

Management of *Striga hermonthica* through Moisture Conservation Practices and Cowpea Intercropping in Eastern Ethiopia

Lemma Degebasa

Haramaya University

Taye Tessema

Ethiopian Institute of Agricultural Research, Post Office

Zelalem Bekeko

zelalembekeko@yahoo.com

Haramaya University

Ketema Belete

Haramaya University

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Abstract

Striga has become the major biological constraints for farmers growing maize, sorghum, millet and rice in SSA, causing devastating losses in yield resulting in shortage of food supply in developing countries including Ethiopia. Field experiments were carried out in the Babile district, eastern Ethiopia during the 2019 and 2020 cropping seasons to determine the effect of moisture conservation practices and cowpea intercropping as trap crop on Striga infestation and sorghum productivity. The trial included eight treatments spread over four replications in a randomized complete block design. The percentage of Striga infestation reduction and yield increase differed considerably between treatment combinations ($P < 0.001$). The use of tied-ridge and cowpea between rows produced the highest sorghum yield (4.1 t/ha) and the highest Striga reduction (90.3%), followed by closed end tide-ridge and cowpea between two sorghum plants in furrows (3.6 t/ha and 84.75%, respectively); and open-ridge and cowpea between rows of sorghum (3.2 t/ha and 77.25%, respectively). The lowest sorghum yield was obtained from the sole susceptible sorghum variety (*Teshale*) in the flat control plot (1.4 t/ha) with the highest striga infestation percentage (80%). According to the findings of this study, moisture conservation practices and cowpea planting are critical for striga management and maximizing sorghum yield in low and erratic rainfall receiving areas such as the Babile district of Eastern Ethiopia. These practices can be adopted by similar regions where striga is abundantly existing in sorghum fields.

1. Introduction

Sorghum [*Sorghum bicolor* (L) Moench] is the primary cereal crop for millions of people in Africa and Asia's semiarid tropics (Winchell et al., 2018; Griebel et al., 2019). After maize, rice, wheat, and barley, it ranks fifth in cereal production (Boyles et al., 2018). The crop is typically grown in marginal locations with high temperatures and limited rainfall (Mabhaudhi et al., 2019; Mundia et al., 2019). It is frequently produced for household food security (Phiri et al., 2019).

Despite the fact that sorghum is an important commodity in Africa, particularly for impoverished farmers, there are numerous production limits. The principal obstacles to sorghum production include drought, low soil fertility, Striga infestation, storage pests, bird damage, a lack of improved varieties, and a shortage of production inputs. Striga ranks the highest among these limitations (Mrema et al., 2017). It is a serious biotic constraint in Ethiopian sorghum-growing areas (Atsbha et al., 2016). The striga problem in Sub-Saharan Africa is aggravated by the plant's exquisite adaptation to semiarid tropic climatic conditions, higher seed production, and the durability of its seed stocks in tropical soils (Kudra et al., 2012). It is a major production constraint in northern and eastern Ethiopia's cereal-growing regions (Fasil et al., 2010). Thus, in the eastern regions, this plant is known as *Aramazab*, which means Satan's weed, and in the northern portions, it is known as *Akenchira* or *Metselem*, which means crop stunting weed (Hayelom Berhe, 2014).

Striga has become the major biological constraints for farmers growing maize, sorghum, millet and rice in SSA (Parker, 2009), causing devastating losses in yield resulting in shortage in food supply in

developing countries. Farmers in areas infested with striga weeds report losses of between 20 and 80% (Atera et al., 2011) and in susceptible cultivars, grain yield losses can end up to 100% under drought conditions and higher infestation. In Africa striga causes economic loss comparable to USD 1 billion yearly (Labrada and Officer, 2008) and this depends on striga seed density, soil fertility, distribution of rainfall and variety of cereal species grown (Teka, 2014). In sorghum, Striga infestation affect post flowering stages, resulting to 45% in grain yield loss (Showemimo, 2010).

In ordinary conditions, the host plants are infested by huge numbers of striga weeds and this parasitism makes striga weed to become metabolic sink for photo assimilates and nutrients (Knutson, 2012). Cultivated sorghum plants affected by Striga display reduction in photosynthetic parameters including electron transport rate through photochemical quenching and photo system (Rodenburg and Bastiaans, 2011). Also elevation of plant hormones such as abscisic acid and cytokinins levels in sorghum plants due to parasitism by Striga have shown to have negative effects on photosynthesis (Frost et al., 1997).

To maintain Striga's pressure to a minimum level, an integrated weed control approach including the practices of small farmers' and technological innovation in a holistic manner is required (Mishra et al., 2021). Striga management is dominated by hand weeding in most smallholder farms in poor countries (Sims et al., 2018), which is time-consuming and labor-intensive (N'cho et al., 2019). Sorghum-based cropping systems, as part of integrated Striga management, increase the efficiency of accessible resources to acquire a range of products from the same piece of land and increase farm revenue from small holding farmers (Lithourgidis et al., 2011). Cowpea intercropping with sorghum, for example, results in greater grain output, which may be related to the benefits of N fixation as well as the stimulation of suicidal germination of striga seeds away from the host roots. Planting these crops in agricultural systems could minimise the striga seed bank while increasing soil fertility and farmer livelihood.

Sorghum with cowpea intercropping is one of the most important farming methods for small-scale farmers in Sub-Saharan Africa's dry and semi-arid lands (Karanja et al., 2014). Hand weeding, which is practiced by farmers in the area, was ineffective in diminishing its infestation. Despite previous research efforts to fix or alleviate the aforementioned biotic production and productivity limits, these issues continue to result in yield and quality losses, compromising food security and self-sufficiency. To that aim, comprehensive Striga management research efforts must be carried out in order to create package recommendations for maintaining sorghum output and productivity in eastern Ethiopia. The purpose of this study was to uncover the underlying factors that account for farmers in the Babile District's integrated control of Striga through moisture conservation and cowpea intercropping with sorghum. Despite greatly expanded area coverage, sorghum productivity per unit area is quite low due to parasitic weeds. Raising production levels and minimizing sensitivity to Striga infection are thus critical for increasing sorghum farmers' food security. As a result, the purpose of this study was to examine the effects of moisture conservation practices and cowpea intercropping with sorghum in minimizing Striga infestation and boosting yield for sustainable sorghum production.

2. Materials and Methods

2.1. Description of the study area

During the main rainy seasons of 2019 and 2020, a field experiment was carried out on farmers' farms in the Babile region of Besidimo. Babile town is located in a semi-arid environment, 35 kilometres from Harar and 570 kilometres east of Addis Abeba. It is located in eastern Oromia, bordering Somalia Regional State to the southeast, Midegatola and Fedis districts to the west, Harar Regional State to the north, and Gursum district to the east. The location is 9° 15' 25" N latitude and 42° 12' 08" E longitude, at an elevation of 1400 m above sea level. The average annual maximum and lowest temperatures are 27.1°C and 11.3°C, respectively, with 700 mm of rainfall falling between 450.2 mm and 1114.5 mm. The rainfall is bimodal, with the short rainy season lasting from March to April and the long wet season lasting from June to September. According to national Ethiopian agro-ecological classifications, Babile District is classed as 'Woinadega', meaning midland (15%), and 'Kola', meaning lowland (85%).

2.2. Experimental Design and Treatments

Due to its susceptibility to *Striga* infection, the sorghum variety Teshale, which was developed by Melkasa Agricultural Research Centre in 2002 for drought-prone areas, was utilized as a test crop. The variety is substantially shorter than the local sorghum and can provide a good yield under *Striga*-free circumstances (3.9 and 2.66 tons/ha, respectively) in research and farmer fields. This type matures quickly (100–120 days depending on altitude/temperature) and can tolerate altitudes of less than 1600 metres above sea level, with an average annual rainfall of 500 to 600 mm. Gobiye, the only *Striga*-resistant sorghum cultivar, was also employed as a control treatment for comparison, with cowpea serving as the trap crop. "Teshale" seeds were obtained from the "Melkasa Agricultural Research Centre" for this study, and Gobiye and cowpea seeds were obtained from the "Fedis Agricultural Research Centre."

The experiment was designed utilizing a randomized complete block design and four replications. The main treatment components were three planting methods [two moisture conservation practices (sorghum planting in tied-ridge, open-ridge, and flat plot) and two cowpea planting patterns, between rows of sorghum and between sorghum plants inside rows] and two cowpea planting patterns. All agronomic practices, including fertility management, were carried out in accordance with local recommendations.

Treatments:

1. Sorghum planted in tied-ridge + cowpea between rows of sorghum
2. Sorghum planted in tied-ridge + cowpea between two sorghum plants in rows
3. Sorghum planted in open-ridge + cowpea between rows of sorghum
4. Sorghum planted in open-ridges + cowpea between two sorghum plants in rows
5. Sorghum planted on flat plot + cowpea between rows of sorghum

6. Sorghum planted on flat plot + cowpea between two sorghum plants in rows
7. Sole resistant sorghum variety (*Gobiye*) on flat plot (control)
8. Sole susceptible sorghum variety (*Teshale*) on flat plot (control)

Field Management Procedures

Prior to planting, the area was ploughed and ridged to conserve moisture. Each plot included four rows of sorghum planted at 75 cm row spacing. The height of the crest was 0.3 m. After emergence; sorghum seeds were drilled and thinned to 20 cm. After emergence, two cowpea seeds were planted 10 cm apart and trimmed to one. Sorghum seeds were planted at a soil depth of 50 mm, one seed per hill, and seedlings were trimmed to one plant per hill two weeks later. Each plot was arranged in four rows of 5 m length. At planting, 50 kg/ha NPS fertilizer was applied to all plots. Nitrogen fertilizer in the form of urea was applied in two splits at a rate of 46 kg N/ha at sowing and knee height stage. All fertilizers were applied in band on ridges. After planting, manual weeding was conducted at 2 and 8 weeks after planting to control grass and late emerging weeds.

2.3. Sorghum parameters

Days to 50% blooming were calculated by counting the number of days between planting and when 50% of the plants in a plot flowered. Days to physiological maturity were calculated as the number of days between planting and the formation of the black layer on the studied plants. During the half-blooming and hard-dough stages, plant height was measured in centimetres (cm) from the surface of the soil to the tip of the panicle. $LAI (i) = AL/Ag$, $LAI (ii) = leaf\ area\ index$ $LAI = leaf\ area\ index$; $AL = leaf\ area$; $b1 = sorghum\ leaf\ regression\ coefficient\ factor\ (0.75)$; $Ag = ground\ area$; $L = leaf\ length\ (cm)$, and $W = leaf\ width\ (cm)$. Leaf length was measured in centimeters from the stem to the tip of the leaf, and breadth was measured in centimeters from one side to the other at the middle third of the leaf during the booting stage and half blooming. The leaf area (cm²) was determined using leaf width and leaf length, and the leaf area index was derived using the linear technique.

Yield components and yield

Sorghum panicles were harvested with knives from the two inner rows, excluding the plants found on the outer hill from each side of the two rows. The harvested panicles were collected, counted, sun-dried to 14% moisture content, packed, and labelled. Data on panicle length and panicle weight were recorded from five selected plants from each harvestable net plot area. Using a beam balance, the threshed grains were weighed and recorded as grammes per area. Grain yield (kg/ha) was calculated using the formula $grain\ yield\ (kg/ha) = [plot\ yield\ in\ kilogramme\ \times\ 10,000]/[number\ of\ harvested\ panicles\ plot\ size\ in\ square\ metres]$. It was afterwards modified to tonnes per hectare. A composite sample of 1000 kernel weight (grammes) was taken from each net plot of harvested grain yield. After assessing the actual moisture content of the seed, the kernel was counted using an electronic seed counter, and the weight was determined using an electronic sensitive balance and adjusted to 12.5% moisture content. Grain yield was calculated by harvesting plants from the net plot area.

The yield collected was adjusted to a moisture content of 12.5% and converted to hectares. The moisture content was adjusted according to the following formula:

$$\text{Adjusted seed weight} = \text{Initial seed weight} \left(\frac{100 - OMC}{100 - DMC} \right)$$

Where OMC denotes the original moisture content and DMC denotes the target moisture content. The harvest index (HI) was calculated by dividing grain yield by dry aboveground biomass yield.

2.4. Striga parameters

Striga shoot measurements were taken at weekly intervals beginning with the appearance of Striga seedlings. Striga dry weight (g/m²): The weight of Striga shoots from net plots was gathered and measured in hot dried air at 700 degrees Fahrenheit for two to three days. Striga height (cm): The distance measured in centimetres (cm) from the soil's surface to the tip of the Striga. Matured Striga capsules from sample plants were counted. Striga infestation (%): This was calculated using a net plot of Striga count and harvested sorghum. Striga infestation = A/B x 100%, where A represents the overall Striga count per plot and B represents the crop stand per plot. Reduction Striga infection level (%): This was calculated using the formula Reduction Striga infestation level = C-D/C x 100%, where C is the Striga count in the solitary sorghum plot and D is the Striga count in the intercropped plot.

2.5. Cowpea Components

Matured pods from sample plants were counted and weighed (g), seed per pod was counted (g), hundred seed weight (g) was determined by randomly counting hundred seeds from threshed pods, yield per plot was measured (kg) and adjusted to 12.5% moisture content in an experimental unit using a digital weighing balance.

2.6. Data Analysis

Data were analyzed using SAS 9.0 software. The standard error of the difference at the 5% level of probability is used to compare the differences between two treatment means with LSD and DMRT. The GLM procedure's contrast statement was used to isolate the significant means.

3. Results and Discussion

3.1. Growth of sorghum

Days to flowering and physiological maturity

The analysis of variance revealed no significant differences between treatments, with the lone planted sorghum on the flat plot serving as the control at P5% on days of flowering and days to physiological maturity in both the 2019 and 2020 cropping seasons (Table 1).

Moisture conservation and cowpea intercropping had no effect on the days to 50% flowering because the rows of sorghum and cowpea planted did not protect the entrance of solar radiation during sorghum blooming and enhanced soil fertility by assisting nitrogen fixation. This finding is consistent with the findings of Nawal Mohammed (2005), who found no significant variations in days to 50% blooming between sorghum intercropping regimes. Zeru (2019) reported similar findings and (J.R.Olupot et al., 2002) also observed that most of the inter-planted pots infested with striga failed to flower, and there were no significant variations in flowering among the non-infested groups.

Table 1
shows the influence of water conservation and cowpea intercropping on sorghum growth characteristics in Besidimo, Babile, Ethiopia over the 2019 and 2020 planting seasons.

Treatments	DF	DPM	LA	LAI	PH
PSTR + CPR	69.75 ^a	91.00 ^a	62.25 ^a	32.77 ^a	180.00 ^a
PSTR + CPP	69.13 ^a	90.38 ^a	45.94 ^b	24.48 ^b	168.63 ^b
PSOR + CPR	69.13 ^a	90.75 ^a	37.13 ^{cb}	19.71 ^{bc}	154.00 ^c
PSOR + CPP	69.13 ^a	90.50 ^a	32.4b ^{cd}	17.30 ^{bc}	144.50 ^d
PSFP + CPR	69.63 ^a	90.88 ^a	27.19 ^{cde}	14.68 ^{bcd}	140.13 ^{ed}
PSFP + CPP	69.38 ^a	90.75 ^a	23.25 ^{de}	12.55 ^{cd}	136.38 ^e
SRSV (control 1)	69.25 ^a	90.63 ^a	20.40 ^e	11.05 ^d	121.25 ^g
SSSV (control 2)	68.88 ^a	90.88 ^a	18.00 ^e	9.81 ^d	129.25 ^f
CV	1.28	0.79	32.09	12.74	3.13
LSD	0.89	0.73	10.79	7.63	4.64

At the alpha (0.05) level of probability, similar letters are not substantially different at the least significant difference. Note: DF = Days to Flowering, DPM = Days to 95% Physiological Mature, LA = Leaf Area Index, PH = Plant Height, CV = Coefficient of Variation, LSD = Least Significant Deference, PSTR + CPR = tied-ridge sorghum + cowpea between sorghum rows, PSTR + CPP = tied-ridge sorghum + cowpea between two sorghum plants, PSOR + CPR = open-ridge sorghum + cowpea between rows of sorghum, PSTR + CPP = Sorghum planted in an open ridge + cowpea planted between two sorghum plants, PSFP + CPR = sorghum planted on a flat plot + cowpea planted between sorghum rows, PSFP + CPP = Sorghum planted on a flat plot plus cowpea planted between two sorghum plants, Sole resistant sorghum variety (SRSV), Sole susceptible sorghum variety (SSSV).

Leaf area (LA) and leaf area index (LAI)

In both seasons, the control treatment had the lowest leaf area and leaf area index, which were 18 cm² and 9.81, respectively (Table 1). Furthermore, there were substantial disparities between the other treatments. In general, the largest increases in LA and LAI of sorghum obtained from the tied-ridge and cowpea planting method treatments were 62.25 cm² and 32.77 cm² over the least effective water conservation strategy (flat plot) and the control plot, respectively. This advantage could be due to the construction of various types of ridges for the soil's water holding capacity and prostrating local cowpea intercropping, as well as cowpea as a "trap crop" for the suicidal germination of striga seeds, which leads to an increase in sorghum growth. This finding was consistent with the findings of (Fikadu et al., 2018), who showed that using cowpea as a trap crop. This result was also consistent with the findings of (Sarmiso, 2015), who found that infested sorghum plants had significantly less shoot and root biomass than striga-free control sorghum plants.

Plant height

Plant heights of solely planted *Teshale* and *Gobiye* sorghum types were 129.25 cm and 121.25 cm, respectively, in both the 2019 and 2020 cropping years (Table 1). In both cropping calendars, sorghum planted in tied-ridges with cowpea between rows of sorghum produced the highest plant height (180 cm) (Table 1). This could be attributed to a decrease in striga infestation and higher moisture content of the soil, which may promote nutrient absorption from the soil, resulting in improved sorghum growth. As a result, an interaction impact between soil moisture conservation and nitrogen fixation by cowpea was discovered to represent a significant change in sorghum plant height. This finding is consistent with the findings of Wubshet et al. (2020), who discovered that cropping strategies improved sorghum plant height considerably. This results, on the other hand, contradicts Islam et al. (2018)'s finding that in Pakistan intercropping lowered plant height due to plant behavior and seed percentage.

3.2. Yield component and yield of sorghum

Panicle length

The maximum dry panicle length (24.3 cm) was recorded from sorghum planted in tied-ridge plus cowpea intercropping between rows, followed by sorghum planted in tied-ridge plus cowpea intercropping within rows of sorghum plants (22.6 cm), though the difference was non-significant. The minimum panicle lengths were measured in the control, which consisted of just *Teshale* and *Gobiye* sorghum types (17.22 cm and 17.31 cm, respectively). This disparity between treatments is most likely owing to moisture conservation and cowpea intercropping treatments, which may improve strong crop development due to moisture and soil fertility gain, which may minimize the amount of parasitic weeds *Striga hermonthica* infection. According to the current study, sorghum-cowpea intercropping performed best with big panicles (Andrew et al., 2016). Contrary to the current finding, (Berhane et al., 2015) found that an intercropped treatment had the shortest panicle length when compared to sorghum alone.

Table 2

shows the impact of integrated Striga control on sorghum productivity in the 2019 and 2020 cropping seasons, using moisture conservation and cowpea as a trap crop.

Treatments	Dry Panicle Length	Panicle Weight	Above Ground Biomass	Thousand Kernel Weight	Yield	Harvest Index
PSTR + CPR	24.30 ^a	3.60 ^a	9473.50 ^a	29.20 ^a	4.10 ^a	55.18 ^a
PSTR + CPP	22.63 ^b	2.96 ^b	9083.20 ^b	28.30 ^b	3.60 ^{ba}	54.14 ^a
PSOR + CPR	21.22 ^c	2.40 ^c	7973.40 ^c	26.14 ^c	3.20 ^b	48.36 ^b
PSOR + CPP	20.44 ^d	2.06 ^d	7578.80 ^d	24.40 ^d	2.60 ^c	45.65 ^c
PSFP + CPR	19.66 ^{de}	1.80 ^e	6738.30 ^e	22.80 ^e	2.40 ^{dc}	43.14 ^d
PSFP + CPP	18.75 ^{de}	1.64 ^f	6104.80 ^f	22.50 ^e	1.97 ^d	40.26 ^e
SRSV (control 1)	17.31 ^f	1.48 ^f	484.00 ^g	21.20 ^f	1.36 ^e	32.66 ^g
SSSV (control 2)	17.22 ^f	1.55 ^f	5044.50 ^g	22.50 ^e	1.40 ^e	35.31 ^f
CV	4.47	7.40	3.75	3.32	21.80	3.05
LSD	0.91	0.16	268.60	0.83	0.56	1.37

Means with the same letter are not significantly different at alpha (5%).

Note

CV = Coefficient of variation, LSD = Least significant difference, PSTR + CPR = Sorghum planted in tied-ridge + cowpea between rows of sorghum, PSTR + CPP = Sorghum planted in tied-ridge + cowpea between two sorghum plants, PSOR + CPR = Sorghum planted in open-ridge + cowpea between rows of sorghum, PSOR + CPP = Sorghum planted in open-ridge + cowpea between two sorghum plants, PSFP + CPR = Sorghum planted on flat plot + cowpea between rows of sorghum, PSFP + CPP = Sorghum planted on flat plot + cowpea between two sorghum plants, SRSV = Sole resistant sorghum variety, SSSV = Sole susceptible sorghum variety.

Panicle weight

Sorghum planted with tied-ridge plus cowpea between rows had a higher panicle weight (3.6 g) than sorghum planted within a row of sorghum plants (2.96 g). Sorghum planted without cowpea intercropping had the lowest panicle weight in both cropping seasons (Table 2). These findings could be attributed to enhanced moisture as a consequence of conservation through linked ridges and higher soil fertility as a result of cowpea intercropping, which could result in fewer Striga infestations. Similar

findings reported by Aliyu and Emechebe (2006). Fikadu et al. (2018) also discovered that using a "trap crop" boosted kernel weight per head, particularly when using cowpea.

Above ground biomass

The highest plant biomass (9473.5 kg/m²) recorded from sorghum planted in tied-ridge plus cowpea between rows (Table 2), followed by tied-ridge plus cowpea within row of between sorghum plants (9083.2 kg/m²) in both 2019 and 2020 cropping season. In both seasons, the minimal plant biomass was reported at p0.001 in the control (Gobiye (484 kg/m²) and Teshale (5044.5 kg/m²) (Table 2). The variations between treatments were related to improved soil moisture and cowpea intercropping as a trap crop for *Striga* management. This discovery is supported by the findings of Siddig et al. (2013), who discovered that intercropping sorghum with ground nut considerably altered its dry matter weight. These findings are also consistent with those of (Sibhatu, 2016) and (Iqbal, 2018).

Thousand kernel weight

In both seasons, sorghum planted in tied-ridge plots with cowpea between rows produced considerably greater thousand seed weights (29.2 g/plot) than their respective treatments. In the 2019 and 2020 production seasons, the control (Teshale (22.5 g/m²) and Gobiye (21.2 g/m²) had the lowest thousand-seed weight (Table 2). These findings could be attributed to moisture conservation and cowpea cultivation, which reduced the frequency of *Striga* infestations and resource competition. This finding is consistent with the findings of Tesfaye Tesso and Gebisa Ejeta (2011). This discovery also supported the findings of (Singh et al., 2019), who found that legume intercropping increased maize and sorghum productivity.

Harvest index

The highest harvesting index (55.18%) was reported in sorghum planted in tied-ridge plus cowpea between rows (p0.001), which was also statistically similar to tied-ridge plus cowpea between sorghum plants (54.14%), followed by the remaining treatments. The lowest harvesting index (35.31%, 32.66%) was recorded in the sole planted striga-susceptible sorghum variety (Teshale) and striga-resistant variety (Gobiye) (Table 2). This could be attributed to good cowpea intercropping and moisture conservation practises. Berhane et al. (2015) reported similar findings. This outcome is also consistent with Karanja et al. (2014)'s findings on sorghum-cowpea intercropping.

Yield of sorghum

Among the treatments tested, planting sorghum in the furrows of closed end tide ridge plus cowpea between rows and between two sorghum plants produced the highest sorghum yield (4.1 t/ha) in both years (Table 2), followed by closed end tide ridge plus cowpea between two sorghum planted in furrows (3.6 t/ha). The lowest sorghum yield was obtained from the lone resistant sorghum variety on the flat plot (1.36 t/ha) control and the sole susceptible sorghum variety on the flat plot (1.4 t/ha) control. In general, the yields achieved by the treatments differed significantly (Table 2). This could be characterized

by greater soil moisture content, and the use of tied-ridge and cowpea intercropping as striga trap crops for striga management. This result supports the findings of Tesfaye Tesso and Gebisa Ejeta (2011). Aliyu and Emechebe (2006) discovered that a higher sorghum yield can also be ascribed to the value of the cropping system, which not only reduces the striga seed bank but also boosts nitrogen delivery to the host crop. Jat et al. (2013) revealed similar findings on the favorable effect of azotobacter on grain and stover yield. Heluf and Yohannes (2002) revealed similar findings. Gabor et al. (2014) demonstrated similar results on the impact of seeding sorghum on ridges and furrows with conventional tillage with fertiliser improved grain production (2.03 t/ha).

3.3. Striga infestation

Striga shoots count

The highest Striga shoot numbers per plot were found 14 weeks after planting (Table 3), out of all sampling times. The sole planted Striga-susceptible sorghum variety (Teshale) produced the greatest mean number of Striga shoot counts/plot at harvest 14 WAP, with 28 Striga/plot (Table 3). The lowest Striga shoot counts/plot were obtained ten weeks after planting with 1 Striga/plot sorghum planted in linked ridges and cowpeas within rows. At 14 WAP, the highest Striga shoot counts/plot were recorded in the sole planted susceptible sorghum variety, and the lowest Striga shoot counts/plot were recorded in the Striga resistant variety (Gobiye) and sorghum planted closed end tied ridges and open end tied ridges with cowpea between rows. In accordance with the sorghum planted plot, the flatbed plot had a greater Striga shoot count than the closed and open end tied ridge. The differences resulted from the efficiency of the linked ridges for moisture conservation and cowpea as a trap crop over the control treatment. In both seasons, the number of Striga counts per metre square was lower in the sorghum-cowpea intercropping and resistant sorghum variety (Gobiye) compared to the control plot (Teshale). Zeyaur et al. (2007) found the similar thing in sorghum. Similar findings have been reported by (Gbehounou et al., 2004) on the quantity of emerging Striga. Tesfaye Tesso and Gebisa Ejeta (2011) also reported similar findings on host plants and Striga.

Table 3
shows the mean number of emerged *Striga hermonthica* in sorghum planted in sole stands and intercropped with cowpea at 14 weeks after planting

Striga shoot count/plot			
Treatments	Striga Count 10 WAS	Striga Count 12 WAS	Striga Count 14 WAS
SSSV (control 2)	7.00 ^a	16.75 ^a	28.00 ^a
PSFP + CPP	2.00 ^b	7.00 ^b	10.50 ^b
PSFP + CPR	2.00 ^b	6.00 ^b	9.50 ^b
PSOR + CPP	1.30 ^{cb}	4.50 ^c	8.00 ^b
PSOR + CPR	1.10 ^{cb}	4.00 ^{dc}	7.25 ^{cb}
PSTR + CPP	1.10 ^{cb}	2.90 ^{de}	4.13 ^{cd}
PSTR + CPR	1.00 ^{cb}	2.00 ^e	3.50 ^d
SRSV (control 1)	0.00 ^c	0.00 ^f	1.00 ^e
CV	56.90	25.20	35.50
DMTR	0.91	1.84	9.86

The means followed with the same letters in a column are not significantly different at alpha (5%) according to Duncan's multiple test range.

Note

CV = coefficient of variation, DMTR = Duncan's multiple test range, WAS = Weeks after sowing, PSTR + CPR = Sorghum planted in tied-ridge + cowpea between rows of sorghum, PSTR + CPP = Sorghum planted in tied-ridge + cowpea between two sorghum plants, PSOR + CPR = Sorghum planted in open-ridge + cowpea between rows of sorghum, PSTR + CPP = Sorghum planted in open-ridge + cowpea between two sorghum plants, PSFP + CPR = Sorghum planted on flat plot + cowpea between rows of sorghum, PSFP + CPP = Sorghum planted on flat plot + cowpea between two sorghum plants, SRSV = Sole resistant sorghum variety, SSSV = Sole susceptible sorghum variety.

Striga shoots counts per plant

The highest Striga shoot counts per plant were recorded from solely planted Striga-susceptible Teshale sorghum varieties (5 Striga/plant) compared to other sorghum-planted flat plots with cowpeas intercropped between rows and within rows (2 Striga/plant) and sorghum planted in closed-and open-

end tied ridges with cowpeas (1 *Striga*/plant), whereas no *striga* were recorded in solely planted *Striga*-resistant sorghum varieties (Table 4) in either cropping season. Jamil et al. (2012) found similar findings on germination stimulants and (Felix et al., 2007) corroborated that *Striga* plants per sorghum plant were reported in Nigeria. However, once soybean was used as a trap crop treatment, the number was dramatically reduced. This suggested that the legume cropping system's lower *Striga* emergence could be attributed to their *Striga* seed bank reduction capabilities.

Striga shoots dry biomass

Sorghum grown in closed end linked ridges with cowpea produced less *Striga* shoot dry biomass (1.92 g/m²) than the other treatments in both seasons. *Striga* shoot dry biomass (6.35 g/m²) was highest in lone sorghum planted plots in both the 2019 and 2020 cropping seasons. Statistical analysis revealed a significant difference (P5%) in *Striga* shoot biomass across treatments (Table 4). This finding was consistent with the findings of (Esra A Mahmoud et al., 2016), who discovered that the dry weight of *Striga* increased with increasing seed bank level on single sorghum. Rodenburg et al. (2006a) discovered a strong relationship between *striga* dry weight and seed capsule number.

Striga height

In both years, the comparison of sorghum planted in closed and open end tied ridges plus cowpea (12 cm) with the control treatment solo Teshale (28.9 cm) revealed a highly significant difference in *Striga* plant height at maturity (Table 4). Differences in *Striga* plant height found among treatments may be attributed to moisture conservation, host crop shade, and cowpea nitrogen fixation. This finding confirms that the host crop (Teshale) significantly reduced the height of *Striga* due to the shading effect of the host crop on the *striga*, and that significant differences in the height of *Striga hermonthica* were observed due to nitrogen rates and varieties. In line with this, the discovery concurs with (Shank, 2002), who observed that host plant shadowing can limit *Striga* growth when significant fertilizer is provided to the soil.

Table 4
shows the mean number of emerged *Striga hermonthica* in sorghum planted in sole stands and intercropped with cowpea as a trap crop at harvest in the 2019 and 2020 cropping seasons.

Treatments	SCP	SH	SC	SDW	RSI
PSTR + CPR	1.13 ^b	12.00 ^f	14.00 ^f	1.92 ^e	90.38 ^b
PSTR + CPP	1.25 ^b	13.25 ^{ef}	15.89 ^e	2.38 ^{ed}	84.75 ^c
PSOR + CPR	1.38 ^b	15.13 ^{ed}	18.00 ^d	2.98 ^{cd}	77.25 ^d
PSOR + CPP	1.63 ^b	16.30 ^d	19.00 ^d	3.25 ^c	71.25 ^e
PSFP + CPR	1.50 ^b	18.94 ^c	24.00 ^c	3.6 ^{cb}	68.25 ^{fe}
PSFP + CPP	1.63 ^b	22.90 ^b	27.25 ^b	4.19 ^b	66.25 ^f
SRSV (control 1)	0.00 ^c	0.00 ^g	0.00 ^g	0.00 ^f	97.89 ^a
SSSV (control 2)	4.75 ^a	28.90 ^a	34.06 ^a	6.35 ^a	20.00 ^g
CV	53.24	12.22	8.12	20.64	5.38
DMTR	0.79	3.79	2.40	0.41	15.01

Means with different letters in a column are significantly different (5%) according to Duncan's multiple range tests. Note: CV = Coefficient of variation, DMTR = Duncan multiple test range, SCP = Striga shoot count per plant (striga/plant), SH = Striga height (cm), SDW = Striga biomass dry weight (g), SC = Striga capsules per plant (capsules/plant), RSI = Reduction of striga infestation (%).

Striga capsules per plant

Striga hermonthica produced the fewest capsules per plant (14 capsules/plant) with the sorghum treatment planted in a closed-tied ridge plot with cowpea intercropped between rows, while the teshale sorghum variety produced the most (34.6 capsules/plant) in both cropping seasons (Table 4). The amount of capsules per plot varied dramatically between treatments. Moisture and soil fertility enhanced by agronomic practices and nitrogen fixation resulted in the lowest number of capsules per plant (Table 4). This finding is consistent with the findings of Hassan et al. (2009), who reported that the suppressive effects of nitrogen on *Striga* infestation. Similarly, (Zarihun, 2016) discovered that nitrogen application resulted in the lowest number of capsules/plant, while zero nitrogen application resulted in the largest number.

Reduction in infestation level

Sorghum planted in a closed tied ridge with cowpea between rows (90.38%) and within rows (84.75%) had a significantly higher reduction in *Striga hermonthica* infestation in sorghum than the sole planted

striga susceptible sorghum variety-Teshale (20%), in other words, the highest Striga infestation (80%) occurred in the sole planted susceptible sorghum variety as control during both seasons (Table 4). This could be due to moisture conservation and suicidal Striga seed germination driven by cowpea and its nitrogen fixation. Hess and Dodo (2003) discovered that using leguminous trap crops such as groundnut, soybean, cowpea, and sesame types increased suicidal germination of Striga seeds to manage Striga. De Groote et al. (2010) discovered that intercropping soybean with maize increases suicidal germination of Striga seeds and lowers the Striga seed bank in the soil.

Combined effect of treatments

Striga infestation, dryness, and soil fertility reduction were the key obstacles in the experimental location, where the infestation was generally high in the control plots. However, combining moisture conservation with cowpea intercropping was crucial for maximal Striga control and soil fertility improvement. Chang et al. (2004) discovered similar results. Treatments 1 and 2 produced the highest combined grain yield (Table 4). This could be related to the cowpea's benefits as a trap crop in minimizing Striga infestation, as well as its contribution to soil moisture retention and reduced competition for nitrogen with sorghum plants due to its ability to fix its own nitrogen. This conclusion was consistent with the findings of Tesfaye Tesso and Gebisa Ejeta (2011), who compared the maximum yield obtained under tied-ridge tillage to the yield gained under flat beds.

Table 5

shows the interaction effect of season, moisture conservation, and cowpea intercropping on the analysis of variance for reducing Striga infestation and sorghum yield at Besidimo in Eastern Ethiopia during the 2019 and 2020 planting seasons.

Source of variation	DF	Mean square of RSI (%)	Mean square of Yield (ton/ha)
Season	1	305	2.47
Rep(Season)	6	10.7	0.32
Trt	7	4513	7.77
MC	2	1703.5	10.6
PM	1	247.5	3.06
MC*PM	2	19.5	0.03
Sole vs. Intercrop	1	3640	29.99
GS vs. TS	1	24258	0.01
Season*Trt	7	9.89	0.23
Season*MC	2	0.021	0.31
Season*PM	1	0.021	0.35
Season*MC*PM	2	0.021	0.28
Sole vs. Intercrop*Season	1	30.09	0.09
GS vs. TS*Season	1	39.07	0.004
Error	42	30	30
R-Square		91%	71%
CV		4.77	21.8
LSD		2.63	0.38

MC = Moisture conservation, Trt = Treatments, PM = Planting method, GS = Gobiye sorghum variety, TS = Teshale sorghum variety.

3.4. Yield component and yield of cowpea

Number of pods per plant

Cowpea intercropped between rows (PSTR + CPR) and between two sorghum plants (PSTR + CPP) planted in tied-ridge produced the highest pods per plant in both seasons (13.5 pods/plant, 12.5 pods/plant), followed by cowpea intercropped between rows (PSOR + CPR) of sorghum planted in open-ridge (10.5 pods/plant). Cowpeas intercropped between two sorghum plants (PSFP + CPP) sown on flat

plots produced the fewest pods per plant (7.5 pods/plant). This decrease in pods per plant was caused by the soil's lower moisture level, which promoted competition among plants for growth factors, reducing the number of effective pod-producing branches. This finding is consistent with the findings of Karanja et al. (2014), who stated that the best value was obtained in purely planted cowpea.

Number of seeds per pod

The analysis of variance revealed that the quantity of seeds per pod of intercropped cowpeas differed substantially between treatments, owing to the primary influence of varied moisture conservation practices and planting procedures (Table 2). This finding is consistent with the findings of (Shouse et al., 1982), who discovered that seed yield was closely associated with pod density, indicating that any stress that alters pod setting will reduce production. Cowpea shuts their stomata to avoid dehydration under water stress conditions, according to (Hamidou et al., 2007). This improves water efficiency and decreases water waste (Souza et al., 2004).

Table 6
shows how moisture conservation and intercropping affect cowpea yield and yield components in the 2019 and 2020 cropping seasons.

Treatments	Pods per Plant	Seeds per Pod	Hundred Seed Weight	Cowpea Grain Yield
PSTR + CPR	13.50 ^a	8.50 ^a	18.50 ^a	1271.25 ^a
PSTR + CPP	12.50 ^a	7.50 ^{ab}	17.50 ^a	1069.00 ^b
PSOR + CPR	10.50 ^b	6.50 ^{bc}	15.50 ^b	963.75 ^c
PSOR + CPP	9.50 ^{bc}	5.50 ^{cd}	14.50 ^{bc}	936.25 ^c
PSFP + CPR	8.50 ^{cd}	5.00 ^{de}	13.50 ^c	876.25 ^d
PSFP + CPP	7.50 ^d	4.00 ^e	11.50 ^d	813.75 ^e
CV	10.89	17.59	8.95	4.90
LSD	1.69	1.11	1.39	49.58

According to the least significant difference, means that are followed by the same letter are not significantly different at alpha (5%). LSD = least significant difference, CV = coefficient of variation, PSTR + CPR = tied-ridge sorghum + cowpea between sorghum rows, PSTR + CPP = tied-ridge sorghum + cowpea between two sorghum plants, PSOR + CPR = Sorghum planted in open-ridge + cowpea between sorghum rows, PSTR + CPP = Sorghum planted in open-ridge + cowpea between two sorghum plants, PSFP + CPR = sorghum planted on flat plot + cowpea between sorghum rows, PSFP + CPP = sorghum planted on flat plot + cowpea between two sorghum plants.

Hundred seed weight

Sorghum planted in tied ridges with cowpeas between rows (18.5 g/pod) and within rows (17.5 g/plot) had higher hundred seed weights, while sorghum planted on flat plots with cowpeas between rows (13.5 g/plot) and within rows (11.5 g/plot) had lower hundred seed weights. The variance in cowpea hundred seed weight may be attributable to higher moisture levels in intercropped treatments compared to pure stand crops, as well as less competition from one row sorghum plants to the established cowpea plants (Table 6). Ahmed El Naim *et al.* (2013) presented a similar outcome, namely that agronomic evaluation of sorghum and cowpea intercropped at varied spatial arrangements had no significant effect on cowpea seed yield.

Cowpea grain yield

Cowpea yield differed significantly ($P=0.001$) due to the interaction effects of moisture conservation and cowpea planting practices. As a result, the highest cowpea yield (1271.25 kg/ha) was achieved from sorghum planted in tied ridges with cowpea intercropped within rows, and the lowest cowpea yield (813.75 kg/ha) was obtained from sorghum planted in flat plots with cowpeas intercropped within rows (Table 6). This finding is consistent with the findings of (Ahmed et al., 2013) about significant moisture contents in intercropped treatments above pure stand crops, as well as a minimum competition of one row of sorghum plants to the grown cowpea plants when compared to other treatments.

4. Conclusion

Striga management necessitates a thorough understanding of the interactions between sorghum, Striga, and moisture conservation, as well as the development of appropriate package choices. Growing sorghum on tied ridges and cowpeas between and within rows was found to be superior for maximizing output and minimizing Striga infestation. The lone susceptible sorghum variety (Teshale) sown as a control on flat plots produced the lowest sorghum yield and the highest Striga infestation. In general, the effects of closed and open end tied ridges (moisture conservation) and cowpea intercropping as trap crops boosted sorghum yield and yield components while reducing Striga infestation during low rainfall distribution.

Declarations

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Conflicts of interest/Competing interests

The authors state that they have no competing financial interests or personal ties that would appear to have influenced the work disclosed in this study.

Ethics approval

'Not applicable'

Consent to participate

'Not applicable'

Consent for publication

'Not applicable'

Availability of data and material

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

'Not applicable'

Authors' contributions

Lemma Degebassa and Zelalem Bekeko developed the idea of the manuscript, conducted the research, collected data, analyzed the data and wrote the original manuscript. Taye Tessema, Zelalem Bekeko and Ketema Bekele advised all research activities and data analysis, as well as review and editing of the manuscript. All authors have read and agreed the prepared version of the manuscript.

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