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Micro-Basin Tillage for Grain Sorghum Production in Semiarid Areas of Northern Ethiopia

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ABSTRACT

The yield of grain sorghum (*Sorghum bicolor* L. Moench) and other crops is often constrained by soil water deficits in semiarid areas of Ethiopia. The effectiveness of micro-basin tillage, in the form of tied-ridging, was evaluated as a means of improving soil water availability through reduced runoff and to increase grain and stover yield. Field research was conducted on a clay soil with vertic properties (Typic Pellustert) in northern Ethiopia in 2003 and 2004. Tied-ridging conducted before planting, at planting, and after planting was compared with planting on a flat soil surface without ridging and with a traditional ridging practice known as *shilshalo*. Planting in-furrow was compared with planting on-ridge. Tied-ridging before or at planting resulted in the best soil water status throughout the season and the best crop performance, especially when planting was in-furrow. Mean soil water content with the most effective tied-ridge treatment was on average 42% and 49% more than with flat tillage and planting in 2003 and 2004, respectively. Overall crop performance was generally worst for flat soil surface planting and for the *shilshalo* treatment, where the respective grain yield was 45% and 62% of yield with in-furrow planting, respectively. Soil water availability in the 0- to 0.90-m soil depth dropped below the permanent wilting point for all treatments before the grain was physiologically mature. Yield can be increased by tied-ridging before or at planting. The results indicate that mean yield can be improved by planting with the onset of the rains.

Grain sorghum is a major food crop in semiarid areas of northern Ethiopia. Production of sorghum in this region is estimated at 105 000 ha, with mean yield of less than 1.3 Mg ha^{-1} (CSA, 2000), largely due to soil water deficits typical for some other sorghum production areas in Ethiopia and Eritrea. Runoff losses of water associated with heavy rainfall events contribute to the soil water deficits.

Tillage to create micro-catchments for retention of water during heavy rainfall events can result in more water for crop production due to reduced runoff losses (Lal, 1977; Gebrekidan, 2003; Gusha, 2002; Pendke et al., 2004). Tied-ridging is a form of micro-basin tillage and has also been called boxed ridging, furrow-diking or -damming, basin listing, basin tillage, micro-basin tillage, and cross-tied ridging (Lawes, 1961; Jones and Clark, 1987; Krishna, 1989; Jones and Stewart, 1990). In tied-ridging, ridge furrows of 0.20 to 0.30 m depth are blocked with earth ties spaced according to the slope of the land, soil water infiltration rate, and expected intensity of rainfall. Tied-ridging has been effective in reducing surface runoff and increasing soil water storage in Tanzania (Macarthey et al., 1971; Gusha, 2002), the USA (Jones and Clark, 1987; Krishna, 1989; McFarland et al., 1991; Howell et al., 2002), Burkina Faso (Hulugalle et al., 1990), Zimbabwe (Piha, 1993; Vogel, 1993; Nyakatawa, 1996), and India (Hiremath et al., 2003). Sanders et al. (1996) estimated that the adoption of tied-ridging for small-scale sorghum production in Africa increased farm income by 12%.

Improper use of tied-ridging can result in problems such as ridge over-topping, ridge failure, water logging, and total loss of the crop in severe storms (El-Swaify et al., 1985; Jones and Clark, 1987). If the most intense and greatest amount of rainfall typically occurs during the growing season, it may be desirable to remove the ties at that time (Lawes, 1961), or tied-ridging may be inappropriate with such a rainfall pattern (Krishna, 1989). Vogel (1993) found that yields were more erratic with tied-ridging for a sandy soil in a semiarid environment due to lower soil water contents in the ridges during dry periods. Wiyo et al. (2000) concluded from their work in Malawi that tied-ridging is not likely to benefit a corn crop in coarse-textured soils regardless of the seasonal rainfall amount because most of the water is lost to internal drainage.

The beneficial effects of tied ridging on crop yield vary due to differences in amount and distribution of rainfall, soil type, slope, landscape position, crop, and the time of ridging, with the most substantial effects in semiarid areas where high-intensity rainfall events often result in significant runoff (McFarland et al., 1991). Jones and Clark (1987) determined that the conditions for the greatest grain sorghum yield response to tied-ridging were continuous annual cropping, large early-season rainfall/runoff events, and soil water deficits during the growing season.

Much of the semiarid sorghum production area of northern Ethiopia has the conditions identified by Jones and Clark (1987) as important to achieving increased sorghum yield with tied-ridging. The objectives of this research were to determine the benefit of micro-basin tillage practices, specifically as tied-ridging, in terms of soil water availability and sorghum grain yield in a semiarid area of northern Ethiopia. Optimal time for making the tied-ridges and best seed placement relative to the ridges were determined.

MATERIALS AND METHODS

The study was conducted at Abergelle, an administrative unit of Tigray region in northern Ethiopia (13°14′06″ N lat;

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Abbreviations: WAP, weeks after planting.

38°58′50″ E long). The elevation of the research site was about 1500 m. Annual rainfall had a uni-modal pattern and ranged between 350 and 700 mm, with about 70% of the precipitation normally falling in July and August. Mean monthly temperatures during the growing season range from 21 to 25°C. The soil at the experimental site was a clay soil with vertic properties (Typic Pellustert), with 4 g kg^{-1} soil organic C, neutral pH, and low available P (Table 1). The slope of the site was about 0.03 m m^{-1}. Bulk density ranged from 1.37 Mg m^{-3} at 0 to 0.30 m depth to 1.42 Mg m^{-3} at 0.60 to 0.90 m depth. The available volumetric water content, calculated as the difference between water content at −3.3 m (field capacity) and −150.0 m (permanent wilting point) suctions, ranged from 0.14 m^3 m^{-3} at 0.30 to 0.90 m depth to 0.16 m^3 m^{-3} at 0 to 0.30 m depth. Permanent wilting point was estimated at 0.25 and 0.30 m^3 m^{-3} for the 0 to 0.30 and 0.30 to 0.90 m depths, respectively.

The tillage treatments included planting with flat soil surface (flat planting), tied-ridging 4 wk before planting with planting in-furrow ($TR_{-4WAP}IF$) or on-ridge ($TR_{-4WAP}OR$), tied-ridging at planting with planting in-furrow ($TR_{0WAP}IF$) or on-ridge ($TR_{0WAP}OR$), *shilshalo*, and tied-ridging at 4 wk after planting (TR_{4WAP}). *Shilshalo* is a traditional ridging and weed control practice using the traditional oxen-drawn plow known as *maresha. Shilshalo* is commonly conducted 4 wk after planting and forms ridges about 0.15 m in height and narrow furrows that are not tied.

The experiment was conducted in 2003 and 2004 with treatments applied to the same experimental units each year in a randomized, complete-block design with three replications. The plot size was 5.25 by 8.0 m separated by alleyways of 2 m between blocks and 1.5 m between plots. The row spacing was 0.75 m. Ridges were tied at 2-m intervals. Planting was with an oxen-drawn row planter, and a plant spacing of approximately 0.20 m was achieved by hand thinning at 21 d after planting.

The entire experimental area was tilled once using the traditional oxen-drawn *maresha* plow before imposing any of the treatments. All plots were weeded manually twice during the cropping season. An oxen-drawn ridging implement was used to construct ridges of 0.30 m height. The traditional *maresha* plow was used for the *shilshalo* treatment. Nitrogen and P were applied to each plot at the rate of 50 kg ha^{-1} of urea and 100 kg ha^{-1} of di-ammonium phosphate with 41 kg ha^{-1} N and 20 kg ha^{-1} P applied. Diammonium phosphate was band-applied at planting time, and urea was applied 4 wk after planting. No chemical was used for pest and weed control. The locally popular, early maturity, sorghum cultivar ‘*Chibal*’ was sown each year. The dates of tied-ridging and planting are presented in Table 2.

Volumetric soil water content was determined gravimetrically by collecting soil samples in 0.30-m increments to 0.90 m depth every 3 wk from the date of planting. Samples were collected at the base of plants using a hand-auger with three subsamples per plot. Samples were weighed wet and dried in a forced-air oven at 105°C until constant weight. Volumetric soil water was calculated as:

$$\theta_v = [(SW_i - SW_d)/(SW_d) \times \rho_b/\rho_v]$$

where θ_v = volumetric water content (m^3 m^{-3}), SW_i = initial weight of the soil (g), SW_d = oven-dry weight of the soil (g), ρ_b = dry soil bulk density (Mg m^{-3}); and ρ_v = density of water (Mg m^{-3}) (Hillel, 1980).

Other observations included daily rainfall, days to 50% flowering and 50% maturity, plant height, plant population at harvesting, panicle length, panicles m^{-2}, grain yield, stover yield, and 100-kernel weight. Plant height was recorded for five random plants in each of the central three rows at 3-wk intervals from the date of planting to harvest by measuring the height from the ground to the top of the leaf whorl before flowering and to the tip of the panicle after panicle emergence. Yield and yield components were recorded from an area of 2.25 by 7.6 m, excluding border areas. Panicle length was measured for 15 random plants. The final stem-plus-tiller density was determined by counting all stems and tillers in the harvest area. Seed weight was determined for a sample of 100 air-dried seeds. Grain samples were tested for water content after threshing, and grain yield was expressed at 125 g kg^{-1} water content. Harvest index was calculated as the ratio of seed yield to the aboveground biomass yield on an air-dry weight basis.

Analysis of variance was conducted using MSTATC statistical software (Freed, 1994). Plant height data were analyzed separately for each time of measurement, and a combined analysis was conducted to determine the significance of treatment interactions with measurement date and year and of the three-way interaction. Soil water volume data were analyzed separate for each depth and time of measurement, and a combined analysis was conducted to determine the significance of treatment interactions with measurement date, depth, and year and of the three- and four-way interactions. Treatment effects were considered significant at the 0.05 probability level.

Table 1. Selected soil physical and chemical properties of the soil (0–0.20 m) at Abergelle, Tigray, Ethiopia.

Soil property	Value
Sand, g kg^{-1}	260
Silt, g kg^{-1}	260
Clay, g kg^{-1}	480
Textural class	Clay
pH, H_2O (1:2.5)	6.8
Electrical conductivity, dS m^{-1}	0.12
Organic carbon, g kg^{-1}	4.0
Total nitrogen, g kg^{-1}	0.3
Olsen P, mg kg^{-1}	5.1
Bulk density at 0–0.30 m, Mg m^{-3}	1.37
Bulk density at 0.30–0.60 m, Mg m^{-3}	1.40
Permanent wilting point at 0–0.30 m, m^3 m^{-3}	0.25
Permanent wilting point at 0.30–0.90 m, m^3 m^{-3}	0.30
Field capacity at 0–0.30 m, m^3 m^{-3}	0.41
Field capacity at 0.30–0.90 m, m^3 m^{-3}	0.45

Table 2. Dates of tillage and planting operations in 2003 and 2004.

Treatments	2003	2004
Tied-ridging for −4 WAP†	18 June	16 June
Tied-ridging for 0 WAP and planting for all treatments	18 July	16 July
Shilshalo and tied-ridging for 4 WAP	17 August	15 August

† −4 WAP, 0 WAP, and 4 WAP: −4, 0, and 4 wk after planting.

RESULTS AND DISCUSSION

Rainfall and Soil Water

Total seasonal rainfall was considered typical in 2003 and 2004, but the patterns of distribution differed between the 2 yr (Fig. 1). Rainfall amount in June was more and less than normal in 2003 and 2004, respectively. August and July were relatively wet in 2003 and 2004, respectively, with an early cessation of rainfall in 2004.

In the combined analysis of variance, the main effects of time of soil water measurement and tillage treatment accounted for most of the variation in soil water availability. In both years, soil water volume was greatest 6 weeks after planting (WAP) and declined as the season progressed (Fig. 2a and b). Soil water volume was more

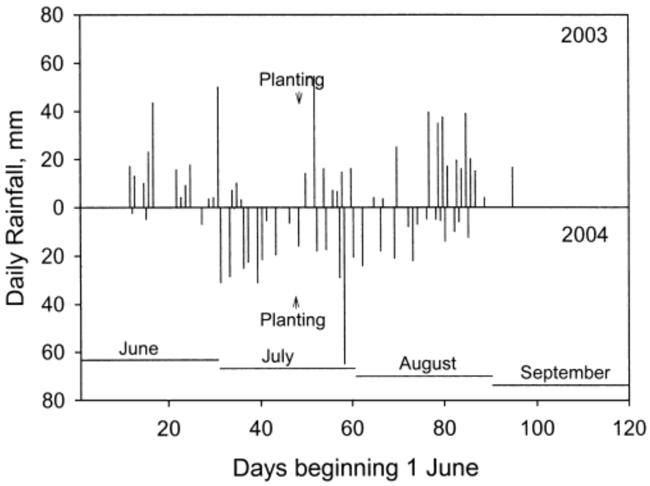

Fig. 1. Daily precipitation beginning 1 June at Abergelle in northern Ethiopia in 2003 and 2004.

with tied-ridged in-furrow planting than with other treatments. Soil water volume also differed with depth with a mean of 28.6% in the upper 0.30 m and 29.3% for the 0.30–0.90 m depth (results by depth not reported).

The effects for the tillage treatment by time of sampling, tillage by year, and the three-way interaction on soil water volume were significant. Beginning 3 WAP, soil water was generally more with in-furrow as compared with on-ridge planting (Fig. 2a and b). This difference was more pronounced in 2004 than in 2003. Soil water volume was similar for tied-ridging at 4 WAP and at planting time for most of the season. After the 6 WAP sampling, soil water volume was least with flat planting. Soil water with *shilshalo* was more than with flat planting only at 15 WAP in 2003 and beginning at 9 WAP in 2004, but soil water volume to 0.90 m depth was already below permanent wilting point in both treatments.

The sampling date × year interaction was significant for soil water volume (Fig. 2a and b) and reflected the difference in rainfall distribution. Soil water volume with all treatments was at or below the permanent wilting point at 14 WAP in 2003. In 2004, when there was little rainfall in August, soil water at 9 WAP was at or below the permanent wilting point with several treatments, and soil water was above the permanent wilting point at 14 WAP for only tied-ridging at −4 WAP with in-furrow planting. In both years, there is no indication that soil water increased once the permanent wilting point was reached.

The results confirm the effectiveness of tied-ridge tillage, conducted before or at planting, in maintaining generally higher levels of soil water volume and for delaying depletion of available soil water for fine-texture soils (Wiyo et al., 2000; Howell et al., 2002). Differences in soil water for in-furrow as compared with on-ridge planting may be partly due to the soil sampling method because samples were collected at the base of the plant. Adjei-Twum (1987) obtained better yield on vertic clay soils when planting sorghum on top of tied-ridges because sorghum planted in-furrow may have suffered due to waterlogging.

Crop Performance

Crop phenology was related to soil water volume. Flowering and maturity were early with flat planting as compared with tied-ridge treatments in 2003 and 2004 (Tables 3 and 4). The latest flowering and maturity occurred with in-furrow planting with tied-ridging before or at planting. Although soil water volume was generally less with flat planting than with early tied-ridging, soil water was well above the permanent wilting point at flowering time in 2003. Time to maturity was apparently reduced by soil water deficits, and the time from 50% flowering to 50% maturity was only 18 and 17 d for flat planting in 2003 and 2004, respectively.

Sorghum plant height exceeded 2.0 and 1.5 m with some treatments in 2003 and 2004, respectively (Fig. 3). The tillage and tillage × days after planting interaction effects were significant for plant height, but the tillage × year and the three-way interactions were not significant. The tillage × days after planting interaction was due to the increasing magnitude of tillage treatment effects on plant height until 15 wk after planting. Height was generally greater with tied-ridging at or before planting, especially with in-furrow planting, than with no tied-ridging. Main stem plus tiller density at harvest was also least with no tied-ridging and most with tied-ridging at or before planting, especially with in-furrow planting (Tables 3 and 4). Performance for these and other crop growth traits was generally superior for earlier tied-ridging as compared with tied-ridging at 4 WAP, although the differences were not always significant.

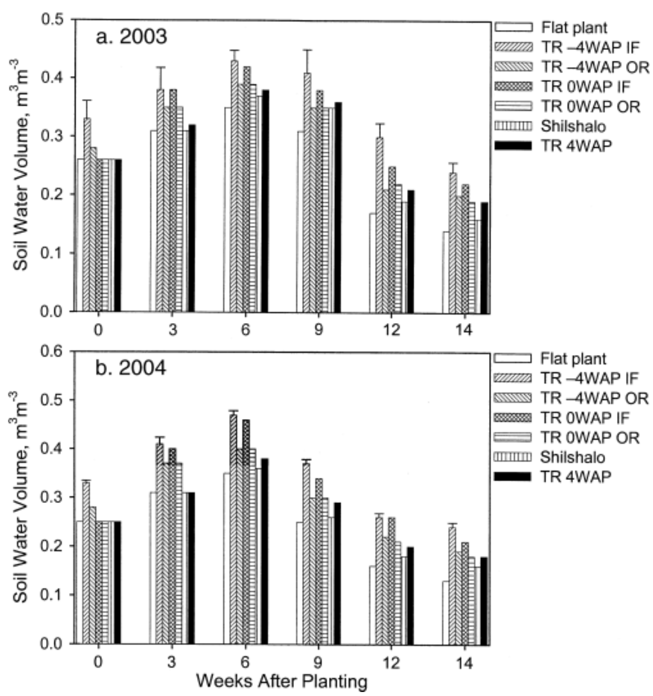

Fig. 2. Soil water volume for 0 to 90 cm as affected by tillage and planting treatments in (a) 2003 and (b) 2004 at Abergelle in northern Ethiopia. Y-bars equal $LSD_{0.05}$ appropriate for that sampling date. Flat plant = planting with a flat soil surface. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. *Shilshalo* = a traditional ridging practice conducted 4 wk after planting.

Table 3. Crop phenology, yield, and yield components of sorghum as affected by tillage treatments in 2003 at Abergelle in northern Ethiopia.

Treatments	DF†	DM	Tillers m^{-2} at harvest	Panicle length	100-seed wt.	Grain yield	Stover yield	HI
				mm	g	Mg ha^{-1}		Mg Mg^{-1}
Flat plant‡	64	82	20.0	177	2.33	1.48	5.92	0.20
$TR_{-4WAP}IF$	75	99	27.8	233	3.30	2.87	11.10	0.29
$TR_{-4WAP}OR$	72	94	24.9	217	2.90	2.38	8.92	0.21
$TR_{0WAP}IF$	73	95	25.7	220	3.03	2.52	10.31	0.20
$TR_{0WAP}OR$	70	91	23.3	213	2.70	2.16	8.30	0.21
Shilshalo	67	87	22.2	183	2.63	1.78	7.02	0.20
TR_{4WAP}	69	90	23.3	200	2.67	2.12	8.31	0.20
LSD 0.05	3.6	2.2	4.25	27.9	0.509	0.725	2.850	0.080

† DF = days to 50% flowering; DM = days to 50% maturity; tillers m^{-2} at harvest includes the main stem and tillers; HI = harvest index.
‡ Flat plant = planting with a flat soil surface. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. *Shilshalo* = a traditional ridging practice conducted 4 wk after planting.

Lawes (1961) also observed better cotton performance with early as compared with late tied-ridging.

Panicle length and 100-seed weight in both years and panicle number (determined in 2004 only) were least with flat planting and *shilshalo* and greatest with tied-ridging at or before planting with planting in-furrow (Tables 3 and 4). Treatment effects on grain and stover yields reflected treatment effects on soil water and on yield components. Grain and stover yields were least with flat planting and greatest with in-furrow planting where tied-ridging was done at or before planting time. Mean stover yields ranged from 5.9 to 11.1 Mg ha^{-1} and from 3.9 to 9.7 Mg ha^{-1} in 2003 and 2004, respectively. Mean grain yields were much less, ranging from 1.5 to 2.9 in 2003 and from 0.8 to 2.5 Mg ha^{-1} in 2004. Harvest index values were very low, generally around 0.20. Nyakatawa (1996), Hiremath et al. (2003), and Pendke et al. (2004) also observed higher yield with tie-ridging relative to flat planting. The conditions of the trial match the criteria for likely yield response to tied-ridging as specified by Jones and Clark (1987): the crop was an annual, there were early heavy rains, and there was limited growing season precipitation.

Crop performance for all growth traits, including plant height and stover yield (which were largely determined during the vegetative stages of growth), were closely related to mean volumetric soil water content to 0.90 m depth. The coefficients of correlation for the treatment means for volumetric soil water, averaged over sampling times and years, with treatment means for growth traits, averaged over years, exceeded 0.95 (data not shown).

The sorghum crop made good early growth in both years, as indicated by substantial stover yield. Soil water volume in the surface 0.90 m of soil was depleted, however, for all treatments in both years before the crop reached physiologic maturity. Although the plants may have had continued access to deeper water (Nakayama and Van-Bauel, 1963), the effects of soil water depletion during the grain-fill period are reflected in small grain size, low grain yield, and very low harvest index values. In the region, stover yield is valued because the stems are used for thatching and for fuel, and the leaves and stems are used as cattle feed during the long dry season. The grain is the most valued part of the harvest because it provides a staple food, and surplus production is marketed.

Management practices to delay depletion of soil water may improve grain yield. Time of planting was not addressed in this study. Planting was nearly a month after the onset of rains in 2003 and nearly 2 wk after onset in 2004. Given that rainfall ceased before 50% flower in each year, planting with the onset of rains seems to be an opportunity to improve water availability during grain-fill and to increase kernel size and grain yield. If soil conditions allow, tied-ridging of dry soil before the onset of rains to increase capture of the earliest rainfall followed by in-furrow planting with the onset of rains seems to offer the best management option for increasing sorghum grain yield.

CONCLUSIONS

Choice of tillage system is important to crop performance in the semiarid areas of northern Ethiopia. Tied-ridging at or before planting improved sorghum grain and biomass yield and resulted in greater soil water availability than other traditional tillage practices.

Table 4. Crop phenology, yield, and yield components of sorghum as affected by tillage treatments in 2004 at Abergelle in northern Ethiopia.

Treatments	DF†	DM	Tillers m^{-2} at harvest	Panicle length	Panicle m^{-2}	100 seed wt.	Grain yield	Stover yield	HI
				mm		g	Mg ha^{-1}		Mg Mg^{-1}
Flat plant‡	59	76	20.4	137	12.1	1.5	0.79	3.87	0.17
$TR_{-4WAP}IF$	72	94	28.3	205	22.1	2.9	2.50	9.67	0.21
$TR_{-4WAP}OR$	69	88	25.2	183	18.1	2.4	2.00	7.53	0.20
$TR_{0WAP}IF$	70	90	26.1	193	19.2	2.6	2.16	8.84	0.19
$TR_{0WAP}OR$	67	86	23.7	183	16.4	2.2	1.70	6.80	0.20
Shilshalo	62	81	22.5	150	15.4	1.9	1.30	5.24	0.19
TR_{4WAP}	66	85	23.4	170	16.1	2.1	1.70	6.64	0.20
LSD 0.05	0.8	1.0	0.14	8.0	0.18	0.08	0.056	0.258	0.037

† DF = days to 50% flowering; DM = days to 50% maturity; tillers m^{-2} at harvest includes the main stem and tillers; HI = harvest index.
‡ Flat plant = planting with a flat soil surface. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. *Shilshalo* = a traditional ridging practice conducted 4 wk after planting.

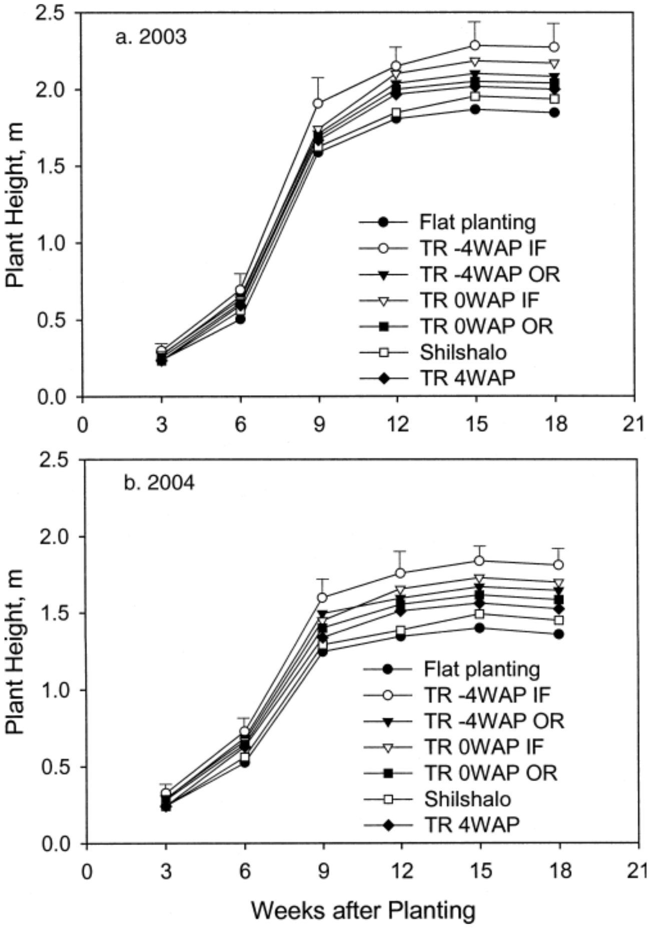

Fig. 3. Sorghum plant height as affected by tillage treatments in 2003 (a) and 2004 (b) at Abergelle in northern Ethiopia. Y-bars equal $LSD_{0.05}$. Flat plant = planting with a flat soil surface. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. *Shilshalo* = a traditional ridging practice conducted 4 wk after planting.

The traditional ridging practice of *shilshalo* resulted in slightly better crop performance than flat planting but resulted in poorer performance than with early tied-ridging. In-furrow planting resulted in better crop performance than on-ridge planting. Considering the timing of crop development, cessation of rainfall, and soil water depletion, it seems that planting with the onset of the rains is critical to having sufficient available water during grain-fill period. This implies that tied-ridging should be done before the onset of rains, if soil conditions allow, to minimize runoff losses from the early rains and to have the field ready for planting once soil water is considered adequate.

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