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Tillage and Crop Residue Effects on Soil Carbon and Moisture for Wheat (*Triticum aestivum* L.) Productivity in Semiarid Regions of Tigray, Ethiopia

Hailemariam Abrha [a*] and Berhe Abraha [a]

[a] Tigray Agricultural Research Institute, Mekelle Agricultural Research Center, Natural Resource Research, Tigray, Ethiopia.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Soil tillage is one of the basic agriculture operations. However, the appropriate tillage type, tillage time, and tillage frequency for effective moisture harvesting and sustainable soil fertility were not investigated for Tigray. A field experiment was conducted during 2016 to 2018 in Enderta district. It was done with the objective of evaluating the effect of different tillage practices on wheat productivity. The treatments were (I) permanent bed+ crop residue,(II) three times tillage with furrow, (III) two times tillage with furrow, and (IV) farmer's practice tillage. A randomized complete block design with three replications was set up. Measurement of soil moisture content was conducted using the gravimetric method. Agronomic parameters were collected and analyzed using GenStat. Marginal rate of return was also estimated from the total revenue and total variable cost. Positive effect was found on soil fertility, soil moisture content, and grain yield due to the tillage practice and crop residue. Permanent bed+ crop residues and three tillage furrow increased soil

**Corresponding author: E-mail: hailemariamabrha90@yahoo.com, hailemariamabrha9@yahoo.com;*

moisture content, organic carbon, and total nitrogen, as well as the yield and yield components at the second and third year of experimentation. The highest grain yield 2952 kg ha-1 and biomass yield 8582 kg ha-1 were recorded at the three tillage furrow in the third year of experimentation. The 59,056 ETB was the highest net revenue recorded at three times tillage with furrows. From this result, it can be concluded that without adding any additional input instead of changing agricultural operation techniques, the economic benefit of farmers' could be improved by 48%. Therefore, three tillage practices with furrow is the most economically feasible technology for farmers to increase wheat productivity in the semiarid area of Enderta district.

Keywords: Grain yield; wheat; tillage; soil moisture; soil carbon.

1. INTRODUCTION

Wheat is an important staple food in the world; about 220 million ha is cultivated for wheat and its production is 750 million tons, with this the average productivity is 3.4 t ha^{-1} globally [1]. Similarly, wheat is one of the important food security crops in Ethiopia and its total production is 6.7 million tons with a total area of 2.1 million hectares annually with a productivity of 3.2 t ha^{-1}. However, the Tigray average yield is 1.9 t ha^{-1} [2]. This productivity is less than the national (Ethiopia) average wheat yield by about 1.3 t ha^{-1}. Hence, there is a large yield gap on wheat grain demand and supply. To fulfil this gap, Ethiopia imports on average 1.2 million tons of wheat grain annually using its insufficient available resources [3]. Ethiopia is suffering from a shortage of wheat grain to feed its people by itself, so it incurs dollars to import wheat grain from other countries. The biotic constraints of wheat production are diseases and abiotic factors, fertility problems, drought, moisture stresses, high cost and limited availability of inputs and poor infrastructure [3-5]. Henao et al. [6] also indicated the most major cause for low soil productivity as a result of nutrient removal due to continuous cultivation, soil erosion, in adequate use of organics and organic fertilizers. The long-term use of inorganic fertilizers without supplementing organic fertilizers such as manure and removal of crop residue, which are the sources of organic fertilizer, damages the soil [7]. Soil tillage is the basic agriculture operation because of its importance for crop productivity, soil moisture availability, and its impact on changing soil properties [8-10]. Twenty (20%) of the crop production factor are affected by tillage [11].

Inappropriate tillage caused undesirable outcomes such as disruption in moisture, loss of soil fertility, soil structure destruction, and accelerated erosion [12]. As soil is comprised of 45% minerals, 5% soil organic matter (SOM), 20-30% water, and 20-30% air; this composition of the soil can be fluctuated by water supply and tillage operation [13]. According to Lobb et al. [14] tillage degrades soil and water unless cautious is not taken. Recommended tillage on the other hand helps for sustainable use of soil resources through its influence on soil properties [15]. Erbach [16] also proved successful crop production and soil physical properties improvement using appropriate tillage.

Crop failure in Northeastern Ethiopia are due to dry spells for about ten days and shorter growing period [17, 18]. In combining national agricultural field surveys, 40% of the total wheat productivity (per hectare) variation was estimated across the country [19]. Tigray is characterized and challenged by higher temperatures and lower rainfall environments [19]. The mean rainfall at Mekelle meteorology station in 2019 is 562 mm (Fig 2). Here in the study area (Enderta district), farmers repeatedly plough their plot of land about three times in one month in the onset of the rainy season and they remove almost 100% of the above ground crop residue for their livestock feed after the crop harvest (see section 2.2.1, I). As many researchers proved, frequent tillage and removal of crop residue from cultivated land results in increased soil runoff, reduces in situ soil moisture and soil fertility as a result decreasing crop yield [4, 20, 21]. Therefore, soil moisture conservation using appropriate tillage practices and leaving crop residue after crop harvesting are expected to improve soil fertility and wheat productivity. However, the appropriate tillage type and tillage frequency for effective moisture harvesting and sustainable soil fertility improvement for the Enderta district remained to be investigated. Thus, the overall aim of the study is to determine the impacts of different tillage types on soil moisture content, select soil fertility and identify the appropriate tillage type, tillage time, and tillage frequency on wheat productivity in the semiarid south ester n zone of Tigray, Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted at Mekelle Agricultural Research Center during 2016 to 2018 in Enderta district for three years in a permanent plot in Enderta district of Tigray, Northern Ethiopia. It is located at latitudes of 13.510º to 13.520º N and longitudes of 39.503º to 39.509º E with an elevation of 1898 ma.s.l (Fig 1).

The mean annual rainfall measured at the Mekelle Agricultural Research Center compound rain gauge station calculated from the recent twenty-four years ranges from 535 to 589 mm. Most of the rainfall (*ca*=72%) is concentrated in July and August of the year. The average temperature ranges from 12 in December, which is the coldest month, to 27 ºC in May, the hottest month (Fig 2).

The optimum moisture for crops is when the line graph of potential evapotranspiration (PET) is below the line graph of the monthly rainfall (Fig 3). Hence, this graph shows a very short duration (July and August) for crops like wheat to mature.

2.2 Experimental Design

The experiment was conducted in a Randomized Complete Block (RCB) Design with a plot size of 6 m wide and 9 m long (54 m^2) along with four treatments and three replications. The soil type of the study area is Cambisols according to the criteria of the world reference group [22].

2.2.1 Treatments description

i. Farmer's practice: The plots were ploughed three times; that is, twice before sowing after the first rain shower followed by one superficial tillage operation during the plantation of the seeds.
ii. Three tillage frequencies + furrow: The plots were ploughed three times, that is, twice before sowing, the first tillage immediately after harvesting the previous crops (Autumn in case of Enderta district), and the second tillage after the first rain shower (Spring) followed by one superficial tillage operation during the plantation of the seeds (Spring). Then contour furrows with 15 cm depth and 30 cm width were made by moldboard at 2 m interval after the third superficial ploughing. Furrow is traditionally called T*erwah* and commonly practiced in *Tef* (*Eragrostis* tef) crops.
iii. Two tillage frequencies + furrow: The plots were ploughed two times, that is, once before sowing (immediately after harvesting of the previous crops) followed by one superficial tillage operation during plantation of the seeds. Then contour furrows were made at 2 m interval after the second superficial ploughing.
iv. Permanent beds + crop residue: Contour furrows were made at 60–70 cm intervals (from the center of the furrow to the center of the furrow) using the traditional ard plough after the first rain shower. No tillage was applied on the center of the beds; seed and fertilizer were placed on the two sides of the raised bed with a moldboard plough, the spacing between rows was 20 cm. Crop residue mulching was also made on the beds (Table 1).

The furrows were interrupted like a tied ridge: hence lateral drainage was avoided or slowed down. All plots were planted with bread wheat (a newly released variety called *Mekelle 2*) in rows with the recommended fertilizer rates 46 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} application for each experimental plot as a basal application. The source of N was Urea and the source of P was TSP (Triple-super phosphate). At planting 50%, the nitrogen fertilizer was applied and the other 50% are applied at 35 days after germination, while P was applied in full dose at planting time.

2.3 Soil Sampling, Data Collection and Analysis

2.3.1 Soil sampling

Soil samples were collected from the top 30 cm soil depth before experimentation using Auger from three spots representing the entire experimental area to form one composite soil sample for initial soil fertility evaluation.

Soil samples were also taken from each plot after three years of experimentation for characterization of selected soil physical and chemical properties. A total of 12 soil samples were collected at the end of the experimentation. The collected samples were labeled and taken to Mekelle University for analysis. Soil carbon was determined using the procedure set by Walkey-Black [23] before starting the experiment and after the end of experimentation. The general conversion factor of SOM is approximately 1.72 times soil organic carbon. Therefore, the results are here reported as soil organic carbon instead of soil organic matter [24]. Soil texture was also determined before the experimentation. TN was examined by the Kjeldahl method [25]. The pH of the soil was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) using a glass-calomel combination electrode [26].

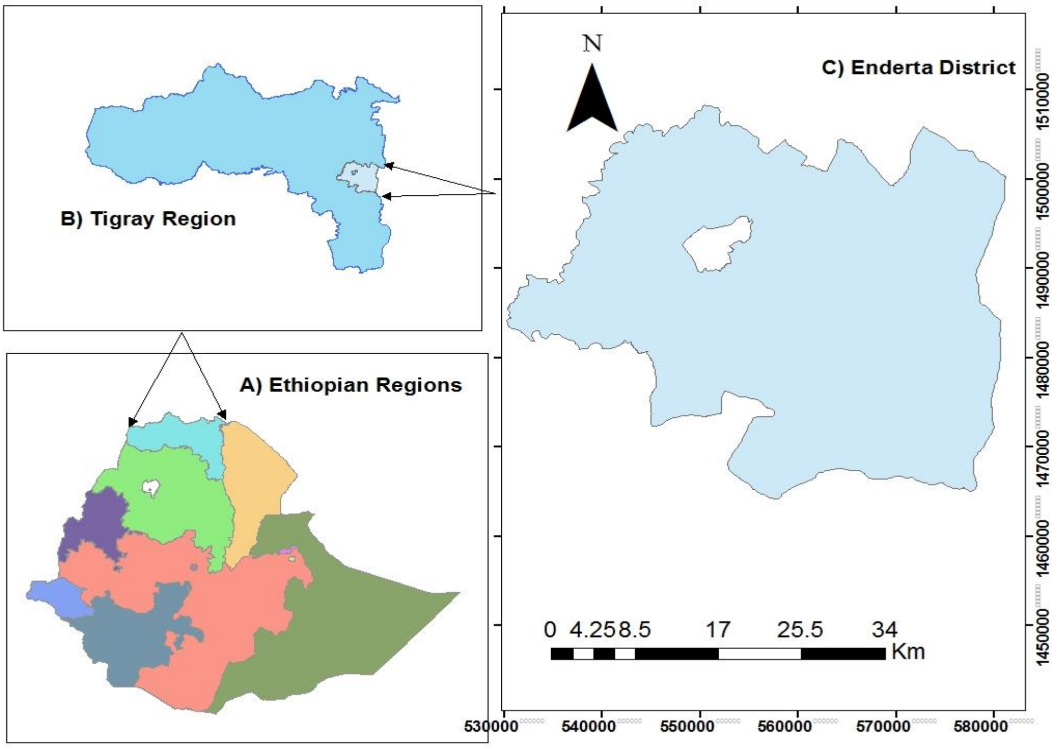

Fig. 1. Map of the study area

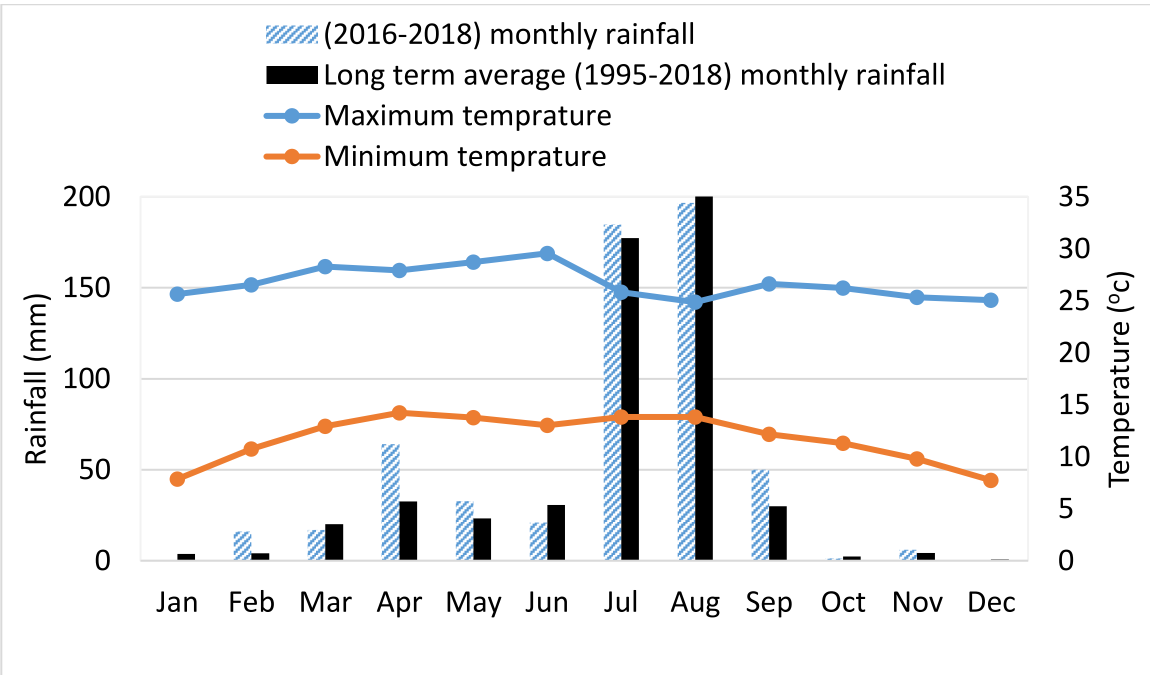

Fig. 2. Monthly average rainfall (mm) and temperature (°c)

Table 1. Description of the treatments

Treatments	Description
1. Permanent bed + crop residue (PM)	The bed is permanent but the furrows are refreshed at sowing
2. Three tillage + furrow (F3T)	1st tillage after harvesting, the 2nd tillage after rain shower, and 3rd at sowing followed by furrow
3. Two tillage + furrow (F2T)	1st tillage after harvesting and the 2nd tillage at sowing followed by furrow
4. Farmer's practice (FP)	Two times tillage before sowing followed by one superficial tillage at sowing

Furrow means contour ploughing at 2 meter interval

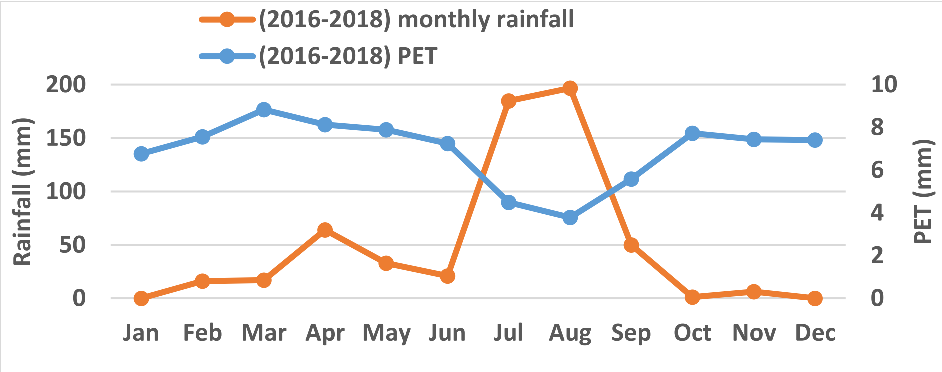

Fig. 3. Long-term (1995 to 2018) monthly average rainfall (mm) and PET (mm)

Soil samples were collected for moisture content analysis at different stages of plant growth, i.e., during planting and at every 14 days intervals from the root zone depth, i.e. 0-30 cm for each plot using a soil auger. The collected samples were weighted using a sensitive balance to take the fresh weight and then the samples were oven-dried (OD) at 105 ^{0}C over 24 hours and then re-weighed to obtain the dried masses of the samples. Then the gravimetric soil moisture content (GSMC) was calculated with the following equation (Eq.2):

Soil moisture content (%) = Weigt of wet soil (g)–Weight of oven dried soil (g) / Weight of oven dried soil (g) * 100 Equation. (1)

2.3.2 Yield and yield components

Yield and yield components were recorded from the central rows of the net-plot area. Plant data were not recorded from the plot borders to control the effect of borders. Plant yield parameters' data were collected at 90% physiological maturity. The biomass and grain yield of the crop in each plot was measured after air dried. The total grain yield and biomass yield harvested from the net plot area were weighed using a sensitive balance after threshing and extrapolated or converted) from the plot to hectare level. Plant height was measured from five randomly selected plants of the harvestable rows of the net plot with the help of meter tape from the ground surface to the tip of the plant. Numbers of tillers were counted from five randomly selected plants of the harvestable plot by counting the number of plants at 90% maturity. Harvest index (%HI) was determined by dividing grain yield by biomass yield [27].

%HI = [Grain yield (kg ha $^{-1}$) / Biomass yield (kg ha $^{-1}$] ×100…………………… Equation. (2)

During the partial budget analysis, tillage costs were calculated by assuming 1400 ETB ha^{-1} and the labor costs were 50 ETB per day per person while revenue was calculated by assuming 15.6 ETB kg^{-1} of wheat grain yield and 3.5 ETB kg^{-1} of wheat biomass yield. Common expenses such as the applied fertilizer as basal application for all treatments are not included in the calculation of partial budget analysis [28] (Table 4).

Table 2. Some Physical and chemical properties of the soil at the experimental site

Treatments	Particle size			Textural Class	pH
	Sand	Silt	Clay		After
PM	30.33	33.67	36	Clay loam	6.22[a]
F3T	31.67	32.66	35.67	Clay loam	5.95[ab]
F2T	32.67	32.33	35	Clay loam	5.31[bc]
FP	30.67	33.67	35.66	Clay loam	4.98[c]
LSD	4.32	1.91	4.91		0.71
CV%	3.7	1.2	2.3		3.40

Table 3. Response of wheat to tillage effects

Treatment	2016		2017		2018				
	Gy (kg ha^{-1})	By (kg ha^{-1})	Gy (kg ha^{-1})	By (kg ha^{-1})	Gy (kg ha^{-1})	By (kg ha^{-1})	HI (%)	Plant height (cm)	Number of tillers
PM	4257	10485	1894[a]	6134[a]	2917[a]	8343[a]	35.1[a]	84.8[ab]	10
F3T	3760	10818	1589[a]	5550[b]	2952[a]	8582[a]	34.4[a]	86.8[a]	10
F2T	3881	10486	1185[b]	4355[c]	2140[b]	8299[a]	25.8[b]	80.4[bc]	8
Farmer's p	3972	10818	1127[b]	4215[c]	1777[b]	7147[b]	24.9[b]	77.6[c]	6
LSD	ns	ns	338.9	380.6	523.7	937	1.9	5.6	3.3
CV%	241.8	265	4.3	2.1	2.6	3.9	4.3	0.9	10.3

2.4 Statistical Analysis

Yield, yield components, and soil moisture data were subjected to statistical analysis. Analysis of variance (ANOVA) was carried out using GenStat16th edition [29] at 5% of significance level [30]. For the profitability of wheat production using different tillage and fertilizer technologies, the marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive net revenue and total variable cost levels [28].

$$MRR (\%) = \Delta NR / \Delta TVC * 100 \quad \text{Equation. (3)}$$

3. RESULTS AND DISCUSSION

3.1 Effects of Tillage on Selected Soil Physico-Chemical Properties

Soil textural class of the experimental site was identified before the experiment were conducted. Accordingly, the textural class of the soil is clay loam, Table 2. Because texture is one of the physical properties of the soil that can determine soil fertility, water holding capacity, and entry of root hairs [31]. The soil fertility such as organic carbon (OC) and total nitrogen (TN) were analyzed before experimentation to characterize the fertility status of the area and after the experimentation in order to evaluate the changes resulted due to the applied treatment Table 2. To minimize biasness, each soil parameter for each treatment was analyzed separately before the experimentation, but there was no significant difference ($p > 0.05$) in OC and TN (Fig 4). After the experiment has been conducted for three consecutive years, OC and TN showed a significant difference ($p < 0.05$) between all treatments F3T, F2T, and PM over the farmer's practice. The relatively high accumulation of OC is due to the high turnover of the high amount of crop residue due to the moisture retained in the crop root zone and frequent tillage of the farmer's practice burning the accumulated OC. Addition of more organic matter or biomass yield (Table 3) regulates the soil structure.

According to Nelson and Sommers [32] pointed out that the actual conversion factors of organic carbon to organic matter vary from 1.72 to 2.00, to solve this variation, analysis and report is put only in the form of organic carbon values. Fig 4 shows that as OC increases, TN also increased. The increment in TN may be due to the increment in OC. Soil organic matter (SOM) is made up of significant quantities of carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur which serves as a large reservoir of macro- and micronutrients essential for crop growth [33]. Of the total nitrogen in the soil, 90 to 95% is held in organic form as soil organic matter including soil organisms [33]. Nitrogen (N) is the most limiting nutrient and frequently deficient nutrient in none legume cropping systems and soils with low SOM. N is very yield limiting in most Ethiopian soils that are also low in SOM content. In Ethiopian soils, with intensive/frequent tillage of soils seldom return crop residue and addition of manure and low crop productivity results in low SOM.

It is well documented that conservation tillage increases SOC levels [34, 35]. In conservation tillage, existed biomass converts agricultural soils from C source to C sink, thereby removing significant amounts of CO_2 from the atmosphere [36]. Intensive agricultural management reduces SOC levels [37]. Many studies proved that OC sequestration in soil is texture dependent and fine particles are highly correlated with carbon sequestration [38-40].

The pH of the soil in the experimental site was also analyzed as it is a yield limiting or controlling factor. At 0-30 cm depth, soil pH value of PM was significantly ($p < 0.05$) affected by the interventions over F2T and farmer's practice (Table 2). The highest pH (6.22) was recorded on PM but the lowest value 4.98 was recorded on Farmer's p. This pH increment is probably due to the increment of OC or SOM from the crop residue. This finding is in agreement with that of Abreha K. [41] who found forest land has higher pH than grazing land.

3.2 Effects of Tillage on Wheat Productivity

The results (Table 3) indicate that grain yield (Gy) and biomass yield (By) did not show significant ($p > 0.05$) difference in the first year (2016) of experimentation. However, in the second (2017) and third year (2018) the yield showed significant ($p < 0.05$) differences. Harvest index and plant height also showed a significant ($p < 0.05$) difference in 2018, because in the first year the moisture content did not show significant difference among treatments, while in the second and third year the difference could be due the availability of moisture (Figure 5) and due to an increase in fertility (Figure 4). In moisture stressed areas such as arid and semi-arid environments, an increase in moisture gives a direct response in yield. An increase in OC and TN also contributes to increasing the yield as the soil is deficient in these nutrients (Table 2). According to Bruce and Rayment [42] the nitrogen rating method, the result of TN presented in Table 2 is low to moderate. The highest grain yield and biomass yield were recorded in the permanent beds with crop residue and three tillage furrow during 2017 and 2018. The highest grain yield of 2952 kg ha^{-1} as well as the corresponding highest net revenue of 59,056 ETB were recorded at three tillage furrow. Therefore, three tillage practices with furrow is the most economically feasible technology for farmers to increase wheat productivity in Enderta district.

Results of yield components such as HI, plant height, and number of tillers are presented in Table 3. Plant height and HI are significantly ($P < 0.05$) affected by the tillage practices (Table 3 of 2018). Percent of HI and plant height are significantly ($P < 0.05$) affected in both permanent bed + crop residue and three tillage furrows treatment. The average plant height ranged from 77.60 cm for farmer's practice plots to 86.8 cm for plot three tillage with furrow treatment. This is in agreement with the findings of Puste et al. [43] who reported that higher plant heights were recorded on plots with optimum moisture than the moisture stressed plots in an irrigated experiment. Number of tillers did not show significant ($P > 0.05$) difference by the tillage treatments.

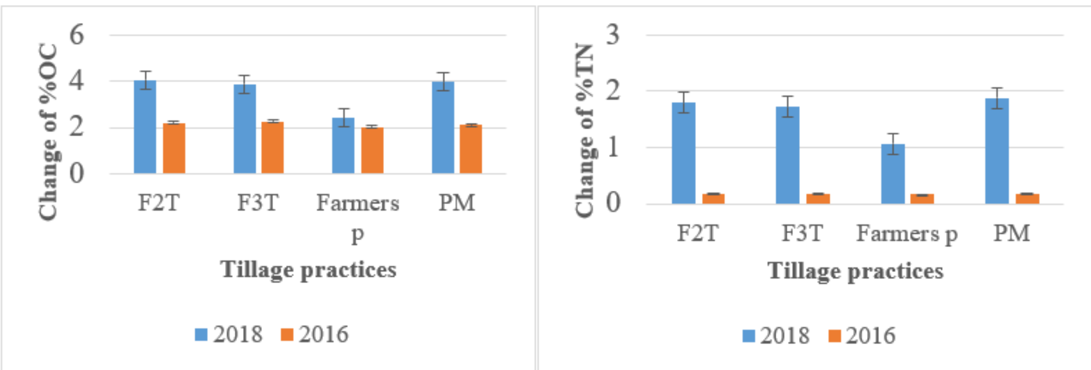

Fig. 4. Change organic carbon and total nitrogen

Table 4. Partial budget analysis

Treatments	Tillage cost (Birr)	Labor cost (Birr)	TVC (Birr)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Revenue (R1)Gy*15.6 (Birr)	Revenue (R2) (By*3.5) (Birr)	Total revenue (TR) (Birr)	Net revenue (TR-TVC)	(MRR) (ratio)	MRR (%)
PM	2800	3200	6000	2917	0	45505	0	45505	39505	-	-
Farmer's P	4200	2400	6600	1777	5370	27721	18795	46516	39916	0.68	68
F2T	2900	2400	5300	2140	6159	33384	21557	54941	49641	Da	Da
F3T	4300	2400	6700	2952	5630	46051	19705	65756	59056	6.72	672

TVC is Total Variable Cost

3.3 Relation between Soil Moisture Content and Wheat Grain Yield with Different Tillage Practices

Results presented in Fig 5 show the variation of average gravimetric soil moisture content (%GSMC) and Gy kg ha^{-1} due to tillage treatments (PM, F3T, F2T and Farmer's P). GSMC was determined at a depth of 30 cm of the soil samples taken starting from planting date and at every 14 days interval of the crop growth period. The results showed that the GSMC and Gy were affected by the tillage types. In the first year, low GSMC was recorded at farmer's practice tillage. However, similar GSMCS were recorded on plots with PM, F3T, and F2T (Fig 5, first year 2016). Gy did not show as such a significant difference in the first year. On the similar plots of the second and third year, the results showed that PM conserved the highest GSMC and resulted to harvest the highest Gy among all other treatments (Fig 5). The lowest GSMC and Gy were recorded at the farmer's practice plot.

Generally, Gy increased as soil moisture increased during the second and third year of the experimentation (Fig 5). The line graph showed a sharp increase in GSMC and Gy as observed from farmer's practice to PM (Farmer's P < F2T < F3T < PM). From the line graph with the average of three years (Fig 5, average 3 years), it can be concluded that the average moisture and average Gy are equally increased in this result. Here the increase in Gy is due to the increased in GSMC. This shows the area is with moisture insufficiency for crops to give its potential yield. The reason for increasing the GSMC in different treatments is due to the permanent furrow at 60 to 70 cm interval that harvests water and the permanent crop residue mulch that prevents evaporation of PM. Likewise, the GSMC increment for F2T and F3T is because of the furrows interrupted with ties; hence lateral drainage was avoided or slowed down during the rain shower and the conserved water can get enough time to infiltrate to the soil. Many researchers [44, 45] proved that tied furrows conserved moisture in field experiments. Rawell [46] also reported evaporation from the soil surface removes water from micropores if it is not muched with mulching material.

Tillage on farmer's practice showed that the soil was not wetted by rainfall because of limited infiltration depth due to saturation of topsoil and swelling of clay minerals leading to the crusted soil surface due to frequent tillage and rainfall washed away as runoff due to slow infiltration rates that gradually wet the soil profile. This is in line with Hazelton & Murphy [48] who reported that infiltration is much higher before rainfall packs and decreases due to swelling of surface soil. Tewodros et al. [48] & Nyssen et al. [49] indicated that at the beginning of the rainy season, most rains infiltrated quickly into the dry, tilled fields. Tillage practices such as furrow and tied ridging is one of the most important techniques to conserve soil and water in the farmland and thereby giving the opportunity time

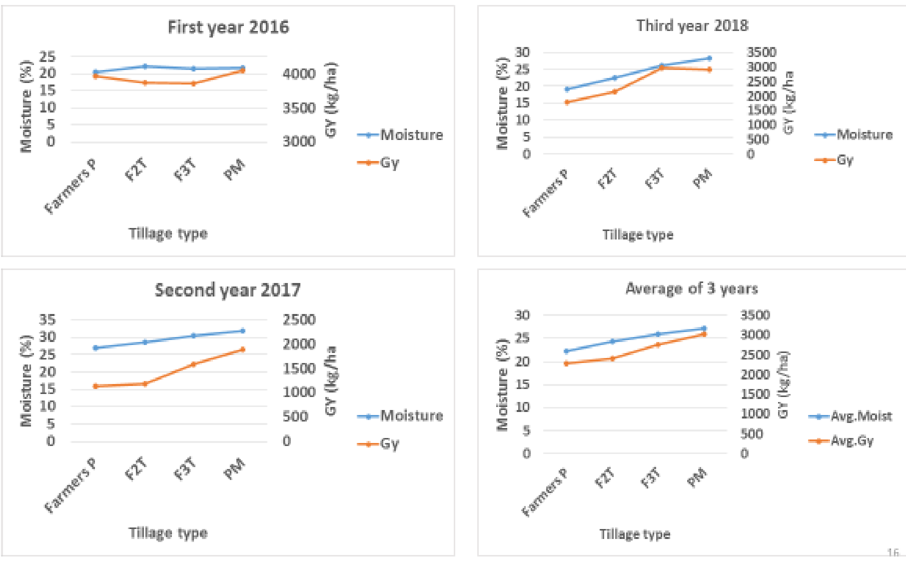

Fig. 5. Average Gravimetric Soil Moisture Content (%) and Grain Yield (Gy)

for more infiltration into the soil [50]. According to Tesfay et al. [51], grain and straw yields of wheat increased by 48% and 33%, respectively, in DER+ (i.e., furrow type of conservation tillage with Vertisol in Ethiopia). Gebreyesus [52] and Abrha, H. [53] also reported sorghum sesame yield increment respectively due to improved tillage as compared to conventional tillage.

3.4 Partial Budget Analysis

Marginal rate of return was estimated from the total revenue and total variable cost. The results of the partial budget analysis of the tillage practices and crop residue for the year 2018 are presented in Table 4. Computing partial budget analysis is done for statistically significant results. Three tillage with furrow and permanent bed + crop residue have a higher positive effect on wheat productivity (Table 3). However, in case of partial budget analysis, three tillage with (672%) and farmer's practice (68%) tillage have positive MRR. The results (Table 3, Fig 5) showed that permanent bed + crop residue and three tillage furrow has increased soil moisture content as well as grain and biomass yield at the second and third year of the experimentation period. However, in permanent bed+ crop residue treatment, the crop residue is incorporated to the soil so that the farmers will not get crop residue forage for their animal feed.
MRR greater than 100% means investing extra money is economical. The net benefit obtained in response to three tillage with furrow is 59,056 ETB (Table4); whereas the net benefits obtained from the other treatments are less than three tillage treatment. For example; the net benefit obtained from the farmer's practice is 39,916 ETB.

This shows that using three tillage furrow has more earnings than farmer's practice tillage by 19,140 ETB; which is a 48% economic benefit improvement over the farmer's practice. From this result, it can be concluded that without adding any additional input but only by changing operational techniques, the economic benefit of farmers' could be improved by 48%. Therefore, due to the principle of CIMMYT [28] manual for profit analysis, the best technology for this study is three tillage furrow which is economically profitable [54] compared to the other treatments.

4. CONCLUSIONS AND RECOMMENDATIONS

Evidence of different tillage practices to increase wheat yield in a sustainable way by leaving crop residue on productivity and healthy soil conditions are essential. The main technology introduced in this study is early tillage immediately after crop harvest (before the crop residue is eaten by animals), which is expected to give the opportunity to incorporate the crop residues to the soil and hence the year-round droplet of water are harvested so that the crop residues are decomposed and the soil fertility increased. The other new technology incorporated in this study is the tied furrows traditionally called *Terwah* and practiced in *Tef* crops. Based on the results of this study, the following conclusions can be forwarded.

- The overall grain yield and soil moisture content were higher at permanent bed + crop residue and three tillage furrow
- All treatments except the farmer's practice increased OC and TN, the increment in OC and TN may be due to the incorporation of the crop residue. An increase in OC showed a direct influence on an increase in TN. However, the decrease in OC and TN in the farmer's practice is due to the burning effect of tillage.
- Permanent bed + crop residue is not profitable in terms of partial budget analysis because farmers feed their animals with crop residue biomass. Therefore, in preference to the sustainable economic benefits, soil fertility improvement and with the ability to conserve a year-round available moisture content in the soil; the best technology for this study is three tillage furrow compared to the other treatments.
- Hence, this finding should be registered as a technology and demonstrated at farmers' field. Permanent bed + crop residue is also another optional technology for increasing soil moisture content, grain yield, and improved soil properties in farmers who do not use wheat biomass yield for animal feed.
- Besides these important findings, we recommend to study the effect of these technologies on soil loss by water erosion.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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