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Soil Management and Crop Practice Effect on Soil Water Infiltration and Soil Water Storage in the Humid Lowlands of Beles Sub-Basin, Ethiopia

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Abstract: To investigate the response of soil management and cropping practice on infiltration, a field experiment was conducted under natural environment on Nitisol of Pawi area. Eight treatments combining two soil management methods (Zero tillage and conventional tillage) and four crop covers (continuous maize, continuous soya bean, rotated maize, and maize soya bean intercrop) were laid out on permanent plots in a randomized complete block design (RCBD) with three replications. The results showed that soil management and crop cover significantly affect both the capacity and rate of infiltration. Relative to conventionally tilled continuous maize, zero tilled maize soya bean intercrop improved infiltration rate and infiltration by 164.6% and 148%, respectively. While maize rotation with zero tillage, maize soya bean intercropping with conventional tillage and maize with zero tillage methods improve infiltration rate by 117.8%, 105.8%, 108%, respectively. The soil management and crop cover practices such as maize with zero tillage, maize soya bean intercrop with zero tillage, rotated maize with conventional tillage, maize soya bean intercrop with conventional tillage, soya bean with zero tillage and rotated maize with zero tillage increased soil water storage in the order of 65mm, 41mm, 41mm, 35mm, 15mm and 13mm. Generally, zero tillage with greater cover is an appropriate method to improve infiltration and soil water storage.

Keywords: Infiltration, Tillage, Crop Pattern, Soil Water, Land Preparation

1. Introduction

Infiltration is the process by which water reaches the surface of the soil and enters the soil body. From the amount of water that reaches the surface of soil about 75% enters to soil [32] which is either evaporates from the soil, used up by plants and transpired, stored in the soil column, or continues deeper to recharge groundwater. Infiltration is the process of water entry from above ground to the subsurface, thus a quantitative understanding of this process under different management techniques is vital to relate subsurface and surface process in describing the hydrologic cycle [16]. Infiltration rate is the velocity of water entering the soil surface while infiltration capacity is the maximum rate at which soil is capable of absorbing water in any condition. Soil is a container that stores water to be available for plants that make basic soil state characteristics. Soil water content can be expressed as a ratio of the volume of water and soil volume called volumetric soil water content or as a ratio of the mass of water in the soil and mass of dry soil contained the water called mass soil water content [39]. Thus, volumetric soil water content gives the direct expression of water that filled the soil pores and most commonly [39]. The soil moisture content at the plot level can be affected by the type of crop, time since wetting, gravel content, bulk density, macro porosity, plant spacing, run-on and runoff area, antecedent moisture, and soil texture. Water can be stored in the soil profile and taken up by crops depending on their root development. Thus, the amount of water stored in the soil column is highly dependent on the water requirement of crops and soil depth.

The residual water content of zero tillage is greater than conventional practice that implies a greater micro pores and water retention [18, 24, 38, 13, 14, 41, 29]. Besides this, the entry of air is also greater in a no-tillage system that indicates a need for more time to unsaturated [18]. Relative to hoe tillage zero tillage significantly improves volumetric water content by improving soil physical properties [27]. Generally, plant available water is greater under zero tillage throughout the soil profile with a significantly higher in the top 15cm layer [19], 30cm soil layer [24]. Thus, during the early part of the growing season zero tillage can maintain soil water storage in the upper profile [50] which is within the plant root depth to be up taken by the plants and avoid climate shock.

Zero tillage with residue retention increase soil moisture relative to conventional tillage system [48]. Mung bean residue incorporation with zero tillage improves the moisture conservation of the soil profile by improving porosity, organic matter, root mass density and available water content with reduced bulk density [3]. This implies the application of leguminous plants as residue retention can maintain soil moisture by improving soil physical properties.

Rotation of maize-wheat-maize and maize-wheat-soya bean combined with zero tillage and residue retention improve soil moisture due to soil porosity improvement [38]. Continuous soya bean and corn and production of their rotation improve the moisture content of the top 15cm soil layer of zero tillage system [19]. Thus, rotation of cereal-legume crop managed with zero tillage and residue retention improve soil moisture content even in deeper soil layer [21]. [26] reported that an additional 150 m^3 /ha of water can be stored in the soil for each percent increase in soil organic matter. Surface mulches and improved soil pore structure reduce evaporation while increasing infiltration and absorption capacity. These benefits contribute to aquifer recharge and make more water available for crops by reducing the risk of erosion and flooding during heavy rains.

The pattern and rate of infiltration vary with the depth of the water table, the hydraulic properties of the subsurface materials, the distribution and rate with which water is supplied at the ground surface, and the antecedent moisture content [16]. Thus, soil management practices like tillage systems affect the infiltration of water due to its influence on other soil properties like soil bulk density, porosity, soil aggregate, and soil moisture content. Tillage management and crop residues retention are known to impact soil properties that affect water infiltration [27]. As time goes on infiltration rate decreases which indicates the duration of water application and infiltration rate are directly related to each other for all tillage systems [2, 24, 3]. A global meta-data analysis by [9] indicates that no-tillage consistently increase the infiltration rate in a humid environment or when combined with residue retention. Hence, the effect of zero tillage on infiltration improvement is supported by residue retention and the environment where it is implemented. On the other hand, it is also recognized that mechanical breakdown of the surface crust by tillage has little long-impact on increasing infiltration as a few rainfalls that create a surface crust can soon destroy the effect of tillage [42].

Entrainment of residue on the soil surface of zero-tillage permits to infiltrate a greater amount of rainfall by reducing surface crusting [15, 48, 37, 20]. Similarly, tillage combined with cover crop increase infiltration and reduce runoff due to a greater proportion of macro pore [23]. It was reported that cultivation of continuous soya bean and their rotation improves the initial infiltration rate and cumulative infiltration than continuous maize under zero tillage cultivation system [19]. Corn crop lower saturated hydraulic conductivity as compared with soya bean [11].

Currently, conservation tillage is practiced in the area. Zero tillage is practiced mainly by the lowlanders (Gumuz peoples). They practice zero tillage system and their main tool used for planting and hoeing is *tiba*. where a blade is inserted approximately at an angle of 45^o, which is unique worldwide. They use a sharpened 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. Thus, conservation tillage i.e., no-till was introduced primarily to improve crop productivity sustainably via government and non-government organizations. Therefore, the ability of soil to infiltrate water and stored in the soil profile is an important parameter in hydrologic design as it was inversely related with surface runoff. Once the water is infiltrated, it can be stored in the soil profile and further utilized by plants. Nevertheless, the effect of land management and crop cover combinations on infiltration and soil water storage were never studied in the study area [40]. Therefore, this study assumed to fill this gap using a permanent experimental site. The objective of this paper was to quantify the effect of different land management methods and crop covers on soil water infiltration and soil water storage.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at the experimental site of Pawe Agricultural Research Center. The site is geographically located in Beles River sub-basin within Abay Basin. 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” longitude (Figure 1).

Based on long-term data gathered at Pawe Agricultural Research Center from 1987 to 2016, the long term mean annual rainfall is 1608.78mm and the mean annual minimum and maximum temperatures of the district are 16.7 and 32.6^0C, respectively (Figure 2). The maximum temperature of the area rises up to 42°C. The area is characterized by a uni-modal rainfall pattern, extends from May to October with peak rainfall in August. The climate of the area is characterized by warm sub-humid low lands. According to [8] by the end of the 21th century, global warming tends to slightly increase rainfall over the basin.

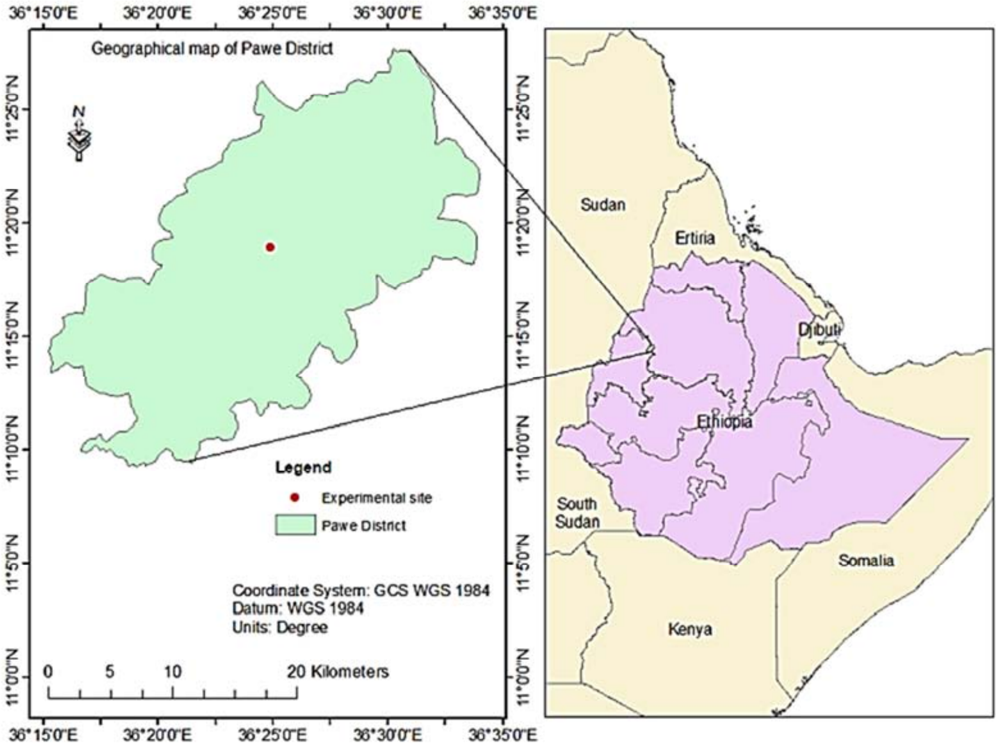

Figure 1. *Geographical map of Pawe District.*

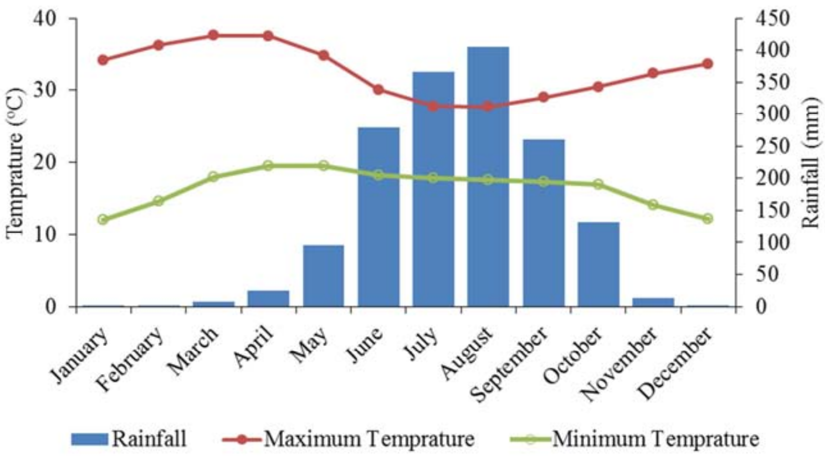

Figure 2. *Thirty years (1987-2017) mean monthly rainfall, minimum and maximum temperature recorded at Pawe meteorological station.*

The elevation of the district ranges from 1000 to 1200 meters above sea level (masl) with slightly undulating from hill-tops towards 'Beles' river [36]. 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 [34] 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. [17] indicate that the dominant soil types are Vertisols, 40 to 45% of the area, Nitisols, 25 to30%, and Luvisols, 25 – 30%. 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 types cultivated in the study area.

2.2. Experimental Setup

A field experiment was conducted on permanent 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 [15] reported that before three years of operation, the effect of tillage on soil hydrological properties was not evident. The rate of infiltration that water enters the soil was affected by tillage system after 11 months of operation [49].

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 plots (8 treatments replicated three times) having 9.75 m× 6m dimensions were established within the experimental site of Pawe agricultural research center to measure infiltration and soil water storage. The spacing between plots and replications was 1m and 4m. The prescriptions of the treatments were:

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
9) Description of treatments

Conventional tillage (CT) for both maize and soya bean. A local tillage practice, where local farmers used and plough pulled by pair of oxen and they do at least two times tillage and remove the residues.

Zero tillage represents no-tillage, no burning and total residues retained as mulch year-round.

Intercropping maize with soya bean represents an intercropping of maize as a main crop keeping an appropriate spacing while soya bean was sown in between the rows of maize.

Rotated maize represents crop rotation when maize was cultivated on plots where previously cultivated with soya bean.

2.3. Measurements of Infiltration

Infiltration measurements were made by ponding water in a double ring infiltrometer [7, 4, 19]. Infiltration of the soil was estimated by recording the water level of the inner cylinder and time taken to be lowered using the falling head method. So, the effect of land management practice and cropping systems on infiltration i.e., infiltration rate and infiltration capacity were estimated.

The scientific procedures followed to measure infiltration were: First appropriate site was selected within the plot. Then, double ring of 30cm inner diameter and 60cm outer diameter were driven into the ground using a hammer at 15cm depth. The soil was pushed gently back, after setting was over, to prevent water loss along the sides. To measure water level a measuring scale was put within the inner cylinder. A plastic sheet was placed at the bottom of the inner ring before pouring water into it to minimize scouring. The outer ring was filled with water to a depth of 15cm while, the inner cylinder filled with water at the same depth and the plastic sheets was then removed. Finally, the initial gauge reading of the water surface level was recorded (15cm). Records of the gauge reading at the periodic intervals were taken. After time T a quantity of water at which greater water dropped below the initial level was added to refill at the first water level. Measurement was continued till the rate of infiltration become relatively constant.

After obtained the data, a functional relationship between the depth of water infiltrated and time elapsed was obtained by computing time interval with a corresponding depth of water infiltrated from successive readings. Then the cumulative infiltration was computed.

2.4. Soil Water Storage

Soil water storage was calculated using the soil moisture content of each soil layer by adopting equations by [45] (Equation 1).

$$W = \sum_{i=1}^{n} (d_i \times \rho_i \times w_i) \times 10 \quad (1)$$

Where:

W=soil water storage in mm

d_i=depth interval for soil samples; unit

ρ=soil bulk density, unit

w_I =soil gravimetric water content, unit the subscript *i* refers to soil layers and

n=number of soil layers.

The moisture content of the soil was measured according to ISO 11461: 2001 [13]. Soil moisture was significantly affected by tillage just after the end of the cropping cycle [3]. 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 93cm [10] where a significant change in soil moisture could be observed [39]. 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 [39]. 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 24hr (Equation 2).

$$MC\ (\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad (2)$$

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

2.5. 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 infiltration rate and soil water storage. Mean values were compared with list significance difference (LSD) at 5% level of rejection. Percent deviations (D in %) from the conventional tillage (CT) was calculated based on [6] (Equation 3).

$$D = \frac{Targeted\ treatment - Control\ treatment}{Control\ treatment} x100 \qquad (3)$$

Where, the parameters are measured data of infiltration and soil water storage obtained in zero tillage treatments while CT represents measured value in the conventional tillage treatment. Whereas, the response rate (RR) was calculated as measured data in target treatment divided by control treatment (Equation 4).

$$RR = \frac{Targeted\ treatment}{Control\ treatment} \qquad (4)$$

3. Results and Discussion

3.1. Infiltration Capacity

Table 1 presents the effect of tillage management and cropping systems on infiltration capacity. The response of tillage and cropping management practices on infiltration capacity was significant. The effect of continuous cultivation of maize on infiltration capacity was significantly lower (57.87 cm) than other treatments. Since there were no residues left on the surface, the continuous maize cultivation practice would probably have the potential of surface sealing and crusting that alter infiltration. Whereas, the highest infiltration capacity (143.3 cm) was recorded in maize soya bean intercropping with zero tillage. This is due to improved soil physical properties where the residue of both crops was retained on the surface year-round.

Table 1. *Effect of soil management and cropping system on infiltration.*

Treatments	Infiltration capacity (cm)	% Increase	Response Ratio (RR)
ZTMSI	143.30[a]	147.64	2.48
ZTRM	117.50[b]	103.05	2.03
CTMSI	112.00[b]	93.54	1.94
ZTM	110.09[b]	90.25	1.90
CTRM	105.40[bc]	82.14	1.82
ZTS	90.37[cd]	56.16	1.56
CTS	80.27[d]	38.71	1.39
CTM	57.87[e]	--	--
LSD (0.05)	18.09		
CV (%)	10.12		

Note: Means with the same letter are not significantly different; ZTMSI=Maize soya bean intercrop with zero tillage, ZTRM=Rotated maize with zero tillage, CTMSI=Maize soya bean intercrop with conventional tillage, ZTM=Maize with zero tillage, CTRM=Rotated maize with conventional tillage, ZTS=Soya bean with zero tillage, CTS=Soya bean with conventional tillage, CTM=Maize with conventional tillage, LSD=least significant different, CV=coefficient of variation

The higher the positive deviation indicates the higher the effectiveness in infiltrating water to the soil. As shown in Figure 3 percent deviation in most zero tillage treatments show that a 5.3 hours cumulative infiltration depth was higher compared with conventional practices. The lowest percent deviation (38.7%) was from conventionally tilled continuous sole soya bean cultivated plot. This implies conventionally tilled continuous sole soya bean cultivation enhance infiltration rate of water to the soil and reduce surface runoff than conventionally tilled sole maize. The highest percent deviation (147.6%) was recorded in no-tilled maize soya bean intercropping practice. This shows that intercropping of maize and soya bean under zero tillage system enhance more water infiltration thereby reduce the production of surface runoff. Therefore, cultivation of multiple crops providing greater biomass and cover can greatly improve infiltration of water to be stored in the soil which further utilized by plants or percolate to recharge ground water thereby reducing loss of water as surface runoff.

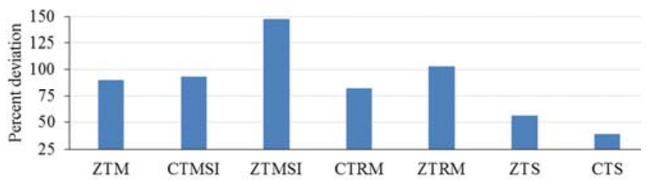

Figure 3. *Percent deviation of cumulative infiltration from maize with conventional tillage.*

Note: CT=conventional tillage, ZT=zero tillage, MSI=maize soya bean intercropping, RM=rotated maize, M=maize, S=soya bean

Compared with conventionally managed maize, the capacity of water infiltration within 5.3 hours was 39, 56, 82, 90, 94, 103, and 148% higher under soya bean with conventional tillage, soya bean with zero tillage, rotated maize with conventional tillage, maize with zero tillage, maize soya bean intercropping with conventional tillage, rotated maize with zero tillage, and maize soya bean intercropping with zero tillage, respectively (Figure 3). Thus, the order of magnitude of infiltration capacity was 1.39, 1.56, 1.82, 1.9, 1.94, 2.03, and 2.48-fold compared to the conventionally managed maize cultivation practice.

Regarding the cropping cover, the capacity of infiltration on maize soya bean intercropping, rotated maize and soya bean was improved by 52%, 33%, and 2% relative to maize cultivation. On the other hand, zero tillage increased volume of infiltrated water over conventional tillage by 90%, 28%, 11%, and 13% under maize, maize soya bean intercropping, rotated maize, and soya bean cropping systems, respectively. Thus, conversion of conventional tillage (89 cm) to zero tillage (115 cm) improved the capacity of water infiltration on average by 30%.

However, inconsistent results have been observed when maize and soya bean crops are managed with zero tillage and conventional practices. Maize and soya bean cropping systems have shown a similar effect on infiltration capacity, however, maize under zero tillage practice significantly improved infiltration capacity relative to the soya bean cover crops. The reverse was true under conventional tillage practices. This implies that maize cultivation can improve infiltration under zero tillage as higher residues left as surface cover while soya bean enhances infiltration when practicing a conventional tillage system. The effect of tillage practices on cumulative infiltration was not significantly different ($P<0.05$) under soya bean crop cover while it was significant under maize crop cover where maize residue likely leads to improvement of porosity and organic matter content thereby reducing bulk density.

3.2. Infiltration Rate

The response of tillage and cropping management practices on infiltration rates was significant at $P<0.05$ (Table 2). The effect of continuous cultivation of maize on infiltration rate, i.e., average infiltration rate (11.59 cm h^{-1}) was significantly lower than other land management practices. The infiltration rate obtained on continuous maize cultivation was significantly lower (-52%) compared to maize cultivation with zero tillage. Whereas, the highest average infiltration rate (30.67 cm h^{-1}) was recorded in maize soya bean intercropping managed under zero tillage. The higher infiltration rate on intercropping under zero tillage management compared to the continuous cultivation is attributed to higher porosity (capillary and non-capillary) and organic matter content and lowered soil bulk density where the residue of both crops was retained on the surface year-round.

A separate analysis was carried out on the sub-set of the practices that compare four cover crop/cropping practices grouped by conventional and zero-tillage practices. This reveals that the mean infiltration rate response of all four cover crops with zero tillage was on average 24.6 cm h^{-1} compared to 8.4 cm h^{-1} measured from the same cover crops managed with conventional tillage. This shows that the zero tillage treatments had nearly 34% higher infiltration rate than conventional practices. Indirectly, the response ratio shows that the infiltration rates of the four cover crops managed under zero tillage were on average 1.34 (ranges between 1.12 and 2.08) times greater than the conventional tillage.

Table 2. *A response ratio of the four cropping practices managed with conventional and zero tillage on the average infiltration rate.*

Cover crops	Tillage practices		Response ratio (RR)
	Conventional	Zero-tillage	
Maize soya bean intercropping	23.85^{b}	30.67^{a}	1.29
Maize under rotation	21.68^{bc}	25.25^{b}	1.16
Maize	11.59^{e}	24.10^{b}	2.08
Soya bean	16.34^{d}	18.30^{cd}	1.12
Average	18.4	24.6	1.34
LSD (0.05)	3.69		
CV (%)	9.81		

Note: Means with the same letter are not significantly different, CV=coefficient of variation, LSD=Least significant difference

Comparison of four crop cover practices managed with zero tillage revealed that infiltration rate was increased in the order of continuous soya bean (18.31 cm h^{-1}), continuous maize (24.1 cm h^{-1}), maize with crop rotation (25.25 cm h^{-1}), and maize soya bean intercropping (30.67 cm h^{-1}). Cover crops managed with conventional tillage provided similar trend of infiltration rate like the zero tillage, where the rate is lower in the order of continuous maize (11.59 cm h^{-1}), continuous soya bean (16.34 cm h^{-1}), maize with crop rotation (21.68 cm h^{-1}) and maize soya bean intercropping (23.85 cm h^{-1}). Change in infiltration rate (initial minus final) also follows almost the same trend as infiltration capacity with the highest record under zero tilled maize soya bean intercrop (52.33 cm h^{-1}) and lowest from conventionally tilled maize crop (8.71 cm h^{-1}). This indicates that, regardless of the tillage management practices, intercropping of maize with soya bean followed by maize under rotation can greatly improve the steady-state infiltration rate. Among the continuous crop cover practices, the average infiltration rate of continuous maize cropping was 1.8 times higher than soya bean due to the higher rooting ability of maize.

Overall, as shown in Figure 4, relative to the conventional maize cultivation practice (as a control), the alternative tillage and cover crop practices increased infiltration rates by 164.6%, 117.8%, 105.8%, 108%, 87%, 58%, and 41%, respectively for maize soya bean intercropping with zero tillage, maize rotation with zero tillage, maize soya bean intercropping with conventional tillage, maize with zero-tillage, maize rotation with conventional tillage, soya bean with zero tillage, and soya bean with conventional tillage. It implies that the response ratio (i.e. it is a ratio of infiltration rate of conservation practice to control practice) increased by a factor of 1.4 to 2.65.

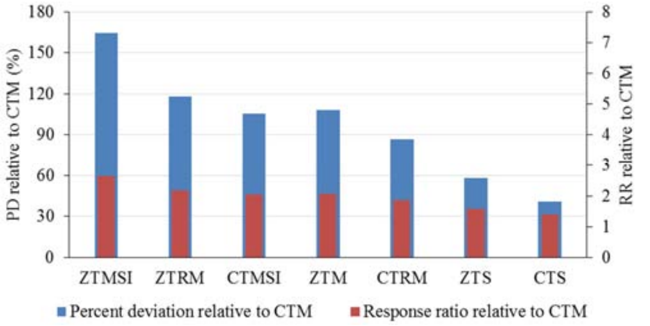

Figure 4. *Percent deviation of infiltration rate relative to maize managed with conventional tillage.*

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

The rate of initial infiltration was higher under zero tilled maize soya bean intercropping practice where sharply decrease as time goes on till 3 hours (Figure 5). The next higher initial infiltration rate till 3 hours duration was observed on zero tilled practices for sole maize, maize under rotation under both tillage systems, and maize soya bean intercropping with conventional tillage. Soya bean managed under both tillage systems recorded lower initial infiltration rate whereas the smallest and gradually decreasing infiltration rate was observed under conventionally tilled maize cultivation practice (Figure 5). However, after 3 and 1/2hours duration, a greater final infiltration rate was measured in most of the cover crops managed with zero tillage practice plus the maize soya bean intercropping under conventional practice.

The highest and lowest final infiltration rate was obtained from maize soya bean intercropping under zero tillage and continuous maize under conventional practice, respectively which is consistent with the initial infiltration conditions (Figure 5). A reverse and inconsistent behavior of initial and final infiltration were observed from two practices: continuous maize under zero tillage and maize under rotation with conventional practice. Even though the rate of initial infiltration under zero tilled continuous soya bean cultivation practice was smaller and finally, it had a relatively higher infiltration rate. The greater initial infiltration rate indicates the lower runoff to be produced hence a higher amount of water can be stored in the soil layer to be available for plants. On the other hand, the slowest initial infiltration means it takes more time to enter the water to the soil hence a rainfall with higher intensity can generate a greater surface runoff.

As shown in Table 3 the highest slope (0.793) indicates the highest change of infiltration rate, was recorded from continuous maize managed with zero tillage followed by zero tilled maize soya bean intercropped (0.727). The lowest infiltration slope (0.352) was from conventionally tilled sole maize, indicates a slow reduction of infiltration rate as time goes on. The negative sign indicates the rate of infiltration is decreased with an increase in time of water application until it reaches a steady-state infiltration rate. Thus, the higher the slope of the trend curve indicates more water infiltration to the soil layer hence reduced surface runoff production.

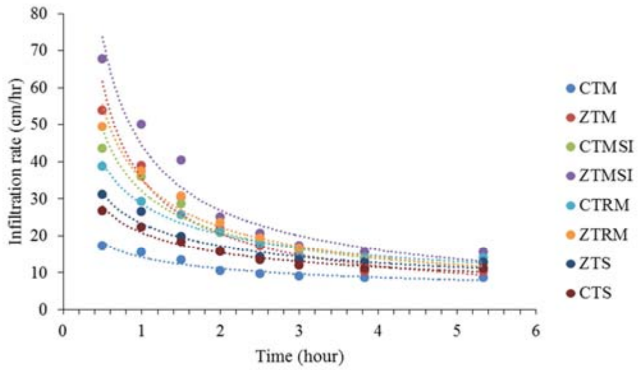

Figure 5. *Rate of water infiltration due to land management practices.*

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

Table 3. *Regression equation for infiltration rate of different soil management practices.*

Treatments	R^2	Regression Model
Maize soya bean intercropping with zero tillage	0.9438	$y=44.438x^{-0.727}$
Rotated maize with zero tillage	0.9625	$y=35.119x^{-0.654}$
Maize soya bean intercropping with conventional tillage	0.9566	$y=32.073x^{-0.605}$
Maize with zero tillage	0.9598	$y=35.511x^{-0.793}$
Rotated maize with conventional tillage	0.9572	$y=28.541x^{-0.485}$
Soya bean with zero tillage	0.9327	$y=23.284x^{-0.435}$
Soya bean with conventional tillage	0.9631	$y=20.797x^{-0.423}$
Maize with Conventional tillage	0.9271	$y=14.252x^{-0.352}$

Note: R^2=coefficient of determination, y=infiltration rate (cm h^{-1}) and x=time in hour

Overall, we found the greatest infiltration rates were associated with practices that entail no-till and presence of better cover crops. These results indicate changes in soil hydrological function which indirectly related to factors such as porosity, crop residue and aggregation that enhance water entry into the soil. The reduced infiltration rates that we found concerning the sole maize under conventional tillage could be related to the excess removal of crop residues. Generally, given no-tillage has a tremendous role, the results suggest that cover crops have an important contribution to improved infiltration rates, which likely related to continuous soil cover and associated soil physical changes.

Consistent findings are reported from different individual experiments and recent global level meta-analysis of infiltration experiments. The findings of our experiment agree well with numerous studies conducted in other areas [46, 29, 9, 43, 24, 22, 44]. They reported that infiltration rate was higher under zero tillage practices. The rate of infiltration under maize crop cover ranges from 12 – 925mm/h [46]. Thus, the higher the infiltration rate indicates the lower surface runoff and higher water storage in the soil for plant use [2]. The total amount of infiltrated water under zero tillage management was 1.4 and 2.0 times as high as minimum tillage management, under 6^{th} and 8^{th} year respectively where zero tillage promotes water infiltration through preferential pathways due to their higher biological macropores [43]. Studies undertaken on lysimeter also showed leachate water under conventional tillage was two times lower than zero tillage [15].

The global meta-analysis found that no-till practices increase infiltration rates by at least 40% relative to the control and even to a factor of two [9]. They also reported increased in infiltration rate by 35% due to cover crop experiments compared to no cover or bare land. Studies under the finest texture of Zambia reported that conservation tillage increased the rate of infiltration by 37% compared with conventional tillage systems [48]. Similarly, relative to conventional practice in Zimbabwe, direct seeding with zero tillage showed a 135% increase in water infiltration [47].

Plant residue cover has a positive correlation with infiltration [44] where the presence of plant residue cover can enhance infiltration, contributing water availability to plants by raising the recharge coefficient of water in soil [25, 9] and protect the soil against surface sealing [30] that makes zero tillage to have appropriate proportion of water and air in the soil [12]. The result was contradicted with the finding of [33, 2] where fast drainage macro-pore and soil water infiltration were higher under conventional tillage system.

3.3. Soil Water Storage

Soil water that was stored within the 100cm soil layer was significantly affected by land management and crop cover pattern (Table 4). The highest (459.46mm/m) soil water was stored under maize crop managed with zero tillage. The lowest (394mm/m) was from maize managed with conventional tillage. With similar crop cover, the depth of water storage was affected by land management was solely significant under continuous sole maize cultivation.

Compared with conventionally tilled maize, different crop patterns managed with zero tillage improved soil water storage, where the range was 3.4% to 17% while 1% to 10.5% when conventionally managed. Thus, tillage and crop cover practices such as maize with zero tillage, maize soya bean intercrop with zero tillage, rotated maize with conventional tillage, maize soya bean intercrop with conventional tillage, soya bean with zero tillage and rotated maize with zero tillage increased soil water storage in the order of 65mm, 41mm, 41mm, 35mm, 15mm and 13mm. Conversion of conventional tillage to zero tillage improves the depth of water stored within 1m soil layer by 17%, 2%, and 3% under cultivation of sole maize, maize soya bean intercrop, and soya bean, respectively. But, conventionally tilled rotation maize increased soil water by 4% than managed with zero tillage. Generally, zero tillage increased soil water by 4% relative to conventional tillage.

Table 4. *Effect of soil management and crop pattern on soil water storage.*

Cover crops	Tillage practices		Average	Response ratio (RR)
	Conventional	Zero-tillage		
Maize soya bean intercropping	429.31^{abc}	437.22^{ab}	433.26	1.02
Maize under rotation	435.43^{ab}	407.26^{bcd}	421.34	0.94
Maize	394^{d}	459.46^{a}	426.73	1.17
Soya bean	397.51^{cd}	408.98^{bcd}	403.25	1.03
Average	414	429		1.04
LSD (0.05)	34.48			
CV (%)	4.675			

Note: Means with same letter are not significantly different, CV=coefficient of variation, LSD=Least significant difference

Regarding the crop cover, the quantity of water stored in the soil profile was in the order of maize soya bean intercrop (433.26 mm/m) > maize (426.73 mm/m) > rotated maize (421.34 mm/m) > soya bean (403.25 mm/m). This indicates the greater the crop cover incorporating cereal-legume cultivation could increase the capacity of soil to infiltrate water. Besides the improvement of above ground biomass which is responsible for addition of organic matter content hence improve porosity and infiltration rate, the greater root biomass at below ground surface leads the formation of holes that increase the rate of infiltration which further stored in the soil profile.

This is in agreement with other studies [45, 28, 13, 1]. It was reported that available moisture content is greater under zero tillage especially during crop critical period than conventional tillage, this consequently increases crop grain yield [48]. Subsequently, the greater available soil moisture under zero tillage minimizes the effect of moisture stress on tasseling of the crop growth period [48]. Studies conducted in Ethiopia also reported that conservation system improves soil moisture than conventional agriculture hence increase rainwater use efficiency and reduce the risk of yield reduction [31, 5, 35].

4. Conclusion

This paper reveals the long-term effect of land management and crop cover on infiltration rate and soil water storage. Cultivation of crops managed with zero tillage improves the capacity and rate of infiltration hence greater water were stored in the soil layer. Regarding the crop covers, crops with greater cover like maize soya bean intercropping enhance water infiltration of the soil which implies reduction of loss of water as surface runoff. These, combination of zero tillage with maximum crop cover greatly improve the capacity and rate of infiltration. This indicates that implementing a land-use policy that promotes zero tillage should incorporate free grazing to provide crop residues year-round.

On the other hand, the amount of soil water stored within the upper 1m soil layer were relatively greater on maize and maize soya bean intercrop managed with zero tillage. Therefore, conversion of conventional tillage to zero tillage can improve the amount of water stored in the soil layer to be up taken by plant roots for rescuing dry spell. Compared with the crop covers, the amount of water stored in soil was higher under maize soya bean intercropping followed by continuous maize. Since the result was solely based on the fourth-year data further research is needed to figure out the long-term effect of tillage and crop pattern on infiltration and soil moisture. This calls further study on cost-benefit analysis of practicing zero tillage.

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