International Journal of Tropical Insect Science
https://doi.org/10.1007/s42690-021-00637-x

ORIGINAL RESEARCH ARTICLE

The effect of Brachiaria rows on stem borer damage on sorghum in Eastern Amhara, Ethiopia

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Received: 15 November 2019 / Accepted: 2 September 2021
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Abstract

The lepidopteron stemborer (*Chilo partellus*) and parasitic Striga weed (*Striga hermonthica)* caused major yield losses in subsistence sorghum production in the Eastern Amhara Region, Ethiopia. This study evaluated different number of Brachiaria (Mulato II) rows planted around sorghum plots. *Desmodium intortum* intercropped with sorghum in each Brachiaria row. The study was conducted on 61 farmers' fields in 2017 and 2018. The treatments were arranged as one row Brachiaria + Desmodium, two rows Brachiaria + Desmodium, three rows Brachiaria + Desmodium and mono-sorghum. The pooled two years and three locations data showed a significant difference ($P < 0.001$) between push-pull and mono-sorghum plots. Sorghum damage of 17.2%, 16.4%, 33.6% in three, two and one rows of Brachiaria, respectively. The mean number of Striga was significantly reduced in push-pull plots (3 Striga/m^2) as compared to mono-sorghum plots (15 Striga/m^2). In addition, significantly high sorghum grain yields were recorded in three rows (4.5 t /ha) and two rows (3.7 t/ha) of Brachiaria. Yield increments of 104.2% and 62.2% and 50.0% over mono-sorghum were recorded in three, two rows and one row of Brachiaria, respectively. In addition to sorghum yield increment, farmers were able to get a dry biomass yield of 1.7-24.6 t/ha in different rows of Brachiaria and 0.47-2.43 t/ha of Desmodium for their livestock feed. The three rows of Brachiaria were superior to the other rows, but farmers could also use the two rows as an alternative option with the combination intercropped Desmodium.

Keywords Weed · Parasitic weed · Farmers perception · FRN · FRG

Introduction

Low production of the main staple crops and livestock remains a key challenge in achieving food security in Africa. These caused high food and nutrition insecurity, malnutrition and poverty for the resource-constrained smallholder farmers (Gurney et al. 2006; World Bank 2007). Sorghum and maize are among the major staple crops playing a great role in the food security of the poorest food insecure people of Africa. Stem borers (*Busseola fusca* and *Chilo partellus*) and Striga (*Striga hermonthica*) are among the biotic constraints known for their devastating effects and causing grain yield losses of up to 100% (Kfir et al. 2002; Oswald 2005). Despite the fact that many alternative stem borer management methods are recommended, farmers have not used them effectively due to the quick knockout effect of synthetic pesticides (Asmare et al. 2011).Moreover, insecticides and herbicides are seldom to achieve complete control. In addition, the resources-constrained-subsistence farmers in Ethiopia cannot afford expensive chemicals.

The push-pull technology is a crop diversification strategy through intercropping of sorghum/maize with *Desmodium* spp., whose semio-chemicals repel stem borers moth (push effect) and *Brachiaria* spp planted at the border as trap crop, which attracts stem borers (pull effect) (Khan et al. 2010; Midega et al. 2015). The striga control is provided by Desmodium that acts through a combination of mechanisms, including abortive germination of striga seeds that fail to develop and attach onto the hosts' roots (Khan et al. 2002). Khan et al. (2010) reported that the reason that Desmodium suppressed *Striga* seed germination was due to an allelopathic mechanism. Their root exudates contain novel flavonoid compounds, which stimulate suicidal germination of Striga seeds and dramatically inhibit its attachment to host roots (Khan et al. 2010).

On-farm implementation of the technology has led to its rapid uptake as it addresses the key constraints, striga

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Published online: 25 September 2021

and stem borer, while also increasing soil fertility and providing much-needed fodder for livestock and Desmodium see for sale (Khan et al. 2008a).This push-pull system also enhanced soil fertility through N-fixation by Desmodium and increased animal feed production (Cook et al. 2007; Khan et al. 2008a).

Sweden International Development Agency (SIDA) organized a trip to International center of Insect Physiology and Ecology (ICIPE) in 2009 for plant science researchers to shop different technologies. The group of crop protection researchers had selected the push pull technology, which was first introduced to Ethiopia by Amhara Agricultural Research Institute (Asmare 2014). The Farmer Research Network (FRN) approach was followed as a participatory technology evaluation strategy to create the opportunity for farmers to interact and learn from each other in a democratized manner (Bellon 2001). FRN is an approach that encourages diverse opinions, attitudes and contexts in adopting new technologies (Rebecca et al. 2019)

Farmer Research Network (FRN) was used as an approach. This approach helps to have an interaction among farmers to learn the Push-Pull Technology (PPT)-practices (Bellon 2001). The involvement of different segments of society at household level has increased in the decision making process and enhanced the participatory push-pull technology and helped to ease scaling up. Therefore, the study aimed at ratifying the optimum number of Brachiaria rows in the PPT system to manage stem borer assuming that the intercropped Desmodium was common to all plots.

Materials and methods

Study sites

Multi-site field studies were conducted during the long rainy season (June to September) in two consecutive years (2017 and 2018) in South Wollo, and Oromiaya zones, Ethiopia. These experiments were conducted in four districts, which are located at 11^0 56'-12018 'N and 39^0 23'-39^0 47' E with an elevation range of 1500-1850 m. The districts received annual mean rainfall of 674-880 mm. All the selected districts are called within the sorghum belt of the country. The four districts were chosen purposively because stem borer and Striga were major issues. These four districts were Ambasel and Kalu from South Wollo; Artuma Fursi and Dawa Chefa from Oromia (Fig. 1).

The volunteer farmers were selected by the development agent (DA) of each district. The development agents were explaining the role and responsibilities of each farmer in their group. A total of 61 farmers were teamed up in a farmers research group (FRGs). Each farmer in a FGR was networked through a farmers' research network (FRN) to exchange opinions and experiences. Each FRG had fifteen farmers, i.e., one FRG in each district. Farmers Research Network (FRN) was used as an approach to network each FRG that brought researchers, farmers and extension workers together and exchange opinions and experiences on treatments and technology (Bellon 2001; Rebecca et al. 2019). In this regard, farmers participated from research planning to implementation, and monitoring and evaluations as well as in data collection.

Treatment set up

The choice of the number of Brachiaria rows was based on farmers' interest. As a result, the treatments were purposefully assigned to different farms. Maturing sorghum variety, Girana-1 and Jigurti, were used in all districts. The treatments were (1) one row of Brachiaria planted at the border of sorghum (2) two rows of Brachiaria planted at the border of sorghum (3) three rows of Brachiaria planted at the border of sorghum (4) mono sorghum. Desmodium was intercropped with sorghum in each field uniformly. Therefore, each farmer had a chance to choose the number of Brachiaria rows as per their interest and one mono-sorghum plot for comparison purpose. Sorghum was sown from early July to late July of the main rainy season. The number of treatments differed from farmers to farmers. Thus, one row of Brachiaria, two rows of Brachiaria rows and three of Brachiaria were selected by 28, 28 and 4 farmers, respectively.

Planting materials

Seedlings of Brachiaria (Mulato-II) and green leaf, *Desmodium intortum,* were established in nursery sites in each of the districts. All nursery sites had irrigation facilities. Healthy seedlings with the appropriate sizes and amount were obtained in each district. The Brachiaria splits were transplanted to the border of sorghum at a space of 50 cm between plants and 50 cm between rows (Khan et al. 2007; Charles et al. 2015). The spacing between seedlings and sorghum was 1 m. Brachiaria splits and Desmodium seedlings were transplanted simultaneously at the time when sorghum was sown.

Green leave was planted between sorghum rows without affecting the sorghum population. Different plot sizes were used by farmers depending on their interest. The plot size varied among farmers, ranging between 20 m x 20 m and 30 m x 30 m. Sorghum was sown with spacing of 75 cm and 20 cm between rows and plants, respectively. The seed rates varied depending on the varieties, which were from 10-12 kg/ha. Recommended fertilizers, Diammonium Phosphate (DAP) (full dose) and urea (split), were applied at planting time at rates of 100 kg/ha and 50 kg/ha, respectively. The remaining half rate of urea was applied at knee height of sorghum.

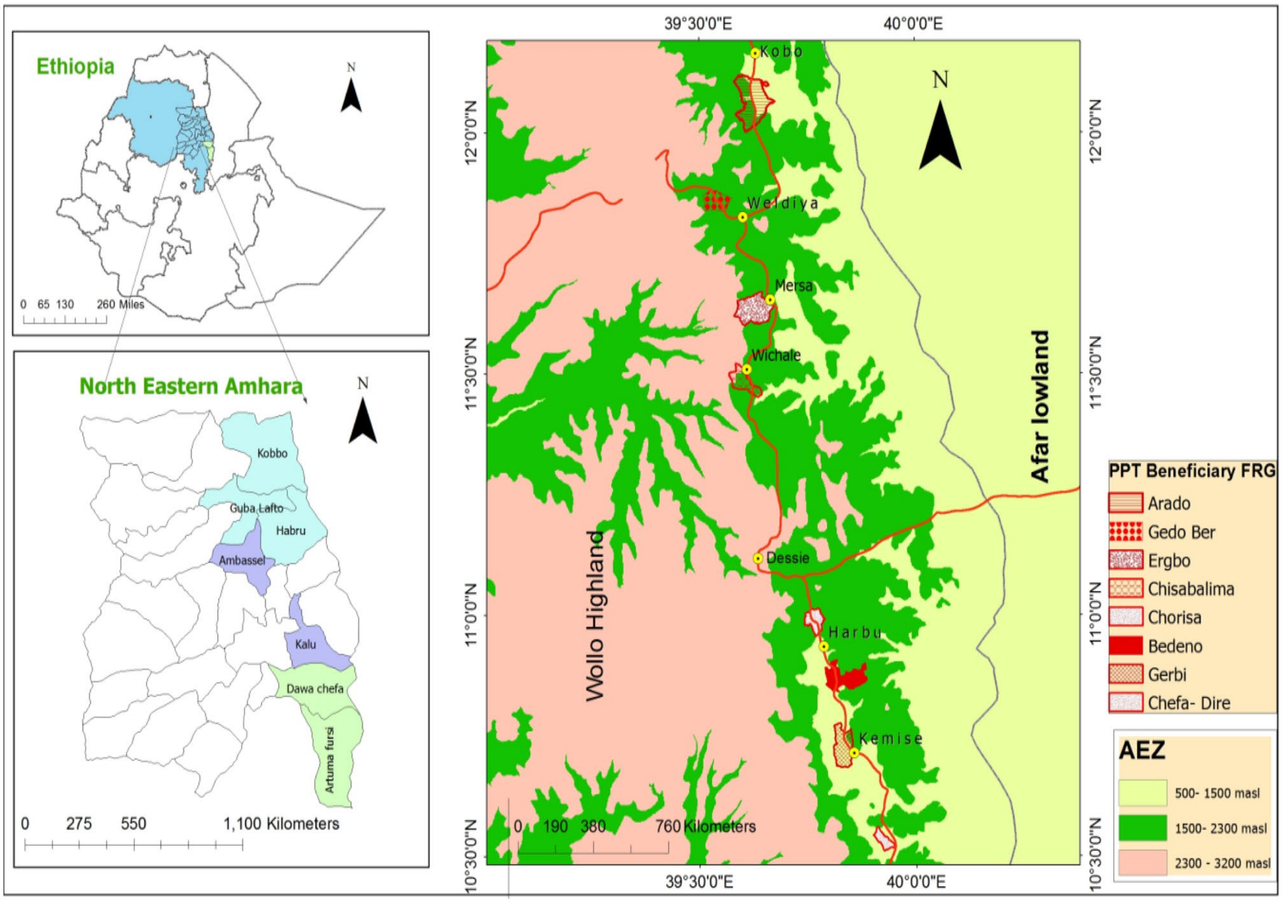

Fig. 1 Study areas-South Wollo and Oromia zones of Amhara National Regional State, Ethiopia

Data collection

The data were collected at booting and at harvesting stages of sorghum. A quadrate of 1 m^2 was prepared to collect data from each FRG field. In order to get appropriate samples, a quadrate was thrown in using a five point sampling method from the centre and four corners of sorghum fields (Xiuliang et al. 2015). The number of sorghum plants per quadrate was counted. The numbers of damaged and undamaged sorghum plants were counted based on the stem borer damage symptoms on leaves, stems, peduncles, and heads. Whereas, the numbers of adult moth exit holes or boring sorghum stems were counted at the harvesting period of sorghum, the number of larvae and sorghum grain yield were collected from each quadrate. The number of larvae and exit holes were collected from five sorghum plants per plot. Each sorghum stem was dissected with a knife to count the number of larvae. Sorghum heads were collected, threshed, and weighed in each quadrate to determine grain yield. The Striga count per quadrate was recorded from five points as indicated above. The Striga population in each quadrate of each field was counted using the method described by (Ekeleme et al. 2014).

The same sampling procedure, i.e. as for stem borer and Striga, was followed for estimating Desmodium biomass yield. All the Desmodium plants lied under the five thrown quadrates were harvested and weighed. For Brachiaria biomass yield estimation, sampling was by using a transect line. Samples were taken from 1 meter line from the four sides of each push pull plot. The dry matter (DM) of each forage species was determined through exposing an oven temperature of 105°C for 24 hrs.

Data analysis

The data analysis was subjected to various packages of the R software (Team 2020). The two years (2017 and 2018) and four locations data were pooled. Farmers Research Group (FRG) was employed as an approach and each FRG was networked with farmers Research Network (FRN). Farmers participated from the start of farm selection to executing research as well as evaluation of the technology. In addition to the treatment (number of pull-plant rows), hypothesized to be associated with the main biological output parameters of sorghum grain yield, Sorghum damaged by *Striga hermonthica* and stem borer had confounded effects, which were associated with these output variables. In this study, there were variations in terms of farm to farm, plot size, location, year and their possible interaction. Therefore, the linear mixed effect model (LMM) was deployed for grain yield, percent of leaf damage, number of exit-hole per plant, number of larvae per plant and *S. hermonthica* count per meter square. Farmers were used as random factors whereas the other variables, including all the possible interaction terms, were considered as fixed factors. Based on the output of these explorations, both LMM and linear models (LM) analysis was used, which depends on the significance of the random factors. In these first analysis, all the interaction terms were not significant and thus removed from the models. The analysis was performed with 'lmer4' package of R software employing the 'lmer' function. Specifically, the number of larvae per plant and forage Dry matter (DM) yield of Brachiaria and Desmodium were modeled using the LM because none of the random factors were significant. Grain yield, percent of stem borer infestation, and number of exit holes per plant were modeled using LMM. Logarithmic transformation ([log10 (x + 1)]) was done for the stem borer infestation and number of larvae per plant data as the residuals of the models violated the homogeneity of variance assumptions.

The second exploration was done specifically to the count data of exit hole per plant and larvae per plant. These parameters are count data summarized in averages over their respective measurement units. Thus, their analysis can be undertaken either by taking their rounded count data as integer or their average value as continuous variables. The continuous data of these variables was modeled in the first exploration. Moreover, in the second exploration, the count data of these variables were modeled following the general linear mixed effect model (GLMM) using a Poisson distribution with log link. The outputs of these variables from the two exploration (LM/LMM and GLMM) were compared using the models' respective Akaike information criterion (AIC) (Akaike 1998) and those models with lower AIC were reported here. The AIC of the models were generated using the 'AER' package of R. Specifically, in the case of exit hole per plant and larva per plant, the LMM and LM performed better than the GLMM, respectively.

The third exploration was used to collect information on the number of *S. hermonthica* per meter square. The data had over dispersion problem. Furthermore, there were some zero values in the data. Thus, Quasi-Poisson, negative binomial, hurdle, zero-inflated Poisson and zero-inflated negative binomial models were explored to select the best fit model that can handle the over dispersion problem and the case of zero values (Cameron and Trivedi 2005). Based on the AIC test, the hurdle model performed better. The hurdle model, first proposed by Mullahy (1986), is a two-component model with a truncated count component for positive counts and a hurdle component that models the zero counts. In the current analysis, the count model is a truncated Poisson regression with log link while the hurdle model is a binomial model with logit link. The analysis was done using the 'pscl' package of R with the function of 'hurdle. In this modeling of *S. hermonthica* infestation, the main explanatory variable was the presence of push-plant, Desmodium, which was compared with control plots with no Desmodium intercropped.

Brachiaria Forage DM yield as an output parameter was not compared among treatments (number of rows). Instead, as a multi-location experiment, location wide performance variation was explored through covariance analysis where numbers of Brachiaria rows were taken as covariates. In this exploration, linear models (LM) were followed because no random factor was found to be significant. Moreover, because the residuals of the yield model violated the homogeneity of variance assumption, the raw data was transformed into logarithmic form before modeling. Desmodium forage DM was explored in its location wide performance variation following the LM.

Results

The pooled analysis with LM and LMM showed that all the interactions among years and locations were not significant and thus they were removed from the models.

The stem borer damage on sorghum was expressed in terms of leaf damage, number of stems with exit holes and number of larvae per plant. The mean summary of the statistical modeling of these parameters and other covariates was presented. The result showed that there was a significant difference ($p < 0.01$) between push-pull and mono-sorghum plots. A significantly ($p < 0.001$) lower sorghum leaf damage by stem borer was recorded on push-pull plots (16.7-33.6%) than mono-sorghum plots (63.4%). The pooled data on two years and four locations revealed that significantly ($p < 0.001$) higher sorghum damage was recorded in the one-row (33.3%) than the two (16.7%) and three rows (17.2%) of Brachiaria (Table 1).

A significantly lower number of exit holes due to stem borer larva on sorghum stem was recorded in push-push plots (2.7-7.4 exit holes/plant) than in mono-sorghum plots (11 exit holes/plant). Although there was no significant difference between the numbers of Brachiaria rows, low exit hole was recorded in two-rows of Brachiaria (4.8).

Regarding the number of larvae per plant, there was a significant difference ($p < 0.001$) between mono-sorghum and push-pull plots. A significantly higher number of larvae per

Table 1 The effect of Brachiaria rows onestimated means (SE) of grain yield (t/ha), leaf damage (%), number of exit holes and stem borer larvae per plant with adjusted for locations, land size, years and sorghum varieties

Output variables	No. of Brachiaria rows				*P*-values		
	Mono-sorghum/control	1-row	2-row	3-row	Treatment	District	Land size (ha)
Exit hole per plant	11.04SE 0.60[d]	7.4SE(0.64)[a]	5.1SE (0.64)[ab]	2.7 SE(1.60)[c]	< 0.001	ns	ns
Larva/plant	8.78SE 0.52[c]	4.7 SE0.57)[a]	3.1 SE(0.56)[a]	2.3 SE(1.51)[b]	< 0.001	ns	0.048
Leaf damage	63.4SE[d]	33.6SE[c]	16.7SE[b]	17.2SE[b]	< 0.001	ns	ns
Grain yield	2.4SE0.195[a]	3.6SE0.21[b]	3.9 (0.19)[b]	4.9SE (0.32)[c]	< 0.001	0.0696	ns
Yield increment (%)	–	50.0	62.2	104.2			

plant was recorded in mono-sorghum (8.8) than in push-pull plots (2.3-4.7). However, there were significant differences between Brachiaria rows and the minimum number of larvae per plant was recorded in the three rows (2.1) (Table 1). This could be due to the lower number of replications in this treatment.

The effect of Desmodium on Striga

The effects of the push pull technology plots were compared with mono-sorghum plots in minimizing Striga infestation. Although the Brachiaria rows were different; the Desmodium (push plant) was inter-cropped in each plot. The analysis was done with the Hurdle model of poison distribution. The estimated mean number of Striga m^{-2} was significantly lower in push-pull plots than in mono-sorghum plots ($p < 0.001$). The zero hurdle model result revealed that the odds ratio for applying Desmodium in the push-pull technology equals 0.022 (exp (-3.82). This showed that the number of striga was 45.6 times higher in mono-sorghum plots than the push-pull plots. On the other hand, the count hurdle model result showed that the rate ratio of intercropping Desmodium with sorghum was equal to 0.39 (exp (-0.94). This indicated that the number of Striga was more than 2.53/m^2 times in mono-sorghum plots as compared to Demodium intercropped plots (Table 2).

Dry matter yields of Desmodium and Brachiaria

There was a significant difference in dry matter yield of Brachiaria between the locations and number of rows.

The highest DMY of Brachiaria was recorded at Kalu district (24.6 t/ha) and followed by Artuma-Fursi (23.5 t/ha). In all locations, the highest DMYs of Brachiaria were recorded in the three rows (6-24.5 t/ha).The DMY of Desmodium recorded in Artuma-Fursi district (2.43 t/ha) was the highest among all locations (Table 3).

Discussion

Brachiaria and Desmodium forage plants were planted around the sorghum and in between the rows of sorghum as pull and push of stem borer moths, respectively. This study showed that sorghum damage was reduced from 63.4% in mono-sorghum to 16.7-33.6% in push-pull plots. Khan et al. (2001) reported that maize damage was reduced from 57.4% in mono-maize plots to 19.7% by stem borer using push-pull technologies. The main sorghum crop was planted with an intercrop, Desmodium, which repels stem borer moths (push) and also attracted their natural enemies (Khan et al. 1997).

Similar results reported that the push-pull technology is appropriate for smallholder mixed cropping systems, and increasing maize and sorghum yields up to 3.5t/ha, 2t/ha, respectively (Khan et al. 2006; Khan et al. 2008a; Khan et al. 2011). The result of the present study showed that sorghum grain yield increased above one to two-folds. This finding is consistent with Khan et al. (2011), who reported that maize grain yields increased three to fourfold and sorghum yields increased twofold. The same author stated that push-pull technology is economical as it is based on locally available plants, not expensive external inputs. Maize and sorghum grain yields for these farmers have increased, from below 1t/ha to about 3.5 and 2t/ha, respectively (Khan et al. 2006; Khan et al. 2008b), achieved with minimal inputs, resulting from effective control of stem borers and Striga, and improved soil fertility.

The dry matter yield (DMY) of Desmodium (*Desmodium intortum*) varied among the locations, which might be due to

Table 2 The effect of Push–pull strategy/Desmodium on *S. hermonthica* with hurdle model

Estimated model coefficients (SE)			Mean separation		
Parameters	Count model	Zero hurdle model	Treatments	Estimated means (SE)	$P(>\chi^2)$
Intercept	1.18 (0.10)	3.53 (1.02)	Treatment	0.75 (0.14)[a]	< 0.001
Treatment	-0.94 (0.23)	-3.82 (1.05)	Control	3.29 (0.31)[b]	

Table 3 Mean dry matter yield of Desmodium & Brachiaria

Districts	Brachiaria Rows	Mean DMY of Brachiaria (t/ha)	Mean DMY of Desmodium (t/ha)
Ambasel	1-row	1.7	0.47
	2-row	5.6	
	3-row	6.0	
Dawachefa	1-row	6.7	1.40
	2-row	8.3	
	3-row	9.4	
Kalu	1-row	3.4	1.47
	2-row	9.4	
	3-row	24.6	
Artumafursi	1-row	11.7	2.43
	2-row	22.5	
	3-row	23.5	

environmental factors. The result revealed that the highest DMY of Desmodium was recorded in Kalu district (24.6 t/m^2) compared to the other districts. The result is in line with the findings of Ndikumana and Leeuw (1996) who reported that the dry matter yield of *Desmodium intortum* in Pokoase district (Ghana) was 0.212 kg/m^2. This finding showed that yield of silver leaf Desmodium is lower than the result reported by Ndikumana and Leeuw (1996), which was up to was 0.45 t/ha at Nyankpala in Ghana. Similarly, the result is lower than the report of Younge et al. (1964) who indicated that DMY of *Desmodium intortum* ranged from 0.897 kg/m^2 to 1.12 kg/m^2.

Moreover, the significantly high ($p < 0.01$) dry matter yield of Brachiaria (Mulato-II) was recorded in Kalu district (24.6 t/ha) compared to other districts and followed by Artuma-Fursi district (23.5 t/ha). The result obtained is higher than the report of Wubetie (2018) who shows the DMY of Brachiaria ranged from 0.43 Kg/m^2 to 0.628 kg/m^2. The yield of Brachiaria in Kalu district was also higher than the findings of Heering (1989) who found that *B. decumbens* performed 0.49 kg/m^2 in Zwai (Ethiopia).

Conclusions

The push-pull plots significantly reduced sorghum damage and hence increased sorghum yield by two-fold and above over the mono-sorghum plots. In terms of the number of Brachiaria rows planted around the sorghum, three rows were the best option for reducing stem borer damage and increasing sorghum grain yield, followed by two rows. The three rows of Brachiaria were superior to the other rows, but farmers could also use the two rows as an alternative option with the combination intercropped Desmodium.

Acknowledgement The authors highly appreciate CCRP-McKnight foundation and Institute for sustainable development as a partner for transiting the research budget from McKnight to Wollo. Dr. Beth Medvecky, Prof. Linnet Gohle, and Mr. Tesfahun Fenta are thanked for their assistance with the project and review of the manuscript. Wollo is also grateful for their vehicle assistance during the project's implementation. Our thanks are also extended to the experts and development agents of districts and peasant associations of the study area.

Declarations

Disclosure of potential conflicts of interest The authors declare that they have no conflict of interest.

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