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Full Length Research Paper

Effects of farmyard manure and straw mulch on runoff, erosion, *in-situ* water conservation (Reservoir), and yield and yield components of wheat at the high ground of Bale, south eastern Ethiopia

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A field experiment was conducted under natural rainfall conditions to investigate the effects of farmyard manure and straw mulch on runoff, soil loss, *in-situ* water conservation, and the yield and yield components of an improved bread wheat variety (HAR-1480) grown on vertisol of Sinana area, south eastern Ethiopian highland. The experimental design used was randomized complete block design (RCBD) with seven treatments involving three levels of farmyard manure (2, 4 and 6 ton ha^{-1}), three levels of barley straw mulch (2, 4 and 6 ton ha^{-1}), and a control without manure and mulch that were replicated three times. The results revealed that there was a highly significant difference (P<0.0001) between the treatments regarding their effect on runoff depth, soil loss and *in-situ* water conservation. However, there was no significant difference in grain yield due to the treatments. Moreover, compared to straw mulch, manuring was found to be less effective in reducing runoff and soil loss in the first season of application. Additionally, the soil loss measured for all straw mulch rates were not significantly different, implying that the 2 ton ha^{-1} mulching rate can effectively check soil erosion under the existing slope and rainfall conditions of the study area.

Key words: Bale highland, runoff depth, soil conservation, grain yield, sediment concentration.

INTRODUCTION

Soil erosion is second only to population growth as the biggest environmental problem that threatens agriculture in Africa and other parts of the world (Eswaran et al., 2001). The problem is becoming increasingly more urgent in developing countries like Ethiopia where the vast majority of the population are dependent on agriculture. According to El-Swaify and Hurni (1996), the Ethiopian highlands that make up 46% of the total land area of the country with over 95% of the regularly cropped land, constitute one of the most degraded lands in Africa. This accelerated soil erosion aggravated the problem of soil fertility depletion by removing organic carbon and other essential plant nutrients and exacerbated household and national food insecurity, thereby negatively impacting on development efforts underway in the country. Various literatures (Sertsu, 2000; Girmay et al., 2009) indicated that sediment associated nutrient losses are beyond tolerable limit under low input agricultural systems of Ethiopia. Meanwhile, considerable efforts have been made in the past to arrest large scale soil erosion, but the major emphasis was given to mechanical soil and water conservation measures in arable lands with little attention to soil organic matter depletion, soil fertility decline, soil physico-chemical and biological degradation (Teklu and

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Selamyihun, 2001). As a result, desirable outcomes were not achieved and still final solution is problematic and elusive. The highlands of Bale are nationally recognized as cereal belt where huge straw is produced annually. Furthermore, these highlands accommodate large number of livestock. In spite of these facts, the re-use of crop residues and farmyard manure within the farming systems to improve soil properties is much below expectation since these products are used for other domestic purposes. It is also not uncommon to see farmers burning crop residues with the intention to control weed and diseases. The soils of the study area, Bale highlands, are dominantly vertisol with poor structure, low infiltration capacity and develop deep cracks in dry seasons. These soils remain devoid of vegetative cover between cropping seasons and are prone to fertile topsoil removal particularly during the onsets of rainfall. To date, no systematic study on effect of manure and crop residue on runoff, soil conservation and yield of wheat under agro-climatic conditions of Bale highland has been made. Therefore, the present investigation was undertaken with the specific objectives of (1) investigating soil loss and water conservation under different surface management practices, (2) evaluating the degree to which rainfall, runoff and sediment losses are related in the presence of surface management practices under Bale highland conditions and (3) assessing the productivity of wheat as affected by surface management practices under the prevailing conditions of Bale highland.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted at Sinana Agricultural Research Centre (Figure 1). Geographically, the experimental site is located at 07°06'12"N, 40°12'40" E with an elevation of 2400 m above sea level. The soil of experimental site is clayey (25% sand, 23% silt and 52% clay). The long term precipitation (1990 - 2010) of the experimental site ranged from 823 to 1566 mm (CV=19%), with an annual average of 1174 mm. The area has bimodal rainfall pattern with distinct peaks in April and September (Figure 2). The seasonal rainfall varies from 346 to 861 mm during the first rainy season (March to July) and 353 to 894 mm during the main season (August to December). The mean annual maximum and minimum temperatures are 21 and 9.5°C, respectively. Furthermore, the geology of experimental area consists of flood basalt belonging to the Arsi and Bale basalts of the Oligocene–Miocene volcanic eruptions and rhyolite belonging to the Ghinir formation of the Quaternary volcanic eruption (Tefera et al., 1996).

Topographically, the area consists of gently undulating plain with average slope gradient of 6%. Crop production in the study area is characterized by cereal dominated cropping system. Wheat is extensively grown followed by barley. Some highland pulses such as field pea, faba bean, and oil crops like mustard and linseed are also grown.

Experimental design and procedures

Twenty-one experimental runoff plots of 2 m wide and 8 m long each were framed by sheet metal that was embedded to a depth of 15 cm and extending 15 cm above the soil surface along the boundaries. The design adopted for collecting tanks was that of multi-slot divisor as suggested by FAO (1993) and Pathak et al. (1997). The collecting tanks were covered with lids to prevent direct entry of rainfall and evaporation losses. Daily rainfall amount during measurement was recorded using a non-recording rain gauge at 8:00 a.m. at a meteorological station located in the close vicinity of the experimental site.

The experiment involved seven treatments: three levels of farmyard manure (2, 4 and 6 ton ha^{-1}), three levels of barley straw mulch (2, 4 and 6 ton ha^{-1}) and a control without any mulch and farmyard manure. The trial was laid out in a randomized complete block design with three replications. Agronomic aspects like tillage, time and method of planting, seed rate and weeding were carried out according to local practices and conditions. Bread wheat variety ['Madda Walabu' (HAR-1480)] was used as a test crop. This variety was selected due to its high yield and being the most widely grown in the area. The cultivar was planted on August 29, 2010, at locally recommended seed rate of 150 kg ha^{-1}. Planting was done by uniformly broadcasting seeds over the plots. Urea and triple superphosphate (TSP) were broadcasted and incorporated into the soil at the time of planting at specified rate of 30 kg ha^{-1} nitrogen (N) and 10 kg ha^{-1} phosphorus (P) to all plots. The applied rate of N was to alleviate temporary adverse effect of N immobilization (Christensen, 1986) and enhance straw decomposition (Schnürer et al., 1985), while TSP was meant to supply half of P fertilizer locally recommended for the area. All weeds were removed twice by hand weeding according to the locally recommended practices at 25 - 30 and 40 - 45 days after seedling emergence.

Soil sampling

Bulk samples of each plot were obtained from 5 points per plot, with a diagonal sampling line across the plot from a depth of 0 - 20 cm using augur prior to the start of the experiment and immediately after harvest. The samples were taken to the laboratory, air-dried, crushed and sieved to pass through a 2 mm mesh. Physical and chemical properties (Table 1) were determined following the standard procedure. Particle size distribution was determined by hydrometer method (Bouyoucos, 1962). The soil pH was measured potentiometrically in the supernatant suspension of 1:2.5 soil: water ratio (Motsara and Roy, 2008). Organic carbon content of the soil was determined by potassium dichromate wet combustion procedure (Walkley and Black, 1934). The available phosphorus content of soils was determined by 0.5 M sodium bicarbonate extraction procedures (Olsen et al., 1954). Total nitrogen content of the soil was determined by wet oxidation procedures of the Kjeldahl method (Motsara and Roy, 2008). Flame photometer (Toth and Prince, 1949) was employed for determination of exchangeable potassium.

Runoff and soil erosion

Total volume of daily runoff from each plot was measured in the collecting tanks after each rainstorm event at 8:00 a.m. The runoff depth was calculated by dividing the total runoff volume collected in a tank by the plot area. The contents of the tanks were vigorously stirred with a wooden stick to ensure a uniform distribution of sediment throughout the depth of water in the collecting tank. Immediately after stirring, 1 L capacity graduated jar was immersed to a substantial depth beneath the surface of water in the collecting tank and 1 L sample of water-sediment mixture was taken in pre-washed 1-L bottles from each collecting tank. Whenever overflow occurred from the collecting tank, the volume of runoff in the second collecting tank was multiplied by a factor of three to obtain

Table 1. Some physical and chemical properties of experimental field prior to the experiment (n= 21).

Data	Particle size distribution (%)			pH	OC	N	P_{av}	K
	Sand	Silt	Clay	(H_2O)	(%)	(%)	(ppm)	(ppm)
Mean	25	23	52	6.4	2.32	0.19	7.8	1131
SD	1.13	0.53	1.13	0.09	0.22	0.02	1.44	69.40

OC, Organic carbon; N, nitrogen; P, phosphorus; K, potassium.

the total volume of overflow from the first tank. The runoff samples were taken to soil and plant testing laboratory of Sinana Agricultural Research Centre, transferred to beakers and allowed to stand for 72 h until the sediments had completely settled (Tang et al., 1993). The clear water was then carefully decanted and the weight of wet sediment per litre of runoff was measured, air dried and kept for further physicochemical analysis except that 2 to 5 g of wet sediments were oven dried at 105°C for 24 h for the determination of moisture correction factor (mcf). Dry sediment concentration per litre of runoff was determined as:

$$Sc = Mw / mcf \quad (1)$$

where Sc is the Sediment concentration (g/L); Mw is the mass of wet sediment (g/L); mcf is the moisture correction factor given as: mcf = (100 + Mc)/100; where, Mc is the moisture content of sediment (%). The product of the sediment concentration and the total runoff per plot per day was used to determine the daily sediment loss as:

$$SL = (Sc*Ro) / 1000 \quad (2)$$

where SL is the daily sediment loss (kg/ ha); Sc is the sediment concentration (g/L) and Ro is the daily runoff (L/ha). Finally, the daily sediment losses were summed up to give seasonal soil loss values.

In-situ water conservation

The total depth of rainwater that was retained *in-situ* under each of the treatments was determined on the basis of runoff producing rainfall and runoff depth as:

$$WC = RF - Ro \quad (3)$$

where WC is the depth of water that was retained in-situ (mm); RF= runoff producing rainfall depth (mm); Ro= runoff depth (mm). Finally, the daily values of retained rainwater were summed up to give seasonal values.

Agronomic data

At physiological maturity, plant height, number of fertile tillers per plant, spike length and seeds per spike were collected on the basis of 10 randomly tagged plants in a 5 m^2 patch in the middle of erosion plot. Kernel weight was determined on the basis of weight of 1000 seeds randomly sampled from the grain yields of the crop under each treatment. To achieve this, seeds were counted by electric seed counter and their weights were measured with sensitive balance. The data on biomass was collected in such a way that the whole crop above the ground surface was cut very close to the ground surface in a 3 m^2 representative areas in the middle of each plot at harvesting stage. The same was air dried and weighted whole with sensitive balance to determine the total biomass. The spikes of the wheat were cut and threshed to separate the grain yield. The weight of the straw was calculated by subtracting the grain yield from the total biomass.

Statistical analysis

The effects of treatments on runoff, soil loss, *in-situ* water conservation and agronomical parameters of wheat were analyzed by subjecting the data collected to analysis of variance (ANOVA) using general linear model (GLM) procedures of statistical analysis system of computer software (SAS, 2004. Version 9.1), and treatment means were compared using the least significant difference at the 5% probability level ($LSD_{0.05}$) where the variance ratio for treatment effects showed significance.

RESULTS AND DISCUSSION

Runoff

The total runoff varied significantly between treatments ($p<0.0001$). All straw mulch treatments showed substantial reduction in runoff compared to the control treatment. As indicated in Table 2, the 6 ton ha^{-1} straw mulch resulted in considerably low runoff depth than all other treatments, except the 4 ton ha^{-1} mulching rate. However, the manure treatments did not show regular trend in runoff reduction, which might be on account of the longer time required for the manure to impact soil physicochemical and hydrological properties.

The runoff reduction as compared to the control was 98.3, 96.7 and 84.7% for 6, 4 and 2 ton ha^{-1} mulch rate, respectively, and similar findings were also reported in other investigations (Dickey et al., 1994; Edwards et al., 1995; Bhatt and Khera, 2006). This substantial reduction in runoff is attributed to increased infiltration due to detention of flow, and also residues dissipated the energy of raindrops, prevented surface sealing and ultimately reduced the quantity of rainwater that become runoff. The results further revealed that manure application was less effective in reducing runoff as compared to straw mulching. Runoff reduction as compared to the control was 11.3, 3.3 and 12.2% for 2, 4 and 6 ton ha^{-1} manure application rates, respectively. This suggests that the benefits of manure in reducing runoff cannot be realized under such a short duration experiments and their in-fluence could be seen as residual effect in the subsequent

Table 2. Total runoff depth, sediment load in runoff and soil loss in the experimental plots.

Treatment	Runoff depth (mm)	Sediment concentration (g/L)	Soil loss (ton ha^{-1})
Control	39.74^{a}	24.9^{ba}	9.83^{a}
FYM-2	35.26^{bc}	18.9^{b}	6.66^{b}
FYM-4	38.43^{ba}	25.4^{ba}	9.60^{a}
FYM-6	34.89^{c}	27.2^{a}	9.51^{a}
STR-2	6.09^{d}	8.4^{c}	0.51^{c}
STR-4	1.30^{e}	8.5^{c}	0.11^{c}
STR-6	0.66^{e}	4.8^{c}	0.03^{c}
LSD (0.05)	3.51	6.53	1.69
CV (%)	8.85	21.72	18.41

Different superscripts following values within a column indicate significant differences between the treatments. FYM-2= Farmyard manure (2 ton·ha^{-1}), FYM-4= farmyard manure (4 ton·ha^{-1}), FYM-6 = farmyard manure (6 ton·ha^{-1}). STR-2 = Straw mulch (2 ton·ha^{-1}), STR-4 = straw mulch (4 ton·ha^{-1}), STR-6 = straw mulch (6 ton·ha^{-1}); CV= coefficient of variation.

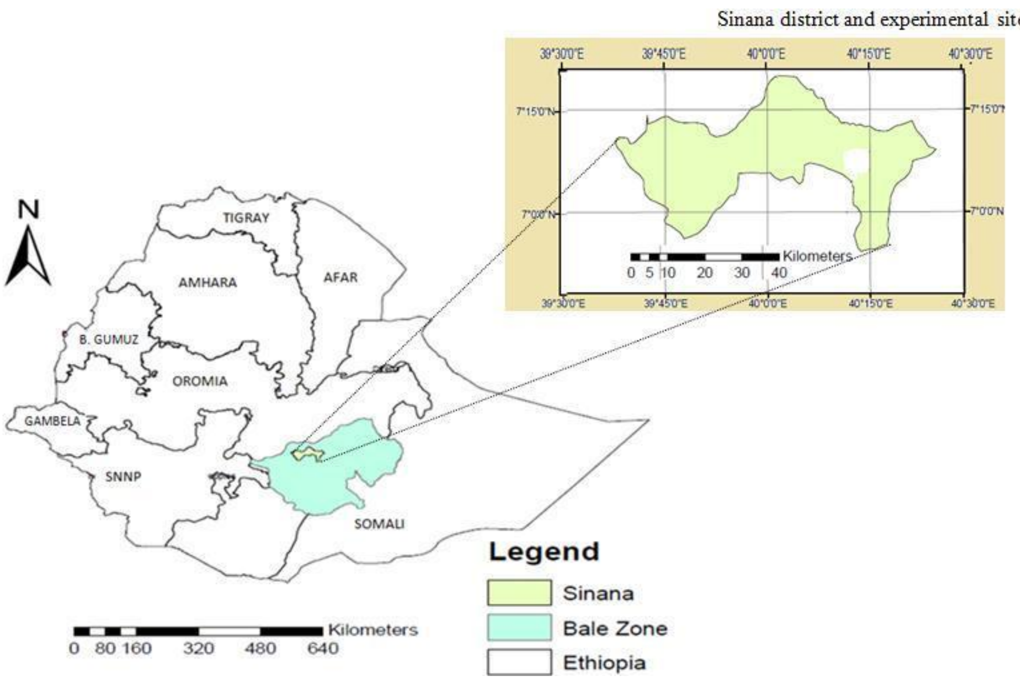

Figure 1. Geographical location of the experimental site.

subsequent crops. Similar findings are also available in several literatures. In rainfall simulation experiment, Ramos et al. (2006) observed that surface application of 30 ton ha^{-1} cattle slurry increased runoff volume by up to 30%. A study by Cabrera et al. (2009) also revealed an 8% higher runoff in manure treated plots than in control in the first year of manure application.

Soil loss

The analysis of variance revealed that the effect of mulching and manuring on soil loss was highly significant ($p<0.0001$). The mean soil loss from experimental plots is indicated in Table 2. All the straw mulch treatments were significantly more effective in checking soil loss than the other treatments considered in the study. However, it was observed that manuring at 4 ton ha^{-1} and 6 ton ha^{-1} resulted in annual soil loss, which was not significantly different from that of the control treatment. This substantial reduction in soil loss with mulching is consistent with the finding of Döring et al. (2005) who reported more than 97% reduction in soil erosion in a rain simulation experiment on potato field of 8% slope with 5 ton ha^{-1} chopped straw applications. Similar results were found in other investigations too. With straw application

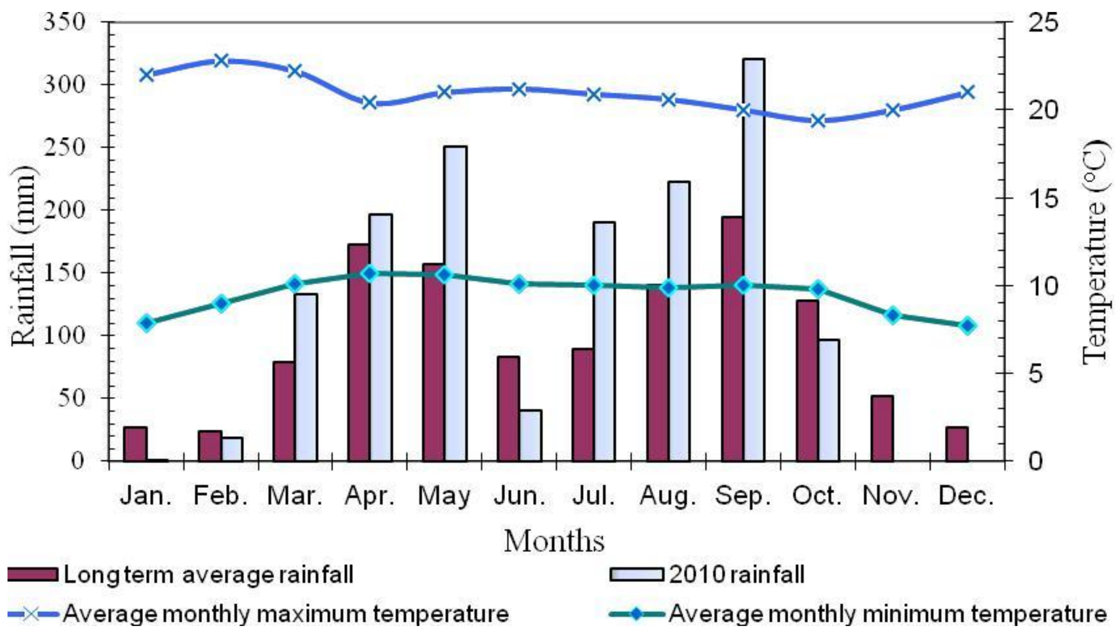

Figure 2. Long term average rainfall and temperature of Sinana Agricultural Research Center (1990 - 2010).

levels of 2 and 4 ton ha^{-1} at 10% slope, Lal (1975) reported that soil loss reduced by 97 and 99.6%, respectively, compared to soil loss in un-mulched plots. These results also agree with the findings of Laflen and Calvin (1981).

Soil loss due to particle detachment by raindrop impact, erosive power of runoff, sediment transportation by raindrop splash, and surface runoff flow are well recognized (Gajri et al., 2002; Kinnell, 2004). Soil surface cover and roughness reduce the raindrop impact and hence soil loss. The amount and velocity of runoff also affects soil loss by water (Gajri et al., 2002). The present result indicates that straw mulching not only reduced the surface runoff, but also provided a cover to the soil surface and hence decreased soil detachment by raindrop impact, reduced runoff erosivity, provided more infiltration opportunity, and trapped the sediments carried by surface runoff. As shown in Table 2, even small amounts of straw mulch (2 ton ha^{-1}) substantially reduced soil loss and sediment concentration in runoff. Soil loss reduction as compared to the control was 99.7, 98.9 and 94.8% for STR-6, STR-4 and STR-2, respectively.

Contrary to the plenty of evidences that farmyard manure incorporation decreases runoff and sediment loss (Gilley and Risse, 2000; Gessel et al., 2004; Ekwue et al., 2009), soil loss from plots that received 4 and 6 ton ha^{-1} FYM was not significantly different from that of control. This could be partially attributed to the higher runoff volume (Table 2) and the longer time required for the organic matter in the manure to become incorporated into the soil and impact soil properties. Similar observation was made by Cabrera et al. (2009) who found insignificant soil loss reduction in the first year of dairy manure application. Moreover, Sauer et al. (1999) ascribed runoff and soil loss from manure treated plots to the time between application and the first rainfall. Soil loss reduction as compared to the control was 32.2, 2.3 and 3.3% for FYM-2, FYM-4 and FYM-6, respectively.

In-situ water conservation

Mulch and manure treatments had a highly significant effect ($p<0.0001$) on *in-situ* rainwater retention. The average depth of rainwater retained *in-situ* under different treatments is shown in Figure 3. The results demon-strated that *in-situ* soil moisture conservation increased significantly for 6 ton ha^{-1} mulch as compared to the control treatment. Soil moisture storage in the 6 ton ha^{-1} mulch treatment was 216.11 mm, which was 39.15 mm higher in comparison to the control. However, the mean soil moisture storage for 4 ton ha^{-1} straw mulch was 215.40 mm, which was statistically at par in comparison to that retained at 6 ton ha^{-1} straw mulch treatment. The average rainwater depth retained for 6 ton ha^{-1} farmyard manure application (181.81 mm) was significantly higher than that retained under control treatment (176.96 mm). These results agreed with earlier findings of Verma and Acharya (2004) who reported 7.2 mm more moisture in 0 - 30 cm soil depth in mulched treatments. The results further indicated that soil moisture storage was increased by 22.1, 21.7, 19.0, 2.7, 0.74 and 2.53% for STR-6, STR-4, STR-2, FYM-6, FYM-4 and FYM-2, respectively, as compared to the control. The results also indicate that leaving crop residues could have the potential to con-serve much of the incoming rainfall and contribute towards

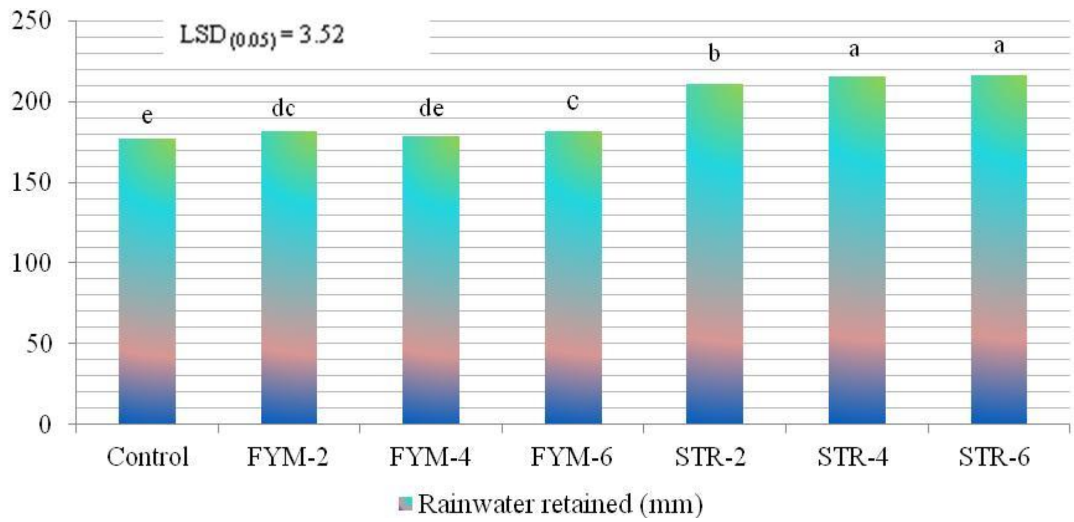

Figure 3. Mean depth of rainwater retained *in-situ* under different surface management practices. Bars sharing the same letter are not significantly different (p<0.05).

Table 3. Grain yield and some yield parameters of wheat as influenced by surface management practices.

Treatments	Plant height (cm)	Number of tillers/plant	Spike length (cm)	Seeds per spike	Biomass (ton/ha)	Straw yield (tons/ha)	Grain yield (kg ha^{-1})	TKW (g)
Control	92.4^{b}	3.7^{bac}	9.2^{ba}	48	13.6^{ba}	9.7^{bac}	3901	42.8
FYM-2	93.0^{b}	3.8^{ba}	9.5^{a}	47	14.5^{a}	10.6^{a}	3959	41.9
FYM-4	93.0^{b}	3.8^{ba}	9.1^{bac}	48	12.6^{bac}	8.4^{bdc}	4132	41.4
FYM-6	99.8^{a}	4.3^{a}	10.0^{a}	52	14.3^{a}	10.1^{ba}	4195	41.9
STR-2	86.0^{c}	3.3^{bc}	8.0^{ac}	51	11.3^{bc}	8.0^{ac}	3374	43.8
STR-4	92.4^{b}	3.2^{bc}	8.2^{bdc}	44	12.3^{bac}	8.2^{ac}	4089	44.3
STR-6	80.6^{d}	2.9^{c}	7.6^{d}	46	10.7^{c}	7.7^{d}	2942	43.6
LSD (0.05)	5.1	0.8	1.2	ns	2.28	1.79	NS	NS
CV (%)	3.1	12.6	7.36	8.9	10.05	11.25	13.5	6.2

Different superscripts following values within a column indicate significant differences between the treatments. TKW= Thousand kernel weight; LSD = least significant difference; CV = coefficient of variation; ns= non significant.

sustainable crop production by alleviating the impacts of drought spells which frequently occur in the growing season.

Wheat yield and yield components

The effect of treatments on plant height, number of tillers per plant, spike length, biomass and straw yield was significantly different (P<0.05). However, treatments had no significant effect on seeds per spike, grain yield and thousand kernel weights (Table 3). Although not significant, the FYM-6 treatment consisting of 6 ton ha^{-1} farmyard manure gave the highest grain yield (4195 kg ha^{-1}) whereas the 6 ton ha^{-1} straw mulching resulted in the lowest grain (2942 kg ha^{-1}) and biomass (10.7 ton ha^{-1}) yields. A relatively lower yield and yield components under high straw mulching rate of 6 ton ha^{-1} might be due to below optimum soil temperature that influences crop growth. Chen et al. (2007) reported reduction in grain yield of winter wheat by 7% with 6 ton ha^{-1} straw mulching as compared to the control, and they attributed this reduction to reduced soil temperature. Rasmussen et al. (1997) also reported 13% yield reduction in winter wheat under standing straw residue. Reduced yields under straw mulch have also been reported due to reduced soil nitrate levels and temporary immobilization of soil nitrogen (N) after straw incorporation into the soil due to the high C/N ratio of straw (Döring et al., 2005; Morgan, 2005).

Comparatively, better agronomic parameters at 6 ton ha^{-1} manure application rate could be on account of higher soil organic matter content of farmyard manure. The role of organic manure in improving crop nutrition, organic matter contents, and enhancing soil physical and biological properties has been documented (Irshad et al., 2002). Besides increasing inorganic N pools, improvement in seasonal soil N mineralization available to plants was also reported due to manure applications (Ma et al., 1999).

Conclusion

Under the prevailing edaphic and agro climatic conditions of the present study (clayey soils, wet *dega* agro ecological zone), light quantity of straw (2 ton ha^{-1}) resulted in significant reduction in sediment concentration in runoff and hence, annual soil loss. However, it was observed that manuring at 4 and 6 ton ha^{-1} resulted in annual soil loss, which was not significantly different from that of the control treatment. Grain yield was not affected by straw mulching and manuring treatments. The results indicate the possibility of benefitting from soil erosion control and water conservation functions of straw mulch, without the risk of yields being reduced under conditions of the study area.

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