation of an appropriate tillage system can provide suitable bedding for the seed [37] and ultimately lead to optimal yield [38].

Soil tillage techniques and mulching markedly influenced the grain yield of chickpea varieties. Results showed that the main effect of varieties and tillage method with mulch as well as the interaction effect of varieties and tillage methods with mulch significantly affected the grain yield of chickpeas (Table 6). The highest grain yield (2048.98 kg ha^{-1}) was recorded from minimum tillage practice with mulch when used along with Mastewal variety although statistically par with farmers' practice with much. However, the minimum value (909.19 kg ha^{-1}) was obtained from the plot that received local variety and zero tillage without mulch. This difference in grain yield might result from increases in pod per plant, seeds per pod and biological yield of the variety. On average, minimum tillage with mulch, compared to farmer practice,

Table 5: Interaction effect of tillage methods with mulching combination on biological yield

Tillage with Mulching	Biological yield (kgha^{-1}) Local	Mastewal
ZT and mulching	2347.31g	2070.97j
ZT and without mulching	1668.82k	1623.81l
MT with mulching	2634.41e	3158.10a
MZ without mulching	2080.65i	2628.47f
FP with mulching	2829.03c	2976.00b
FP without mulch	2286.02h	2650.54d
CV (%)	9.3	
LSD (0.05)	0.98	

Means in a column with different letters are significantly different at $p \leq 0.05$; ZT - Zero Tillage; MT- Minimum Tillage; FP - Farmers practice; LSD - Least Significant Difference; CV- Coefficient of Variation.

Table 6: Interaction effect of varieties and tillage methods with mulching on yield

Tillage with mulching	Grain yield (kgha^{-1}) Local	Mastewal
ZT and mulch	1050.08^{e}	1057.63^{e}
ZT and without mulch	909.19^{e}	1126.05^{de}
MT with mulch	1536.67^{b}	2048.98^{a}
MT without mulch	1139.00^{de}	1346.9^{bcd}
FP with mulch	1575.88^{b}	1829.54^{a}
FP without mulch	1179.11^{cde}	1401.83^{bc}
CV (%)	9.80	
LSD (0.05)	232.20	

Means in a column with different letters are significantly different at $p \leq 0.05$; ZT - Zero Tillage; MT - Minimum Tillage; FP - Farmers Practice; LSD - Least Significant Difference; CV- Coefficient of Variation.

allowed a 31.58 percent grain yield increase. This agreed with Bana and Prijono [39] who reported tillage and mulching had significantly increased grain and biological yield of crops. Several authors also showed the effect of different soil tillage practices such as minimum tillage with mulch and conventional tillage on the productivity of chickpeas and reported improvement in average grain yield recorded from minimum tillage than conventional tillage [40-42].

CONCLUSION AND RECOMMENDATIONS

The current study showed tillage methods with mulching combination have an important impact on soil physico-chemical properties and the production of chickpeas. The effects of tillage with mulch were more prominent in the chemical properties of the soil and the yield of chickpeas. Soil organic matter and total nitrogen were significantly influenced by a combination of tillage methods with mulching while other soil chemical parameters such as (pH, av. P, K, Ca and Mg) did not significantly change due to the use of tillage methods together with mulching. Similarly, yield and yield components of chickpeas are significantly influenced by the interaction effect of varieties and tillage methods with mulching combinations. Thus, maximum chickpea yield (2048.98 kg ha-$^{1)}$ was obtained from the interaction of improved variety and minimum tillage with mulching combination. It is, however, important to note that in designing sustainable agricultural production consider the characteristics of various resources like soil types, soil moisture and climatic conditions of the area. Therefore, the use of minimum tillage + mulching together with improved variety could be the best option for both enhancing soil condition and improving chickpea yield under vertisol conditions using residual moisture.

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