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Skip-row planting of maize and sorghum in semi-arid Ethiopia

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Soil water deficits during grain fill constrain crop production in semi-arid areas of Ethiopia. Skip-row planting is a means of saving soil water for grain fill while tie-ridging can improve soil water availability throughout the season by reducing runoff. The hypotheses were that where rainfall ceases before or during early grain fill 1) maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) yield can be increased by skip-row planting, 2) skip-row planting and tie-ridging interact positively, and 3) productivity can be further increased by planting an early maturity crop in the skip-row area. Skipping a row after planting one or two rows resulted in similar yields compared with planting all rows. Maize yield was 43% greater with tie-ridge compared with flat tillage. There was no tillage by skip-row interaction. Productivity was increased by 20% when a relatively short season bean (*Phaseolus vulgaris* L.) was planted in the skipped rows of both maize and sorghum as cereal yield was not affected but bean added to productivity. Tie-ridging presents an opportunity for increasing maize yield. Skip-row planting for similar conditions is unlikely to increase productivity unless bean or another crop is planted in the skip-row area.

Key words: Dry bean, intercrop, Sahel, soil water deficits, late season stress, tie-ridging.

INTRODUCTION

Rainfall often ceases before or during early grain fill of maize and sorghum in many semi-arid areas of Ethiopia. Severe stress due to soil water deficits during grain fill is common resulting in low grain weight, grain yield, and harvest index. Such stress has been estimated to account for more than 300,000 Mg year^{-1} grain yield loss for grain sorghum in Ethiopia (Wortmann et al., 2009).

Skip-row planting is a means of delaying root access to available soil water until later growth stages as the root system extends (Milroy et al., 2004). Within-row plant density is commonly increased with skip-row planting to compensate for fewer planted rows and the crop is more likely to experience stress during the vegetative stage while having greater soil water availability during grain fill (Nielsen et al., 2007). Skip-row planting may therefore result in increased kernel weight, improved harvest index, and increased grain yield where soil water deficit stress is common during grain fill. Skip-row planting is expected to

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result in reduced yield where terminal stress due to soil water deficit is not severe or not common but may increase yield and safeguard against crop failure when such stress is severe (Whish et al., 2005). Potential for increased yield with skip-row planting increases as frequency of severe soil water deficits during grain fill increases, accompanied by potential for deep rooting depth and good soil available water holding capacity. Increased evaporative loss of soil water with skip-row planting is a concern, although saving more deep soil water for later in the season can compensate for these losses (Myers et al., 1986; Spackman et al., 2000). Maintenance of good crop residue ground cover to reduce soil water evaporation enhances the potential of skip-row planting (Klein et al., 2007).

In Australia, skip-row planting was advantageous when mean sorghum grain yield was less than 2.5 Mg ha^{-1} because of soil water deficits (Spackman et al., 2000). Clark and Knight (1996) observed increased sorghum grain yield with skip-row planting when mean grain yield was less than 2 Mg ha^{-1}, but decreased grain yield when mean yield was more than 3 Mg ha^{-1}. In Ethiopia, planting two rows alternated with a skipped row resulted in increased sorghum grain yield in northern Ethiopia where mean yields were less than 2.5 Mg ha^{-1} but not in the Central Rift Valley where mean yields were more than 2.5 Mg ha^{-1} (Mesfin et al., 2010).

On the US Great Plains, skip-row planting resulted in a corn and sorghum grain yield advantage compared with conventional planting if mean grain yield was less than 4 Mg ha^{-1} but a disadvantage when yield was more than 5 Mg ha^{-1} (Vigil et al., 2008). Planting maize skipping alternate pairs of rows had more yield compared with planting all rows if soil water deficits limited yield to 4.7 Mg ha^{-1} and skipping alternate rows was advantageous to 6.9 Mg ha^{-1} (Lyon et al., 2009). In Nebraska, skipping alternate rows was advantageous for grain sorghum when soil water deficits limited grain yield to less than 4.5 Mg ha^{-1} (Abunyewa et al. 2010). Water use of sorghum was more and less efficient with skipping alternate rows compared with planting all rows in Nebraska when mean in-season precipitation was less than 2 and more than 2.5 mm day^{-1}, respectively (Abunyewa et al., 2011).

Runoff loss of water with intense rainfall events can be reduced by tie-ridging with inter-row furrows of 20 to 30-cm depth blocked with earthen ties spaced according to the slope of the land, water infiltration rate, and expected intensity of rainfall (Lal, 1977; Gusha, 2002; Gebrekidan, 2003; Pendke et al., 2004). Sorghum grain yield in northern Ethiopia was 62% more with tie-ridging compared with flat planting (Brhane et al., 2006). Mesfin et al. (2009) reported 33 and 18% more sorghum grain yield in northern and Central Rift Valley locations of Ethiopia, respectively, with tie-ridging compared with flat planting. Highland pulse grain yield was increased with tie-ridging by 31 to 96% in northern Ethiopia (Brhane and Wortmann, 2008). In eastern Kenya, maize and cowpea (*Vigna unguiculata* [(L.)] yield was inconsistently increased with tie-ridging (Miriti et al., 2007). The tie-ridging effect was enhanced with skip-row planting of sorghum in northern Ethiopia but this interaction did not occur in the Central Rift Valley (Mesfin et al., 2009). The tie-ridging by skip-row planting interaction has not been previously investigated for maize.

Smallholder farmers of Ethiopia are reluctant to leave land unplanted as required with skip-row planting. Planting an early maturing crop with a relatively shallow root system, such as bean, in the skip-row area of maize or sorghum may preserve benefits of skip-row planting while giving some bean yield. Workayehu and Wortmann (2011) found that maize planted skipping alternate rows with bean in the skipped row gave a mean land equivalent ratio of 1.6. In another study, a maize intercrop was 55% more productive compared with the sole crops (Bhatnagar and Chaplot, 1991).

The objectives of this research were to determine the impact of skip-row planting and tie-ridge tillage on maize yield, and of skip-row planting of maize and sorghum with an intercrop of bean on yields in an important semi-arid agricultural production area of the Central Rift Valley in Ethiopia. The hypotheses addressed were that where water deficit stress is severe during grain fill 1) maize and sorghum yield can be increased by skip-row planting to save soil water for the reproductive stage, 2) there is a positive interaction of skip-row planting with tie-ridging, and 3) productivity can be further increased by planting an early maturity crop in the skip-row area.

MATERIALS AND METHODS

Trials were conducted in 2006 to 2010 for study I and in 2010 to 2012 for study II at Melkassa Agricultural Research Center of the Ethiopia Agricultural Research Institute located at 8°24'N, 39°12'E, and 1500 m elevation. The study I trial of 2009 was not completed because of severe drought stress. The soil was a calcareous clay loam of volcanic parent material classified as a Typic Haplustand with low wet aggregate stability, a propensity for crusting, more than 1-m rooting depth, and slopes ranging from 0.02 to 0.04 m m^{-1}. Soil pH was 7.4 and soil organic matter was 12 g kg^{-1} for the 0 to 20-cm depth. Cumulative rainfall for the growing season of June to October was more than the long term average and ranged from 635 mm in 2011 to 818 mm in 2012 (Figure 1) with a mean of 65% falling in July and August. The trial site was moved each year. The previous crops were onion (*Allium cepa* L.), maize, and dry bean in 2009, 2010, and 2011, respectively.

The complete factorial combination of treatments for study I consisted of three or four planting treatments and two tillage treatments. The maize planting treatments, based on 0.75 m inter-row spacing, were: planting all rows; skipping alternate rows; skipping alternate pairs of rows; and planting two rows alternated with a skipped row. The treatment of planting two rows alternated with a skipped row was included in 2008 and 2010 only. The tillage treatments were flat and tie-ridge tillage. The complete factorial combination of treatments for study II was in a split plot design with corn or sorghum as the main plots and three planting practices as the sub-plots including planting all rows, planting two rows alternated with a skipped row, and planting two rows alternated with bean planted is the skipped row. Treatments included a bean sole

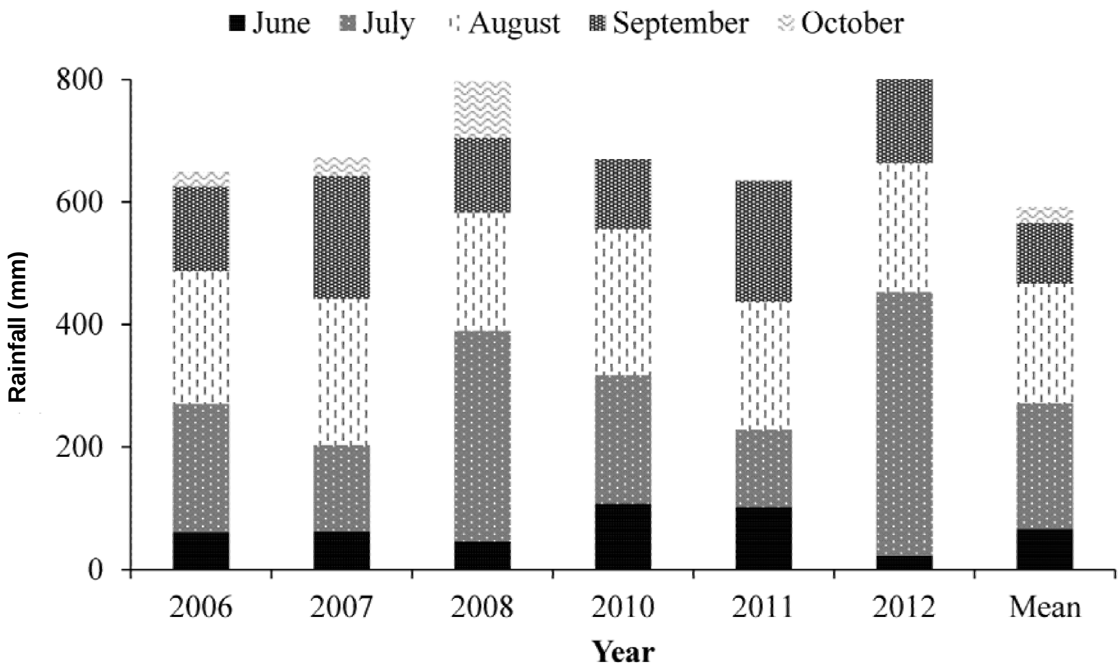

Figure 1. Growing season (May to October) monthly rainfall for trials conducted to evaluate skip-row planting and tie-ridging effects on maize in central Ethiopia.

crop. Study II was planted with tie-ridging. Individual plot size was 10 × 6 m for each study and each had three replications.

The entire experimental area was tilled with a tractor drawn plow and then ridged with a tractor drawn 4-furrow ridger before planting and application of the treatments. Ridges were of 0.30 m height with 0.75 m spacing that were tied at the ends of the plots to create the tie-ridges. Planting followed the on-set of the rains and occurred during the first two weeks of July. Harvest was in November. Maize and sorghum were planted in the furrow. Ridges were reshaped by ridging the soil around the lower stems of the plants and retied at weeding time.

Plant stands were thinned to desired density by manual uprooting at about two weeks after emergence. The targeted maize and sorghum plant densities were 6.7 plants m^{-2} with greater within-row densities with skip-row planting. Bean was also planted in the furrow at 25 and 6.3 plants m^{-2} for sole crop and intercrop, respectively. The maize, sorghum, and bean cultivars were Melkassa II, Meko, and Awash Melka, respectively. Melkassa II, Meko, and Awash Melka require 125, 115, 90 to 95 days to maturity, respectively, at 1500 m elevation. Fertilizer was band-applied at the rate of 20 kg ha^{-1} each of N and P at planting time as di-ammonium phosphate and 23 kg ha^{-1} of N was side-dress applied as urea for all plots. The sites were manually weeded twice. No pesticides were used for pest and weed control.

Five randomly selected plants per row were measured to determine maize and sorghum plant height at maturity. The maize and sorghum plants from 7 m of row from the center three rows of each plot (15.75 m^2) were cut at the soil surface and air-dried after counting the plants and ears. Grain was shelled from the ears and the cobs were combined with the other stover to obtain stover dry weight. Air-dried grain water content was not affected by planting treatments and was found to average 123 g kg^{-1} for maize and bean and 118 g kg^{-1} for sorghum. Grain yields were expressed at 150 g kg^{-1} water content.

The air-dried weight of 100 kernels was determined. Kernel ear^{-1} and $panicle^{-1}$ were calculated. The harvest index was calculated as the ratio of grain yield to the above-ground biomass yield with grain and stover water content adjusted to a water content of 80 g kg^{-1}. For P2S1 with bean treatments, the one bean row in the area for yield determination was harvested by uprooting the plants and threshing after air-drying. Bean grain yield was also expressed at 150 g kg^{-1} water content.

The analyses of variance for study I were conducted combining 2006 with 2007 data and 2008 with 2010 data using Statistix 9 (Analytical Software, Tallahassee, FL). The ANOVA for study II was combined for 2010-2012. Grain yield was related to yield components using regression and correlation analyses. Means were compared with the ANOVA protected LSD means separation test. Treatment effects and relationships were considered significant at *P* less than 0.05.

RESULTS

Study I

There were no treatment effect on days to anthesis ($\overline{X}$ = 81 in 2006-7 and $\overline{X}$ = 69 in 2008 and 2010) and days to physiological maturity ($\overline{X}$ = 135 in 2006-7 and $\overline{X}$ = 120 in 2008 and 2010). Mean plant height was 11 cm taller with tie-ridging compared with flat tillage but not affected by row configuration (Table 1). In 2006 and 2007, grain yield and grain yield components were not affected by interactions. Grain yield and kernel weight were increased by 29 and 19% with tie ridge compared with flat tillage, respectively. Tillage effects were not significant for the other yield components in these years. Grain yield was 24% less with skipping alternate pairs of rows compared with planting all rows. Grain yield and its components were not different with skipping alternate rows and planting two rows alternated with a skipped

Table 1. Maize performance as affected by tie-ridging and skip-row planting in the Central Rift Valley of Ethiopia. PF, P1:S1, P2:S1B and P2:S1, and P2:S2 are planting configurations with all rows planted, single planted and skipped rows alternated, two planted alternated with one skipped row with and without bean planted in the skipped row, and planted with skipped pairs of rows alternated, respectively.

Factor level	Plant height (cm)	Ear plant^{-1}	Kernel ear^{-1}	100 kernel weight (g)	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	HI
2006 and 2007; three row configurations‡							
Year							
2006	242		363	23.6	3.96	4.89	0.42
2007	241	0.90	347	23.6	4.78	3.72	0.53
Tillage							
Flat tillage	236	0.88	359	21.6	3.81	4.27	0.44
Tie-ridge	246	0.92	350	25.6	4.93	4.34	0.50
	**	ns	ns	*	*	Ns	**
Row configuration							
PF	246	0.92	339	25.2	4.60a	4.78a‡	0.47
P1:S1	238	0.91	374	23.9	4.39ab	4.29ab	0.49
P2:S2	240	0.88	352	21.7	3.50b	3.84b	0.46
	Ns	ns	ns	ns	*	**	Ns
2008 and 2010; four row configurations§							
Year							
2008	286	0.87	419	25.9	3.87	6.22	0.37
2010	207	0.87	200	25.4	2.74	6.77	0.27
Tillage							
Flat tillage	240	0.84	304	24.2	2.65	5.83	0.30
Tie-ridge	252	0.90	315	27.3	3.96	7.16	0.34
	*	**	ns	**	***	***	*
Row configuration							
PF††	252	0.89a	332	26.0	3.63a	6.91a	0.33
P1:S1	252	0.90a	302	26.8	3.48a	6.36ab	0.33
P2:S2	244	0.83b	284	23.6	2.62b	5.58b	0.31
P2:S1	240	0.86ab	321	26.2	3.51a	7.13a	0.31
	ns	*	ns	ns	***	**	ns

Ns,*, *, **, ***: Not significant and significant at *P* = 0.05, 0.01, and 0.001, respectively. Letters denote differences within columns and sets of years using the ANOVA-protected LSD 0.05 means comparison test.

row compared with planting all rows.

Grain yield was affected by the year x tillage interaction because yield was 43 and 17% less in 2008 and 2010, respectively, with flat tillage compared with tie-ridging (Table 1). Grain yield was not affected by other interactions but was consistently more with tie-ridge compared with flat tillage with a mean increase of 43%. Grain yield was consistently less with skipping alternate pairs of rows compared with other row configurations but planting all rows, skipping alternate rows, and planting two rows alternated with a skipped row had similar mean yields.

The increase in ear plant^{-1} was greater with planting all rows and planting two rows alternated with a skipped row compared with skipping alternate rows and skipping alternate pairs of rows in 2008 than in 2010 (Table 1). The main effect of tie-ridging compared with flat tillage was a 49% increase in grain yield, a 13% increase in kernel weight, and a 7% increase in ears plant^{-1}. Mean grain yield and ear plant^{-1} were 28 and 7% less with skipping alternate pairs of rows compared with planting all rows. Grain yield and its components were not different with skipping alternate rows and planting two rows alternated with a skipped row compared with planting all rows.

Stover yield was more in 2006 and 2008 and less in 2007 with tie-ridging compared with flat tillage with no significant tillage effect in 2010 (Table 1). The reduction in stover yield with skipping alternate pairs of rows compared with planting all rows was greater in 2007 than in 2006, with a mean reduction over all four years of 20% with skipping alternate pairs of rows compared with

Table 2. Analysis of variance results for the effect of planting pattern on maize, sorghum, and bean in the Central Rift Valley of Ethiopia.

Factor level	Plant height (cm)	Ear (m^{-2})	Kernel (ear^{-1})	Kernel weight (mg)	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	HI
Maize							
2010		5.53	219	247	3.09	7.84	0.26
2011	202	6.38	273	218	3.87	7.05	0.33
2012	181	6.36	236	213	3.37	6.81	0.29
Planting (P)	ns	ns	ns	ns	ns	ns	ns
Year x P	ns	ns	*	ns	*	ns	***
Sorghum	**Plant height (cm)**	**Panicle $plant^{-1}$**	**Kernel $panicle^{-1}$**	**Kernel weight (mg)**	**Grain yield (Mg ha^{-1})**	**Stover yield (Mg ha^{-1})**	**HI**
2010		6.10	960	38.3	2.25	5.71	0.28
2011	161	5.76	1229	36.1	2.61	8.20	0.23
2012	150	6.39	1684	29.0	3.07		
Planting	ns	ns	ns	ns	ns	ns	ns
Year x P	ns	ns	*	ns	ns	ns	ns
Bean		**Pod $plant^{-1}$**	**Kernel pod^{-1}**	**Kernel weight (mg)**	**Grain yield (Mg ha^{-1})**	**Stover yield (Mg ha^{-1})**	**HI**
2010		23.3	4.93	188	1.65	2.33	0.39
2011		14.9	6.59	175	0.93	0.56	0.62
2012				158	1.68		
Planting		ns	ns	ns	***	***	ns
Year x P		ns	ns	*	**	ns	ns

ns,*, *, **, ***: Not significant and significant at P = 0.05, 0.01, and 0.001, respectively.

planting all rows. Mean harvest index for the four years was 13% greater with tie-ridge compared with flat tillage but was not affected by interactions or row configuration.

Variation in kernel ear^{-1} accounted for more variation in grain yield compared with other yield components. The significant Pearson correlation coefficients of yield components with grain yield were 0.18, 0.68, and 0.49 for ear m^{-2}, kernel ear^{-1}, and 100-kernel weight, respectively. In total, variation in yield components accounted for 99% of the variation in grain yield: Grain yield = -9.64 + 0.206 * 100-kernel weight + 0.014 kernel ear^{-1} + 0.801 ear m^{-2}.

Study II

Maize and sorghum plant height, ear or panicle m^{-2}, kernel wt., and stover yield were not affected by treatments (Table 2). Grain yield and harvest index of sorghum were also not affected by treatments. Maize grain yield was 30% more for planting all rows compared with planting two rows alternated with a skipped row in 2011 and kernel ear^{-1} was 40% more in 2012 with planting all rows compared with planting two rows with bean planted in the skipped row but these variables were not affected in other years (Table 3). Maize harvest index was low and high, respectively, in 2010 and 2011 with planting all rows compared with planting two rows alternated with a skipped row. Sorghum panicle m^{-2} was 12% more with planting two rows alternated with a skipped row compared with the other planting arrangements in 2010 but otherwise not affected by treatments.

Maize kernel ear^{-1} and kernel m^{-2} were highly correlated (r = 0.97) and both were related to maize grain yield (r = 0.86). Kernel weight was not related to maize yield but ear m^{-2} was related to yield (r = 0.50). Kernel m^{-2} accounted for 73% of the variation in maize yield. Sorghum kernel $panicle^{-1}$ and kernel m^{-2} were highly correlated (r = 0.96), both were related to sorghum grain yield (r = 0.83 and 0.85, respectively), and together accounted for 96% of the variation in yield. Kernel weight and panicle m^{-2} were not related to sorghum yield.

Bean pod $plant^{-1}$, kernel pod^{-1}, stover yield, and harvest index were not affected by treatments (Table 3). Intercrop bean yield was 31% of sole crop bean yield. Bean yield was less suppressed by intercropping with sorghum compared with maize in 2010 but yields were similar for the two intercrops in 2011 and 2012. Bean kernel weight was 11% less with intercropping compared with sole cropping in 2011. The maize: bean land equivalent ratio

Table 3. Planting configuration by year interaction effects on maize, sorghum, and bean in the Central Rift Valley of Ethiopia. PF and P2:S1 are planting configurations with all rows planted and two planted alternated with one skipped row, respectively.

Factor level	2010	2011	2012	2010	2011	2012
	Maize yield (Mg ha^{-1})			Maize kernel (ear^{-1})		
PF	2.77^{c}	4.38^{a}	3.84^{ab}	193^{c}	299^{a}	286^{ab}
P2:S1	3.46^{bc}	3.37^{bc}	2.90^{bc}	251^{abc}	226^{abc}	220^{bc}
P2:S1 with bean	3.03^{bc}	3.85^{ab}	3.32^{bc}	213^{bc}	296^{a}	203^{c}
	Maize HI			Sorghum panicle (m^{-2})		
PF	0.23^{c}	0.42^{a}	0.31^{b}	5.76^{bc}	5.74^{bc}	6.38^{ab}
P2:S1	0.31^{b}	0.31^{b}	0.31^{b}	6.55^{a}	5.53^{c}	6.38^{ab}
P2:S1 with bean	0.30^{b}	0.32^{b}	0.29^{bc}	6.00^{bc}	6.00^{bc}	6.42^{ab}
	Bean grain yield (Mg ha^{-1})			Bean kernel weight (mg)		
Bean, sole crop	3.11^{a}	1.49^{b}	2.83^{a}	180^{ab}	189^{a}	157^{c}
P2:S1, maize	0.63^{d}	0.74^{cd}	0.71^{cd}	191^{a}	167^{bc}	163^{bc}
P2:S1, sorghum	1.23^{bc}	0.57^{d}	0.72^{cd}	193^{a}	170^{bc}	156^{c}

Ns,*, *, **, ***: Not significant and significant at P = 0.05, 0.01, and 0.001, respectively. Letters denote differences within columns using the ANOVA-protected LSD 0.05 means comparison test.

was 1.42, 1.43, and 1.01 in 2010, 2011, and 2012, respectively. The sorghum:bean land equivalent ratio was 1.19, 153, and 1.19 in 2010, 2011, and 2012, respectively. Overall mean land equivalent ratio for planting two rows with bean planted in the skipped row was 1.30.

DISCUSSION

In all trials, there was little rainfall after flowering. Tie-ridge compared with flat tillage resulted in more maize grain yield in all years with planting all rows which is generally consistent with results for sorghum and pulses in northern Ethiopia (Brhane et al., 2006; Brhane and Wortmann 2008; Mesfin et al., 2010). Stover yield was increased with tie-ridging in two of four years. Tie-ridging is potentially widely beneficial to maize production on moderately sloping land with soil of medium texture and weak aggregate stability.

Results from the above cited studies indicate the benefits of tie-ridging for vertic soils that have slow infiltration when wet. All of these studies were done on moderately sloping land. The risk of ridges breaking during heavy rainfall when used on steeply sloping land is of concern and the practice should be used in such cases only if other practices are in place, such as terraces or vegetative barriers, that reduce runoff or otherwise stabilize the slope against erosion. Tie- ridging requires tillage but tillage is already the usual
practice to break soil crusts and for weed control.

Skip-row planting did not result in increased maize yield. Grain yield was generally well above 2.0 to 2.5 Mg ha^{-1}, the upper grain yield level at which skip-row planting was found to be advantageous compared with planting all rows for grain sorghum when practiced without good crop residue cover (Spackman et al. 2000; Clark and Knight 1996). Mean grain yields were less but near the 4.7 Mg ha^{-1} yield level identified by Lyon et al. (2009) for skip-row planting to be advantageous to maize yield under no-till conditions with good ground cover on the US Great Plains.

However, even with flat tillage where mean maize grain yield was 3.1 Mg ha^{-1} in the current study, skip-row planting did not have an advantage. There also was no advantage to planting two rows alternated with a skipped row planting of sorghum compared with planting all rows. Greater kernel weight and harvest index of maize and sorghum would be expected if stress were reduced during grain-fill; these were not increased by skip-row planting indicating that this practice was not effective in reducing late season stress. Therefore, skip-row planting is not likely to have an advantage for maize and sorghum production in Ethiopia unless considerably more severe late season soil water deficit stress conditions occur than encountered in this study. More severe stress does commonly occur with sorghum production in northern Ethiopia where yield was greater with planting two rows alternated with a skip row compared with planting all rows (Mesfin et al., 2010).

There may be greater advantage with skip-row planting if some form of reduced tillage or no tillage is practiced coupled with maintaining ground cover by crop residues sufficient to reduce evaporation and to reduce the potential for erosion. However, crop residues are highly valued and account for 30 to 40% of the value of the sorghum crop in Ethiopia (Wortmann et al., 2009). Therefore, fields in semi-arid areas are nearly bare of crop residue when land is prepared for planting. Any remaining crop residue is commonly consumed by termites once the rains begin. Despite much promotion, practice of conservation agriculture by smallholders is rare in semi-arid areas of Ethiopia.

The planting two rows with bean planted in the skipped row is promising for maize and sorghum production where bean or another legume of similar growth habit is adapted. Bean is an important food and market crop in Ethiopia. Other pulses may replace bean at elevations where bean is less well adapted.

Conclusion

Tie-ridging is likely to result in improved maize yields for semi-arid areas of Ethiopia on moderately sloping land with soil of medium texture and weak aggregate stability, including much of production in the Central Rift Valley of Ethiopia. There is no indication that skip-row planting will result in increased maize or sorghum grain yield in the Central Rift Valley of Ethiopia but other information indicates that skip-row planting is appropriate where late season soil water deficits are more severe such as in northern Ethiopia and in many places throughout the Sahel. Planting bean or another pulse crop of similar growth habit in the skip-row area increases productivity relative to planting all rows of maize or sorghum alone.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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