Comparing the effects of different organic mulching materials on weed control, soil moisture conservation, and wheat (Triticum aestivum) productivity in the moisture deficit areas

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Abstract

Wheat (*Triticum aestivum*) productivity, in water deficit areas such as Ethiopia, is threatened by low soil fertility, weed infestation and moisture stress. Organic Mulch was believed to avert these challenges but only limited scientific information, on its level of effects (crop yield, soil moisture conservation and weed control), was available. Hence, an experiment was carried out on Cambisols in Tigray/Ethiopia during the 2019/20 growing season following a Randomized Complete Block Design (RCBD). Four organic mulch types (maize stalk, sorghum stalk, wheat straw, and finger millet straw), each at the rates of 2 ton ha^{-1} were compared against the control (no mulch). Their economic visibility was evaluated using partial budget analysis. Our experimental results revealed that mulched plots had a significantly higher weed control efficiency, soil moisture content, grain yield, and net benefit as compared to the control. Mulching in general improved Wheat grain yield by 26.8%, soil moisture (at 0–20 cm) by 73.7%, weed control efficiency by 57.4%, and net benefit by 19.7% as compared to the control. Maize and sorghum stover mulches were the most profitable mulch types which increased net benefit by 38.2 and 27.6%, respectively. It can be concluded that organic mulching with Maize and Sorghum stover is a good option to improve crop production, soil moisture and reduce weed infestation in the moisture deficit areas.

1. Introduction

Wheat is one of the major cereal crops produced in Africa (Jayne et al. 2010; Negassa et al. 2013). Nevertheless, countries in the dry lands such as Ethiopia where the study took place produce merely around 30 to 40% of their domestic requirements (Negassa et al. 2013). In Ethiopia, the estimated area of wheat cultivation was 1,696,907.05 ha, with 4.64 million tons annual production and an average productivity of 2.73 $Mt\ ha^{-1}$ (CSA 2018). This is by far less than the global average, which is 4.48 Mt ha^{-1} (Langemeier and Zhou 2002).

Moisture deficiency, low soil fertility, weed infestations and crop diseases are among the reasons for low wheat productivity (Singh et al. 2008; Teferi and Gebreslassie 2015). Manual weeding and application of herbicides were used for weed control; in-situ soil moisture conservation activities such as small trenches and soil bunds were practiced to improve moisture content in soils. However, these activities were not enough to solve the above mentioned proximate causes. Organic mulching, which is the method of covering the soil surface around the plants or crops to produce optimal condition for crops development (Bakshi et al. 2015), could be a possible solution (Shirgure et al. 2003; Pande et al. 2005; Sharma and Kathiravan 2009). In moisture deficit areas such as Tigray (northern Ethiopia), where the study took place, only few studies reported on the role of organic mulching on in-situ moisture conservation and yield of Wheat yield, water use efficiency and soil properties (Javed et al. 2020), Sorghum (Fikre et al. 2018), water use efficiency of winter Wheat (Hu et al. 2017), in-situ moisture conservation and yield of Sesame (Teame et al. 2017), Grain Yield and Yield Components of Wheat (Khan et al. 2014) and *Coffee arabica* (Bekeko 2013).

However, the level of effect on weed infestation control was not studied. Heavy weeds infestation not only deplete soil moisture but also compete for light, nutrients and space with the main crop (Ahmed et al. 2007). The existing studies were also limited to only few mulch types such as plastic film and straw mulching (Javed et al. 2020); straw mulch (Hu et al. 2017); rice straw, sorghum straw, sesame straw, and Sudan grass (Teame et al. 2017); straw mulch litter mulch and gypsum (2014). Furthermore, the comparative effect of the dominant organic mulch sources in the semi-arid areas such as maize stalk, sorghum stalk, wheat straw, and finger millet straw were not studied. Hence, this study aimed at comparing the effects of four organic mulches (maize stalk, sorghum stalk, wheat straw, and finger millet straw) on: i) weed control; ii) soil moisture conservation; iii) wheat productivity in the moisture deficit northern highlands of Ethiopia..

2. The Study Area

The experiment was conducted at Megab area in Eastern Tigray, northern Ethiopia. The area is geographically situated between $13^0 50'0"$ and$14^0 10'0"$ N and $39^0 16'30"$ and $39^0 37'30"$ E (Fig. 1).

Figure 1 near here

Based on the National Metrological Agency Tigray Service (NMATS 2018), the area had an average annual temperature and rainfall, respectively, ranging from 10.9 to 29.1°C and 325 mm to 690 mm. The major reference soil group in the study area is classified as Cambisols. A mixed farming, crop-livestock, is the dominant farming system in the study area. Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), teff (*Eragrostis tef*), maize (Zea mays), millet finger (*Eleusine coracana*) and sorghum (*Sorghum bicolor*) are dominant crops typically produced by small holder farmers mainly for domestic/ family consumption.

3. Method

3.1. Treatments and experimental design

The field experiment was carried out following a Randomized Complete Block Design with five mulching materials (wheat straw, sorghum stalk, maize stalk, finger millet straw and no treatment) replicated three times. Mulching materials were equally applied to all experimental plots at the rate of 2 ton ha^{-1} based on the suggestions of Bekeko (2013). These mulching materials were selected as they were easily available in the study area. The total size of the experimental field was 9 m x 18 m (162 m^2), having a plot size 2 m x 3 m (6 m^2) separated by 1 meter space between blocks, 50 cm between plots, with 30 cm between rows. The wheat variety 'Kekaba', the commonly grown variety by farmers in the study area, was sown at the rate of 120 kg ha^{-1} by drilling (Muhammad et al. 2018). NPS and Urea, each, were applied at the rate of 100 kg ha^{-1} as recommended in Muhammad et al. (2018). One third (1/3) of the Urea was used at the time of seeding/sowing, while the remaining portion was used 35 days after sowing as suggested in Muhammad et al. (2018).

3.2. Parameters

3.2.1. Weed parameter

Weed parameters (weed density, weed dry matter, weed species/types and their numbers, weed control efficiency and weed index) data were collected following recommendations by Bobby et al. (2017). Weed density and weed species/types, expressed as number per square meter, were recorded from each experimental plot (1 m x 1 m size) at 42, 63 and 84 days after sowing (DAS). Weed dry matter was determined by oven drying fresh weed at 65°C for 48 hours. The weed control efficiency (WCE, %) was calculated following Eq. 1 as suggested by Patil and Patil (1993).

$$\mathrm{WCE} = \frac{\mathrm{DMC} - \mathrm{DMT}}{\mathrm{DMC}} \times 100 Equation 1$$

Where, DMC = Dry Matter of weed in control plot, DMT is = Dry Matter of weed in plots with treatment and WCE = Weed Control Efficiency

The weed index (WI, %), defined as the reduction in yield due to the presence of weeds in comparison with minimum weed competition (maximum weed control efficiency) plot, was worked out for each plot using Eq. 2 as suggested by Gill and Vijay (1966).

$$\text{W}\text{I} =\frac{\text{X} - \text{Y}}{\text{X}} \times 100$$ Equation 2

Where, X is = yield from maximum weed control efficiency of experimental plot; Y is = yield from the experimental plots; WI is = Weed index.

3.2.2. Soil moisture parameter

Soil moisture content (SMC) was investigated from soil samples collected from each experimental plot at a depth of 0–20 cm, 21–40 cm and 41–60 cm, which is an ideal wheat root depth (Whalley et al. 2007; Whalley et al. 2008). The sampling was done at 3 weeks interval for 21, 42, 63 and 84 days after sowing as suggested in Fikre et al. (2018). Each soil sample was oven dried for 24 hours at 105˚C. Finally, the SMC was estimated by gravimetric methods using Eq. 3 (Chavan et al. 2009).

$$\text{Moisture content in} \left(\text{\%}\right)=\frac{\text{Wet field weight} - \text{Oven dried weight}}{\text{Oven dried weight}}\times 100$$ Equation 3

3.2.3. Agronomic parameter

Data on agronomic parameters (Days to emergence/germination, flowering and milking and maturity; plant height and spike weight) were recorded from four rows in each plot. Days to maturity were recorded as the number of days from planting to the final growth stage when 90% of the plant reached physiological maturity, i.e. when the plants and the grains turned pale yellow in color (Muhammad et al. 2018). Ten randomly selected plants in the net plot area were tagged just 30 days after sowing for measuring plant height (from bottom of plant to the tip of spikes at physiological maturity). Spike weight (g) was recorded by weighing five dry spikes selected in each plot and then their average was determined. Number of grains spike^{-1} was recorded by counting wheat grains from the selected five spikes in each plot and averaged appropriately. Number of tillers m^{-2} was obtained by counting the number of tillers in the four rows of each plot, and then transformed into numbers of tillers m^{-2}. Biological and grain yields (kg ha^{-1}) were estimated from harvest in the four central rows in each plot. Hence, harvest index was estimated following Eq. 4 proposed by Muhammad et al. (2018).

$$\text{Harvest index} =\frac{Economic/grain\ yield}{Biological\ yieid}\times 100$$ Equation 4

3.2.4. Economic parameter

Economic feasibility of the different treatments was estimated using partial budget analysis (Eq. 5–7) as described in CIMMYT (1988). Economic analysis was done using the market price for inputs at land preparation and for grain yield at the time the crop was harvested. All costs and benefits were calculated on hectare basis in Ethiopian Birr (1 USD = 30 birr). Grain yield was adjusted down by 10% to minimize the effect of researcher managed small plots as compared to the farmers managed large plots (CIMMYT 1988). The dominance analysis procedure described in CIMMYT (1988) was used to select profitability treatments from the range tested. The marginal rate of return (MRR) was also calculated using Eq. 7 by considering a pair of non-dominated treatments listed in the order of increasing net benefit. The results of marginal analysis were further checked by the residuals which are calculated by subtracting the rate of return that farmers require (that is, the minimum of return multiplied by the total variable costs) from corresponding net benefits. Following the analysis, treatments with highest residuals are recommended to farmers.

$$\text{Gross benefit} = \text{Grain yield return} \times \text{price birr/kg} \quad \text{Equation 5}$$

$$\text{Net profit} = \text{Gross benefit} - \text{Total cost that vary} \quad \text{Equation 6}$$

$$\text{MRR} = \frac{\text{change in NB}}{\text{change in TCV}} \quad \text{Equation 7}$$

Where, MRR = is the marginal rate of return, NB = is net benefit Birr ha^{-1} for each treatment, TCV = is the total variable costs Birr ha^{-1} for each treatment.

3.3. Statistical data analysis

The measured variables were subjected to analysis of variance (one way ANOVA) appropriate to Randomized Complete Block Design by using R-Software, and interpretations were made following the procedure described by Gomez and Gomez (1984). Whenever the effects of the treatments were found to be significant, the means were compared and separated using the least significant differences (LSD) test at 5% level of significance. Normality and homogeneity were tested using Levene and Shapiro Tests, respectively.

4. Results And Discussion

4.1. Effect on weed control

The results revealed a very highly significance difference ($p < 0.001$) on weed density, weed dry natter and weed type (Table 1). Organic mulching reduced weed density by an average of 56% compared to the control. Both Sorghum and Maize stovers recorded the lowest weed density which was by 65% lower as compared to the control. The lower weed density under these mulch types as compared to other treatments is related to their hard stem (lower decomposition rate) with large leaves which have the ability to prevent different types of weed seed germination and suppress weed sprout. These results are in line with the findings of Broschat (2007), Muhammad et al. (2018), and Ngouajio et al. (2008) that reported organic mulch of any type reduced weed density. Similarly, Bobby et al. (2017) reported that mulch blocked the weeds, except a few, which emerged through the planting holes. These authors revealed that organic mulching materials act as physical barrier and prevent light to enter the soil.

Table 1

Effect of different organic mulch materials on weed density (number m^{-2}), weed dry matter (g m^{-2}) and weed type (type m^{-2}) at different growth stages of wheat.

Treatments	weed density(number m^{-2})			weed dry matter(gm^{-2})			weed type (m^{-2})		
	42 DAS	63 DAS	84 DAS	42 DAS	63 DAS	84 DAS	42 DAS	63 DAS	84 DAS
WS	66.33^{b}	102.67^{c}	109.33^{b}	25.75^{bc}	56.08^{c}	82.83^{c}	4.75^{ab}	$5.41b^{c}$	4.41
SS	22.17^{c}	86.67^{d}	61.33^{e}	21.45^{c}	45.4^{d}	101.00^{b}	3.76^{b}	5.4^{bc}	4.12
MS	21.13^{c}	69.33^{e}	82.67^{c}	13.42^{d}	33.47^{e}	57.33^{d}	3.74^{b}	4^{c}	4.09
FM	60.87^{b}	114.77^{b}	73.43^{d}	27.67^{b}	66.74^{b}	90.78^{c}	4.43^{b}	6.75^{b}	4.15
C	125^{a}	230^{a}	135^{a}	$56..33^{a}$	108.33^{a}	196.67^{a}	5.83^{a}	9^{a}	4.5
p value	1.30E-11	5.70E-11	1.85E-09	4.35E-08	5.36E-08	4.91E-11	0.00894	0.00046	0.58
LSD	5.78	9.96	6.64	5.06	9.14	8.28	1.19	1.57	0.61
CV%	5.4	4.52	3.93	9.62	8.1	4.3	14.58	14.16	7.88

Ns = non significance, WS = Wheat straw mulch, SS = Sorghum stalk mulch, MS = Maize stalk mulch, FM = Finger millet mulch and C = Control, LSD = least significance difference, CV = coefficient of variation

Table 1 near here

Weed dry matter content also showed very highly significance difference ($p < 0.001$). Organic mulching reduced weed dry matter by an average of 66% as compared to the control. Maize stover had the maximum influence on all growth stages, which reduced weed dry matter by 77%. These results are in agreement with the findings of Jodaugiene et al. (2006) that reported application of organic mulch was effective in suppressing weed growth. The lowest weed dry matter on mulched plots was related to the higher role of organic mulching materials in reduced weed density through suppressing weed germination (Yang et al. 2003; Jodaugiene et al. 2006). According to these authors, the lower decomposition rate and higher leaf composition in maize stalk mulch helped in preventing weed germination, and in suppressing and restricting the growth of weed that were once emerged through preventing sun light.

The presence of different weed types were also highly significantly influenced ($p < 0.01$) by the application of different mulching treatments as compared to their corresponding control plots (Table 2). Mulch treated soils decreased weed type by an average of 30% as compared to the control. Maize stalk treated plots had the lowest number of weed types, which was by 39% lower as compared to the control. This corresponds with the findings reported in Pupalienė et al. (2015) that stated application of organic mulch reduced weed types. This can be related to the positive effect of organic mulches in reducing weed growth by suppressing their germination (Yang et al. 2003; Jodaugiene et al. 2006).

Table 2
Effects of different mulch materials on weed control efficiency (WCE) and weed index (WI) at different growth stages in wheat crop.

Treatments	Weed Control efficiency (%)			Weed index (%)
	42 DAS	63 DAS	84 DAS	
WS	54.25^{c}	48.19^{c}	57.95^{b}	19.29^{b}
SS	62.04^{b}	57.86^{b}	48.63^{d}	7.49^{c}
MS	76.24^{a}	69.32^{a}	70.84^{a}	0^{d}
FM	50.69^{c}	38.40^{d}	53.92^{c}	20.82^{b}
C	0.00^{d}	0.00^{e}	0.00^{e}	30.53^{a}
p value	1.51e-09	6.03e-09	2.90e-11	3.34e-09
LSD	6.36	6.72	4.01	2.86
CV %	7.19	8.63	4.77	10.04

WS = Wheat straw mulch, SS = Sorghum stalk mulch, MS = Maize stalk mulch, FM = Finger millet mulch and C = Control, LSD = least significance difference, CV = coefficient of variation

The results presented in Table 2 indicated a very highly significance difference ($p < 0.001$) on weed control efficiency (WCE). Mulched soils increased weed control efficiency by an average of 57.4% as compared to the control. Maize stover had the highest weed control efficiency, which was 72.1%. Similar results were also reported in Aniekwe et al. (2013) for cucumber, Hartmann et al. (1981) for tomato and Choudhary et al. (2012) for capsicum. The restriction in the penetration of solar radiation on organic mulch treated plots resulted to the smallest weed germination and weed infestation, hence, lowest weed control efficiency (Yang et al. 2003; Jodaugiene et al. 2006).

Table 2 near here

Weed index (WI) was very highly influenced ($p < 0.001$) by the different mulch treatments. Mulched treated soils reduced weed index by an average of 61% as compared to the control. Maize stalk had a minimum weed index as compared to the other treatments (Table 2). Similar results were also reported in Aniekwe et al. (2013) for cucumber, Sha and Karuppaiah (2005) for brinjal, and Choudhary et al. (2012) for capsicum upon organic mulching. The lowest weed index observed for maize stalk mulch (MS) was due to suppression of different weed types at critical periods and minimum weed competition that led to highest weed control efficiency (Yang et al. 2003; Jodaugiene et al. 2006).

4.2. Effect on soil moisture content (SMC)

4.2.1. Soil moisture content at 21 DAS

A significantly higher ($p < 0.001$) soil moisture content was reported on all mulched treatments as compared to the control ones. Average soil moisture content (SMC) on the top soil (0–20 cm) of mulched treatments was by

45% higher as compared to the control. The highest value was recorded from wheat straw treated plots, and was by 54.5% higher as compared to the control (Table 3). The influence of the mulching materials continued across soil depth. At the middle soil depth (21–40 cm), SMC on mulched treatments increased by an average of 71% as compared to the control ones. The highest SMC was recorded from Maize stover treated plots, and was by 89.2% higher as compared to the control (Table 3). At the lower soil depth (41–60 cm), a 70% higher SMC was recorded from mulched treatments as compared to the control ones. The highest SMC was recorded from wheat straw treated plots, and was by 76.6% higher as compared to the control (Table 3).

Table 3
Effect of mulching on soil moisture content (SMC, %) at different soil depth and days after sowing

Treatments	soil depth in cm	Days after sowing (DAS)			
		21	42	63	84
WS	0–20 cm	20.44^{a}	21.24^{a}	23.70^{ab}	11.67^{c}
SS		18.27^{b}	20.50^{ab}	25.06^{a}	15.06^{b}
MS		19.59^{ab}	19.18^{ab}	24.14^{ab}	18.40^{a}
FM		18.24^{b}	17.99^{b}	23.21^{b}	15.31^{b}
C		13.23^{c}	13.82^{c}	15.85^{c}	8.70^{d}
P value		5.11e-05	0.00161	1.14e-06	6.03e-06
LSD		1.85	2.91	1.62	1.94
CV %		5.66	8.64	3.98	7.71
WS	21–40 cm	17.42^{b}	19.72^{b}	22.41^{ab}	13.93^{b}
SS		17.84^{b}	23.11^{a}	23.66^{a}	17.81^{a}
MS		19.96^{a}	20.32^{ab}	23.19^{a}	17.26^{a}
FM		16.77^{b}	19.38^{b}	21.36^{b}	15.09^{b}
C		10.55^{c}	13.05^{c}	16.77^{c}	8.70^{c}
P value		2.72e-07	9.38e-05	4.01e-06	2.98e-06
LSD		1.33	3.1	1.38	1.75
CV %		4.42	8.92	3.53	6.62
WS	41–60 cm	17.22^{a}	21.34^{ab}	25.2^{ab}	21.55^{ab}
SS		17.03^{a}	21.57^{ab}	25.68^{a}	20.42^{ab}
MS		15.55^{a}	22.89^{a}	24.29^{ab}	19.95^{b}
FM		16.56^{a}	20.24^{b}	22.76^{c}	22.29^{a}
C		9.75^{b}	13.71^{c}	13.85^{d}	11.72^{c}
P value		2.67e-05	0.000115	6.51e-09	5.25e-06
LSD		1.92	2.61	1.25	2.19
CV %		6.92	7.19	3.07	6.28

WS = Wheat straw mulch, SS = Sorghum stalk mulch, MS = Maize stalk mulch, FM = Finger millet mulch and C = Control, LSD = least significance difference, CV = coefficient of variation

Table 3 near here

These results agreed with the findings of Fikre et al. (2018), Teame et al. (2017) and Jimenez et al. (2017) that stated organic mulches (sorghum stalk, sesame straw and grass mulch) at the rate of 2.2 ton ha^{-1} and 3 ton ha^{-1} conserved higher soil moisture than the control plots. This is probably due to the positive role of organic mulches in protecting soil moisture from evaporation loss and its effectiveness in retaining water with in the soil profile (Jordan et al. 2010; Rhoades et al. 2012). Researches elsewhere also reported a 100 percent organic mulch soil cover reduced soil evaporation by 50% (Raes et al. 2009) and 34–50 percent (Hatfield et al. 2001).

4.2.2. Soil moisture content at 42 DAS

A significantly higher ($p < 0.001$) soil moisture content was also reported across all mulched treatments as compared to the control ones. At the top soil (0–20 cm), SMC on mulched treatments increased by an average of 43% as compared to the control ones. The highest SMC was recorded from wheat straw treated plots, and was by 53.7% higher as compared to the control (Table 3). At the middle soil depth (21–40 cm), SMC on mulched treatments increased by an average of 58% as compared to the control ones. .The highest SMC was recorded from sorghum stover treated plots, and was by 77.1% higher as compared to the control (Table 3). At the lower soil depth (41–60 cm), SMC on mulched treatments showed an increment by 57% as compared to the control ones. The highest SMC was recorded from maize stover treated plots, and was by 67% higher as compared to the control (Table 3). This finding still correlates with the findings of Teame et al. (2017) and Fikre et al. (2018) that revealed mulches at 45 DAS are able to conserve soil moisture by minimizing evaporation loss and through improved soil structure, which in turn lead to improved soil water holding capacity.

4.2.3. Soil moisture content at 63 days after sowing

A significantly higher SMC was recorded on mulch treated plots as compared to the control ones. At the top soil (0–20 cm), SMC on mulched treatments increased by an average of 52% as compared to the control ones. The highest SMC was recorded from Sorghum stover treated plots, and was by 58.1% higher as compared to the control (Table 3). At the middle soil depth (21–40 cm), SMC on mulched treatments increased by an average of 35.1% as compared to the control ones. The highest SMC was recorded from sorghum stover treated plots, and was by 41.1% higher as compared to the control (Table 3). At the lower soil depth (41–60 cm), a 77% higher SMC was recorded from mulched treatments as compared to the control ones. The highest SMC was recorded from sorghum stover treated plots, and was by 85.4% higher as compared to the control (Table 3). These results correspond with the findings of Stelli et al. (2018) that reported organic mulch treated soils had higher soil moisture content after around six weeks compared to the control plots. These findings also correspond with that of Teame et al. (2017) and Fikre et al. (2018) that described organic mulches at the rate of 2.2 ton ha^{-1} recorded the highest soil moisture at 60 DAS.

4.2.4. Soil moisture content at 84 days after sowing

A significantly higher SMC was recorded on mulch treated plots across all soil depths as compared to the control ones. At the top soil (0–20 cm), SMC on mulched treatments increased by an average of 74% as compared to the control ones. The highest SMC was recorded from Maize stover treated plots, and was by 111.5% higher as compared to the control (Table 3).,The highest SMC was recorded from maize stover treated plots, and was by 111.5% higher as compared to the control (Table 3). At the middle soil depth (21–40 cm), a 84% higher SMC was recorded on the mulched treatments as compared to the control ones. The highest SMC was recorded from

Sorghum stover treated plots, and was by 104.7% higher as compared to the control (Table 3). At the lower soil depth (41–60 cm), a 80% higher SMC was recorded from mulched treatments as compared to the control ones. The highest SMC was recorded from finger millet treated plots, and was by 90.2% higher as compared to the control (Table 3). These findings correspond with the results reported in Fikre et al. (2018) that described organic mulches at the rate of 2.2 ton ha^{-1} and 3 ton ha^{-1} retained higher soil moisture at 90 DAS compared to the control. Furthermore, Jordan et al. (2010) and Rhoades et al. (2012) and Teame et al. (2017) reported that organic mulch treated soils recorded higher soil moisture compared to control at 75 DAS. These are attributed to the improved soil porosity, aggregate stability, more abundant organic matter, lower bulk density, and thus enhanced infiltration and available water capacity upon organic mulching (Jordan et al. 2010; Rhoades et al. 2012).

4.3. Effect on Wheat growth and yield

4.3.1. Days to flowering and milking

Days to flowering and milking showed a highly significant difference ($p < 0.001$) among treatments. Organic mulching treated plots delayed days to flowering by an average of 9.2% and milking by 11.7%. Maize stover had the highest both days to flowering (by 10.8%) and milking (by 12.3%). This is in line with the result of Li et al. (1999) and Van Donk et al. (2011) that reported longer number of days for flowering and milking stage in the mulched soil as compared to the control plots. This was related to a higher soil moisture conservation and weed suppression under mulched plots (Van Donk et al. 2011; Teame et al. 2017).

4.3.2. Days to maturity

The present result revealed that organic mulching treated plots delayed days to maturity by an average of 6.1%. A longer number of days to maturity were recorded under maize stover mulched soils, which was by 8.1% longer as compared to the control. This corresponds with the results of Teame et al. (2017) that reported longer number of days because of its influence on reducing environmental stress such as water stress by conserving moisture that serves for the plant to facilitate growth and development.

4.3.3. Number of tillers

The number of tillers increased by an average of 7.8% upon mulching as compared to the control. Maize stover had the highest performance, by 18.9% higher, as compared to the control. These findings are in line with that of Rahman et al. (2005) and Muhammad et al. (2018) that reported a higher plant tillers m^{-2} in the organic mulched plots as compared to the control plots.

Table 4 near here

Table 4
Some growth parameters of wheat as affected by mulch type

Treatment	Days after sowing				Height (cm)(Ns)	Tiller m^{-2}
	Emergence(Ns)	flowering	milking	maturity		
WS	7	47^{a}	72.00^{a}	90^{b}	91	410.83^{b}
SS	7	47.67^{a}	73.00^{a}	92^{a}	91.91	379.08^{c}
MS	7	**48.00**^{a}	**73**.00^{a}	**93**^{a}	91.6	**447.67**^{a}
FM	7	46.67^{a}	72.33^{a}	90^{b}	91.33	385.92^{c}
C	7	43.33^{b}	65.00^{b}	86^{c}	90.8	376.50^{c}
p value	0.69	0.00056	3.81e-06	6.50e-05	0.962	2.84e-05
LSD	1.82	2.7	1.69	1.82	3.2	18.44
CV %	14.29	3.19	1.31	1.11	6.86	2.53

Ns = non-significant, WS = Wheat straw mulch, SS = Sorghum stalk mulch, MS = Maize stalk mulch, FM = Finger millet mulch and C = Control, LSD = least significance difference, CV = coefficient of variation

4.3.4. Plant Height (cm)

Mulching in this study did not show significant difference ($p < 0.05$) on plant height. However, mulched soils showed a little higher (by 0.73%) plant height as compared to the control. The maximum plant height was measured under maize straw, which was by 0.9% higher than that of control treatment. This slightly higher plant height recorded from mulching materials as well as the Maize stover treated plots was due to better soil water conserved, which was essential for nutrient transporting, translocation of assimilate, cell division, and cell differentiation (Teame et al. 2017).

4.3.5. Spike weight and grains spike^{-1}

Highly significance difference ($P < 0.001$) on spike weight and grains spike^{-1} exist among the different treatments. Organic mulching exhibited significantly higher average spike weight (by 41% higher) and grains spike^{-1} (by 15% higher) as compared to the control plots. Sorghum stover treated plots had the highest spike weight and grains spike^{-1}, which is by 50.3 and 18.3% higher respectively as compared to the control. These findings are in line with that of Rahman et al. (2005) and Muhammad et al. (2018) that reported higher spike weight and grains spike^{-1} on mulched plots as compared to the control plots. According to these authors, the heavier spike weight and maximum grains spike^{-1} on the mulched plots might be due to their positive effect of mulches on soil moisture content and weed control.

Table 5 near here

Table 5

Spike weight, grains spike^{-1}, Biological yield, Grain yield and Harvest index (%) of wheat as affected mulch types

Treatment	spike weight (g)	Grains spike − 1	biological yield ton ha-1	grain yield kg ha-1	harvest index in%
WS	2.47^{a}	43.53^{a}	9.39^{abc}	4199.53^{c}	44.82^{b}
SS	2.60^{a}	44.13^{a}	10.78^{a}	4812.32^{b}	44.84^{b}
MS	2.40^{a}	42.67^{a}	10.36^{ab}	5203.08^{a}	50.38^{a}
FM	2.27^{a}	40.67^{ab}	9.22b^{c}	4119.20^{c}	44.83^{b}
C	1.73^{b}	37.33^{b}	8.73^{c}	3613.50^{d}	41.41^{c}
p value	0.000177	0.0453	0.0449	1.31e-09	0.000196
LSD	0.37	4.85	1.40232	135.1292	2.48
CV %	22.3	15.97	7.95036	1.692135	3.02

WS = Wheat straw mulch, SS = Sorghum stalk mulch, MS = Maize stalk mulch, FM = finger millet mulch and C = Control, LSD = least significance difference, CV = coefficient of variation

4.3.5. Biological yield, grain yield and harvest index

A significance difference ($p < 0.05$) on biological yield, grain yield and harvest index was also recorded among treatments (Table 5). Mulching increased biological yield by an average of 15%, grain yield by 27%%, and harvest index by 12%. Sorghum stover treated plots had the highest biological yield (by 23.2% higher); while both grain yield (by 44%), and harvest index (by 21.7% higher) were recorded from Maize stover treated plots as compared to the control. These outcomes are similar with that of Muhammad et al. (2018) that reported higher biological yield and grain yield on mulched plots compared to the control ones. These are related to a better vegetative growth of wheat with increased soil moisture content and decreased weed competition for nutrients and moisture (Teame et al. 2017).

4.4. Economic impacts of the treatments

Among the five treatments tested, two treatments (wheat and finger millet straw mulches) were dominant and were excluded from the marginal analysis (Table 6) for their non-profitability to farmers. The Net benefit was by an average of 19.7% higher on mulched plots as compared to the control. Maize stover treated plots had the highest net benefit, which was by 38.2%. Moreover, the highest marginal rate of return was obtained from maize stalk mulch treated plots (MRR = 5526.96%). This indicates that farmer can obtain extra 55.27 Birr by investing one Birr on land management using maize stalk mulch (1 USD = 30 ETB). This was also confirmed by the residual analysis results that indicate the highest profitability which can be gained by maize stalk mulched farms.

Table 6
Marginal rate of return and residual analysis of organic mulch on wheat

Treatment	TCV (Birr)	Gross benefit (Birr)	Net benefit (Birr)	MRR (%)	Minimum rate of return (100%×TCV)	Residual	Rank
C	0	52034.4	52034.4		0	52034.4	3
SS	2900	69297.4	66397.4	495.3	2900	63497.4	2
MS	3000	74924.4	71924.4	5527	3000	68924.4	1
FM	4000	59316.5	55316.5	-	-	-	D
WS	5000	60473.3	55473.3	-	-	-	D

C = Control, SS = Sorghum stalk mulch, MS = Maize stalk mulch, TCV = total cost that vary; NB = Net benefit; MRR = Marginal rate of return, D = Dominance

Table 6 near here

5. Conclusions

The results on the effects of organic mulches on weed control, soil moisture content, and growth and yield of wheat indicated an improvement in these parameters up-on soil mulching. The effect of organic mulch on weed control indicated that Maize and sorghum stalk mulch had good control of weed density in that it resulted in minimum weed dry matter, minimum weed types, maximum weed control efficiency and minimum weed index. Moreover, these treatments resulted to higher soil moisture content. However, the no mulch (control) plots had recorded the lowest amount in all parameters. Mulched soils also resulted to a higher wheat agronomic and grain yield. Longer days to flowering and milking were recorded in all organic mulches. A relatively longest day to maturity was found on maize and sorghum stalk mulched plots. The highest grain yield was also obtained from maize stalk mulched plots followed by sorghum stalk mulched plots. Of all the organic mulch treatments, maize stalk mulch was the most profitable in which investing one ETB on maize stalk mulch returns 55.27 ETB. Therefore, wheat growers having similar bio-physical and socio-economic set up to the study area can benefit more by using maize and sorghum stalks for mulching than the other mulching materials and the control.

Declarations

Authors Contribution: HM, GG, KT designed the research; HM performed the experiment; HM, GG, KT analyzed the data; KT, HM wrote and edited the manuscript'.

Data Availability Statement: there is no data submitted with this manuscript

Statements and Declarations: The authors declare that this work is our original work and is solely submitted to this journal.

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Figures

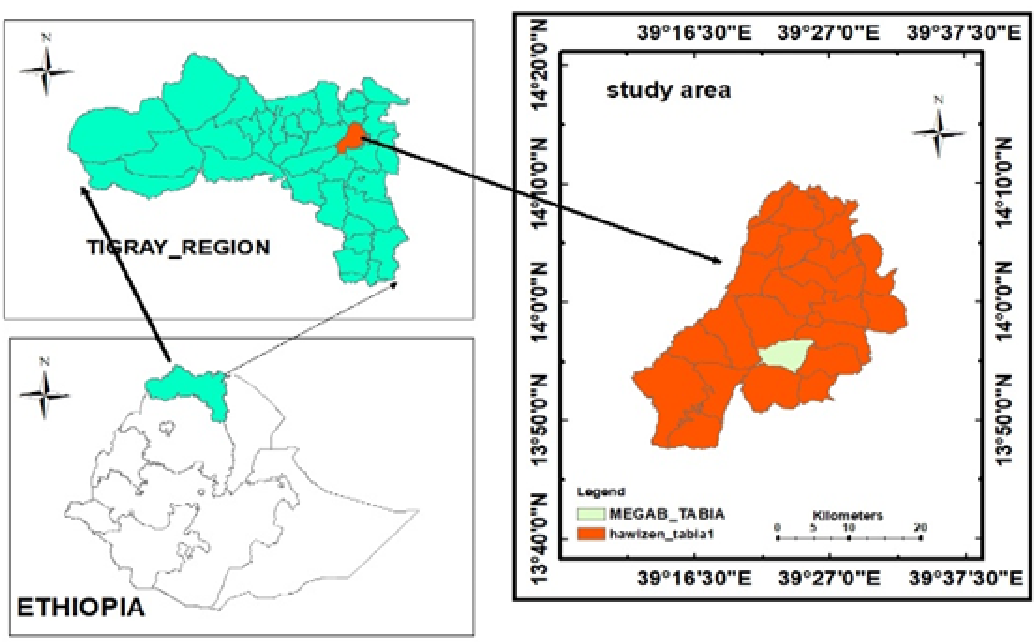

Figure 1

Map of the study area