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Effect of Tillage Practices and Cropping Pattern on Soil Properties and Crop Yield in the Humid Lowlands of Beles Sub-Basin, Ethiopia

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Abstract: Tillage is a land management practice where a sequence of manipulating the soil for crop production. To investigate the response of land management and cropping pattern on soil properties and crop yield, a field experiment was conducted under natural environment on Nitisol of Pawi area. Nine treatments combining two tillage methods (Zero and conventional), four crop covers (continuous maize, continuous soya bean, rotated maize, and maize soya bean intercrop) were laid out in RCBD with three replications. The result showed that land management and crop cover significantly affect bulk density, porosity, soil moisture, nitrogen, organic carbon, available phosphorus, and yield of a crop. Relative to conventionally tilled continuous maize, maize soya bean intercropping managed under zero tillage improve capillary porosity, non-capillary porosity, organic carbon, available phosphorus, and total nitrogen with a response ratio of 1.7, 2.7, 1.3, 2, and 1.3, respectively while reducing bulk density by 10%. Conversion of tillage system from conventional to zero tillage improves grain yield, biomass yield, and soil moisture by 6%, 10%, and 6%, respectively. Generally, zero tillage with greater cover is an appropriate approach to improve soil properties without negatively affecting grain yield. To understand and quantify the long-term impact of tillage and crop cover on soil health and productivity in Ethiopia long-term study is needed as this study was based on one-year data from four years permanent plots.

Keywords: Bulk Density, Porosity, Soil Moisture, Tillage, Yield

1. Introduction

Maize (*Zea mays L.*) is most important food crop in Ethiopia, grown by small holder farmers which ranked second in area coverage and first in production [26]. Maize production generally used for food, and source of cash also its straw can be used as fuel, animal feed, and construction. The national average of maize production in Ethiopia was 39.92 quintal per hectare [26] mainly with traditional or conventional tillage system. Conventional tillage system can degrade the soil by disturbing important soil properties, which further affect crop production.

Conservation agriculture is a win-win management option in dry areas of Ethiopia that improves yield and soil properties [20]. A review of conservation tillage in the Ethiopian highlands indicates that the effect of tillage on soil properties were both spatially and temporally inconsistent [13]. Conservation tillage increased grain yield of maize up to 1.5t/ha [66], equal (non-significance) [47] relative to conventional tillage. Zero tillage with intercropping retained more nutrients than conventional [3]. Studies at Minjar and Alem Tena reported that the effect of tillage on Ethiopian teff yield was inconsistent [8]. Research report from Melkassa indicated that intercropping and monocropping of maize managed with conservation agriculture improve grain yield compared with conventional agriculture by 32% and 40%, respectively [43]. Beside this, almost all tillage research in Ethiopia was conducted in the humid highlands and dry areas of the region.

Depending on the time where tillage was conducted, soil and climate conditions of the site implementation of particular tillage affect soil properties [55]. Crop type also affects soil properties [17]. Therefore, the effect of zero tillage on soil physical and hydrological properties is either neutral or positive [23]. Meanwhile, the adoption of zero-tillage practice under permanent pasture improves soil physical and chemical properties and soil quality [36]. Continuous cereal-legume rotation managed with zero tillage favor soil hydrological properties than conventional tillage [31]. Generally, zero tillage cultivation with residue retention, crop rotation and nutrient management affect the soil physical, biological, and chemical properties [35].

Bulk density of the soil indicates the compaction or looseness of the soil and other soil physical properties. Soil physical properties are related to each other either positively or negatively. Soil compaction is an important parameter in evaluating soil loss and the hydrological response of re-vegetation [44] also an indicator of soil structure [63].

Porosity is an important soil parameter that indicates the air and water composition of the soil. Therefore, it affects infiltration, soil moisture content, or water holding capacity of the soil. Soil pore can be capillary or non-capillary pore. Capillary pores (pore size < 0.1mm) are those which filled their pores by water with the action of capillary force. Thus, it is responsible for water storage/retention. Non-capillary pores (pore size > 0.1mm) are those critical for water infiltration and transmission where soil water freely moves via the action of gravity and belongs to macropore [33].

Studies conducted in the rift valley of Ethiopia was reported that the amount of organic matter, available phosphorus and bulk density was greater under conservation tillage than conventional tillage [20].

Researchers conducted in Ethiopia also reported that zero tillage improves organic carbon [68, 48, 12, 20]. Conversion of conventional tillage to zero tillage under crop rotation system improves total nitrogen from low to medium range [20].

However, opposing trends were reported in the literature. Finding from central rift valley of Ethiopia revealed that zero tillage reduce maize yield ranged from 40-55% and also mulching improve maize grain yield ranged from 23% to 33% than no mulch [58]. Bulk density under zero tillage increased by 13% [37], 10% [27, 42], 7% [14] over conventional tillage.

The peoples lived in the lower and middle of Beles sub-basin practices shifting cultivation. Within the river sub-basin where Gumuz peoples are living, there is a frequent replacement of semi-natural vegetation by open cropland hence reduce carbon storage and aggravate soil erosion [53]. They practice zero tillage system and their main tool used for land clearing is *tiba* and fire. *Tiba* is their hoeing material where a blade is inserted approximately at an angle of 45°, which is unique worldwide. They use a sharpen iron fitted on a stick to open a hole and place the seeds. On the other hand, some parts of the area where the highlanders live, it is a very degraded area due to deforestation, animal intensification, mismanagement of land, and permanent cultivation system. But, the effect of land management practices in the study area like zero tillage were not studied [53]. Currently, conservation tillage i.e., no-till was introduced primarily to improve crop productivity sustainably via government and non-government organizations.

Therefore, this study examines the response of tillage practices and cropping pattern systems on soil properties and yield of crop focusing on the dominant cereal and pulse crops in Pawe area, Benishangul Gumuz Regional State. The objective of the study was to investigate the effect of land management and crop cover on soil properties and crop yield.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at the experimental site of Pawe Agricultural Research Center. Pawe District is located at a distance of about 565 Km from Addis Ababa in North-Western direction in Metekel zone of the Benishangul-Gumuz Regional State, Ethiopia. Geographically it is located between 11°18′40′′ and 11° 19′ 29′′ latitude and 36° 24′ 26′′ to 36° 25′ 27′′ longitudes (Figure 1). The site is geographically located in Beles River sub-basin within the great Abay Basin.

Based on long-term meteorological data gathered at Pawe Agricultural Research Center from 1987 to 2016, the mean annual rainfall is 1608.78mm and the mean annual minimum and maximum temperatures of the district are 16.7 and 32.6°C, respectively (Figure 2). The maximum temperature of the area rises up to 42°C. The area is characterized as a uni-modal rainfall pattern, extends from May to October with high rainfall in August. The climate of the area is characterized by warm sub-humid low lands. According to [15] by the end of the 21th century, global warming tends to slightly increase rainfall over the basin.

The elevation of the district ranges from 1000 to 1200 meters above sea level (masl) with slightly undulating from hill-tops towards 'Beles' river which is the economic growth corridor of Ethiopia [49]. Along the riverside, the slope is very undulating towards the waterway and flooding and waterlogging occur in most places where the slope is very flat. *'Ali Wenz', 'Chankur'* and '*Ketem*' rivers are tributaries of Beles main river. According to [45] geologically the study area comprises meta conglomerate and quartzite of the Precambrian basement complex where the geological formation of the area is characterized by Tulu Dimtu groups with tolalite, metabasalt, greenschist, marble and precious metals like gold. [32] Indicate that the dominant soil types are Vertisols (40 – 45% of the area), Nitisols, (25 – 30%), and Luvisols (25 – 30%) with the pH of subsurface soils is higher than surface soil (5.5 to 6.9).

Before the start of the national resettlement program in 1985, Pawe district was covered by natural forest which was dominated by lowland bamboo, Acacia, and Hyperenia species of grass. Since the beginning of resettlement, these forest covers are diminished due to deforestation for farmland, construction of settlement, fuelwood, and infrastructure.

The majority of the farming system is oriented towards grain production. Cereals and legume crops are the major crop production system in the district in which the major crops grown in the area are maize, sorghum, finger millet, rice, soybean, haricot bean, sesame, and groundnut. To improve soil fertility farmers practice crop rotation of cereal with a legume. Among all crop types, Sorghum (*Sorghum bicolor L. Moench)*, maize (*Zea mays*), sesame (*Sesamum indicum*), soya bean (*Glycine max*), and groundnut (*Arachis hypogaea*) are the most common crop species cultivated in the study area.

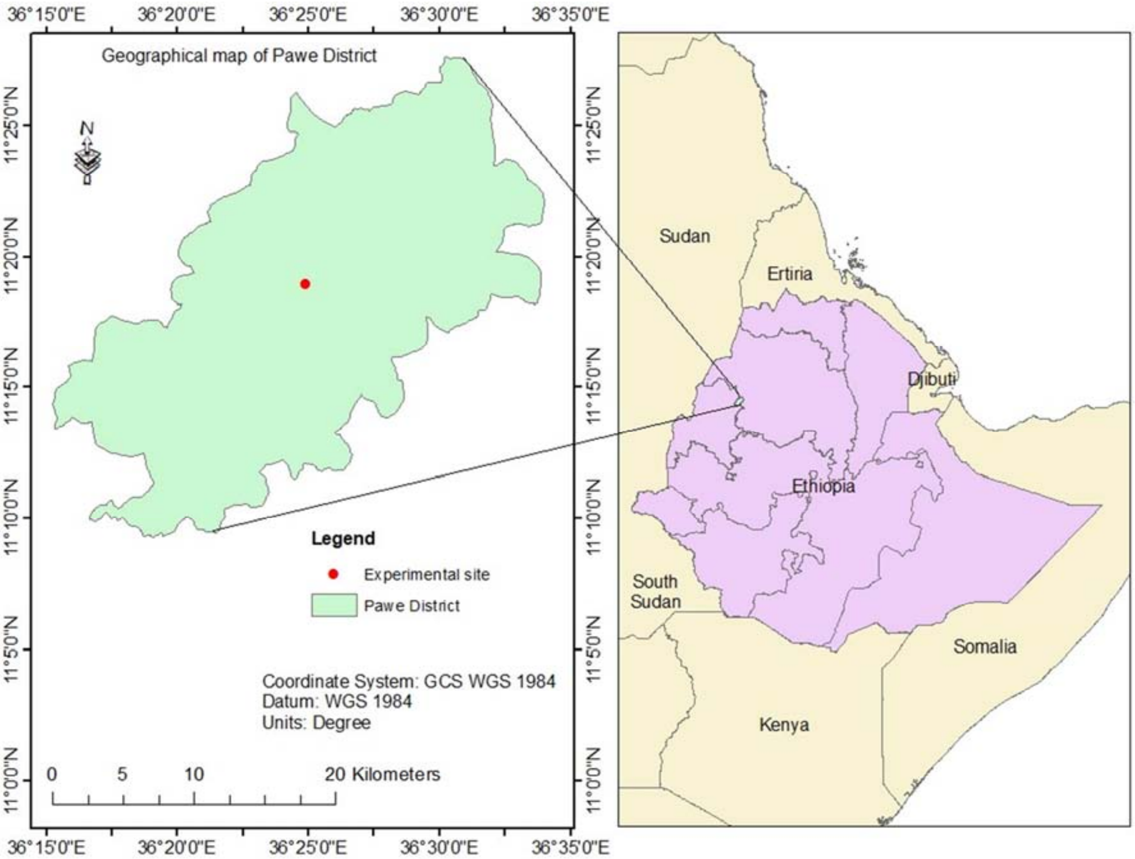

Figure 1. *Geographical map of Pawe District.*

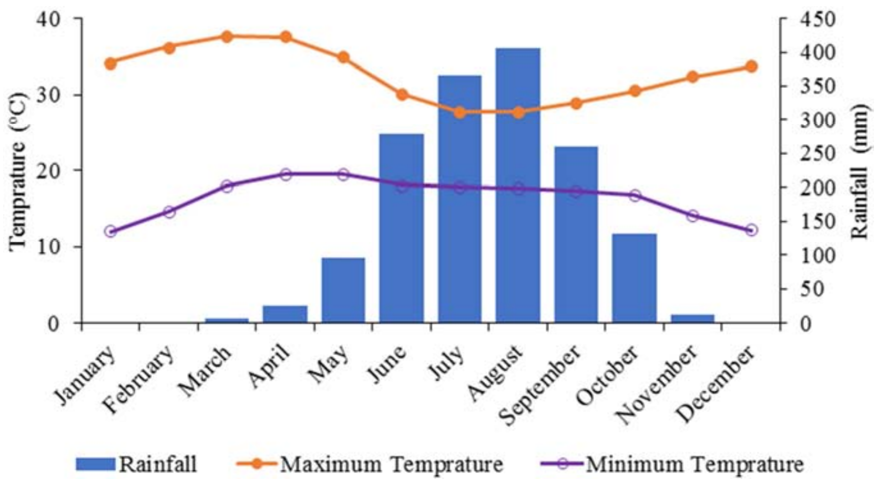

Figure 2. *Thirty years (1987-2017) mean monthly rainfall, the minimum and maximum temperature recorded at Pawe meteorological stations.*

2.2. Experimental Setup

A field experiment was conducted on permanent experimental plots established for conservation agriculture at Pawe research site. The current research takes the advantage of a four years old permanent plots managed with different tillage and cropping pattern practices. This was because [29] reported that before three years of operation, the effect of tillage on soil hydrological properties was not evident in different parts of the world. Studies in Ethiopia also indicates the significant effect of conservation agriculture on crop yield was observed after three years of implementation [9].

The experiment was conducted on permanent plots at the age of four from the start of implementation. The experiment consists of a factorial combination of two levels of tillage method (conventional and zero tillage) and four crop cover types (maize, soya bean, maize soya bean intercrop, and rotated maize). The experiment was arranged using a randomized complete block design. A total of twenty-four experimental run-off plots (8 treatments replicated three times) having 9.75m×6m dimensions were established within the experimental site of Pawe agricultural research center to measure its response on soil properties and crop yield [62, 2]. The spacing between plots was 1m while replication was 4m apart.

Treatments

1. Maize with Conventional Tillage
2. Maize with Zero Tillage
3. Intercropping of maize and soya bean with Conventional Tillage
4. Intercropping of maize and soya bean with Zero Tillage
5. Rotation of maize and soya bean with Conventional Tillage
6. Rotation of maize and soya bean with Zero Tillage
7. Soya bean with Zero Tillage
8. Soya bean with Conventional Tillage

Description of treatments

1) Conventional tillage (CT) for both maize and soya bean. A local tillage practice, where local farmers practiced in the study area, where they do at least two times tillage by oxen plow and remove the residues.
2) Zero tillage: no-tillage, no burning & total residues retained as mulch year-round.
3) Intercropping maize with soya bean: Maize was used as a main crop keeping an appropriate spacing while soya bean was sown in between the rows of maize.
4) Rotated maize: maize was cultivated on plots where previously cultivated with soya bean.

Maize (*BH 545*) and soya bean *(TGX)* varieties were used to test the effect of land management and crop cover on soil properties, and yield. The inter and intra row spacing of maize and soya bean crop were 75cm by 30cm and 60cm by 5cm, respectively. All treatment plots received blanket recommendation of DAP (100kg/ha) and Urea (100kg/ha) fertilizer for maize. Whereas, 100kg/ha DAP were applied for soya bean. Oxen plow was used to till conventional plots with two tillage frequency. These conventional plots were leveled using a rake to avoid waterlogging. Crops under zero-tillage plots were sown by opening holes to place the seeds via hoe which also used for agronomic management. Weeds under conventional tillage and after crop emergency in zero tilled plots were managed using labor. Glyphosate (roundup) was sprayed under zero tilled plots prior to emergency of crop.

2.3. Data Collection and Measurement

2.3.1. Soil Sampling and Measurements

The effect of tillage and crop cover on soil properties were studied by taking both disturbed and undisturbed soil samples from each plot. The sampling design of the soil sample was the X-shape method to address the plot area. The soil samples were collected from a depth of 20cm as it is the upper plow layer of the soil. Disturbed samples were collected using a soil auger and then air-dried and stored in plastic bags. These samples were carefully sealed, tagged, and labeled to avoid errors. Finally, these samples were transported to the laboratory with the parameters to be analyzed (Table 1).

Table 1. *Selected soil physical and chemical properties and method of analysis.*

Parameters	Method
Soil texture	Hydrometer method and then triangular textural classification
Bulk density (BD)	Undisturbed soil/core sample using Oven-dried mass of soil/Volume of sample
Soil organic carbon (C)	Walkley- black method
Total nitrogen (N)	Kjeldahl extraction method
Available Phosphorus (P)	Available Phosphorus (Bray-II).

Undisturbed samples were collected using cylinder cores to determine soil physical and hydraulic properties including bulk density (BD) using Equation 6, capillary porosity (CP) using Equation 7, non-capillary porosity (NCP) using Equation 8. In the laboratory, all these parameters were determined in a proper sequence [54]. First, the cylinder cores were dipped in 5 mm depth water to absorb water through capillary action for roughly 8hr before a constant weight reached; the corresponding weights were recorded as m1. Second, the cores were soaked in 4.8cm depth water for approximately 24hrs until saturated, and the respective weights were recorded as m2. Third, soil samples were put on dry sand for 48hr and the resulting weights were recorded as m3. Finally, the cores were subjected to oven-dried at 105°C for approximately 24hrs and the weights were recorded as m4. Then the parameters were calculated by the following formulas:

$$BD(\rho) = \frac{m4}{V} \tag{1}$$

$$CP = \frac{m2 - m4}{V} \tag{2}$$

$$NCP = \frac{m2 - m1}{V} \tag{3}$$

Where; V is the volume of the cylinder core (m^3).

2.3.2. Soil Moisture Content

The soil moisture content of the soil was measured according to ISO 11461: 2001 [24]. Soil moisture is significantly affected by tillage just after the end of the cropping cycle [5]. Therefore, soil moisture content after the harvest of maize and soya bean crop was undertaken. Soil core samples at 0-100cm with a 20cm interval were collected for soil moisture analysis just after harvesting. This was because of the rooting depth of maize is about 86cm [33, 52]. Even though there is a variety of methods for measuring soil moisture, measuring the weight of soil water called gravimetric soil moisture content is the only way which is used as a reference for other methods [52]. Therefore, moisture content of the soil in the study site was determined by laboratory/gravimetric method which is a standard method of soil water measurement by taking a physical sample of soil where the water lost via drying in an oven with a temperature of 105°C for 24hrs. As indicated in Equation 9 mass soil moisture content (%) was calculated from the sample weight taken using the core sampler. Then, the volumetric moisture content was obtained by multiplying the mass moisture content by corresponding bulk density [52, 24, 28, 41, 16, 1].

$$MC\ (\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (4)$$

Where:
W1=Weight of tin (g)
W2=Weight of moist soil + tin (g)
W3=Weight of dried soil + tin (g)

Soil water content at field capacity and permanent wilting point were determined by pressure plate method subjected to 3bar and 15bar, respectively. These were measured at Debre Zeyt Agricultural Research Centers` laboratory.

2.3.3. Agronomic Data

Sole maize, sole soya bean, maize soya bean intercropping, and rotated maize was sown via the recommended spacing between rows and among plants. Maize and soya bean crops were harvested from the net plot by leaving the border rows to see the effect of tillage and crop cover on maize and soya bean yield. The yield of crops was adjusted to a moisture content of 12% for maize and 12.5% for soya bean and converted to t/ha. The biomass of each crop was measured by air drying the harvested biomass for two days. Finally, land equivalent ratio (LER) was used to see yield advantages of intercrop over sole crop cultivation. The land equivalent ratio is a ratio of intercropped crop yield by the yield of the sole crop for each crop and finally summed the ratios (Equation 11).

$$LER = \frac{yield\ of\ intercroped\ maize}{yield\ of\ sole\ maize} + \frac{yield\ of\ intercropped\ soya\ bean}{yield\ of\ sole\ soya\ bean} \quad (5)$$

2.4. Method of Data Analysis

The collected data as per the objective of the study were managed with Microsoft excel and subjected to analysis of Variance (ANOVA) using SAS statistical package with PROC GLM procedure to compare the effects of land management and crop cover on yield and soil properties. Mean values were compared with list significance difference (LSD) at 5% level of rejection. Percent deviations (D in %) from the control plot or conventional tillage (CT) was calculated based on [10] (Equation 15).

$$D = \frac{Targeted\ treatment - Control\ treatment}{Control\ treatment} x100 \quad (6)$$

Where, the parameters are measured data (soil properties, grain yield, and biomass yield) obtained in zero tillage treatments while CT represents measured value in the conventional tillage treatment.

Whereas, the response ratio (RR) or relative values was calculated as measured data in target treatment divided by control treatment (Equation 16).

$$RR = \frac{Targeted\ treatment}{Control\ treatment} \quad (7)$$

3. Results and Discussion

3.1. Effect of tillage practice and Cropping Pattern on Soil Properties

3.1.1. Bulk Density

The effect of tillage practices on soil bulk density was statistically insignificant at 5% level of significance (Table 2). The highest bulk density (1.22g/cm^3) was recorded from continuous maize managed with conventional tillage followed by conventional soya bean (1.21 g/cm^3). Whereas, the lowest (1.1g/cm^3) were from continuous maize, rotated maize, and maize soya bean intercrop. Soil bulk density was lower under sole maize, maize soya bean intercropped and rotated maize managed with zero tillage practices than the same cropping pattern with conventional tillage practices. Zero tillage reduced bulk density in a range of 1% to 10%, relative to conventionally tilled continuous maize cropping practices. The highest reduction (10%) was due to zero tilled maize soya bean intercropping and continuous maize while the lowest (1%) were due to conventionally tilled soya bean. It could be concluded that conventional tillage with continuous cultivation of maize and soya bean facilitate soil compaction due to complete removal of residues.

Regardless of tillage, conversion of conventional tillage to zero tillage could reduce soil compaction by 0.6%, 1.7%, 7.4%, and 10.1% under rotated maize, maize soya bean intercropping, soya bean, and maize cultivation system. Generally, zero tillage reduced soil compaction by 5% as compared with conventional tillage system due to multiple benefit of zero tillage as it reduces surface crusting and allowing more water to be infiltrated. Whereas, crop cover affects bulk density in the order of maize soya bean intercrop=rotated maize < continuous maize < continuous soya bean. This could be inferred by maximum soil disturbance together with full residue removal reduce organic matter content and enhance surface crusting.

This is in agreement with the finding of other studies [40, 22]. In continuous maize and maize-soybean intercrop zero tillage reduced soil bulk density by 6% than conventional tillage [62]. As reported by [38, 5, 6, 4], zero tillage reduced soil bulk density and improved macro-porosity and organic matter than the conventional land management system. Besides this soil compaction increase at the deepest soil layer on fields managed with conventional tillage [18].

Table 2. *Effect of land management practices on soil physical properties.*

Treatments	Bd	CP	NCP	Porosity	Soil particle size (clay soil)		
					Sand	Silt	Clay
ZTMSI	1.10 (10)	0.58^{a} (17.5)	0.04^{a} (172.5)	0.61^{a} (22)	39.3	6.7	54
ZTRM	1.10 (9.6)	0.57^{a} (17)	0.02^{bc} (82.5)	0.60^{b} (19)	36.3	9	54.7
CTMSI	1.12 (10)	0.55^{b} (12.6)	0.01^{c} (7.5)	0.57^{c} (12)	38.7	10	51.3
ZTM	1.10 (10)	0.56^{ab} (14)	0.03^{ab} (132)	0.59^{b} (17)	34	9.33	56.7
CTRM	1.11 (9)	0.52^{c} (6.5)	0.01^{c} (7.5)	0.54^{d} (6.5)	40	11.3	48.7
ZTS	1.12 (8.4)	0.51^{cd} (3.4)	0.02^{c} (15)	0.52^{d} (3.7)	41.3	7.4	51.3
CTM	1.22 (--)	0.49^{de} (--)	0.01^{c} (--)	0.50^{e} (--)	44.67	8	47.33
CTS	1.21 (1)	0.48^{e} (-2.5)	0.02^{bc} (57.5)	0.50^{e} (--)	38.67	11	50.33
LSD (0.05)	ns	0.02	0.01	0.02	ns	ns	ns
CV (%)	3.83	1.99	28.28	1.79	12.63	26.25	10.09

Note: Means with the same latter are non-significant; Values in the parenthesis are percent improvement, CTM=Maize with conventional tillage, ZTM=Maize with zero tillage, CTMSI=Maize soya bean intercrop with conventional tillage, ZTMSI=Maize soya bean intercrop with zero tillage, CTRM=Rotated maize with conventional tillage, ZTRM=Rotated maize with zero tillage, ZTS=Soya bean with zero tillage, CTS=Soya bean with conventional tillage, CP=capillary pore, NCP=non-capillary pore, LSD=least significant difference, CV=coefficient variation, ns=non-significant.

Regarding the effect of cover crop/residue on bulk density, higher bulk density was reported on maize crop system than soya bean cropped fields [17]. Crop residue with tillage reduction improved soil organic matter and accelerate the formation of macro aggregate through an increase in microbial biomass content in soil [42]. Generally, both tillage management and cropping systems significantly affect soil compaction [22]. However, opposing trends were reported in the literature due to planting machines. Bulk density under zero tillage increased by 7% [14], 10% [27, 42], 13% [37] over the conventional tillage.

3.1.2. Porosity

As shown in Table 2, the volume of the capillary and non-capillary pores of maize soya bean intercrop and continuous maize cultivated plots under zero tillage were significantly higher than conventionally tilled continuous maize cultivated plots. Zero tillage with maize soya bean intercrop and continuous maize cultivation practices increases non-capillary and capillary pore volume by 2.72 and 2.32 times, and 17% and 14%, respectively relative to conventionally tilled continuous maize. The lowest capillary pore was observed from continuous maize (0.49) and soya bean (0.48) managed with conventional tillage whereas non-capillary pores (0.01) were from maize, rotated maize, and maize soya bean intercrop.

Generally, the total porosity of soil shows a 3% to 22% increment relative to conventionally tilled continuous maize and soya bean cultivation practices with the greatest improvement under zero tilled maize soya bean intercrop. The total pore volume was significantly highest in maize soya bean intercrop followed by continuous maize managed with zero tillage. The result was concomitant with other results. Zero tillage practice resulted in a significantly greater number of smaller pores but interconnected compared to conventional tillage [23, 22]. Crop rotation with zero tillage improves porosity [51, 31]. Even though total porosity is inconsistent, greater macropore connectivity was observed under zero tillage than conventional [60]. Generally, both tillage management and cropping systems significantly affect porosity [22].

3.1.3. Soil Moisture Content

The effect of land management and crop pattern on soil moisture is depicted in Figure 3. Soil moisture content, which was measured at crop harvesting, due to the conservation practices over different depths showed a similar trend except on the surface layer. At the surface layer, moisture content under continuous maize cultivation was within the range of plant available water which accounts for 14% and 73% under conventional and zero tillage, respectively. Soil moisture under the cereal-legume cultivation system was below the permanent wilting point at the surface layer. In the lower 20-40cm soil layer, plant-available moisture content stored in the soil due to land management and crop cover was ranged from 67% to 103% with the highest value in maize soya bean intercrop and lowest under soya bean both managed with conventional tillage. For deeper depths, the soil moisture is above the field capacity except for conventionally tilled rotated maize which was within the range of plant available water until a depth of 80cm and conventionally tilled soya bean until 60cm.

Regardless of the practices, soil moisture content increased as go deep till 100cm. The response of conservation practices to soil moisture was distinct for the top 40cm and below 40cm soil depths. For soil depths below 40cm, all cropping practices managed under zero tillage showed lower soil moisture compared to the same cropping practices under conventional tillage. The reverse was true for depths deeper than 40cm. Exceptionally, at all depths, soil moisture for sole soya bean, rotated maize and sole maize under conventional tillage was lower than for similar cropping under no-till practices. In terms of the cropping system, except for conventionally tilled rotated maize, maize cultivation improves moisture content than soya bean crop.

The distinction in soil moisture trends between the surface and sub-surface depths indicates the contribution of zero tillage and crop cover practices to enhance soil water availability at lower depths and able to tolerate stress conditions during dry spells. At the deepest layer, soil moisture was greater than field capacity in the range of 5% (conventionally tilled soya bean) to 18% (zero tilled maize soya bean intercrop). Zero tillage improved soil moisture on average by 6% than conventional tillage; 3%, 6%, 7% and 7% greater under maize soya bean intercrop, soya bean, rotated maize and sole maize cultivation. Thus, the cultivation of maize relatively improved soil moisture by 4.5% than soya bean cultivation. Generally, practicing zero tillage improves soil moisture than conventional tillage.

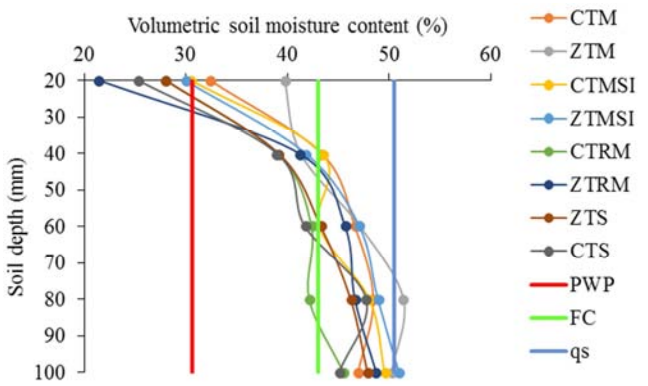

Figure 3. *Effect of land management and crop pattern on soil moisture trend.*

Note: CTM=Maize with conventional tillage, ZTM=Maize with zero tillage, CTMSI=Maize soya bean intercrop with conventional tillage, ZTMSI=Maize soya bean intercrop with zero tillage, CTRM=Rotated maize with conventional tillage, ZTRM=Rotated maize with zero tillage, ZTS=Soya bean with zero tillage, CTS=Soya bean with conventional tillage, FC=moisture content at field capacity, qs=moisture content at saturation and PWP=moisture content at permanent wilting point.

3.1.4. Organic Carbon

Soil organic carbon content was significantly affected by land management and cropping practices (Table 3). Soil organic carbon was lowest in conventionally tilled maize and highest in maize soya bean intercrop managed with zero tillage. Among the cropping practices, maize soya bean intercropping, rotated maize, continuous maize, and soya bean cultivation practices managed with zero tillage shows 32%, 23%, 13%, and 11% increase in OC relative to conventionally tilled maize cultivation practices.

Thus, zero tillage increase soil organic carbon by 15% relative to conventional tillage. On the other hand, under zero tillage maize soya bean intercrop, maize rotation, continuous maize, and continuous soya bean improve soil organic carbon content than conventional tillage system by 20%, 22%, 13%, and 11% respectively. This could be due to the removal of crop residues from conventionally managed plots. Regardless of crop cover, soil organic carbon was improved in the order of soya bean, maize, rotated maize, and maize soya bean intercrop. This implies intercropping and rotation of cereal with legume crop increase organic carbon due to the highest biomass and decomposition rate of legume crop like soya bean.

Table 3. *Effect of tillage practice and cropping pattern on soil chemical properties.*

Treatments	Available Phosphorus (ppm)	Soil organic carbon (%)	Total Nitrogen (%)
ZTMSI	4.36^{b} (0.94)	3.16^{a} (1.32)	0.24^{a} (1.27)
ZTRM	3.96^{b} (0.85)	2.94^{ab} (1.23)	0.22^{ab} (1.19)
CTMSI	7.08^{a} (1.52)	2.64^{bc} (1.10)	0.20^{bc} (1.09)
ZTM	4.82^{b} (1.04)	2.71^{bc} (1.13)	0.21^{bc} (1.11)
CTRM	4.36^{b} (0.94)	2.41^{c} (1.00)	0.19^{c} (1.00)
ZTS	4.49^{b} (0.97)	2.66^{bc} (1.11)	0.20^{bc} (1.09)
CTM	4.65^{b} (--)	2.40^{c} (--)	0.19^{c} (--)
CTS	3.30^{b} (0.71)	2.51^{c} (1.04)	0.20^{c} (1.08)
LSD (0.05)	2.19	0.39	0.02
CV (%)	26.98	8.22	6.25

Note: Means with the same letter are non-significant; Values in the parenthesis are response ratio relative to CTM; CTM=Maize with conventional tillage, ZTM=Maize with zero tillage, CTMSI=Maize soya bean intercrop with conventional tillage, ZTMSI=Maize soya bean intercrop with zero tillage, CTRM=Rotated maize with conventional tillage, ZTRM=Rotated maize with zero tillage, ZTS=Soya bean with zero tillage, CTS=Soya bean with conventional tillage, Pav=available phosphorus (ppm), OC=Organic carbon (%), TN=Total Nitrogen (%), LSD=least significant difference, CV=coefficient variation, ns=non-significant.

This result agrees with the findings from experiments done for four years [5] and eight years [39]. Soil organic matter was affected by tillage operation where higher organic matter content was observed under zero tillage [51, 7]. Studies from Zimbabwe indicate that the conservation system increased soil carbon by 31% over the conventional system [62]. Studies conducted in Ethiopia also reported that zero tillage improves organic carbon compared with conventional tillage [68] by 68% [48], 14% in northern Ethiopia [12], 33% in the rift valley of Ethiopia [20]. Generally, soil particles are glued together by soil organic carbon to enhance soil structure by forming a stable soil aggregate which improves soil water-holding capacity, aeration and infiltration of water [25].

3.1.5. Phosphorus and Nitrogen

Available phosphorus and nitrogen also affected due to treatment applications (Table 3). Available phosphorus under conventional tillage with maize soya bean intercropping was significantly highest and almost two-fold of conventionally tilled continuous soya bean cultivated plot. About 38% improvement of available phosphorus due to maize soya bean intercrop was observed under conventional tillage than zero tillage while the soya bean cultivation system reduces available phosphorus by 36%. Compared with zero tillage, about 9% improvement of available phosphorus was observed under conventional tillage. Cultivation of maize with zero tillage increases available phosphorus by 7% than zero tilled soya bean while conventionally tilled maize shows 41% improvement of available phosphorus compared with conventionally tilled soya bean. Regardless of crop cover, the concentration of available phosphorus was reduced in the order of maize soya bean intercrop, maize, rotated maize, and soya bean. Under similar management system cultivation of maize improved available phosphorus than soya bean. This indicates that a greater concentration of available phosphorus was lost with associated sediment or up taken by soya bean root.

Studies reported that zero tilled maize is effective in reducing the loss of absorbed phosphorus than conventional practice [56]. The concentration of available phosphorus was greater in the upper soil layer ranged from 5cm to 15cm [39] and below 10cm of conventional tillage than zero tillage [21]. Continuous tillage with minimum soil disturbance improves the availability of phosphorus for maize roots, increase abundance of phosphorus fraction, and increase the activity of alkaline phosphate [67]. Thus, the uptake of available phosphorus by maize was improved due to a continuous zero tillage method.

Since total nitrogen is directly related to organic matter content (Table 3), it was affected by land management and cropping pattern and follows the same trend. The highest total nitrogen was observed from the maize soya bean intercropped plot managed with zero tillage. Compared with conventionally tilled continuous maize, crop covers managed with zero tillage improved total nitrogen by 27%, 20%, 11%, and 9.3% under maize soya bean intercropping, rotated maize, maize, and soya bean. Whereas, conventionally tilled maize soya bean intercrop and soya bean improve the concentration of total nitrogen by 8.6% and 7.9% respectively. With similar crop cover, conversion of management practice from conventional to zero tillage improved total nitrogen by 17%, 10.7%, 10.7%, and 9.3% under maize soya bean intercrop, rotated maize, maize, and soya bean, respectively. The residues left on the ground surface of untilled plots could further be decomposed to improve soil nitrogen. Generally, zero tillage improves total nitrogen by 12% relative to conventional tillage. But, regarding the crop covers the concentration of total nitrogen was similar (0.2) which indicates crop cover did not affect soil total nitrogen.

The result was concomitant with research reported from Ethiopia where conservation tillage increases total nitrogen over conventional practice [68] by 42% [12]. Studies also showed the level of nitrogen was changed from low to medium due to the conversion of conventional tillage to conservation tillage in the central rift valley wherein the conventional tillage system remains low [20]. Regarding crop covers, cultivation of maize-legume rotation improves the availability of phosphorus and total nitrogen that minimizes the application of fertilizers by improving soil health [65].

3.2. Effect of Land Management on Biomass and Grain Yield

3.2.1. Maize Crop Biomass and Grain Yield

Table 4 depicts the effect of tillage practice and crop pattern on biomass and grain yield of maize (*Zea mays*.). The biomass of maize ranged from 6.7 to 9.99 t/ha while grain yield ranged from 3.93 to 6.8 t/ha. The highest biomass yield (9.99t/ha) and grain yield (6.8t/ha) were recorded from conventionally tilled maize soya bean intercrop which was tailed by zero tilled intercropped. Whereas, the lowest grain yield (3.93t/ha) and biomass yield (6.71t/ha) were recorded from conventionally tilled continuous sole maize cultivated plot. The largest yield benefit (73%) was recorded from conventionally tilled maize soya bean intercrop tailed by zero tilled maize soya bean intercrop (65%), zero tilled maize soya bean rotation (45%), conventionally tilled maize soya bean rotation (41%), and zero tilled continuous maize (19%) over conventionally tilled continuous maize.

Table 4. Effect of tillage practice and cropping pattern on maize yield.

Treatments	Biomass yield t/ha	Grain yield t/ha
Intercropped with conventional tillage	9.99[a]	6.80[a]
Intercropped with zero tillage	8.40[ab]	6.50[a]
Rotated with zero tillage	8.92[ab]	5.72[ab]
Rotated with conventional tillage	9.08[ab]	5.54[ab]
Sole with zero tillage	7.47[bc]	4.69[bc]
Sole with conventional tillage	6.71[c]	3.93[c]
CV (%)	10.85	15.60
LSD (0.05)	16.63	15.70

CV=coefficient of variation, LSD=Least significant difference.

On average, grain yield of treatments managed with zero tillage had a 6% yield advantage over conventional tillage with a slight grain yield penalty (-4%) on maize soya bean intercrop and 19% yield advantage on sole maize. Compared with continuous maize; grain yield of maize soya bean intercrop and rotation outperformed by 39% and 22% on plots managed with zero tillage similarly by 73% and 41% under conventional management.

Biomass yield of maize from conventionally tilled continuous maize treatment was significantly lower than biomass yield of conventionally tilled maize soya bean intercrop, conventionally tilled rotated maize, zero tilled rotated maize and zero tilled maize soya bean intercrop by 49% and 35%, 33% and 25%, respectively. Relative to conventionally tilled continuous sole maize cultivation, the grain yield was increased by 65%, 19%, 45%, 41%, and 73% higher due to zero tilled intercrop, zero tilled sole maize, zero tilled rotated, tilled rotated and tilled intercropped plots, respectively (Figure 4).

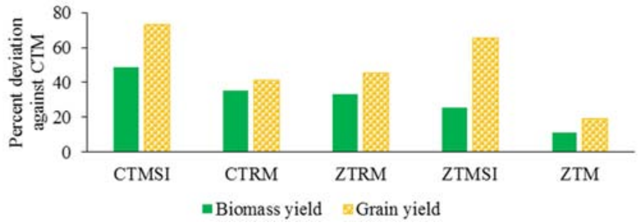

Figure 4. Biomass and grain yield deviation from CTM.

Note: CTM=Maize with conventional tillage, ZTM=Maize with zero tillage, CTMSI=Maize soya bean intercrop with conventional tillage, ZTMSI=Maize soya bean intercrop with zero tillage, CTRM=Rotated maize with conventional tillage, ZTRM=Rotated maize with zero tillage, ZTS=Soya bean with zero tillage, CTS=Soya bean with conventional tillage.

Generally, zero tillage had a 6% grain and 10% biomass yield advantage over conventional tillage. Weed density is suppressed by residues retained under zero tillage system [58, 57] and due to intercropping [68]. This implies continuous sole maize cultivation reduces grain and biomass yield due to lowered soil surface nutrient and relatively higher absorbed nutrient loss. On the other hand, conventionally tilled continuous sole maize cultivated field were recorded with greater surface runoff and soil loss. The higher grain yield under conventionally tilled maize soya bean intercrop was due to a relatively higher phosphorus content of the soil.

3.2.2. Soya Bean Crop Biomass and Grain Yield

The grain yield and biomass yield of soya bean (*Glycine max L.*) were highly influenced by land management and cropping pattern at a 5% level of significance (Table 5). The lowest biomass and grain yield were observed from conventionally tilled maize soya bean intercropped plot while the highest were recorded from conventionally tilled continuous sole soya bean cultivated plots. as shown in table 5 both grain and biomass yield were greatly reduced due to intercropping whereas sole soya bean has 95% and 75% yield advantage, grain yield and biomass yield respectively. This was because of the shading effect of maize on intercropped soya bean. Intercropping, especially in zero tillage, were greatly reduce surface runoff and soil loss due to its beneficial effect as surface cover where it did not negatively affect the yield of soya bean. Biomass and grain yield of zero tilled intercropped soya bean was almost two times that of conventionally tilled. Zero tillage was better for improving soil nutrient due to crop residues left on the surface.

Table 5. *Effect of land management and cropping pattern on soya bean yield.*

Treatments	Above-ground biomass yield Quintal/ha	Grain yield Quintal/ha
Sole Soya bean with conventional tillage	59.72[a]	18.20[a]
Sole Soya bean with zero tillage	52.18[a]	17.63[a]
Intercropped soya bean with zero tillage	17.26[b]	5.35[b]
Intercropped soya bean with conventional tillage	11.51[b]	2.44[b]
CV	16.66	20.10
LSD	11.705	4.3895

CV=coefficient of variation, LSD=Least significant difference.

But, the cultivation of intercrop over monoculture is determined by land equivalent ratio and values greater than one indicates the advantage of intercrop against the sole. Thus, the land equivalent ratio under conventional tillage (1.86) and zero tillage (1.7) indicates the cultivation of maize soya bean intercrop was advantageous than their sole crop cultivation.

A study in Gedarif, Sudan showed that zero tillage in the second season gave higher grain yield of sorghum (*Sorghum bicolor L. Moench*) crop compared with conventional practice [50]. Zero tillage integrated with green/legume manure was effective in improving soil properties and maximize crop yield under the rice-wheat system of Bangladesh [6]. A 28 years study at Nebraska under rainfed condition indicates that corn grain yield greatly influenced by crop rotation then tillage system where its response was inconsistent [59]. Grain yield of zero tilled soya bean was consistently higher and stable after an 11 year-lag period that crop rotation has a significant impact [59]. A study from 15-year age of implemented zero tillage, maize incorporated management i.e., continuous maize and maize-soya bean rotation improves yield production [34]. A research report from silty loam soil (Albic Luvisol) of Zagreb, Croatia indicates that the yield of maize crop was greater with zero tillage management than conventional tillage system [24]. Generally, zero tillage improves the yield of both maize and soya bean as compared with the conventional system hence greater economic return [19].

Whereas, studies from the humid highland of Ethiopia reported that conventional tillage with sufficient residue increases the yield of wheat [2]. Grain and biomass yield in different crop type managed with zero tillage were higher relative to conventional practice [61, 30, 11, 2, 66, 10]. A study at Melkassa, rift Valley reported that conventional systems increase grain yield by 7% [43], 28% [46] relative to conventional practice. In addition to this, zero tilled sole maize had a yield advantage over similarly managed crops with conventional tillage systems [68, 46]. Generally reduced tillage with maize soya bean intercrop is the best alternative for resource-poor farmers [64].

4. Conclusion

Appropriate soil management strategies such as conservation tillage and crop cover having maximum cover has the capacity in reducing the degradation rate of the soil and reducing runoff generation. A field experiment under the natural environment was undertaken during the cropping season (June – November) of 2018 on Nitisol of Pawi Agricultural Research Center research station for studying the response of land management on hydrological properties of the area.

The results obtained from a permanent plot of field experiment showed that tillage and cropping system slightly improve soil properties by applying zero tillage practice continuously over four years. This implies a residue left on the surface of soil due to zero tillage has tremendous importance to enhancing the hydrological properties of soil. The result indicates that zero tillage with increased cover crop i.e., intercropping improved capillary porosity, non-capillary porosity, soil organic matter content and the moisture content of the soil. Moreover, zero tillage increased available phosphorus and total nitrogen by 2 and 1.3-fold, respectively. Application of zero tillage with maize soya bean intercropping increased the capillary pore by 17% over conventional tilled maize, which intern in, increase soil water holding capacity. While an increase in non-capillary pores by 2.7-fold improved infiltration of water to the soil. Thus, application of zero tillage with greater cover has environmental benefit in reducing the loss of plant nutrients and allowing more water to infiltrate and stored in the soil profile which can be available for plants later on. On the other hand, loss of soil organic carbon due to tilled plots allows the vulnerability of erosion by losing the slaking resistance.

Besides tillage and crop cover significantly influenced soil properties, susceptibility to erosion and runoff production, its effect on maize crop productivity was significant. Conventionally tilled with greater cover had a 73% grain yield advantage over tilled maize. Whereas, intercropped soya bean greatly reduced its yield while almost half yield was recorded from continuous cultivation over zero tilled. Hence, maize-legume cultivation greatly increased the yield of maize. Since the study was undertaken in the fourth year of implementation it does not indicate the long-term effect of tillage and cropping on soil properties and yield of crops. Therefore, to figure out the long-term impact of tillage and cropping pattern on soil properties and crop yield in Ethiopia a long-term study is needed by strategically establishing monitoring plots.

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References

[1] Abu-Hamdeh, N. H. 2004. "The Effect of Tillage Treatments on Soil Water Holding Capacity and on Soil Physical Properties." In *13th International Soil Conservation Organisation Conference*, 1–6. Brisbane, Australia: Conserving Soil and Water for Society: Sharing Solutions.

[2] Adimassu, Zenebe, Getachew Alemu, and Lulseged Tamene. 2019. "Eff Ects of Tillage and Crop Residue Management on Runoff, Soil Loss and Crop Yield in the Humid Highlands of Ethiopia." *Agricultural Systems* 168. Elsevier: 11–18. doi: 10.1016/j.agsy.2018.10.007.

[3] Adugna, Obsa, Shoeb Quarishi, and Bobe Bedadi. 2017. "Effects of Water Erosion on Soil Chemical Loss under Different Tillage and Cropping System in Clay Loam Soil at Assosa, Ethiopia." *Journal of Bioscience and Agriculture Research* 14 (02): 1222–1230. https://doi.org/10.18801/jbar.140217.150.

[4] Akinbile, Christopher O, Olanipo A Famuyiwa, Fidelis O Ajibade, and Toju E Babalola. 2016. "Impacts of Varying Tillage Operations on Infiltration Capacity of Agricultural Soils." *International Journal of Soil Science* 11 (2): 29–35. doi: 10.3923/ijss.2016.29.35.

[5] Alam, Khairul, Monirul Islam, Nazmus Salahin, and Mirza Hasanuzzaman. 2014. "Effect of Tillage Practices on Soil Properties and Crop Productivity in Wheat-Mungbean-Rice Cropping System under Subtropical Climatic Conditions." *The Scientific World Journal* 2014.

[6] Alam, Khairul, N Salahin, S Islam, R A Begum, M Hasanuzzaman, M. S. Islam, and M. M. Rahman. 2017. "Patterns of Change in Soil Organic Matter, Physical Properties and Crop Productivity under Tillage Practices and Cropping Systems in Bangladesh." *Journal of Agricultural Science* 155: 216–238. doi: 10.1017/S0021859616000265.

[7] Alberts, E E, R. C Wendt, and R. E Burwell. 1985. "Corn and Soybean Cropping Effects on Soil Losses and C Factors." *Soil Science Society of America Journal* 49: 721–728.

[8] Almaz, Meseret Gezahegn, Tafes Desta Bizuwork, Takele Abuhay, and Eshetu Sisay. 2019. "Productivity of Tef [Eragrostis Tef] under Conservation Tillage Practices in Central Ethiopia." *Cogent Food & Agriculture* 5 (1). Cogent. doi: 10.1080/23311932.2019.1707038.

[9] Araya, Tesfay, W. M Cornelis, J Nyssen, B Govaerts, H Bauer, Tewodros Gebreegziabher, Tigist Oicha, et al. 2011. "Effects of Conservation Agriculture on Runoff, Soil Loss and Crop Yield under Rainfed Conditions in Tigray, Northern Ethiopia." *Soil Use and Management* 27: 404–414. doi: 10.1111/j.1475-2743.2011.00347.x.

[10] Araya, Tesfay, Wim M Cornelis, Jan Nyssen, Bram Govaerts, Fekadu Getnet, Hans Bauer, Kassa Amare, Dirk Raes, Mitiku Haile, and Jozef Deckers. 2012. "Medium-Term Effects of Conservation Agriculture Based Cropping Systems for Sustainable Soil and Water Management and Crop Productivity in the Ethiopian Highlands." *Field Crops Research Jou* 132: 53–62. doi: 10.1016/j.fcr.2011.12.009.

[11] Araya, Tesfay, Jan Nyssen, Bram Govaerts, Jozef Deckers, and Wim M Cornelis. 2015. "Impacts of Conservation Agriculture-Based Farming Systems on Optimizing Seasonal Rainfall Partitioning and Productivity on Vertisols in the Ethiopian Drylands." *Soil & Tillage Research* 148. Elsevier B. V.: 1–13. doi: 10.1016/j.still.2014.11.009.

[12] Araya, Tesfay, Jan Nyssen, Bram Govaerts, Jozef Deckers, Rolf Sommer, Hans Bauer, Kindeya Gebrehiwot, and Wim M Cornelis. 2016. "Seven Years Resource-Conserving Agriculture Effect on Soil Quality and Crop Productivity in the Ethiopian Drylands." *Soil & Tillage Research* 163. Elsevier B. V.: 99–109. doi: 10.1016/j.still.2016.05.011.

[13] Asmamaw, Desale Kidane. 2014. "Conservation Tillage Implementation under Rainfed Agriculture: Implication for Soil Fertility, Green Water Management, Soil Loss and Grain Yield in the Ethiopian Highlands." *International Journal of Agricultural Sciences* 4 (9): 268–280.

[14] Bachchan, Ravi Kalam, Shah Satyendra, and Vallabhbhai Singh. 2018. "Soil Physical Properties under Zero and Conventional Tillage Systems for a Rice Wheat Cropping System." *Int. J. Soil. Sci. Agron.* 5 (2): 167–178.

[15] Barnes, J. 2017. "The Future of the Nile: Climate Change, Land Use, Infrastructure Management, and Treaty Negotiations in a Transboundary River Basin." *Wiley Interdisciplinary Reviews: Climate Change* e449 (8): doi: 10.1002/wcc.449.

[16] Black, C. A. 1965. *Methods of Soil Analysis: Part I Physical and Mineralogical Properties*. Madison, Wisconsin, USA: American Society of Agronomy.

[17] Blanco-Canqui, Humberto, Clark Gantzer, Stephen H Anderson, and E. E. Alberts. 2004. "Tillage and Crop Influences on Physical Properties for an Epiaqualf." *Soil Science Society of America Journal*, no. July 2014. doi: 10.2136/sssaj2004.5670.

[18] Bogunovic, Igor, Paulo Pereira, Ivica Kisic, Krunoslav Sajko, and Mario Sraka. 2018. "Tillage Management Impacts on Soil Compaction, Erosion and Crop Yield in Stagnosols (Croatia)." *Catena* 160. Elsevier: 376–384. doi: 10.1016/j.catena.2017.10.009.

[19] Buah, Saaka Samuel Jeduah, Hashim Ibrahim, Mavis Derigubah, Martin Kuzie, James Vuuro Segtaa, Jules Bayala, Robert Zougmore, and Mathieu Ouedraogo. 2017. "Tillage and Fertilizer Effect on Maize and Soybean Yields in the Guinea Savanna Zone of Ghana." *Agriculture & Food Security* 17 (6). BioMed Central: 1–11. doi: 10.1186/s40066-017-0094-8.

[20] Burayu, Worku, Sombat Chinawong, Rungsit Suwanketnikom, Thongchai Mala, and Sunanta Juntakool. 2006. "Conservation Tillage and Crop Rotation: Win-Win Option for Sustainable Maize Production in the Dryland, Central Rift Valley of Ethiopia." *Kamphaengsaen Acad. J.* 4 (1): 48–60.

[21] Calegari, Ademir, Tales Tiecher, William L Hargrove, Ricardo Ralisch, Daniel Tessier, Stéphane de Tourdonnet, Maria de Fátima Guimarães, and Danilo Rheinheimer dos Santos. 2013. "Long-Term Effect of Different Soil Management Systems and Winter Crops on Soil Acidity and Vertical Distribution of Nutrients in a Brazilian Oxisol." *Soil and Tillage Research* 133: 32–39. doi: 10.1016/j.still.2013.05.009.

[22] Capowiez, Yvan, Stéphane Cadoux, Pierre Bouchant, Stéphane Ruy, Jean Roger-Estrade, Guy Richard, and Hubert Boizard. 2009. "The Effect of Tillage Type and Cropping System on Earthworm Communities, Macroporosity and Water Infiltration." *Soil & Tillage Research* 105: 209–216. doi: 10.1016/j.still.2009.09.002.

[23] Castellini, Mirko, Francesco Fornaro, Pasquale Garofalo, Luisa Giglio, Michele Rinaldi, Domenico Ventrella, Carolina Vitti, and Alessandro Vittorio Vonella. 2019. "Effects of No-Tillage and Conventional Tillage on Physical and Hydraulic Properties of Fine Textured Soils under Winter Wheat." *Water* 484 (11). doi: 10.3390/w11030484.

[24] Copec, K, D Filipovic, S Husnjak, I Kovacev, and S Kosutic. 2015. "Effects of Tillage Systems on Soil Water Content and Yield in Maize and Winter Wheat Production." *Plant Soil Environment* 61 (5): 213–219. doi: 10.17221/156/2015-PSE.

[25] Corsi, Sandra, and Hafiz Muminjanov. 2019. *Conservation Agriculture: Training Guide for Extension Agents and Farmers in Eastern Europe and Central Asia*. Rome: FAO.

[26] CSA. 2019. *Area and Production of Major Crops: Private Peasant Holdings, Meher Season*. Vol. I. Addis Ababa, Ethiopia.

[27] Dam, R. F, B. B Mehdi, M. S. E Burgess, C. A Madramootoo, G. R Mehuys, and I. R Callum. 2005. "Soil Bulk Density and Crop Yield under Eleven Consecutive Years of Corn with Different Tillage and Residue Practices in a Sandy Loam Soil in Central Canada." *Soil & Tillage Research* 84: 41–53. doi: 10.1016/j.still.2004.08.006.

[28] Dangolani, Saied Khajeh, and M C Narob. 2013. "The Effect of Four Types of Tillage Operations on Soil Moisture and Morphology and Performance of Three Varieties of Cotton." *European Journal of Experimental Biology* 3 (1): 694–698.

[29] Dick, W. A., R. J. Roseberg, E. L. McCoy, W. M. Edwards, and F. Haghiri. 1989. "Surface Hydrologic Response of Soils to No-Tillage." *SOIL SCI. SOC. AM. J.* 53: 1520–1526.

[30] Erkossa, T, K Stahr, and T Gaiser. 2005. "Effect of Different Methods of Land Preparation on Runoff, Soil and Nutrient Losses from a Vertisol in the Ethiopian Highlands." *Soil Use and Management* 21: 253–259. doi: 10.1079/SUM2005319.

[31] Feng, G, B Sharratt, and F Young. 2011. "Influence of Long-Term Tillage and Crop Rotations on Soil Hydraulic Properties in the US Pacific Northwest." *Journal of Soil and Water Conservation* 66 (4): 233–241. doi: 10.2489/jswc.66.4.233.

[32] Franco, A. 1992. "Resettlement and Rural Development in Ethiopia and Economic Research and Technical Assistance in the Beles Valley." *Poolo Dieci and Calavdio Viezzolieds, Milano, pp. 67-71.*

[33] Gao, Yang, Aiwang Duan, Xinqiang Qiu, Zugui Liu, Jingsheng Sun, Junpeng Zhang, and Hezhou Wang. 2010. "Distribution of Roots and Root Length Density in a Maize/Soybean Strip Intercropping System." *Agricultural Water Management* 98 (1). Elsevier B. V.: 199–212. doi: 10.1016/j.agwat.2010.08.021.

[34] Gharahassanlou, Amin Nouri. 2017. "Long-Term Impact of Tillage and Cropping Managements on Soil Hydro-Physical Properties and Yield." University of Tennessee, Knoxville.

[35] Govaerts, Bram, and Antonio Castellanos-Navarrete, eds. 2008. *Compendium of Deliverables of the Conservation Agriculture Course 2008*. Mexico, D. F.: CIMMYT. www.cgiar.org.

[36] Guo, X. W., W. G. D. Fernando, and M. Entz. 2005. "Effects of Crop Rotation and Tillage on Blackleg Disease of Canola." *Canadian Journal of Plant Pathology* 27 (1): 53–57. doi: 10.1080/07060660509507193.

[37] Haruna, Samuel I., Stephen H. Anderson, Nsalambi V. Nkongolo, and Syaharudin Zaibon. 2017. "Soil Hydraulic Properties: Influence of Tillage and Cover Crops." *Pedosphere: An International Journal* 160. Soil Science Society of China: 1–23. doi: 10.1016/S1002-0160(17)60387-4.

[38] He, Jin, Qingjie Wang, Hongwen Li, J N Tullberg, A D Mchugh, Yuhua Bai, Xuemin Zhang, Neil Mclaughlin, Huanwen Gao, and Qingjie Wang. 2009. "Soil Physical Properties and Infiltration after Long - Term No - Tillage and Ploughing on the Chinese Loess Plateau." *New Zealand Journal of Crop and Horticultural Science* 37 (3): 157–166. doi: 10.1080/01140670909510261.

[39] Hussain, I, K R Olson, and S A Ebelhar. 1999. "Long-Term Tillage Effects on Soil Chemical Properties and Organic Matter Fractions." *SOIL SCI. SOC. AM. J.* 63: 1335–1341.

[40] Jabro, J D, W B Stevens, W M Iversen, and R G Evans. 2010. "Tillage Effects on Bulk Density and Hydraulic Properties of a Sandy Loam Soil in the Mon-Dak Region, USA." In *19th World Congress of Soil Science, Soil Solutions for a Changing World*, 2008–2011. Brisbane, Australia: DVD.

[41] Kováč, K, M Macák, and M Švančárková. 2005. "The Effect of Soil Conservation Tillage on Soil Moisture Dynamics under Single Cropping and Crop Rotation." *Plant Soil Environment* 51 (3): 124–130.

[42] Kushwaha, Chandra Prakash, Shri Kant Tripathi, and K P Singh. 2001. "Soil Organic Matter and Water-Stable Aggregates under Different Tillage and Soil Organic Matter and Water-Stable Aggregates under Different Tillage and Residue Conditions in a Tropical Dryland Agroecosystem." *Applied Soil Ecology* 13: 229–241. doi: 10.1016/S0929-1393(00)00121-9.

[43] Liben, Feyera, Solomon Jemal Hassen, Hae Koo Kim, and Mekonnen Kidane. 2017. "Conservation Agriculture for Maize and Bean Production in the Central Rift Valley of Ethiopia." *Agronomy Journal* 109 (6): 1–10. doi: 10.2134/agronj2017.02.0072.

[44] Liu, Yu, Bojie Fu, Yihe Lü, Zhi Wang, and Guangyao Gao. 2012. "Hydrological Responses and Soil Erosion Potential of Abandoned Cropland in the Loess." *Geomorphology* 138. Elsevier B. V.: 404–414. doi: 10.1016/j.geomorph.2011.10.009.

[45] Mengesha Refers, Tewodros Charente and Workineh Haro. 1996. *Explanation of the Geological Map of Ethiopia.* 2nd edition. Institute of Geological Survey, Addis Ababa, Ethiopia.

[46] Merga, Feyera, and Hae Koo Kim. 2014. *Potential of Conservation Agriculture Based Maize-Common Bean System for Increasing Yield, Soil Moisture, and Rainfall-Use Efficiency in Ethiopia*. Mexico, D. F.

[47] Mesfine T, Abebe G, Abdel-Rahman M Al-T. 2005. "Effect of Reduced Tillage and Crop Residue Ground Cover on Yield and Water Use Efficiency of Sorghum (Sorghum bicolor (L.) Moench) Under Semi-Arid Conditions of Ethiopia." *W. J. Agric. Sci., 1 (2): 152-160.*

[48] Minase, N A, M M Masafu, A E Geda, and A T Wolde. 2016. "Impact of Tillage Type and Soil Texture to Soil Organic Carbon Storage: The Case of Ethiopian Smallholder Farms." *African Journal of Agricultural Reaserch* 11 (13): 1126–1133. doi: 10.5897/AJAR2014.9233.

[49] MoFED. 2007. Ministry of Finance and Economic Development. PASDEP Annual Progress Report 2006/07, Building on Progress: A Plan for Accelerated and Sustained Development to End Poverty. Addis Ababa, Ethiopia.

[50] Mohamed, Hassan Ibrahim, Adil Bashir Karrar, Haitham Ragab Elramlwai, Amir Bakhit Saeed, and Atif Elsadig Idris. 2012. "Performance of Soil Moisture Retention and Conservation Tillage Techniques as Indicated by Sorghum (Sorghum Bicolor L. Moench.) Yield and Yield Components." *Global Journal of Plant Ecophysiology* 2 (1): 31–43.

[51] Mtyobile, Mxolisi, Lindah Muzangwa, and Pearson Nyari Stephano Mnkeni. 2020. "Tillage and Crop Rotation Effects on Soil Carbon and Selected Soil Physical Properties in a Haplic Cambisol in Eastern Cape, South Africa." *Soil and Water Research* 15: 47–54.

[52] Novák, Viliam, and Hana Hlaváčiková. 2019. *Applied Soil Hydrology*. Vol. 32. doi: 10.1007/978-3-030-01806-1.

[53] Nyssen, J., Fetene Fikre, Dessie Mekete, Alemayehu Getachew, Sewnet Amare, Wassi Alemayehu, Kibret Mulugeta, et al. 2018. "Persistence and Changes in the Peripheral Beles Basin of Ethiopia." *Regional Environmental Change, in Press*, 1–57.

[54] Pan, Tao, Shuai Hou, Shaohong Wu, Yujie Liu, Yanhua Liu, Xintong Zou, Anna Herzberger, and Jianguo Liu. 2017. "Variation of Soil Hydraulic Properties with Alpine Grassland Degradation in the Eastern Tibetan Plateau." *Hydrol. Earth Syst. Sci.* 21: 2249–2261. doi: 10.5194/hess-21-2249-2017.

[55] Rhoton, F. E. 2000. "Influence of Time on Soil Response to No-till Practices." *Soil Science Society of America Journal* 64 (2): 700–709. doi: 10.2136/sssaj2000.642700x.

[56] Richardson, C W, and K W King. 1995. "Erosion and Nutrient Losses From Zero Tillage on a Clay Soil." *J. Agric. Engng. Res.* 61: 81–86.

[57] Serna, J de la. 2015. "The Effect of Conservation Agriculture Management Practices on Weed Abundance, Weed Diversity and Wheat Growth in the Mexican Highlands." Ku Leuven. http://www.academia.edu/download/50185389/Thesis_Juan_de_la_Serna.pdf.

[58] Sime, G, J B Aune, and H Mohammed. 2015. "Agronomic and Economic Response of Tillage and Water Conservation Management in Maize, Central Rift Valley in Ethiopia." *Soil & Tillage Research* 148. Elsevier B. V.: 20–30. doi: 10.1016/j.still.2014.12.001.

[59] Sindelar, Aaron J, Marty R Schmer, Virginia L Jin, Brian J Weinhold, and Gary E Varvel. 2015. "Long-Term Corn and Soybean Response to Crop Rotation and Tillage." *Agronomy Journal* 107 (6): 2241–2252. doi: 10.2134/agronj15.0085.

[60] Strudley, Mark W, Timothy R Green, and James C Ascough II. 2008. "Tillage Effects on Soil Hydraulic Properties in Space and Time: State of the Science." *Soil & Tillage Research* 99: 4–48. doi: 10.1016/j.still.2008.01.007.

[61] Temesgen, M, W B Hoogmoed, J Rockstrom, and H H G Savenije. 2009. "Conservation Tillage Implements and Systems for Smallholder Farmers in Semi-Arid Ethiopia." *Soil & Tillage Research* 104: 185–191. doi: 10.1016/j.still.2008.10.026.

[62] Thierfelder, Christian, Stephanie Cheesman, and Leonard Rusinamhodzi. 2012. "A Comparative Analysis of Conservation Agriculture Systems: Benefits and Challenges of Rotations and Intercropping in Zimbabwe." *Field Crops Research* 137. Elsevier B. V.: 237–250. doi: 10.1016/j.fcr.2012.08.017.

[63] Thurow, T. L., W. H. Blackburn, and C. A. Taylor. 1986. "Hydrologic Characteristics of Vegetation Types as Affected by Livestock Grazing Systems, Edwards Plateau, Texas." *Journal of Range Management* 39 (6): 505–509. doi: 10.2307/3898758.

[64] Tsegay, Alemtsehay, Asmeret Kidane, Girmay Tesfay, Girmay Kahsay, Berhanu Abrha, and Jens B. Aune. 2018. "Reduced Tillage and Intercropping as a Means to Increase Yield and Financial Return in the Drylands of Tigray, Northern Ethiopia: A Case Study under Rainfed and Irrigation Conditions." *Momona Ethiopian Journal of Science (MEJS)* 10 (2): 221–239.

[65] Uzoh, Ifeyinwa Monica, Charles Arizechukwu Igwe, Chinyere Blessing Okebalama, and Olubukola Olularanti Babalola. 2019. "Legume-Maize Rotation Effect on Maize Productivity and Soil Fertility Parameters under Selected Agronomic Practices in a Sandy Loam Soil." *Scientific Reports* 9 (8539): 1–9. doi: 10.1038/s41598-019-43679-5.

[66] Welderufael, Worku, and Pieter Le Roux. 2009. "Quantifying Rainfall-Runoff Relationships on the Mieso Hypo Calcic Vertisol Ecotope in Ethiopia Quantifying Rainfall-Runoff Relationships on the Melkassa Hypo Calcic Regosol Ecotope in Ethiopia." *Water SA* 35: 639–648. doi: 10.4314/wsa.v35i5.49189.

[67] Xomphoutheb, Thidaphone, Shuai Jiao, Xinxin Guo, Frank Stephano Mabagala, Biao Sui, Hongbin Wang, Lanpo Zhao, and Xingmin Zhao. 2020. "The Effect of Tillage Systems on Phosphorus Distribution and Forms in Rhizosphere and Non-Rhizosphere Soil under Maize (Zea Mays L.) in Northeast China." *Scientific Reports, Natureresearch* 10 (6574). doi: 10.1038/s41598-020-63567-7.

[68] Zerihun, Abebe, Birhanu Tadesse, Tadesse Shiferaw, and Degefa Kifle. 2014. "Conservation Agriculture: Maize-Legume Intensification for Yield, Profitability and Soil Fertility Improvement in Maize Belt Areas of Western Ethiopia." *International Journal of Plant & Soil Science* 3 (8): 969–985.