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Research article

Effect of ridging and tie-ridging time on yield and yield component of sorghum in Northern Ethiopia

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ABSTRACT

Soil moisture stress and low soil fertility are the main constraints to sorghum production in the semi-arid region of northern Ethiopia. A field experiment was conducted in Lasta and Sekota Woreda of Amhara Region, eastern Ethiopia, to evaluate the effect of ridge and tie ridge time on the yield and yield component of sorghum (Sorghum bicolor). The experiment consisted of eight treatments of ridging time & time of tie (Tie-ridging at planting, Ridge at planting tying 2 Weeks After Planting, Ridge at planting tying 4 Weeks After Planting, Tie-ridging 3 Weeks After Planting, Ridging 2 Weeks After planting & tying 4 Weeks After Planting, Ridge 3 Weeks After Planting & tying 6 Weeks After Planting, Tie-ridging 6 Weeks After Planting); including Shilshalo as a control farmer practice which was arranged in a randomized complete block design (RCBD) with three replication. The results of the experiment revealed that the timing of ridging and tie ridging had a significant effect on sorghum yield. The results showed that tie ridging at planting time increased sorghum yield by about 37.9% in Sekota compared to the control (farmer practice), and tie ridging three weeks after planting in Lalibela increased sorghum yield by 30.11% compared to the control (farmer practice). The highest yields of 3.642 tons/ha were obtained with tie ridging at planting in Sekota and 1.903 tons/ha with tie ridging three weeks after planting in Lalibela. Therefore, tie ridging and ridging at planting may be appropriate for sorghum production in the Sekota and sorghum growing areas. However, in Lalibela and sorghum growing areas, tie-ridging three weeks after planting may be appropriate for sorghum production.

1. Introduction

A total of 66.6% of Ethiopia's land area is comprised of dry land regions, which have been identified by minimal annual precipitation [1]. In the semi-arid zone, the mean annual precipitation varies from 400 to 600 mm, while in the drier semi-arid to dry sub-humid zone, it varies from 200 to 1000 mm [2]. Throughout the crop-growing period, precipitation in this semi-arid area can be not enough, unevenly distributed, brief, and ranges in quantity. Moisture stress is the primary challenge restricting sorghum production in East Africa. Deficits in soil water in crop establishment and grain fill were identified as substantial obstacles, particularly in Ethiopia [3].

Among the world's major cereal crops, maize, rice wheat, and barley, the fifth largest is sorghum (sorghum b.) [4]. As a consumption base, it is the second major cereal crop after teff (Eragrostis tef). In Ethiopia, sorghum is the main traditional food crop, with 297,000 ha produced annually in northern Ethiopia [4]. Sorghum crop production is 15–20% of the country's cereal production [3],

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especially in the Wag-himra zone of Amara Region with an average production of 1.52 tons/hectare [5]. In Ethiopia, it is a major crop in the semi-arid areas of the country, although it is often affected by water scarcity [6,4&24]], low fertility and crust-sensitive soils [7, 8], and other climatic instabilities that make it susceptible to moisture.

The most utilized available water is taken from soil that is used for crop growth and development in dryland areas, rain should be entered into the soil that was radially available for plant development as well as for water storage in the soil profile and the plant used in critical time. A practice that facilitates and situates the storage and increment of water storage is important [9]. Ridging and Tied Ridge Technologies are part of in-situ moisture conservation practices that facilitate water storage over the soil profile to increase sorghum production [9]. As a comparison, Farmer practices and tie-ridge it is about 46% sorghum yield and its productivity has increment in Ethiopia [10]. The importance of tillage such as tied ridge on crop yield has an effect the reasons are amount and distribution of rainfall, soil type, landscape position, crop type time of ridging, and the condition where rainfall events result in significant runoff. An additional source tells tied-ridge increased sorghum production by 40% and soil moisture by 25% in comparison with the traditional tillage practice in northern Ethiopia [11].

Ridging and tying Ridging increases surface water storage and prevents runoff by creating ridges and furrows and tying or damming the furrows with small mounds. Ties increase the availability of soil moisture to crops because they provide a barrier to rainwater movement and increase the contact time available for infiltration [9]. In tie ridging, ridges are made 20–30 cm high, usually 75 cm apart, either before, during, or after planting. Row crops such as sorghum and corn may be sown on top of the ridges or in furrows. Crop furrows are tied at intervals of 2 m or more, depending on field conditions, to prevent runoff in crop furrows. The effect of tie ridging on water storage and subsequent crop yield varies considerably from year to year and location to location [12]. The effectiveness of tie ridging depends on weather conditions, soil properties, slope, crop, and other factors [11]. Research has revealed that the most important constraint to sorghum production in East Africa is water stress. Especially in Ethiopia, soil water scarcity during crop establishment and kernel enlargement has been identified as a major constraint [3].

[13] Suggested that in the dry lands of Wag himra 75-cm spacing tied ridge resulted in significant yield improvements over other moisture conservation practices and farmers' practices. Thus, in areas where soil moisture availability is the most limiting factor for overall crop production, the use of effective moisture conservation practices is the most important issue.

Tie ridging resulted in significant yield gains compared to other common moisture retention practices and farmers' practices. In general, one of the most limiting factors for crop production in the Wag-lasta region of northern Ethiopia is low rainfall, irregular nature, and uneven distribution during the cropping season [14]. On the other hand, the inadequate and erratic nature of rainfall in many parts of Ethiopia, including the study area, results in water stress during the crop growth phase. These factors require water management techniques for dryland crop production at appropriate times, including ridging and tie-rigging. Therefore, this study evaluated the effects of proper timing of ridging and tie ridging on sorghum productivity in dryland areas.

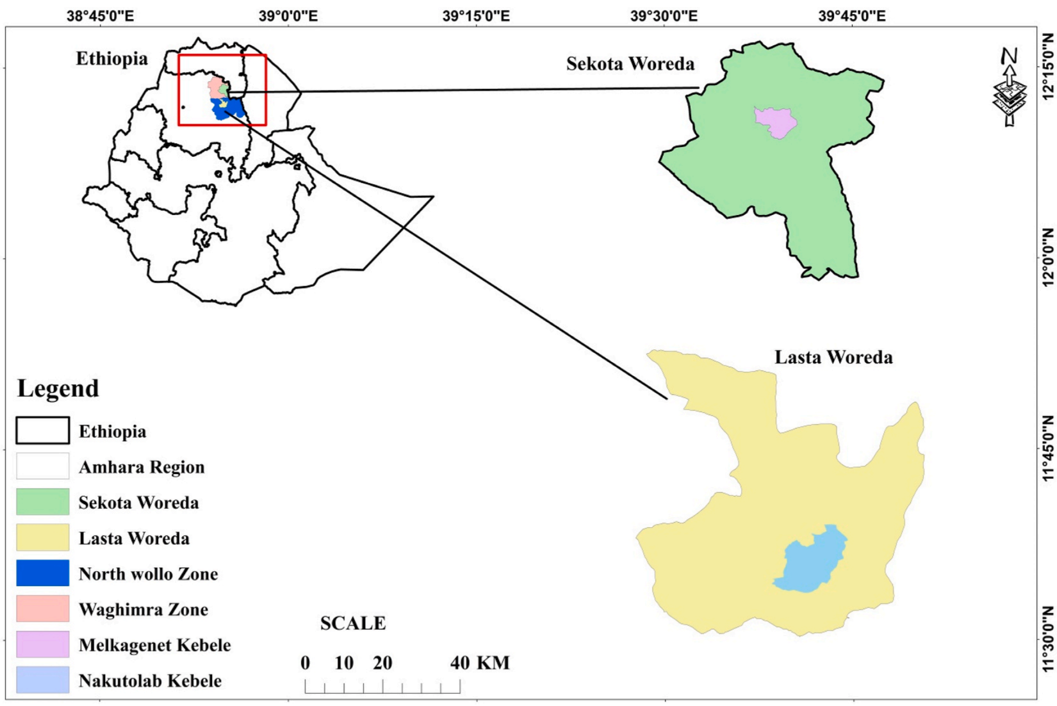

Fig. 1. Location map of experimental sites.

2. Methodology

2.1. Description of study area

The trial was done in Wag-himra zone Sekota Woreda and North Wollo administrative zone Lasta Woreda Amhara regional state. The experimental areas were geographically located at 11° 58′ 20.442″ N (latitude) 039° 03′ 00.804″E (Longitude) and 12° 437.482″N (latitude) 39° 01′09.594″Elongitude an altitude of 2159 m and 1928 m above sea level (masl) respectively shown in (Fig. 1). The study areas are categorized by a gentle slope (less than 5%) with soils appropriate for crop production.

The precipitation pattern of the experimental areas is unimodal and commonly happens between July and August. The precipitation distribution is categorized as short, inconsistent, and flexible across the planting seasons. According to 10 years of meteorological data collected from nearby stations, Sekota has an average annual precipitation of 660.8 mm and maximum and minimum temperatures of 26.55 °C and 14.97 °C, respectively. Similarly, in Lalibela, the annual mean precipitation is 737 mm, the maximum temperature is 25 °C, and the minimum temperature is 13.6 °C shown in (Table 1). Precipitation in the experimental areas generally runs from about mid-July to the end of August. However, the growing season for the main crops grown in these areas is mostly from early July to the end of October, as shown in (Fig. 2). Precipitation generally stops early, mainly during the flowering and grain-enrichment periods of the main crops, so low soil moisture and low soil fertility in most croplands during this period are the main limiting factors for crop production in the study area. According to Ethiopia's climate zone classification [15], based on elevation, precipitation, average annual temperature, and length of the growing season, Sekota (Merkagenet Kebele) and Lalibela (Nakhtlab Kebele) belong to the lowlands and midlands, respectively.

2.2. Experimental design and treatments

Field trials were done during the growing season (Kirmet) of 2016/2017 and 2017/2018 to study the effects of ridge and tie-ridging time on the yield and yield component of sorghum. Throughout the experimental periods, each experiment was done in a randomized complete block design with three replications shown in (Fig. 3).

The treatments considered were; (1) tie ridging at planting; (2) ridging at planting and tie two WAP; (3) ridging at planting and tie four WAP (4) tied ridge three WAP; (5) ridging two WAP and tie four WAP; (6) ridging three WAP and tie six WAP; (7) tie ridging six WAP (8) control (farmers' practice shilshalo 6 and 8 WAP moisture harvesting techniques for sekota and Lalibela respectively). The plot size of the treatment areas was 4.5 m width by 5 m length and the distance between plots and blocks was 1 m and 1.5 m, respectively.

The test crop was Misker, an improved sorghum variety. The plots were mainly plowed three times and sowing was done in the first week of July. The crop was planted in plots 4.5 m wide by 5 m long with rows spaced 75 × 15 cm. The tie rows were 20–30 cm deep and spaced 75 cm apart, with 2 m spacing between the ridges and 1 m spacing between the tie rows, in staggered zigzag lines. The recommended nitrogen and phosphorus fertilizer requirements for sorghum production were 50 kg/ha of urea and 100 kg/ha of NPS at Sekota and 50 kg/ha of urea and 50 kg/ha of NPS at Lalibela, respectively. Nitrogen fertilizer was applied in split applications, half at planting and the other half in the form of urea 45 days after planting. Phosphorus was applied once at planting in the form of NPS. Weeding, plowing, fertilization, and other agricultural practices were uniformly applied in all treatments as needed. Weed infestation was monitored regularly and weeding was done by hand three times.

2.3. Data collected

2.3.1. Soil data

Composite soil samples were collected from 0 to 20 cm depth using an auger from representative locations in the study site and analyzed in the laboratory for key physicochemical and soil moisture properties. For each sample collected, a texture class was defined using the USDA (U.S. Department of Agriculture) texture classification triangle. In addition, soil samples were collected periodically at 2- to 3-week intervals from each treatment to monitor soil moisture with a core sampler during the growing season. The gravimetric method was used to determine soil moisture content in this experiment.

2.3.2. Biological data

Agronomic data, including average plant height, sorghum head length, average weight of sorghum heads, grain yield, and above-ground biomass of sorghum, were collected on all rows except the border rows of each plot. In addition, plant height and head length data were taken on five randomly selected plants from the sorghum excluding the border rows.

Table 1
The experimental site's annual precipitation and temperature in the growing season.

	Precipitation (mm)		Temperature (°c)			
Location	2017	2018	2017		2018	
			Max	Min	Max	Min
Lalibela	818.7	886.5	24.7	13.4	23.6	13.08
Sekota	673.7	713.6	24.2	10.02	27.2	12.6

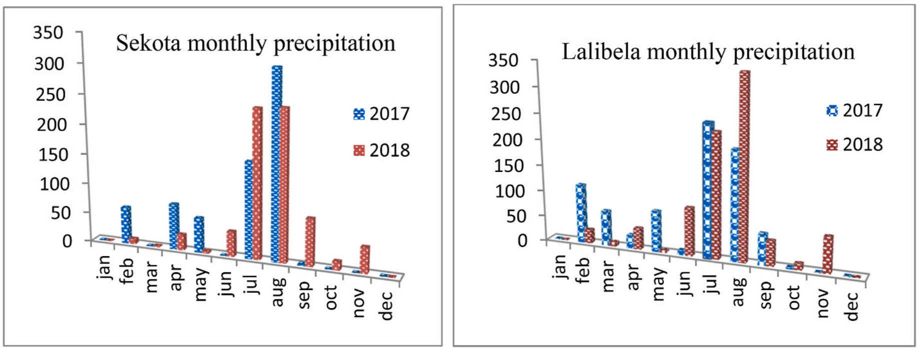

Fig. 2. Sekota monthly rainfall 2017 and 2018 cropping season left and Lalibela monthly rainfall for the 2017 and 2018 cropping season right.

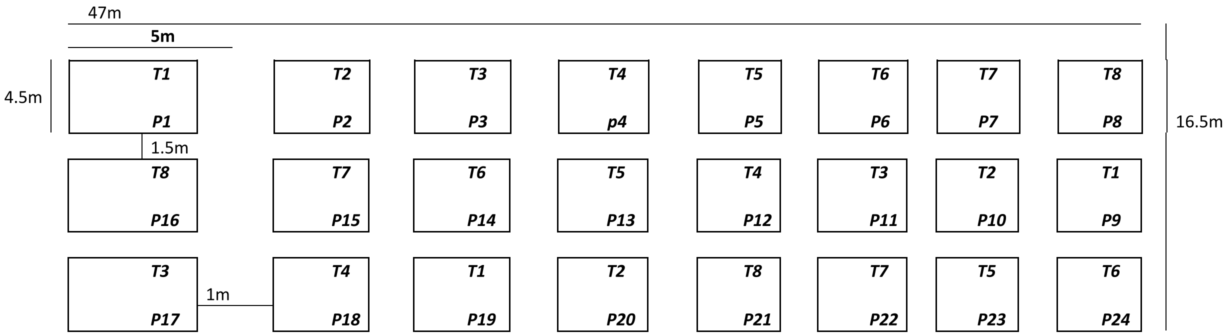

Fig. 3. Schematic diagram of the layout of the treatment arrangement
Where T = treatment p = plot.

2.3.3. Statistical analysis

The agronomic data obtained were subjected to analysis of variance using SAS version 9.1software, following the standard procedure of Gomez and Gomez, using Fisher's Least Significant Differences test with significant mean differences in the treatment interval calculated at the 5% probability level by the least significant difference (LSD) was calculated at the 5% probability level. Before applying the statistical analysis, the data were first checked for normality and homogeneity of errors. Normality was checked with the Shapiro-Walk test and homogeneity of errors was checked with the Levenen test.

2.3.4. Soil analysis

The soil was air-dried and sieved through a 2 mm sieve. Soil pH was measured from a filtered suspension with a soil-to-water ratio of 1:2.5 using a glass electrode attached to a digital pH meter. Soil organic carbon was measured according to the wet digestion method described in Ref. [16], and soil organic matter percentage was determined by multiplying the percent organic carbon value by 1.724. Total nitrogen was determined by trace Kjeldahl digestion, distillation, and titration methods. Available phosphate was determined by the Olsen method [17]. Field volume and permanent wilting point were determined by pedotransfer function using soil organic matter, electrical conductivity, and soil texture.

Table 2
The soil Physico-chemical properties of the experimental site.

Parameter		pH	EC ds/m	%OM	%TN	avi. P (ppm)	Texture class FC % PWP%
Location	Year						
Sekota	2017	6.1	0.14	0.538	0.025	16.1	sandy loam 14.6 5.9
	2018	5.2	0.13	1.076	0.028	3.78	sandy loam
Lalibela	2017	7.6	0.04	0.666	0.045	15.95	sand clay loam 26.5 17.1
	2018	6.8	0.11	0.37	0.032	4.13	sand clay loam

Where pH = Power of Hydrogen EC = Electrical conductivity OM= Organic Matter TN = Total Nitrogen avi. P = Available Phosphorus FC= Field Capacity PWP= Permanent Welting Point.

3. Result and discussion

3.1. The experimental sites soil physico-chemical characteristics

The major physiochemical characteristics of the soils in the experimental sites are summarized in (Table 2). The soil textural classes were found to be sandy loam and sandy loam for Sekota and Sandy clay loam and sandy clay loam for Lalibela experimental sites. Many agronomic practices require knowledge of the relation between the physical properties of the soil and the amount of soil water contained in a particular soil volume. Based on the results obtained from soil analysis as shown in (Table 2) the soil pH of the trial sites according to Ref. [18]; ranged from moderately alkaline and neutral for Lalibela and strongly acidic and slightly acidic for the Sekota experimental site. The average total nitrogen (%TN) ranges from 0.025 to 0.045, according to Ref. [18]; was categorized under very low and low, and it needs N fertilizer sources for optimal crop production and productivity. Available phosphorus (Av. P) ranged from 3.78 to 16.1 PPM, according to Ref. [19]; which is grouped under low, medium, and high classes, which need phosphorous fertilizer sources for optimum crop production and productivity. Soil organic matter (% OM) status of the trial site ranged from 0.37 to 1.076, according to Ref. [18], it was very low and low for both locations.

3.2. Effect tie and ridging time on soil moisture content and grain yield of sorghum

In the sandy clay loam soil at Sekota, the soil moisture content in the plots that were ridged at planting averaged 22.22% higher than in the control plots. The results indicated that sorghum grain yield was affected by moisture content (Fig. 4). Soil moisture accumulation in the tie-ridging plots was considerably higher than the farmer's practice (shilshalo) throughout the growing season of Sekota, except for the plots that were tie-ridging 6 weeks after planting. The highest moisture content and grain yield were obtained from tie and ridging at planting 38.25% and 3.64 tons/ha for Sekota. The lower moisture content was recorded in tie ridging 6 weeks after planting at 28.25% and the lower grain yield was obtained from ridging 3 WAP and tie 6WAP 2.22ton/ha. The study found that decreasing the time of ridge and tie-ridge time increased the yield of the crop.

The gravimetric soil moisture content on plots with tied ridge at planting was significantly higher than the control plot in sandy loam at Lalibela. This indicates a clear impact of moisture content on the grain yield of sorghum, as illustrated in (Fig. 5). Additionally, the observation that the soil moisture content stored in plots with tie ridging was considerably 26.39% higher than the farmer's practice (Shilshalo) throughout the growing seasons in Lalibela is quite significant.

The results showed that sorghum grain yield was affected by moisture content, with Lalibela having the highest moisture content of 41.67% in tie-ridging at planting and the highest grain yield of 1.90 tons/ha in tie-ridging 3 WAP. Lalibela had the lowest moisture content of 29.33% and yield of 1.22 tons/ha in tie-ridging 6 weeks after planting. As shown in (Fig. 5), yields increased from 1.20 to 1.90 tons/ha by shortening the timing of tie rows and ridge planting.

3.3. Effect tie and riding time on yield and yield component of sorghum at sekota

Ridging and tie ridging time had a significant ($P \leq 0.05$) effect on sorghum plant height, biomass, and yield parameters, but not on sorghum head length at Sekota.

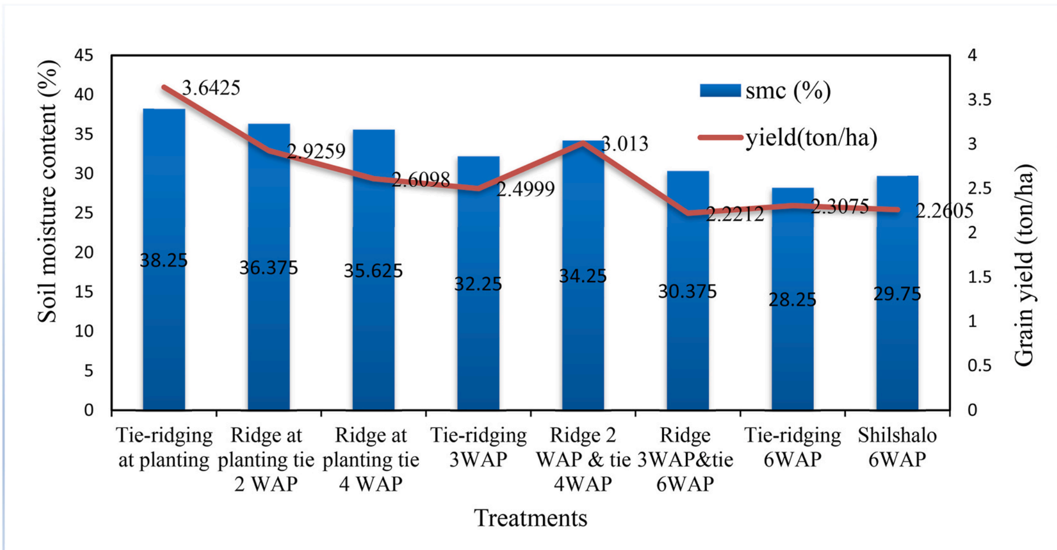

Fig. 4. Effect of tie ridging time on soil moisture content and grain yield of sorghum in sekota.

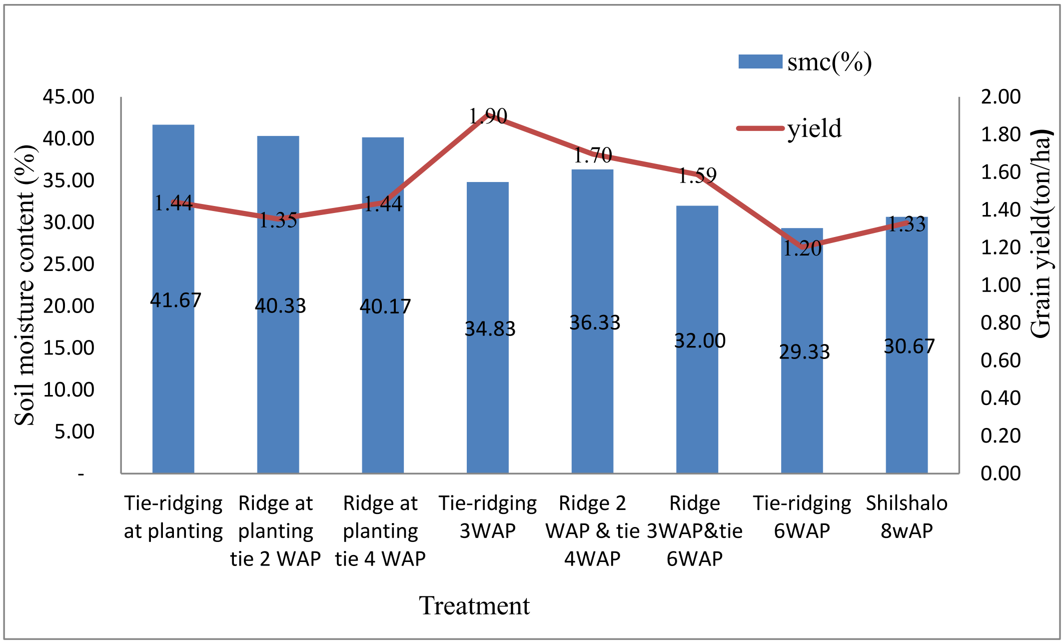

Fig. 5. Effect of tie ridging on soil moisture content and grain yield of sorghum in Lalibela.

3.3.1. Plant height and head length

The study showed that riding and tie riding time significantly ($P \leq 0.05$) affected the plant height of sorghum, with the higher combined mean plant height (175.17 cm) at the tie and riding at planting being significantly higher than the farmers' practice, resulting in an 11.6% increase compared to the farmers' practice. The lower mean plant height (153.4 cm) was recorded at the tie and riding 6 weeks after planting. However, riding and tie riding time did not significantly affect the head length of sorghum as shown in (Table 3), although the highest mean plant head length (21.6 cm) was recorded at the tie and riding at planting. The present results are in agreement with [20] who reported that 18 kg/ha of nitrogen and 46 kg/ha of phosphorus with tie ridge had a significant effect on plant height in an area in southern Ethiopia. Similarly [12], observed higher plant height when nitrogen and phosphorus were applied at 18 kg/ha and 46 kg/ha with in situ moisture conservation [20].

3.3.2. Biomass and grain yield

The biomass yield of sorghum was significantly affected by ridge and tie-ridge time at ($P \leq 0.05$). Proper management of ridge and tie-ridging time led to an increase in biomass yield. The highest biomass yield (15.515 ton/ha) was recorded at ridge and tie-ridge at planting, while the lowest biomass yield (8.453 ton/ha) was recorded at ridging 3 weeks after planting and tied 6 weeks after planting treatment. The result indicates that tie riding at planting with the recommended rate of nitrogen and phosphorus (23/46 kg/ha) fertilizer increases the biomass yield by 32.38% over farmers' practice shown in (Table 4). Biomass yield is very important because the leaves and stems are used for mixed farm livestock feed during the long dry season. These results are similar to the results of another study that showed that sorghum biomass yield was significantly affected by moisture retention practices, with the highest (15.50 tons/

Table 3
Combined mean value for the effect of tie and ridging time on the plant height and head length at Sekota.

Treatment	Plant height (cm)			Head length (cm)		
	2017	2018	Combined PH	2017	2018	Combined HL
Tie-ridging at planting	186.47^{a}	163.87^{a}	175.17^{a}	22.4^{a}	20.8^{a}	21.60^{a}
Ridge at planting tie 2 WAP	179.33^{ab}	154.07^{ab}	166.7^{ab}	22.73^{a}	16.88^{bc}	19.81^{a}
Ridge at planting tie 4 WAP	172.6^{abc}	149.87^{ab}	161.23^{ab}	21.8^{a}	16.31^{bc}	19.05^{a}
Tie-ridging 3WAP	171.07^{abc}	145.8^{ab}	158.43^{ab}	22.46^{a}	16.19^{bc}	19.33^{a}
Ridge 2 WAP & tie 4 WAP	179.2^{ab}	145.27^{b}	162.23^{ab}	21.86^{a}	14.24^{c}	18.05^{a}
Ridge 3WAP&tie 6 WAP	169.2^{bc}	148.13^{ab}	158.67^{ab}	21.86^{a}	16.43^{bc}	19.15^{a}
Tie-ridging 6WAP	158.33^{cd}	148.47^{ab}	153.4^{b}	21.33^{a}	17.53^{b}	19.43^{a}
Shilshalo 6 WAP	151.13^{d}	158.47^{ab}	154.8^{b}	20.26^{a}	17.86^{b}	19.06^{a}
CV	5.61	6.87	9.94	7.9	9.44	16.7
LSD (0.05)	16.78	18.24	18.73	3.02	2.81	Ns

Where the same letters are not significantly different at p = 0.05 (5 % level of significance) PH = plant height HL = head length WAP = week after planting CV = coefficient of variation LSD = list significance difference Ns = no significance.

Table 4
Combined mean value for the effect of tie and riding time on grain yield and biomass of sorghum at Sekota.

Treatment	Total biomass(ton/ha)			Grain yield (ton/ha)		
	2017	2018	Combined BM	2017	2018	Combined GY
Tie-ridging at planting	16.22^{a}	14.80^{a}	15.51^{a}	3.59^{a}	3.69^{a}	3.64^{a}
Ridge at planting tie 2 WAP	12.11^{bc}	11.38^{bc}	11.74^{bc}	2.99^{bc}	2.85^{bc}	2.92^{b}
Ridge at planting tie 4 WAP	10.37^{d}	9.81^{cde}	10.09^{de}	2.46^{cde}	2.75^{c}	2.60^{bc}
Tie-ridging 3WAP	11.93^{bcd}	10.50^{bcd}	11.21^{bcd}	2.87^{cd}	2.12^{d}	2.49^{cd}
Ridge 2 WAP & tie 4WAP	12.66^{b}	11.47^{b}	12.06^{b}	3.28^{ab}	2.74^{b}	3.01^{b}
Ridge 3WAP&tie 6WAP	8.40^{e}	8.49^{e}	8.45^{f}	2.33^{e}	2.10^{d}	2.22^{d}
Tie-ridging 6WAP	10.69^{cd}	8.92^{de}	9.80^{ef}	2.50^{cde}	2.11^{d}	2.30^{cd}
Shilshalo 6wAP	11.14^{bcd}	9.84^{cde}	10.49^{cde}	2.45^{de}	2.06^{d}	2.26^{cd}
CV	8.31	8.56	10.75	10.73	8.9	11.79
LSD (0.05)	17.016	15.97	14.04	4.79	4.075	3.75

Where the same letters are not significantly different at p = 0.05 (5 % level of significance) BM = biomass GY = grain yield WAP = week after planting CV = coefficient of variation LSD = list significance difference Ns = no significance.

ha) and lowest (9.53 tons/ha) total biomass of tie-ridging and farmer-practice sorghum in southern Ethiopia, respectively similar to the results of another study [21].

The grain yield of sorghum was significantly affected by the ridge and tie-ridge time at ($P \leq 0.05$). The study found that decreasing the time of ridge and tie-ridge time increased the yield of the crop from 2.260 tons/ha to 3.642 tons/ha. When using the recommended rate of N and P_2O_5 (23/46 kg/ha) with tie-ridge at planting, the sorghum grain yield increased by 37.9% compared to the farmer's practice. This suggests that proper management of tie-ridge time can lead to additional grain yield of sorghum. This suggests that proper management of tie ridge time can increase the grain yield of sorghum. Consistent with the findings of [22], this study observed a 15–38% increase in sorghum grain yield when 46 P_2O_5 and 18 N fertilizers were applied to tie ridges in moisture moisture-stressed area in Eastern Ethiopia. According to other research findings, tied ridging integrated with furrow planting of sorghum yielded 19.39% in 2015 and 39.11% in 2016 over farmers' practices (flat planting) under fertilizer application conditions [21]. Additionally the result agrees with the finding [20] that the grain yield of sorghum was higher by 55.72% compared to farmers' practices in southern Ethiopia.

3.4. *Effect of tie and riding time on yield and yield component of sorghum at Lalibela*

Riding and tie riding time significantly affected sorghum biomass and yield parameters at Lalibela ($P \leq 0.05$), but there were no significant differences in plant height and head length.

3.4.1. *Plant height and head length*

The study shows that riding and tie riding time did not significantly affect the plant height of sorghum, as indicated in (Table 5). The higher mean plant height of sorghum at tie-riding 3 weeks after planting was significantly higher than the farmers' practice, while the lower mean plant height was recorded at riding 3 weeks after planting and tied 6 weeks after planting. However, riding and tie riding time did significantly affect the head length of sorghum, with the highest mean plant head length recorded at riding two weeks after planting and tie 4 weeks after planting.

3.4.2. *Biomass and grain yield*

The biomass yield of sorghum was significantly ($P < 0.05$) affected by the time of ridging and ties ridging. Biomass yield was

Table 5
Combined mean value for the effect of tie and riding time on the plant height and the head length of sorghum at Lalibela.

Treatment	Plant height (cm)			Head length (cm)		
	2017	2018	Combined PH	2017	2018	Combined HL
Tie-ridging at planting	110.07	130.60	120.33	15.46	14.2^{ab}	14.833
Ridge at planting tie 2 WAP	114.4	143.07	128.73	15.53	14.8^{ab}	15.167
Ridge at planting tie 4 WAP	116.13	144.93	130.53	15.40	15.733^{a}	15.567
Tie-ridging 3WAP	116.00	145.27	130.63	16.00	15.80^{a}	15.90
Ridge 2 WAP & tie 4WAP	120.67	135.67	128.17	17.20	14.93^{ab}	16.067
Ridge 3WAP&tie 6WAP	114.13	124.47	119.30	15.45	14.37^{ab}	14.912
Tie-ridging 6WAP	114.67	136.33	125.50	15.33	13.86^{ab}	14.60
Shilshalo 8wAP	117.73	133.60	125.6	16.067	13.13^{b}	14.60
CV	8.41	10.76	13.55	9.84	9.1	10.05
LSD	Ns	Ns	Ns	Ns	2.32	NS

Where the same letters are not significantly different at p = 0.05 (5 % level of significance) PH = plant height HL = head length WAP = week after planting Ns = no significance.

increased by proper management of ridging and tie-ridging time. The highest biomass yield (14.299 tons/ha) was recorded 3 weeks after ridging and tie-rowing, while the lowest biomass yield (9.775 tons/ha) was recorded 6 weeks after tie-rowing. The results showed that when tie-riding was applied 3 weeks after planting and the recommended nitrogen and phosphorus fertilizer rates (23/23 kg/ha) were applied, biomass yield increased by 31.6% and 18.07%, respectively, compared to tie-riding 6 weeks after planting and the farmer's practice (shilshalo). Biomass yield increased by 31.6% and 18.07%, respectively. Biomass yield is very important because the leaves and stems are used as fodder for cattle during the long dry season.

Ridging three weeks after planting resulted in higher yields than the other treatments because the soil was better suited to sorghum production than the other treatments. Closed ridging with integrated ridging and ridging with integrated ridging resulted in significantly higher dry biomass yields in both fertilizer- and no-fertilizer cropping seasons. The closed-row ridging with integrated ridging and ridging had significantly higher dry biomass yields in both fertilizer- and no-fertilizer cropping seasons. The dry biomass yield was significantly higher in the closed-row with integrated ridge and furrow construction in both the fertilizer- and no-fertilizer cropping seasons. Ridging three weeks after planting resulted in higher yields than the other treatments because the soils were more suitable for sorghum production than the other treatments. Enclosed ridging, which integrates ridging and rowing, had significantly higher dry biomass yields in both fertilizer- and non-fertilizer-applied cropping seasons. As compared to closed tie ridging practice planting in-furrow, conventional practice (flat planting) reduced sorghum biomass yield by 14.07–27.22% under fertilized conditions [21].

Grain yield was significantly ($P \leq 0.05$) affected by ridging and tie ridging time. Sorghum grain yield was affected by tie and ridging time. Yield increased (from 1.331 tons/ha to 1.903 tons/ha) when ridging and tie-ridging times were reduced. Thus, compared to farmers' practices, tie-ridging three weeks after planting at the recommended N and P_2O_5 rates (23/23 kg/ha) increased sorghum grain yield by 30.11% shown in (Table 6). This suggests that proper management of tie ridge timing can increase grain yield in sorghum. The results of this study are consistent with the findings of [23], who observed a 15–38% increase in sorghum grain yield when tie ridges were fertilized with 46 P_2O_5 and 18 N in a moisture-stressed area in Eastern Ethiopia. According to other research findings, sorghum yields under the combination of tie-ridging and furrow planting exceeded farmers' practices (flat planting) under fertilized conditions by 19.39% in 2015 and 39.11% in 2016 [21].

The grain yield of sorghum at the Lalibela experimental site is lower compared to Sekota because in Lalibela there was a soil fertility difference in the soil analysis result shown in Table 2. The Organic matter is under a very low range and the electrical conductivity of soil at Sekota is better than the Lalibela experimental site.

4. Conclusion and recommendation

The study shows that the effectiveness of in situ moisture conservation practices for sorghum production in dry-land areas, such as in Wag-lasta, varies based on climatic and soil conditions. The research findings suggest that the appropriate timing of ridge and tie-ridge, along with the recommended rate of nitrogen and phosphorus fertilizer, can significantly contribute to soil moisture improvement and increase production and productivity in these areas. Further research on soil moisture content and fertilizer is recommended to strengthen these findings and to develop strategies for increased yield and improved sorghum production in the area.

This ongoing research will be crucial for enhancing sorghum cultivation in dry-land regions like Wag-lasta. The study clearly shows that the grain yield of sorghum is influenced by the different times of tie and ridge time. Decreasing the time of ridge and tie ridge time increased the yield of sorghum crops from (2.260 tons/ha to 3.642 tons/ha). Thus, compared to the farmer's practice, tie-ridge at planting increased sorghum grain yield by 37.9%. Tie ridging at planting is found to be the appropriate timing for the productivity of sorghum in sekota (Aybira). Tie ridging at planting is recommended for Sekota (Aybira) and similar agro-ecology areas. The grain yield of sorghum is also influenced by the different times of tie and ridge time at Lalibela. Decreasing the time of ridge and tie ridge time increased the yield of sorghum crops from 1.331 tons/ha to 1.903 tons/ha). Thus, compared to the farmer's practice with tie-ridge 3 weeks after planting increased sorghum grain yield by 30.11%. Tie-ridge 3 weeks after planting is found to be the appropriate time for the productivity of sorghum in Lalibela (Kechinabeba) and similar agro ecology areas.

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Availability of data and materials

Data that were used to generate these results are available upon request from the corresponding author.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Table 6
Combined mean value for the effect of tie and riding time on the grain yield and biomass of sorghum at Lalibela.

Treatment	Total biomass (ton/ha)			Grain yield (ton/ha)		
	2017	2018	Combined BM	2017	2018	Combined GY
Tie-ridging at planting	10.48[cd]	11.73[bc]	10.91[cd]	1.57[bc]	1.31[c]	1.44[cd]
Ridge at planting tie 2 WAP	12.23[b]	12.26[b]	12.25[b]	1.33[cd]	1.37[bc]	1.35[de]
Ridge at planting tie 4 WAP	12.50[ab]	12.53[b]	12.52[b]	1.46[bcd]	1.41[bc]	1.43[cd]
Tie-ridging 3WAP	12.12[bc]	12.95[ab]	12.54[b]	2.03[a]	1.77[a]	1.90[a]
Ridge 2 WAP & tie 4WAP	14.12[a]	14.47[a]	14.29[a]	1.79[ab]	1.59[ab]	1.696[ab]
Ridge 3WAP&tie 6WAP	12.25[b]	11.97[b]	12.11[bc]	1.47[bcd]	1.70[a]	1.587[bc]
Tie-ridging 6WAP	9.51[d]	10.04[c]	9.77[d]	1.171[d]	1.23[c]	1.202[e]
Shilshalo 8wAP	11.38[bc]	12.04[b]	11.71[bc]	1.46[bcd]	1.20[c]	1.331[de]
CV (%)	8.06	8.3	9.01	13.11	9.16	12.87
LSD(0.05)	16.7	17.8	12.65	3.52	2.32	2.24

Where the same letters are not significantly different at p = 0.05 (5 % level of significance) BM = biomass GY = grain yield WAP = week after planting CV = coefficient of variation LSD = list significance difference.

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CRediT authorship contribution statement

Yalelet Abie: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yonas Reda:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Haymanot Lamesign:** Writing – review & editing, Visualization, Methodology, Data curation, Conceptualization. **Tilahun Esubalew:** Writing – review & editing, Visualization, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing interests.

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References

[1] K. Georgis, M. Temesgen, S. Goda, On-farm evaluation of soil moisture conservation techniques using improved germplasm, in: Seventh Eastern and Southern Africa Regional Maize Conference, Kenya, Nairobi, 2004, pp. 313–316.
[2] Kidane Georgis, Melese Temesgen, Shilima Goda, On-farm Evaluation of Soil Moisture Conservation Techniques Using Improved Germplasm, 2001.
[3] C.S. Wortmann, Martha Mamo, Girma Abebe, K. Kaizzi, C. Mburu, E. Letayo, S. Xerinda, An Atlas of Sorghum Production in Eastern Africa, 2006. http://intsormil.org. (Accessed 15 June 2010).
[4] FAOSTAT, Food and Agriculture Organization of the United Nations, 2013 (FAO).
[5] Central Statistics Authority (CSA), Agricultural sample survey 2006/2007. Report on area and production for major crops (private peasant holdings, main season), Statistical Bulletin No. 227. Addis Ababa, Ethiopia (2017).
[6] Alemie Araya, L. Stroosnijder, Effects of tied ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in northern Ethiopia, Agric. Water Manage. 97 (2010) 841–847.
[7] H. Breman, J.J.R. Groot, H. Van Keulen, Resource limitations in Sahelian agriculture, Global Environ. Change 11 (2001) 59–68.
[8] J. Morin, Soil crusting and sealing in West Africa and possible approaches to improved management, in: FAO (ed.) Soil Tillage in Africa: Needs and Challenges, vol. 69, FAO Soils Bulletin, 1993, pp. 95–128.
[9] D.S. Rana, Integrated Water Management, Management of Rainfed Agriculture, Indian Agricultural Research Institute, New Delhi, 2007. – 110 012.
[10] G. Abebe, Effect of Np fertilizer and moisture conservation on the yield and yield components of Haricot bean (phaseolus vulgaris L.) in the semi-arid zones of the central rift valley in Ethiopia, Adv. Environ. Biol. 3 (2009) 302–307.
[11] B. Gebreyesus, C.S. Wortmann, M. Martha, G. Heluf, B. Amare, Micro-basin tillage for grain sorghum production in semiarid areas of northern Ethiopia, Agron. J. 98 (2006) 124–128.
[12] G. Brhane, T. Mesfin, C. Wortmann, M. Mamo, A. Belay, A decision guide for tie-ridging in the semi-arid areas of Ethiopia, in: ASA-CSSA-SSSA International Annual Meetings (November 6-10, 2005), ASA-CSSA-SSSA, 2005, November.
[13] Demlie G. sillassie, A. shawl, Evaluation of In-Situ Moisture Conservation Techniques on Sorghum(sorghum Bicolor L.) Production at Dry Low Lands of Wag Himra, Ethiopia, 2010.

[14] H.F. Murphy, A report on fertility status and other data on some soils of Ethiopia, in: College of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture, Alemaya, Ethiopia, 1968, p. 551.
[15] A. Dejene, Integrated Natural Resources Management to Enhance Food Security. The Case for Community-Based Approaches in Ethiopia, Environment and natural resources working paper, 2003, p. 16.
[16] A.J. Walkley, I.A. Black, Estimation of soil organic carbon by the chromic acid titration method, Soil Sci. 37 (1934) 29–38.
[17] S.R. Olsen, C.V. Cole, F.S. Watanabe, L.A. Dean, Estimation of available phosphorus in soils by extraction with sodium carbonate, USDA Circular 939 (1954) 1–19.
[18] Tekalign Tadesse, Soil, plant, water, fertilizer, animal manure, and compost analysis, in: Working Document No. 13, International Livestock Research Center for Africa, Addis Ababa, Ethiopia, 1991.
[19] A. Cottenie, Soil and Plant Testing as a Basis of Fertilizer Recommendations, in: FAO Soil Bulletin, 38/2, Food and Agriculture Organization of the United Nations, Rome, Italy, 1980.
[20] Y. Tekle, G. Wedajo, Evaluation of different moisture conservation practices on growth, yield, and yield components of sorghum, Journal of Agriculture and Environmental Management 4 (3) (2015) 169–173.
[21] H. Legesse, L. Gobeze, Growth and grain yield response of sorghum (*Sorghum Bicolor* L. Moench) varieties to moisture conservation practices and NP Fertilizer at moisture stress area of Amaro, Southern Ethiopia, Ashese Journal of Agricultural Science 1 (2015) 1–5.
[22] Gebreyesus Brhane, Tewodros Mesfin, Charles Wortmann, Martha Mamo, Amare Belay, A decision guide for tie-ridging in the semi-arid areas of Ethiopia, in: Mekelle Agric. Res., Cen, Mekelle, Ethiopia1; Melkassa Agric. Res. Cen, Nazret, Ethiopia2 Dep. Agron. & Hort., Univ. of Nebraska3, 2005.
[23] Demoz, Hailemariam Abrha. "A Review on Effect of Tie Ridging on Crop Productivity in Dry Land Agro-Ecosystems of Ethiopia."..