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Grain Yield Response of Sorghum (Sorghum bicolor) to Tied Ridges and Planting Methods on Entisols and Vertisols of Alemaya Area, Eastern Ethiopian Highlands

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Abstract

Field experiments were conducted under rain-fed conditions between 1986 and 1995 to investigate the effects of soil and water conservation treatments (tied ridges and planting methods) on the yield of an improved sorghum variety (ETS-2752) grown with and without N and P fertilizers on two major soils of Alemaya area, eastern Ethiopian highlands. The yield responded significantly ($P \leq 0.01$) to the treatments both under fertilized and unfertilized conditions of the soils studied. However, the magnitude of the yield response and the relative efficiency of the tied ridges and planting methods varied with soil type, fertilization, and total rainfall and its distribution during the cropping season. Regardless of the type of tied ridge used, furrow planting, specifically, closed end tied ridge planting in furrows gave the highest yield in three of the four sets of experiments. Flat bed planting produced the lowest grain yields on all sets of experiments except under the unfertilized condition of Entisols in which open end planting on ridges produced the lowest sorghum yield. Within the tied ridges, closed end performed better than open end in all except the Vertisols without N and P fertilizers. Compared with the traditional (flat bed) planting method, the highest yield increment of 1361 kg/ha (34.5%) due to tied ridges was obtained on the Entisols with NP followed by 1255 kg/ha (48.5%) on the Alemaya black clay soils (Vertisols) under fertilized condition, indicating that the yield response to water conservation treatments was higher under fertilized than under unfertilized conditions on the two soils. Fertilization increased the yield of sorghum by as high as 1576 kg/ha (69.5%) on Vertisols and by 1468 kg/ha (38.3%) on Entisols both from planting in the furrows of closed end tied ridges. The study also revealed that the yield response was higher in seasons with low or poorly distributed rains and on shallow and coarse textured soils. The results indicate that in areas with low and erratic rainfall such as the Alemaya area, soil and water conservation is indispensable for increasing crop yield.

Keywords: Entisols, Flat bed planting, Furrow planting, NP fertilizer, Ridge planting, Tied ridge, Vertisols

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1 Introduction

Periodic low soil moisture due to erratic and poorly distributed rainfall, severe soil erosion and runoff loss of water and the resultant low soil fertility are the prominent causes for the low agricultural productivity in the Ethiopian highlands (>1500 meters above sea level (masl) which form 46% of the total land area and where over 95% of the regularly cropped lands are found (Tamirie Hawando, 1986; Heluf Gebrekidan and Yohannes Uloro, 2002). Accordingly, about 50% (27 million ha) of the highlands are significantly eroded, 25% (13.5 million ha) seriously eroded and over 4% of the former farmlands are severely eroded and converted to rock outcrops (EHRS (Ethiopian Highlands Reclamation Study), 1984). The rates of annual loss of soil due to erosion for Ethiopia vary from almost zero on lowland grasslands to over 200 tons/hectare/year (t/ha/yr) on steep slopes of the highlands cultivated with erosion promoting crops such as maize or sorghum (Getachew Teklemedhin, 1998). In addition to accelerated soil erosion and the alarming rate of land degradation, the loss of water as runoff coupled with periodic drought during the cropping season on degraded lands supporting rain-fed crop production was also equally important (Tamirie Hawando, 1986; Asfaw Belay *et al.*, 1998; Heluf Gebrekidan and Yohannes Uloro, 2002).

These problems are mainly attributed to the inadequate efforts and absence of technologies proved to conserve the soil and water resources, the consequence of which is the need to increase productivity on limited and marginal land and water resources. Soil and water conservation is called upon to alleviate both the problems of erosion and drought which are symptoms of two different extremes of rainfall conditions. As rainfall erosivity, soil erodibility and landform are inherent properties of climate, soil and land, respectively, only little can be done to modify their effects appreciably. Therefore, control of soil erosion and runoff water depends on judicious soil and crop management practices (Lal, 1977a,b; Hudson, 1977). The practice of judicial water conservation undoubtedly plays a significant role in increasing agricultural production in arid, semi arid and sub-humid areas where agriculture is hampered by periodic droughts and low soil fertility (Tamirie Hawando, 1986; Heluf Gebrekidan, 1989; Heluf Gebrekidan and Yohannes Uloro, 2002).

Soil or land management practices to reduce soil loss and runoff to negligible amounts are usually based on a combination of practices which help to maintain soil infiltration rates at sufficiently high levels and on measures which help safe disposal of runoff water from the field, should rainfall exceeds the infiltration capacity of the soil (Lal, 1977a). Cultural practices, which maintain a high soil infiltration rate and feasible in cultivated lands are essentially based on farming techniques, which maintain a mulch or live vegetation (stubble mulching and no- or minimum-tillage and use of cover crops) on the soil. The safe disposal of runoff may involve physical manipulation of soil including land shaping, contour bunds, terraces, waterways and ridges. However, although the methods of conservation may be either known or could be predicted, more local and/or regional level studies are justified for their demonstrative values (Lal, 1977a; Hudson, 1977).

An erosion-promoting crop such as sorghum can be grown without causing serious soil erosion provided that proper soil and water conservation techniques are used than a soil-conserving crop grown with erosion-promoting practices (AINA *et al.*, 1976; LAL, 1977a,b). AINA *et al.* (1976) observed 221 t/ha/yr of soil loss and 30% of runoff from monoculture cassava, and a soil loss of 137 t/ha/yr and runoff of 19% from Nigerian Alfisols on 15% slope in a cassava-maize mixed cropping system. Management of crop residues on the farm lands increased the grain yields of maize, sorghum and wheat crops both by improving soil fertility and conserving water on the two major soils of Alemaya area that are used in the present study (HELUF GEBREKIDAN, 1989; ASFAW BELAY *et al.*, 1997, 1998; HELUF GEBREKIDAN *et al.*, 1999; HELUF GEBREKIDAN and YOHANNES ULORO, 2002). LAL (1977b)Lal observed a runoff of 1.2% and a soil loss of 0.05 t/ha with mulch at a rate of 6 t/ha and a runoff water of 50% and a soil loss of 4.83 t/ha without mulch.

Although the economic variability, availability of labor and the social factors involved in getting widespread acceptance of suitable methods for a specific region require much more attention, mechanical measures in controlling soil erosion are well studied (KOWAL, 1970a,b; MACARTNEY *et al.*, 1971; MOLDENHAUER and ONSTAND, 1977; FAUCK, 1977; HELUF GEBREKIDAN and YOHANNES ULORO, 2002; ASFAW BELAY *et al.*, 1998). Among these, tied ridging is an effective practice particularly in lands with slopes less than 3-4% and by adding terrace on steeper slopes (MOLDENHAUER and ONSTAND, 1977) in increasing crop yields by increasing the time for the water to penetrate into the soil. PHILIPS and YOUNG JR. (1973) showed zero to 40% increases in maize yield for no tillage sod planting over the conventional plow-disk-harrow system. HELUF GEBREKIDAN and YOHANNES ULORO (2002) observed maize yield increments of 15 to 50% due to tied ridges on the soils reported in this paper and 15 to 38% for sorghum on different soil types of eastern Ethiopia. KOWAL (1970a,b) reported that ridges that are not tied at intervals were not effective in controlling runoff and soil loss in the Savannah region of northern Nigeria. In Upper Volta, tied ridges led to only 0.9% runoff as compared to 6.3% with open graded ridges and 12.2% in the case of flat cultivation (FOURNIER, 1967).

Proper mechanical soil and water conservation schemes increased maize and sorghum yield by 700-3400 kg/ha in the eastern Ethiopian highlands (TAMIRIE HAWANDO, 1986; TAMIRIE HAWANDO *et al.*, 1986; ASFAW BELAY *et al.*, 1998; HELUF GEBREKIDAN and YOHANNES ULORO, 2002). ASFAW BELAY *et al.* (1998) reported maximum maize yield increases of 10, 18 and 23% on Entisols and 54, 35 and 26% on Vertisols of eastern Ethiopia, with crop residue, with residual NP and with both crop residue and residual NP, respectively, due to the combinations of tied ridges and furrow planting over flat planting. Thus, the efficiency of the physical soil and water conservation techniques depends on the soil type, climate, the crop grown and the cropping methods followed.

However, despite the significance of the problems of soil erosion and drought in the Ethiopian highlands, research aimed at generating soil and water conservation techniques and farming practices that reduce soil erosion and harvest rain water for use by plants, on cultivated lands in the country, is inadequate. Therefore, the present studies were initiated to evaluate the relative efficiency and effectiveness of tied ridges and planting methods and their interaction on sorghum yield on Entisols and Vertisols of Alemaya area both under fertilized and unfertilized conditions. Such information is particularly scanty for the Alemaya region of eastern Ethiopian highlands.

2 Materials and methods

2.1 Site description

Four sets of field experiments were conducted between 1986 and 1995 both on fertilized and unfertilized conditions on Entisols and Vertisols of Alemaya area, eastern Ethiopian highlands at the Alemaya University Research Station. The Research Station is located at 9° 26' N latitude, 42° 2' E longitude and an altitude of 1970-1980 masl. The area is characterized by low and highly variable rainfall requiring a thorough understanding of the climate if increased and sustained crop production with the use of improved farming technologies is to be realized. The average monthly rainfall (1979-1994) for these highlands revealed a bi-modal pattern with small rains in March-May and big rains in July-September. The long-term total annual rainfall at the study area indicates the occurrence of rainfall fluctuation from year to year and displays a decreasing trend over the years. Hence, the yearly mean rainfalls at the site were 807 mm for 1957-1994 and 774 mm for 1979-1994 (Alemaya University of Agriculture, 1998). The average annual potential evapotranspiration (PET) is 1427 mm. Rainfall is greater than PET only for about 45 days (in July and August) in a given year. The long term mean annual, mean monthly minimum and mean monthly maximum temperatures at Alemaya are 16.9, 10.0 and 23.5°C, respectively (Alemaya University of Agriculture, 1998). Entisols and Vertisols are the major agricultural soils in the area. Attributed to continuous nutrient depletion resulting from intense soil erosion, cereal mono-cropping, complete removal of crop residues and very low mineral and organic fertilizer use, both soils are poor in fertility. Formed in situ (residual) mostly on truncated erosional surfaces (eroded phase) on landscapes with slopes of 3 to 15% or greater and covering 50 to 65% of the total land area in the Alemaya region, the Entisols are reddish brown in color, sandy loam to sandy clay loam in texture and very shallow in depth, with the combined thickness of the A and AC horizons ranging from 30 to 40 cm. They are low in organic matter (1.5-2.0%), total N (0.08-0.11%), Olsen extractable P (6.9 mg/kg) and cation exchange capacity (Eylachew Zewdie, 1994). As a result of these and other factors, the Entisols are unproductive unless supplied with considerably high amounts of mineral fertilizers, especially N.

The Vertisol (Alemaya black clay) meets the requirements of depth, cracking, intersecting slickensides, churning or argillipedoturbation and other characteristics to be classified as Typic Pellusterts (Eylachew Zewdie, 1994). This soil occurs on slopes ranging from 0-3% mostly on valley bottoms and plateaus in the region. It is clayey ($>$ 50% clay to a depth of 2m) in texture, has low permeability, high P retention capacity and presents very hard physical conditions for the plant roots to develop and to work with both when dry and wet. It is very droughty and produces only little sorghum or maize crop yield if rainfall during the cropping season is less than 600 mm (Tamirie

HAWANDO, 1986; HELUF GEBREKIDAN and YOHANNES ULORO, 2002). The N level of this soil is moderate ranging from 0.1 to 0.2%, K and P contents are fairly low but CEC is high and Ca and Mg are abundant (EYLACHEW ZEWDIE, 1994). Generally, unless properly managed, the comparative capacity of this soil for the production of food crops is low in most years.

2.2 Experimental Design and Procedure

Field experiments were conducted on Entisols (Typic Ustorthents) and Vertisols (Typic Pellusterts) at the Alemaya University Research Station to investigate the effects of soil and water conservation (tied ridges and planting methods) treatments on the yield of sorghum. The field experiments on both soil types were conducted one without and another with the application of recommended rates of N and P fertilizers side by side. Throughout the study period, each experiment was laid down in a randomized complete block design with four replications. The treatments considered were (a) flat bed planting (control); (b) open end tied ridge, planting on ridges; (c) open end tied ridge, planting in furrows; (d) closed end tied ridge, planting on ridges; and (e) closed end tied ridge, planting in furrows (Fig. 1).

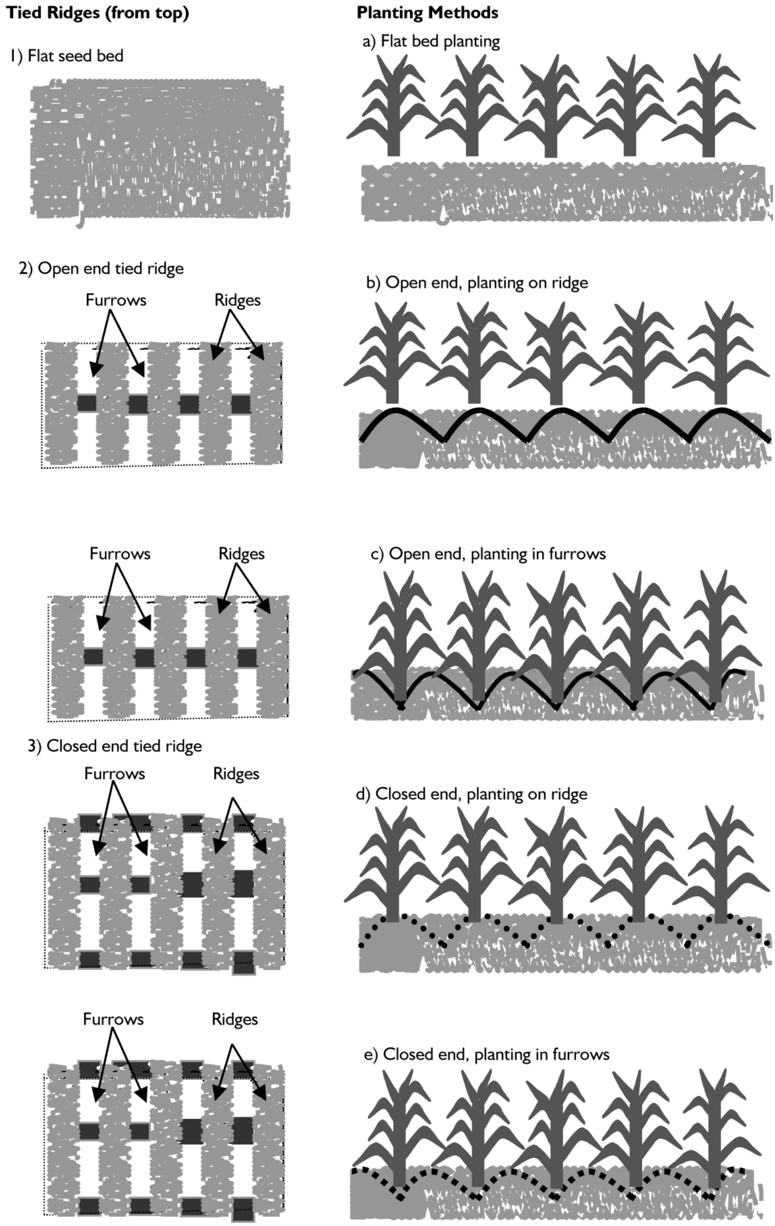
The improved sorghum variety ETS-2752 was used as a test crop on all of the four sets of trials whereby planting was made at the onset of the short rains in April on which a dry spell occurs in June several weeks after the establishment of the seedlings. Each set of experiment was conducted for six to eight seasons between 1986 and 1995. The crop was planted on a plot size of 4.5m x 4.5m (20.25m^2) in rows of six per plot at a spacing of 75 by 25 cm. The rates of fertilizers applied for the crop on the plots of the fertilized set of trial on the Entisols were 138 kg N and 30 kg P/ha, and 92 kg N and 40 kg P/ha on the Vertisols. Half of the rate of N and the full rate of the P fertilizers were applied 5 cm below the seed at time of planting as urea (46% N) and as triple super phosphate or TSP (20% P), respectively. Whereas the second half of the N fertilizer was applied 30-40 days after planting at 7-10 cm away from the plant as two side dressing at about 5 cm below the surface. Grain yields and all other desirable data and samples were collected from the four central rows of each plot. Apart from grain yield data, total above ground biomass, agronomic characters and soil samples at 0-25 and 25-50cm depths (for soil moisture and NP determinations) were also collected from each treatment and used in interpreting the grain yield data. The mean yield data were subject to statistical analysis using MSTAT computer software appropriate to the design and significantly differing treatment means were separated using the least significant difference (LSD) test.

3 Results an discussion

3.1 Sorghum Grain Yields on Entisols without NP Fertilizers

The average grain yield (1986-1995) data of sorghum (ETS-2752) produced under rain-fed conditions without NP fertilizers on Entisols as influenced by tied ridges and planting methods are depicted in Table 1. The mean grain yield of sorghum was significantly different ($P \leq 0.01$) due to the effects of soil and water conservation (tied ridge and

Figure 1: Sketch diagram of the different tied ridges and planting methods used in the study.



planting method) treatments. Among the treatments considered in the study, planting in the furrows of closed end tide ridge produced the highest sorghum grain yield (3836 kg/ha) followed by open end tied ridge, planting in furrows (3559 kg/ha). However, there was no significant difference ($P > 0.01$) between the yields produced on the furrows of closed end and furrows of open end tied ridges and between the yields produced on open end planting in furrows and closed end planting on ridges (Table 1).

The lowest sorghum grain yield (3026 kg/ha), among the treatments considered in the study, was obtained when the crop was planted on the ridges of open end tied ridge (Table 1). However, the mean yield due to this low yielding treatment did not significantly differ from the yield produced on the flat bed planting treatment. In general, the maximum increments in yield of sorghum obtained due to tied ridge and planting method treatments were 675 and 810 kg/ha over the traditional (flat bed) planting and over the least effective water conservation technique. Regardless of the type of the tied ridge used, furrow planting methods produced higher grain yield of sorghum than ridge and flat bed planting methods. Similarly, within the same planting method, closed end tied ridges gave higher yields of sorghum than open end tied ridges.

Table 1: Mean grain yield (kg/ha) of sorghum (ETS-2752) grown without NP fertilizers on Entisols as influenced by tied ridges and planting methods between 1986 and 1995 crop seasons.

Tied ridge treatment	*Replication*				*Mean**
	I	*II*	*III*	*IV*	
Flat bed planting (control)	3169	3153	3090	3231	3161^{ab}
Open end, planting on ridges	2871	3192	2933	3106	3026^{a}
Open end, planting in furrows	3608	3537	3647	3443	3559^{cd}
Closed end, planting on ridges	3396	3373	3490	3467	3432^{bc}
Closed end, planting in furrows	4118	3655	3796	3773	3836^{d}

* Means followed by the same letter are not significantly different at $P = 0.01$.

The higher yields of sorghum recorded for planting in the furrows and for closed end tied ridges over ridge planting and open end tied ridges, respectively, are attributed to the higher water harvesting and retaining capacities of the former as compared to the latter treatments and the flat bed planting. Closed end tied ridges and furrow methods gave more time to penetrate and infiltrate rain water than open end tied ridges and flat beds and than ridge planting methods and therefore allow crop plants to use the water that could have been lost as runoff. The impacts of closed end tied ridges and furrow planting method in improving crop growth and yield were significantly higher during crop seasons with low total rainfall and/or with poorly distributed rains and were in agreement with similar findings reported by MACARTNEY *et al.* (1971); MOLDENHAUER and ONSTAND (1977); HELUF GEBREKIDAN (1989); ASFAW BELAY *et al.* (1998); HELUF GEBREKIDAN and YOHANNES ULORO (2002).

Analysis of the four years mean yield data of sorghum produced on the Entisols clearly indicated that the yield and monetary benefits accrued due to water conservation were surprisingly high and encouraging. Among the different soil and water conservation techniques evaluated, one can recommend based on the grain yield data, the use of closed end planting in furrows as the first and open end planting in furrows as the second efficient methods of tied ridges for this specific condition. Generally, the results indicate that the use of proper soil and water conservation practice is imperative on areas like the Alemaya region, which is characterized by erratic and generally low total rainfall, and on the Entisols, which is characterized by shallow root depth, coarse texture and low water holding capacity.

3.2 Sorghum Grain Yields on Entisols with N and P Fertilizers

The mean yield data of sorghum (ETS-2752) produced on Entisols with the application of N and P fertilizers and as influenced by different soil and water conservation treatments varied from 3943 to 5304 kg/ha (Table 2). The differences in mean sorghum yield due to the different soil and water conservation treatments were significant ($P \leq 0.01$). In accordance with the unfertilized set of the experiment conducted side by side under similar other conditions (Table 1), planting in the furrows of closed end tied ridge followed by open end planting in furrows produced the highest yield of sorghum. In this experiment, the mean yield differences between the first three high yielding tied ridge and planting method treatments were highly significant. However, unlike the unfertilized set of the same experiment, open end planting on ridges yielded better than flat bed planting although the yield difference due to these treatments was not significantly different ($P > 0.01$).

Regardless of the type of tied ridges, furrow planting methods produced comparatively higher yields of sorghum than their counterpart ridge and flat bed planting (Table 2). Taking the same planting methods into account, closed end tied ridges performed better than open end tied ridges. In general, the data recorded over the years of field investigations clearly indicated that the grain yield and the monetary benefits obtained from the use of water conservation practices on cultivated land of Entisols along with N and P fertilizers are high and encouraging. The higher maximum sorghum yield increment over the control (Tables 1 and 2) due to tied ridges from the fertilized (1361 kg/ha) than from the unfertilized set (675 kg/ha) indicated that soil, especially water conservation practice on nutrient poor, coarse textured, shallow and droughty soils such as the Entisols of Alemaya area is more effective when used with fertilization. Furthermore, it should be expected that the benefits obtained from water conservation will be much higher in regions and crop seasons with erratic and low total rainfall and with crops/varieties that are more sensitive to soil moisture deficit.

The reasons that have been advanced to explain similar yield conditions in the unfertilized set of the same experiment can also be applied to explain the higher grain yield records observed in furrow planting compared with ridge planting method and in closed end compared with open end tied ridges. Many researchers (Fournier, 1967; Kowal, 1970a,b; Macartney *et al.*, 1971; Moldenhauer and Onstand, 1977; Heluf Ge-

Table 2: Mean (1986-1995) grain yield (kg/ha) of sorghum (ETS-2752) grown with NP fertilizers on Entisols (Alemaya series) as influenced by tied ridges and planting methods.

Tied ridge treatment	*Replication*				*Mean**
	I	*II*	*III*	*IV*	
Flat bed planting (control)	3960	4024	3796	3984	3943^{a}
Open end, planting on ridges	4188	4055	4055	4251	4137^{ab}
Open end, planting in furrows	4878	4839	4549	4565	4708^{c}
Closed end, planting on ridges	4643	4282	4094	4353	4343^{b}
Closed end, planting in furrows	5427	5247	5192	5349	5304^{d}

* Treatment means followed by the same letter are not statistically significant at $P = 0.01$.

BREKIDAN, 1989; ASFAW BELAY *et al.*, 1998; HELUF GEBREKIDAN and YOHANNES ULORO, 2002) have also reported the importance of the practice of tied ridging in increasing crop yields by increasing the time for the water to penetrate into the soil. As it is to be expected, regardless of the tied ridge treatments, the yield of sorghum produced with the applications of N and P fertilizers was superior compared with that produced on the same soil type without N and P fertilizers (Tables 2 and 1). The response of sorghum to applied N and P fertilizers on Entisols of the region was in agreement with similar fertility research results reported by TAMIRIE HAWANDO (1986); HELUF GEBREKIDAN (1989).

In line with the unfertilized trial, closed end planting in furrows and open end planting in furrows could be safely recommended as the first and second effective types of tied-ridges for use as a means of soil and water conservation for fertilized sorghum crop under the prevailing conditions. Apparently, it can be predicted that sorghum (ETS-2752) grown in the furrows of closed end tied ridges could give lower yields in seasons and regions receiving higher total rainfall that can create a water logged soil condition.

3.3 Sorghum Grain Yields on Vertisols without NP Fertilizers

The mean grain yield data of sorghum produced on Vertisols under natural soil fertility status differed significantly ($P \leq 0.01$) due to the effects of the different soil and water conservation treatments (Table 3). The highest (2408 kg/ha) and lowest (1659 kg/ha) grain yields of sorghum were obtained when the crop was planted in the furrows of open end tied ridge and the flat bed planting treatments, respectively. However, the highest grain yield recorded for open end planting in furrows was not significantly different ($P > 0.01$) when compared with the yields obtained both from closed end planting in furrows (2267 kg/ha) and closed end planting on ridges (2180 kg/ha).

Within the same tied ridge, planting in furrows produced higher grain yields of sorghum than planting on ridges. However, the yields of sorghum attributed to the type of tied ridges (open end and closed end) were not consistent when compared either with their respective or across all planting method methods. The lowest yield of sorghum produced on the flat bed (traditional) planting method was highly significantly lower than the mean yields produced on all other tied ridge treatments, except open end planting on ridges. In this specific set of experiment, the maximum yield increment due to tied ridge treatments was 749 kg/ha (Table 3).

Table 3: Mean grain yield (kg/ha) of sorghum (ETS-2752) grown as influenced by soil and water conservation treatments on Vertisols (Alemaya black clay) without NP fertilizers

Tied ridge treatment	*Replication*				*Mean**
	I	*II*	*III*	*IV*	
Flat bed planting (control)	1608	1624	1616	1788	1659^{a}
Open end, planting on ridges	1859	2071	1945	1796	1918^{ab}
Open end, planting in furrows	2290	2196	2424	2722	2408^{c}
Closed end, planting on ridges	2173	2141	2298	2110	2180^{bc}
Closed end, planting in furrows	2220	2157	2424	2267	2267^{c}

* Treatment means followed by the same letter are not significantly different at $P = 0.01$.

The higher water harvesting and retaining capacity of the furrows than the ridges and flat beds (Kowal, 1970a,b; Asfaw Belay *et al.*, 1998; Heluf Gebrekidan and Yohannes Uloro, 2002), as to supply the plants with enough available water throughout the growing period, might be responsible for the higher sorghum grain yields produced when the crop was planted in the furrows. Moreover, the higher sorghum yield production on the furrows of open end than in the furrows of closed end tied ridges suggest the optimum water retention capacity and drainage of open end than closed end furrows. This, in general indicates that the black clay soils (Vertisols) of the Hararghe highlands require a system of land preparation, which conserves water and at the same time provides optimum drainage. This is to be expected for the fact that the water conservation relaxes the soil moisture stress occurring as a result of the sparsely distributed and low total rainfall during the cropping season, which is often a typical characteristic of the region, and the drainage removes the excessive water (water lodging stress) retained by the soil. Attributed to its fine texture (high clay content, mainly montmorillonitic clays) and relatively high water holding capacity; the black clay soils are often prone to water logging stress.

3.4 Sorghum Grain Yields on Vertisols with N and P Fertilizers

The mean grain yield of sorghum produced on Alemaya black clay soil as affected by different physical soil and water conservation techniques and planting methods, and with the application of recommended rates of N and P fertilizers varied from 2588 kg/ha on flat bed planting to 3843 kg/ha on the furrows of closed end tied ridge (Table 4). Analysis of variance and mean difference test made on the yield data revealed a highly significant difference due to the effects of the soil and water conservation treatments. In accordance with the unfertilized set of experiment, furrow planting methods produced superior yields of sorghum regardless of the type of tied ridges involved (Tables 3 & 4). However, unlike the unfertilized set of experiment on the same soil, where planting in furrows of open end tied ridge yielded the highest grain of sorghum (Table 3), closed end planting in furrows produced the highest yield of sorghum in the fertilized experiment (Table 4).

Taking furrow and ridge planting methods independently into consideration, closed end tied ridges produced comparatively higher sorghum grain yields than open end tied ridges. As indicated in Table 4, the differences in the mean grain yield among and within each of the tied ridge and planting method including the control (flat bed planting) treatments were significant ($P \leq 0.01$). In line with the unfertilized set of experiment, flat bed planting produced the lowest grain yield of sorghum in the fertilized set of experiment. The maximum yield increment obtained as a result of the differences in the effectiveness of the tied ridges and planting methods over the control treatment was 1255 kg/ha. This increment in sorghum yield is much higher compared with its increment of 749 kg/ha obtained due to the same effect from the unfertilized set of experiment on Vertisols (Tables 3, 4 and 5) indicating that water conservation is more effective when used on fertilized than on unfertilized field condition.

Table 4: Mean (1986-1995) grain yield (kg/ha) of sorghum (ETS-2752) with NP fertilizers on Alemaya black clay as influenced by soil and water conservation treatments.

Tied ridge treatment	*Replication*				*Mean**
	I	*II*	*III*	*IV*	
Flat bed planting (control)	2408	2494	2729	2722	2588^{a}
Open end, planting on ridges	2800	2824	2800	2941	2841^{b}
Open end, planting in furrows	3176	3302	3373	3247	3275^{d}
Closed end, planting on ridges	2933	3122	3067	3184	3077^{c}
Closed end, planting in furrows	3851	3733	3875	3914	3843^{e}

* Treatment means followed by the same letter are not significantly different at $P = 0.01$.

In general, from the average sorghum grain yield data produced both under unfertilized and fertilized conditions of the soil, it could be realized that considerably high yield and monetary benefits would be accrued due to water conservation practices even on soils characterized by high water holding capacities. This is to be expected for the fact that the water harvested and retained by furrows of tied ridges (Asfaw Belay *et al.*, 1998) could relax the water deficit periods' characteristic of the eastern Ethiopian highlands where the study is conducted. It could be shown that sorghum requires more available soil water and at the same time tolerates excessive soil water more when grown with fertilizers than without fertilizer applications. Moreover, the substantial yield response of the crop to tied ridging on both the fertilized and unfertilized experiments indicated that in regions with poor rainfall distributions such as the Hararghe highlands, soil and water conservation is a necessary agricultural operation even on heavy clay soils such as the Alemaya black clay (Vertisols) which suffer from poor drainage in seasons and/or regions receiving high rainfall.

3.5 Summary of results and conclusion

In summary, flat bed and open end planting on ridges produced the lowest grain yields of sorghum in three and one sets of the four experiments, respectively (Table 5). Generally, furrow planting produced higher grain yields of sorghum than ridge and flat bed, and closed end produced higher yield than open end tied ridges and flat bed under both soil fertility statuses of both soils. Accordingly, except on the unfertilized set of the Vertisols, which was surpassed by open end tied ridge planting in furrows, closed end planting in furrows gave the highest yield of sorghum on all experiments. As it is to be expected from the low fertility levels of the soils (HELUF GEBREKIDAN, 1989; EYLACHEW ZEWDIE, 1994; ASFAW BELAY *et al.*, 1997; HELUF GEBREKIDAN *et al.*, 1999; HELUF GEBREKIDAN and YOHANNES ULORO, 2002), the yields of sorghum produced on both soils under the influences of tied ridges and planting methods without NP fertilization were lower than their respective yields with NP fertilization (Table 5). The maximum yield increment due to N and P fertilizer applications on the Entisols was 1468 kg/ha (38.3%) and on the Vertisols it was 1576 kg/ha (69.5%) both obtained on closed end planting in furrows. Compared with flat bed planting, the Entisols gave the highest absolute increment of sorghum grain yield (1361 kg/ha) with NP and the Vertisols gave highest yield (749 kg/ha) without fertilizers due to the use of water conservation practices (Table 5).

The highest sorghum yields in the furrows of closed end contradict with maize, which yielded highest in the furrows of open end tied ridges when planted under identical conditions on these and other soil types in the region (ASFAW BELAY *et al.*, 1998; HELUF GEBREKIDAN and YOHANNES ULORO, 2002). This could be ascribed to the differences of these crops in their water requirement and tolerance to periodic water logging or periodic soil moisture stress conditions. Apparently, the results thus revealed that sorghum is more tolerant both to periodic soil moisture stress and water logging conditions than maize and the latter requires a planting method which conserves enough water while providing optimum drainage. It is to be noted that the flat bed planting method that yielded the least on three of the four sets of experiments is the farmers' practice where sorghum is planted broadcast. Moreover, planting on the ridges of open end tied ridge, which gave the lowest yield on the unfertilized condition of Entisols, is the farmers' practice wherever sorghum is planted in rows. Therefore, in line with results of the studies the following conclusions could be drawn:

(1) The improved variety of sorghum responded significantly to tied ridge and planting methods both under fertilized and unfertilized conditions of the two major soils studied,

(2) The magnitude of yield response to water conservation and the relative effectiveness of the different tied ridges and planting methods tend to vary with soil type, level of soil fertility and distribution and total rainfall during the crop season,

Table 5: Mean grain yield (kg/ha) of sorghum (ETS-2752) grown without and with N and P fertilizers on Entisols (Alemaya series) and Vertisols (Alemaya black clay) as influenced by tied ridges and planting methods.

Tied ridge and planting method	*Entisols with no NP*		*Entisols with NP*		Yield due to NP	*Vertisols with no NP*		*Vertisols with NP*		Yield due to NP
	Yield *	Increment	Yield *	Increment		Yield *	Increment	Yield *	Increment	
Flat bed planting (control)	3161^{ab}	-	3943^{a}	-	782	1659^{a}	-	2588^{a}	-	929
Open end, planting on ridges	3026^{a}	-4.2	4137^{ab}	4.9	1111	1918^{ab}	15.6	2841^{b}	9.8	923
Open end, planting in furrows	3559^{cd}	12.6	4708^{c}	19.4	1149	2408^{c}	45.1	3275^{d}	26.5	867
Closed end, planting on ridges	3432^{bc}	8.6	4343^{b}	10.1	911	2180^{bc}	31.4	3077^{c}	18.9	897
Closed end, planting in furrows	3836^{d}	21.4	5304^{d}	34.5	1468	2267^{c}	36.6	3843^{e}	48.5	1576
Maximum increment due to tied ridges/NP over control (kg/ha or %)	675	21.4	1361	34.5	1468	749	36.6	1255	48.5	1576

* Treatment means within a column followed by the same letter are not significantly different at $P = 0.01$.

(3) Regardless of the type of the tied ridge, furrow planting proved to be more effective in conserving water and increasing the yield of sorghum with relatively consistent effects in most seasons than ridge and flat bed methods on both soils and soil fertility levels,

(4) Within the furrows, closed end tied ridge is more efficient than open end tied ridge as indicated by increased yield, and the relative effectiveness of the tied ridges and planting methods in increasing crop yields increased with increasing level of soil fertility.

In general, the results apparently indicated that in the Alemaya region of the eastern Ethiopian highlands where the rainfall is low and erratic and the soils are degraded, low total rainfall or its uneven distribution during the cropping season is one of the principal factors limiting the yield of crops. Hence, regardless of the water holding capacity and fertility levels of the soils, soil and water conservation and particularly, in situ water harvesting practices are indispensable agricultural operations. Accordingly, efforts have to be made to extend the results of the present studies to the end users and, giving priority, further research on this field is imperative if boosting crop yield and sustainable production is to be realized in these areas.

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