Effect of Farming Techniques on Sorghum Midge Infestation and Damage of Sorghum, and the Existence of its Natural Enemies

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Abstract: Sorghum, *Sorghum bicolour* (L.) Moench, ranks second as Africa's major and significant cereal food crop, and third for Uganda. About one third of the population in Tanzania, Kenya and Uganda depend on sorghum for their livelihoods. However, sorghum yields have persistently kept lower than average due to several production factors. Rural subsistence farmers engage farming practices that enhance and sustain some sorghum pests that cause damage and substantial crop losses. A study to establish the impact of farming techniques on infestation and damage by the midge *Stenodiplosis sorghicola* Coquillett, and its existing natural enemies was conducted. Farming practices (mixed cropping of sorghum with maize as a barrier to interfere with sorghum midge flight, resistant sorghum varieties, and sole sorghum or intercrop with cowpea against the sorghum midge). Results showed that use of resistant sorghum variety significantly ($P < 0.05$) reduced sorghum yield loss, while the interaction between sorghum–cowpea intercrop and maize barriers around the sorghum crop ($P < 0.05$) significantly reduced sorghum yield loss. Having no barrier around sorghum crop significantly ($P < 0.05$) increased sorghum midge numbers per panicle. Sole sorghum interaction with sorghum-cowpea intercrop without a barrier condition significantly ($P < 0.05$) increased sorghum midge infestation. Similarly, the interaction between sorghum sole crop and sorghum-cowpea intercrop with susceptible sorghum crop significantly ($P < 0.01$) increased the sorghum midge infestation compared to the resistant sorghum variety. Results indicate that use of resistant sorghum varieties intercropped with cowpea, having tall maize plants around the sorghum fields reduced sorghum yield loss caused by the sorghum midge pest. Having no crop barrier around the sorghum field increased the abundance and severity of damage by the sorghum midge to grain sorghum.

Keywords: *Sorghum, Stenodiplosis Sorghicolar, Infestation, Intercrop.*

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I. INTRODUCTION

The sorghum midge pest *Stenodiplosis sorghicola* Coquillett., is extensively found in most of the grain sorghum growing agro-ecological zones of Uganda (Lubadde *et al.*, 2019), apart from the Western Highlands where the temperatures are too cold and is elevated higher than 1,800 masl, to sustain the midge. Up to 100% yield loss can be caused by sorghum midge pests (Geering, 1953; Teetes, 1985; Harris 1985). 84% of Uganda's population living in rural areas as smallholder subsistence farmers produce the national agricultural output (Farm Africa, 2016). Majority of farmers engage in subsistence farming and employ a mix of traditional crop production farming practices, with an average farmland area of 2.5 Ha. Murrell, (2017) reported the effects of climate mitigating agricultural practices on arthropod pests and its predators in agronomic cropping systems. A number of farming techniques have been noted to suppress or increase the occurrence and prevalence of both sorghum pests and their natural enemies. Among these, include; planting the crop early at the onset of rains, planting resistant sorghum cultivars, destruction of alternative plant hosts such as Johnson grass *Sorghum halepense,* planting uniformly (at the same time) over large areas etc. Involving pest parasites, host plant resistance, predators, entomo-pathogens, use of pesticides, crop rotation, altering plant population, tillage methods, irrigation management, fertilizer management etc., are all examples of biotic and abiotic pest management techniques (Teetes, 2004; Pendleton *et al.*,2000; Ca´rcamo, 1995; Root, 1973).

Sharma, (1985) and Summers *et al*. (1976I) reported that sorghum midge damage is commonly high in low sorghum plant density, but also Hardas *et. al.*, 1980 observed

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that sorghum midge damage reduces when sorghum is intercropped with leguminous plants. Meanwhile, Boyd and Bailey, (2000); Pendleton and Teetes, (1994) found out that naturally, the sorghum midge flies tend to be limited at movement during flight and thus, are poor fliers. However, wind is important in aiding midge flight movement. Since sorghum midge flies are poor flyers, plant obstacles or barriers that are tall in height as sorghum plants, such as maize plants, if intercropped with sorghum, interfere with midge flies flight movement, thereby limiting their occurrence on sorghum plants thus, causing less damage to sorghum plants. No efforts have yet been sought to properly understand the impact of integrated farming techniques on sorghum midge abundance and damage caused to the grain sorghum crop. Also, no efforts have been made to catalogue the range of midge flies natural enemies existent in the field in Uganda. It is thus, important to devise effective sorghum midge pest control techniques, through assessing the effect of integrating some of the crop farming practices on the occurrence and damage by the sorghum midge pest, as well as their effect on the prevalence of natural enemies of the midge flies. This study, investigated the effect of integrating farming techniques in sorghum crop production including the use of crop obstacles as barriers against free sorghum midge flight, sorghum plant variety resistance status, and the effect of intercropping sorghum plants with cowpea (a legume crop) on sorghum midge occurrence and damage caused to the sorghum crop. Under these different sorghum crop production techniques, the range and abundance of the sorghum midge flies natural enemies was also assessed on the grain sorghum crop.

II. MATERIALS AND METHODS

The field experiment was conducted at the National Semi Arid Resources Research Institute (NaSARRI), located 35 Km South of Soroti City, in Serere district, during the rainy seasons of 2015B, 2016A and 2017A. To understand the effect of farming practices on the occurrence of sorghum midge flies, an experiment using a split-split plot in a randomized complete block design was set up at the National Semi Arid Resources Research Institute (NaSARRI), Serere district. The experiment was planted four weeks after the actual onset of the seasons' rainfall. Main plots of sorghum plants having 5 maize rows spaced 75 X 30cm as a barrier around them, and others without maize rows (midge barriers) around them were planted. Moderately resistant sorghum variety AS21 to sorghum midge flies, and the susceptible one GA010/010 sorghum variety were planted and tested against the midge pest in sub plots during the rainy seasons of 2015B and 2016A, while the sorghum midge resistant variety IESV25009SH and midge susceptible sorghum variety GA010/010 were tested in season 2017A. The IESV25009SH sorghum variety had performed relatively better in resisting the midge fly in the previous screening trials at the research station. Sorghum cropping patterns of sole sorghum crop (monocrop) and sorghum – cowpea (intercrop) were also planted in sub-sub plots of size 6 X 5m, and all treatments replicated 3 times. The sorghum sole crop sub-sub plot had 5 sorghum rows and 6m long, while the sorghum – cowpea intercrop sub-sub plots had 2 rows of cowpea intercropped in 3 rows of sorghum.

Data on midge infestation of sorghum heads (midge flies/head) was obtained by destructive sampling of 3 randomly selected sorghum heads at flowering and having pollen on them, using a transparent polythene bag. The midge flies therein together with other arthropods especially the midge natural enemies at the time were trapped therein and their numbers per head counted. Sorghum midge incidence data was collected from 10 sorghum plants randomly selected from the inner rows of sorghum per sub-sub plot and percentage of midge presence taken. Data for damage caused by sorghum midge was obtained using a visual score scale of 1 – 9; (1 = $\leq$ 10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = $\geq$ 80%), midge damaged sorghum (Sharma *et al.*, 2003) from 3 randomly selected sorghum panicles / sub-sub plot naturally infested with sorghum midge flies at flowering, and caged thereafter, to exclude other panicle pests from damaging the sorghum grain. Some sorghum heads were caged at pre-pollen formation stage before the midge flies were attracted to the sorghum flowers to lay eggs. The midge un-infested sorghum heads were used to get yield loss data at maturity. More natural enemies were trapped at physiological maturity growth stage of grain sorghum by destructive sampling of sorghum heads using transparent polythene bags and later identified and their numbers taken per sorghum head. Yield loss was obtained from the difference between midge un-infested dry sorghum panicle grain weights and that of midge infested dry sorghum panicles (at storage moisture content) and percentage yield loss got. Data was analyzed using GenStat 17th version statistical package software, and subjected to analysis of variance (ANOVA).

III. RESULTS

- *Effect of Farming Practices and Natural Enemies on Sorghum Midge Occurrence, Damage and Yield Loss caused to Grain Sorghum*

- *Effect of Farming Practices on Sorghum Midge Flies Infestation*

During the sorghum growing season, the number of sorghum midge flies counted from flowering sorghum heads (infestation) was significantly ($P \leq 0.05$) higher under the sorghum main plots without maize rows as a barrier around them, compared to those with maize barriers around them (Table 1 & 2a). The number of sorghum midge flies was observed to be significantly ($P \leq 0.05$) higher in susceptible sorghum variety GA010/010 compared to those found on the moderately resistant sorghum variety AS21 during season 2016A. In seasons 2015B and 2017A, the midge flies trend was the same as in season 2016A, although not statistically significant ($P \geq 0.05$). Under the cropping pattern of sole sorghum and the sorghum-cowpea intercrop, more midge flies were observed to be significantly ($P \leq 0.05$) higher in the sorghum - legume intercrops compared to the number of flies under the sole sorghum plots during season 2016A, (Table 2a). Significant interactions ($P \leq 0.05$) were also observed under barrier status (with and without maize barrier

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sorghum plots) X cropping patterns (sole sorghum and sorghum - legume intercrops). Under this interaction, sorghum plots without maize barriers around them had significantly (P ≤ 0.05) more sorghum midge flies observed under both sole sorghum (monoculture) and sorghum – cowpea intercrop sub plots, compared to the main plot having maize barriers with sole sorghum and sorghum - legume intercrop sub plots during seasons 2015B and 2016A, (Table 3 & 4).

Similarly, significant interactions (P ≤ 0.05) were also observed between sorghum variety status (moderately resistant and susceptible) X cropping patterns. Under the main plot with moderately resistant sorghum variety, there was significantly (P ≤ 0.05) less sorghum midge flies seen on sole sorghum crop compared to the susceptible sorghum variety GA010/010. Similarly, the sorghum - cowpea intercrop sub plots with moderately resistant sorghum variety had significantly (P ≤ 0.05) less sorghum midge flies compared to the midge susceptible sorghum – legume intercrop sub-plots during seasons 2015B and 2016A, (Table 3 & 4). In general, this interaction had significantly (P ≤ 0.05) more number of sorghum midge flies infesting midge susceptible sorghum variety GA010/010 grown both as sole sorghum crop and sorghum - legume intercrop, (Tables 3 & 4).

- *Effect of Farming Techniques on Sorghum Midge Damage*

Midge resistant sorghum variety AS21 was significantly (P ≤ 0.05) less damaged by the sorghum midge compared to the susceptible sorghum variety GA010/010 during season 2015B and 2016A, (Tables 1 and 2b). Sorghum planted as a sole crop was significantly (P ≤ 0.05) less damaged compared to the sorghum intercropped with cowpea during season 2016A, (Table 1 & 2b). Significant interactions were also observed in interactions of barrier status X cropping pattern. The midge resistant variety IESV25009SH was significantly (P ≤ 0.05) less damaged in sole sorghum plot compared to the sole plots of the susceptible sorghum variety GA010/010. A similar trend was observed in sorghum–legume intercrops having midge resistant variety IESV25009SH and midge susceptible sorghum GA010/010 during season 2017A, (Tables 1 and 6). Interactions were observed in barrier status X variety status X cropping pattern on sorghum damage during season 2016A (Table 5). Under the main plot having the maize barrier, the moderately resistant sorghum variety AS21 planted as sole sorghum was significantly (P ≤ 0.05) less damaged compared to the midge susceptible variety GA010/010 and without a maize barrier. The same trend was observed on sorghum intercropped with cowpea. More damage was significantly (P ≤ 0.05) inflicted on the susceptible sorghum GA010/010 planted in both sole sorghum and sorghum - cowpea intercrop sub-sub plots without maize barriers. In general, sorghum damage was significantly (P ≤ 0.05) higher on susceptible sorghum varieties (Table 5). A similar trend was observed in season 2017A interactions of barrier status X variety status X cropping pattern, although not significant (P ≥ 0.05) statistically (Table 6).

- *Effect of Farming Techniques on Sorghum Yield Loss*

There was a significantly (P ≤ 0.05) higher yield loss observed on sorghum grown in the main plots without maize barriers around them during season 2017A, (Table 1 & 2c). The moderately resistant sorghum variety AS21 had significantly (P ≤ 0.001) less yield loss caused by the sorghum midge during season 2015B (Tables 1 & 2c). Similarly, the sorghum–cowpea intercrop sub-sub plots had significantly (P ≤ 0.001) high yield loss compared to the sole sorghum sub-sub plots during seasons 2016A and 2017A, (Tables 1 & 2c).

Significant interaction effects were also observed under variety status X cropping pattern during season 20261A, (Tables 1 & 7). Under the interaction, the moderately resistant sorghum variety AS21 grown as sole sorghum had a significantly (P ≤ 0.05) less yield loss compared to the midge susceptible variety GA010/010 grown as a sole crop. Similarly, under the sorghum - cowpea intercrop sub-sub plots the midge susceptible sorghum variety GA010/010 had significantly (P ≤ 0.05) high yield loss compared to the moderately midge resistant sorghum variety AS21 during season 2016A, (Tables 1 & 7). Significant interactions (P ≤ 0.05) of barrier effect X variety status X cropping pattern were observed during the growing season of 2016A. The moderately resistant sorghum variety AS21 grown in main plots and a maize barrier had significantly (P ≤ 0.05) less yield loss under sole sorghum plots compared to main plots without maize barriers having midge susceptible sorghum variety GA010/010, under sole sorghum plots. This trend was similar to the sorghum varieties grown under the sorghum-legume intercrop sub-sub plots during season 2016A, (Tables 1 & 7).

During the growing season of 2017A, interactions of barrier X variety status were also observed. The midge resistant sorghum variety IESV25009SH grown in the main plots having a barrier around it had a significantly (P ≤ 0.05) less yield loss compared to the sorghum plot that did not have a maize barrier around it. Similarly, the main plots that had midge susceptible sorghum GA010/0101 with a maize barrier around them had significantly (P ≤ 0.05) less yield loss compared to the main plot that did not have a maize barrier around it (Tables 1 & 8). The barrier X cropping pattern interactions were observed in which sorghum planted as sole crop in sub-sub plots having maize barrier had significantly (P ≤ 0.05) less yield loss compared to sub-sub plots that did not have maize barriers around them. The same trend was observed in sorghum – cowpea intercrop sub-sub plots. The sorghum intercrop plots had generally, higher sorghum yield losses compared to sole sorghum plots (Tables 1 & 8). Interactions of variety X cropping pattern were also observed. Midge resistant sole sorghum variety IESV25009SH plots had significantly (P ≤ 0.05) less yield loss compared to plots that had midge susceptible sorghum variety GA010/010 plots. A similar trend was observed in sorghum-cowpea intercrop plot (Tables 1 & 8). Interactions of barrier status X variety status X cropping pattern were observed during the growing season of 2017A. Sole midge resistant sorghum variety IESV2509SH plots with a maize barrier grown around them had significantly (P ≤ 0.05) less

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yield loss compared to plots that had midge susceptible sorghum variety GA010/010 and without a maize barrier around them (Table 1 & 8).

- *Influence of a Maize Barrier for Sorghum as a Farming Practice on the Occurrence Sorghum Midge Natural Enemies*

A number of sorghum midge natural enemies were found on the sorghum panicles, including; assassin bugs (Reduviidae), lacewings (Chrysopidae) spiders (complex), wasps (Eupelmid and Eulophid), pirate bugs *Orius spp*., and coccinellids (Coccinellidae). In this study, the occurrence of the common sorghum midge natural enemies on sorghum heads under different cropping practices was assessed.

- *Effect of Farming Techniques on the Occurrence of Assassin Bugs as Natural Enemies of the Sorghum Midge*

During the growing season of 2017A, assassin bugs were found to be significantly ($P \leq 0.05$) more in number on sorghum plots that had maize barriers around them compared to the plots that had no barriers around them (Table 9 & 11). In the growing season of 2016A, an interaction of barrier status X cropping pattern on the occurrence of the assassin bugs was also observed. Significantly ($P \leq 0.05$) more assassin bugs were found on sorghum heads of sorghum planted with a maize barrier around them, and as sole sorghum crop compared to plots without a maize barrier around them (Table 13). Further still, more assassin bugs were found to be significantly ($P \leq 0.05$) more on sorghum-cowpea intercrop plots without a maize barrier around them (Table 13). In general, the rest of the sorghum midge natural enemy counts were captured and observed but their numbers were not statistically significant ($P \geq 0.05$) although the trend showed that sorghum plots that had maize barriers around them had more of the natural enemies compared to plots that did not have maize barriers around them (Figure 1, Table 11).

IV. DISCUSSION

The study sought to understand the influence of integrated farming techniques and the occurrence of natural enemies on the prevalence of sorghum midge flies and damage inflicted to the sorghum plants. Study results demonstrated that occurrence of sorghum midge flies and damage caused to sorghum, were influenced by different cropping practices of sorghum as well as the occurrence of midge natural enemies, including the nature of sorghum variety, and the pattern in which sorghum is planted with other crops. The best options that limit the occurrence of the sorghum midge on the sorghum crop would be beneficial in pest management and therefore, increase the sorghum grain yields. Several farming techniques have been reported to reduce or enhance the prevalence and abundance of sorghum pests (Teetes, 2004). Similarly, the sorghum midge pest is reported to have natural enemies that include preditors; pirate bugs *Orius Spp.*(adults and nymphs), a complex of adult spiders, coccinelids (adults and larvae), hover fly larvae (Syrphids), lacewing larvae *Chrysoperla spp.*, playing mantis *Mantis religiosa* , assassin bugs (Reduviidae), two spotted stink bugs *Perillus bioculatus*, spined soldier bugs *Podisus maculiventris*, black ants *Lasius niger*, and earwigs (Dermaptera). Parasites and parasitoids include; Eupelmid wasps *Eupelmus popa* Gir., (Eupelmidae) as the most abundant and effective parasitoids, *Aprostocetus spp.*(Eulophidae), and *Tetrastichus spp.* (Eulophidae) (Fadlelmua, 2014; Sharma *et al.*, 1994; Gahukar, 1984; Kausalya *et al.* 1997; Baxendale *et al.*, 1983; Bowden, 1965; Harris, 1965).

- *Effect of Farming Techniques on Sorghum Midge Infestation of Sorghum Plants*

Sorghum midge flies are poor flyers, and wind plays a key role in aiding their movements (Pendleton and Teetes, 1994; Boyd and Bailey, 2000). This study, rows of maize that were about the same height with the sorghum plants were planted around the sorghum plots to create a form of barrier that would interfere with the flight or movement of the midge flies from reaching the host flowering sorghum plots in abundance, exceeding the economic injury level (EIL). The study found that significantly ($P \leq 0.05$) more sorghum midge flies infested the sorghum plots that did not have maize barriers around them compared to those that had maize as barriers to ease midge flight. Having no barrier eased the mobility of the sorghum midge flies by flying and aided by wind to easily access the flowering sorghum panicles without much interference from maize barriers thus, increasing their occurrence in the sorghum without barriers. A significantly ($P \leq 0.05$) higher number of sorghum midge flies were observed on sorghum in the sorghum-Legume intercrop plots.

A similar observation was taken under the interactions of the sorghum plots (with and without maize barriers) X the cropping pattern. The abundance of midge flies was observed to be significantly ($P \geq 0.05$) more in plots of sole sorghum (monoculture) stands and sorghum-legume intercrops that did not have maize barriers around them. The opposite was however, true on sorghum plots that had maize barriers. The maize rows interfered with the movement of the midge flies and were seen to harbour on sorghum plants without barriers more than the plots that had the barriers. In Uganda, Sorghum midge flies are relatively more abundant during the second rainy season September – December compared to the first rains March – August, due to the presence of more alternative host plants during offseason following first rainy season in a year. The midge larvae or pupae diapause in cocoons during the offseason harsh conditions to survive through to the next second rainy season, and after, develop into adults to begin new reproduction cycles in course of a new and second rainy season in Uganda.

The occurrence of more sorghum flies on sorghum without barriers and sorghum-legume intercrops was due to absence of physical interference of midge flight movements than any other factor. Significant interactions were also observed in variety status X cropping pattern in which significantly ($P \leq 0.05$) more sorghum midge flies were observed on the resistant sorghum variety under the sorghum-legume intercrop plots compared to the midge resistant sole sorghum plots. The same trend was observed on the susceptible sole sorghum and sorghum-cowpea intercrop plots. The abundance of the sorghum midge flies was high in

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the sorghum-cowpea intercrop plots because the sorghum plant density was low compared to the sole sorghum plots. As observed by Dissemond and Hindorf (2009); Amoako-Atta and Omolo, 1983 Omolo, 1986; intercropping sorghum / maize / cowpea reduced stem-borer pest population. Meanwhile, El-Dessouki *et al.,* (2014), reported a negative relation between aphid pest occurence and Faba bean *Vicia faba* L. plant density. Similarly, the mortality of sorghum shoot fly increased with decrease in sorghum plant density (Delobel, 1982).

Host plant resistance in plants especially sorghum is also important in managing the sorghum midge infestation on grain sorghum. Host plant resistance in sorghum was observed to keep midge fly populations below economic threshold levels (Sharma 1993; Sharma *et al.* 1993). A number of plant resistance mechanisms have been reported to confer resistance to grain sorghum against the sorghum midge pest including antixenosis which is a very important resistance mechanism against midge flies in sorghum, antibiosis resistance mechanism that makes it hard for midge young growth stages to survive through to adult stage (Franzmann, 1993; Sharma *et al*. 1990), chemical contents of the sorghum grain and tolerance (Sharma *et al.* 1993).

- *Influence of Farming Practices on Sorghum Midge Severity of Damage*

The study revealed that the sorghum crop planted as sole crop (monocrop) was significantly ($P \leq 0.05$) less damaged compared to the sorghum intercropped with cowpea. This finding is however, in agreement with Sharma, (1985) and Summers *et al*., (1976) study reports where the sorghum midge damage was found to be high in low sorghum plant population. The sorghum plant population under the sorghum - legume intercrop plots is less compared to the plant density of sole sorghum plots of the same area size. On the contrary, Hardas *et al*., (1980) reported a reduction in sorghum midge and shoot fly *Atherigona soccata* incidence when sorghum was intercropped with leguminous plants, and the highest yields were attained when sorghum was intercropped with soybean *Glycine max* (I.) Merr. Similarly, Vandermeer, (1989) observed that higher crop diversity, in the field by intercropping, cover cropping, or even tolerating weed growths may enhance the presence of natural enemies that subsequently reduce pest damage.

Significant interaction effects between variety status X cropping pattern on severity of damage to sorghum by the sorghum midge were observed. It is however, important to note that under natural sorghum midge infestation, finding stable sources of resistance to sorghum midge pest is made difficult due to changing midge populations and staggered flowering of different sorghum varieties (Sharma *et al.* (1988).

Significant interactions of maize barrier status X variety status X cropping pattern were also observed on sorghum damage caused by the sorghum midge. The moderately resistant sorghum variety AS21 planted as sole sorghum crop in a plot without a maize barrier around it was significantly ($P \leq 0.05$) less damaged by midge compared to the moderately midge resistant sorghum variety grown under the sorghum-cowpea intercrop. A similar trend of midge damage was observed on moderately resistant sorghum variety AS21 grown as sole crop and sorghum-legume intercrop with a maize barrier around the plots. Under the interaction with midge susceptible sorghum varieties, significantly ($P \leq 0.05$) more damage was inflicted on the susceptible sorghum variety GA010/010 grown both as sole crop and sorghum-cowpea intercrop under 'with and without' maize barrier plots, compared to plots that had no maize barriers around them. In general however, the severity of damage inflicted on the sorghum plots grown with a maize barrier around it was significantly ($P \leq 0.05$) less compared to sorghum plots grown without maize barriers around them.

The sorghum crop in plots that had maize barriers around them were less damaged, probably because of the barrier created by the maize and therefore interfering with the midge flight to access the flowering sorghum. Randlkofera *et al.*, (2010) observed that under natural environments, the structure of plant vegetation influences plant volatile diversity and thus, affects the arthropod orientation. Differences in odours from flowering sorghum panicles of different species have been reported to attract female sorghum midge flies (Sharma and Franzmann, 2001; Sharma and Vidyasagar, 1994). Once attracted, the female flies settle to lay eggs in the panicle spikelets. As such, the few sorghum midge flies that may have managed to fly or blown across the maize barriers onto the flowering sorghum plants settled comfortably with minimum further disturbance of the wind, and thus, concentrated on laying more eggs sufficient enough to cause severe damage to grain sorghum compared to sorghum that had no maize barrier around them.

- *Effect of Farming Practices on Sorghum Yield Loss*

Sorghum plants that had a maize barrier around them were less damaged, and thus, had significantly ($P \leq 0.05$) less yield loss compared to sorghum that had no maize barrier. It was observed that sorghum grown as a sole crop had significantly less yield loss compared to sorghum-cowpea intercrop plots, particularly in plots that had maize barriers. There was a significant ($P \leq 0.05$) interaction between the sorghum grown with a maize barrier X cropping patterns of sorghum sole crop and sorghum – cowpea intercrop. The study also revealed that sorghum grown as a sole crop (monocrop) with a maize barrier had a significantly ($P \leq 0.05$) less yield loss compared to sorghum intercropped with cowpea and had no maize barrier around their plots. Sorghum midge damage to grain sorghum is high in low sorghum plant population (Summers *et al*., 1976; Sharma, 1985), and indeed sorghum intercropped with cowpea has low sorghum plant density compared to sole sorghum plots. The sorghum here suffered more yield loss probably because of less or lack of sorghum midge natural enemies in the intercrop with cowpea plants, which would otherwise reduce on midge pest population and activity against the grain sorghum. The midge flies also had less interference in flight to the sorghum plants because of the low sorghum plant density and thus allowing more midge infestation.

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Significant interactions were observed under the variety status X cropping pattern on sorghum yield loss during both seasons of 2016A and 2017A. Midge moderately resistant sorghum variety AS21 and midge resistant sorghum variety IESV2009SH both planted as sole sorghum plots had significantly ($P \leq 0.05$) less yield loss compared to the resistant varieties planted in sorghum-cowpea intercrops. Significantly ($P < 0.05$) more yield loss was observed on susceptible sorghum variety GA010/010 grown as sole crop, but most yield loss experienced under the sorghum-cowpea intercrop.

- *Effect of Cropping Techniques on the Occurrence of Sorghum Midge Natural Enemies on Sorghum Crop*

- *Influence of Cropping Practices on the Occurrence of Assassin Bugs on Sorghum*

Significantly ($P \leq 0.05$) more assassin bugs (Reduviidae) were found on sorghum grown with a maize barrier around it compared to the one that did not have maize barriers around them in both growing seasons of 2016A and 2017A. The occurrence of the assassin bugs was higher probably because of the availability of their prey - the sorghum midge, but also the microclimate and protection created by the maize barrier around the sorghum plots appears to have been conducive for their stay in plots with maize barriers around them.

A significant interaction of barrier status X cropping pattern on the occurrence of assassin bugs was also observed although the trend was not consistent in both sorghum growing seasons of 2016A and 2017A. Significantly ($P \leq$ more assassin bugs were found in sorghum plots with more sorghum midge flies in sorghum - cowpea intercrop plots during the growing season. Under the interaction effect, the assassin bug infestation observed was 1 – 3 bugs per sorghum panicle, and relatively few bugs infested sorghum in season 2017A. Sorghum plants that had a maize barrier around the plots had significantly ($P \leq$ o.o5) more assassin bugs than the number of all natural enemies found in sorghum plots that did not have a maize barrier around them. Although the number of spiders, lace wings, pirate bugs and coccinellids found on sorghum was not statistically significant ($P \geq 0.05$), the trend of their numbers on sorghum indicated that most of them were commonly found on sorghum that had a barrier around the sorghum compared to sorghum without a maize barrier around them. This could be as a result of the conducive micro-climate created by the maize barrier around the sorghum plots and a good hiding place to capture the prey - sorghum midge and others for feeding. However, the occurrence of a majority of the sorghum midge natural enemies was low during season 2016A compared to season 2017A (Figure 1). Majority of the midge natural enemies were found on grain sorghum that was at physiological maturity, a later stage when the sorghum midge had already damaged the sorghum kernels at flowering. Sharma, (1985) and Baxendale et al., (1983), also made this observation.

V. CONCLUSION

The study sought to investigate the influence of utilizing a combination of common farmer farming techniques including the use of crops to interfere with mobility or flight of the sorghum midge flies. The status of sorghum variety resistance as well as sorghum intercropped with a leguminous crop (cowpea) were co-opted as common farming practices to understand their contribution towards sustaining or failing the normal occurrence of the sorghum midge flies during a sorghum cropping season. It is however worth noting that the study revealed that use of some farming practices in combination had an effect on the occurrence, sorghum damage, and loss of yield caused by the sorghum midge pest. Equipped with such information and properly utilized, sorghum midge attack on sorghum can be naturally managed and the sorghum yields subsequently increased.

Use of the maize crop in the sorghum field as an obstruction to the free movement of the sorghum midge - the poor flyer was demonstrated. The maize served as a barrier to the free movement of the midge fly into sorghum plots. The maize barrier around the sorghum plots prevented the free entrance of midge flies to easily access the sorghum plots, and that is why the midge flies were abundant in sorghum without barriers. Sole sorghum was less damaged compared to sorghum-cowpea intercrop because of the plant population. Sorghum midge resistant varieties were relatively less damaged except in a few instances under the effects of interaction of farming practices.

Thus, integrating the farming techniques that reduce the impact of the midge flies can be important in reducing damage to sorghum and thus, increase the sorghum yields. These farming practices need to be integrated with other known pest control practices including; early planting at the onset of the rainy season, destruction of the sorghum plant remains after harvesting. Planting sorghum at around the same time in most sorghum growing communities, destruction of alternative host plants available, such as the wild sorghums like Johnson grass *Sorghum halipense*, and Sudan grass *Sorghum sudanense* etc., that maintain the existence of the sorghum midge during offseason when the grain sorghum crop is already removed.

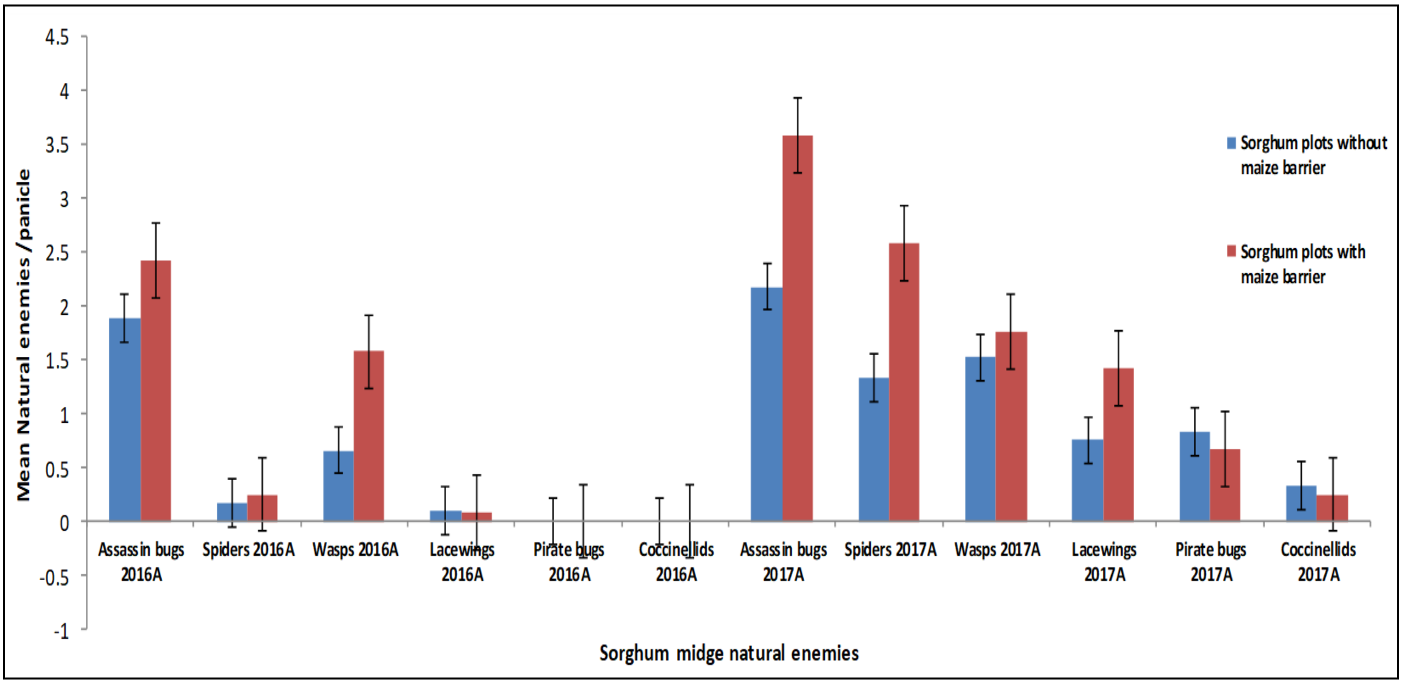

Fig 1 Occurrence of Sorghum Midge Natural Enemies on Sorghum Influenced by a Maize Barrier During Seasons 2016A and 2017A

Table 1 ANOVA Summary for Effects of Farming Practices on Sorghum Midge Infestation, Incidence, Damage and Sorghum Yield Loss - Seasons 2015B, 2016A and 2017A

		Sorghum midge infestation (flies / head)				Sorghum midge severity of damage				Sorghum yield loss			
Source of Variation	**df**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**
Season 2015B													
Block stratum	2	39.4	19.7	0.08		1.434	0.717	1.66		564.7	282.3	1.93	
a). Barrier status	1	4419.1	4419.1	17.04	0.054	0.005	0.005	0.01	0.928	74.70	74.70	0.51	0.549
Residual	2	518.7	259.3	1.17		0.863	0.431	0.62		293.1	146.6	0.95	
b). Variety status	1	84.4	84.4	0.38	0.571	52.01	52.01	75.11	0.001	2043.5	2043.5	13.24	0.022
c). Cropping pattern	1	4.4	4.4	0.03	0.857	0.561	0.561	2.30	0.168	449.2	449.2	2.24	0.173
d). Barrier status X Variety	1	111.2	111.2	0.50	0.518	0.781	0.781	1.13	0.348	4.10	4.10	0.03	0.879
Residual	4	886.1	221.5	1.73		2.769	0.693	2.84		617.6	154.4	0.77	
e). Barrier status X Cropping pattern	1	1218.4	1218.4	9.54	0.015	0.019	0.019	0.08	0.789	291.9	291.9	1.46	0.262
f). Variety X Cropping pattern	1	2911.3	2911.3	22.79	0.001	0.116	0.116	0.48	0.501	130.3	130.3	0.65	0.444
g). Barrier X Variety X Cropping pattern	1	16.1	16.1	0.13	0.732	0.91	0.91	3.73	0.09	74.90	74.90	0.37	0.558
Residual	8	8	1021.9	127.7		1.949	0.244			1604.4	200.5		
Total	23	11231.1				61.42				6148.3			

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Season 2016A													
Block stratum	2	4.29	21.15	0.65		0.141	0.0706	0.25		55.55	27.78	7.24	
a). Barrier status	1	30455.3	30455.3	933.5	0.001	0.122	0.1218	0.43	0.581	48.26	48.26	12.58	0.071
Residual	2	65.25	32.63	0.18		0.572	0.2858	0.18		7.67	3.84	0.21	
a). Variety status	1	5705.91	5705.91	31.57	0.005	78.81	78.81	48.31	0.002	4746.2	4746.2	258.04	0.001
b). Cropping pattern	1	1901.22	1901.22	34.73	0.001	10.79	10.79	31.45	0.001	1638.93	1638.93	132.13	0.001
c). Barrier X Variety	1	9988.5	9988.5	55.27	0.002	0.021	0.021	0.01	0.915	2.80	2.80	0.15	0.716
Residual	4	722.84	180.71	3.30		6.525	1.6311	4.76		73.57	18.39	1.49	
d). Barrier X Cropping pattern	1	3835.06	3835.06	70.05	0.001	0.46	0.46	1.33	0.28	41.38	41.38	3.34	0.105
e). Variety X Cropping pattern	1	268.56	268.56	4.91	0.058	0.05	0.05	0.14	0.714	98.63	98.63	7.95	0.022
f). Barrier X Variety X Cropping pattern	1	1.88	1.88	0.03	0.857	7.81	7.81	22.77	0.001	329.25	329.25	26.54	0.001
Residual	8	437.95	54.74			2.744	0.343			99.23	12.40		
Total	23	53424.8				108.03				7141.46			
Season 2017A													
Block stratum	2	133.66	66.83	28.14		2.511	1.255	0.30		6.68	3.34	0.09	
a). Barrier status	1	24.55	24.55	10.34	0.085	5.558	5.558	1.33	0.368	2144.86	2144.86	57.06	0.017
Residual	2	4.75	2.38	0.12		8.361	4.180	5.10		75.18	37.56	4.87	
b). Variety status	1	32.61	32.61	1.61	0.273	0.00	0.00	0.00	0.992	0.65	0.65	0.08	0.787
c). Cropping pattern	1	24.35	24.35	1.13	0.318	0.046	0.046	0.04	0.853	2028.74	2028.74	105.68	0.001
d). Barrier X Variety	1	26.30	26.30	1.30	0.318	0.271	0.271	0.33	0.596	288.92	288.92	37.46	0.004
Residual	4	80.93	20.23	0.94		3.28	0.82	0.65		30.85	7.71	0.40	
e). Barrier X Cropping pattern	1	1.37	1.37	0.06	0.807	0.046	0.046	0.04	0.853	863.48	863.48	44.98	0.001
e). Variety X Cropping pattern	1	54.08	54.08	2.52	0.151	6.988	6.988	5.56	0.046	986.32	986.32	51.38	0.001
f). Barrier X Variety X Cropping pattern	1	0.02	0.02	0.00	0.977	0.008	0.008	0.01	0.937	2383.64	2384.64	124.16	0.001
Residual	8	171.71	21.46			10.059	1.257			153.58	19.20		
Total	23	554.33				40.882				8962.90			

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Table 2 Summary Table of Means for Effects of Farming Practices on Sorghum Midge Infestation, Severity of Damage and Sorghum Yield Loss Due to Sorghum Midge During Seasons 2015B, 2016A and 2017A

a. Sorghum midge infestation (flies / head)		**Growing Seasons**			
	Farming practices	**Season 2015B**	**Season 2016A**		**Season 2017A**
Main plots	Sorghum plots without maize barrier	115.0	116.20		8.36
	Sorghum plots with maize barrier	87.9	45.00		6.34
	Fpr	0.054	0.001		0.085
	CV (%)	7.9	3.5		10.5
Sub plots	Sorghum variety AS21 (Mod. midge resistant)	99.60	96.00		6.19
	Sorghum variety GA010/010 (midge susceptible)	103.00	65.20		8.52
	Fpr	0.571	0.005		0.273
Sub-sub plots	Sole sorghum plot	101.0	71.70		6.34
	Sorghum – cowpea intercrop	101.9	89.50		8.36
	Fpr	0.857	0.001		0.318
b. Damage scores to grain sorghum by sorghum midge					
	Farming practices	**Season 2015B**	**Season 2016A**		**Season 2017A**
Main plots	Sorghum plots without maize barrier	7.26	5.97		4.78
	Sorghum plots with maize barrier	7.29	5.82		3.81
	Fpr	0.928	0.581		0.368
	CV (%)	4.5	4.5		23.8
Sub plots	Sorghum variety AS21 (Mod. midge resistant)	5.81	4.08		4.29
	Sorghum variety GA010/010 (midge susceptible	8.75	7.71		4.30
	Fpr	0.001	0.002		0.992
Sub-sub plots	Sole sorghum plot	7.12	5.23		4.34
	Sorghum – cowpea intercrop	7.43	6.57		4.25
	Fpr	0.168	0.001		0.853
c. Sorghum yield loss caused by sorghum midge (%)					
	Farming practices	**Season 2015B**	**Season 2016A**		**Season 2017A**
Main plots	Sorghum plots without maize barrier	89.2	63.68	Sorghum plots without maize barrier	69.22
	Sorghum plots with maize barrier	85.6	66.51	Sorghum plots with maize barrier	50.32
	Fpr	0.549	0.071	Fpr	0.004
	CV (%)	6.9	1.5	CV (%)	5.10
Sub plots	Sorghum variety AS21 (Mod. midge resistant)	78.2	51.03	Sorghum variety IESV25009SH (midge resis	59.94
	Sorghum variety GA010/010 (midge susceptible)	96.6	79.16	Sorghum variety GA010/010 (midge suscep	59.61
	Fpr	0.022	0.001	Fpr	0.787
Sub-sub plots	Sole sorghum plot	83.1	56.83	Sole sorghum plot	50.58
	Sorghum – cowpea intercrop	91.7	73.36	Sorghum – cowpea intercrop	68.97
	Fpr	0.173	0.001	Fpr	0.001

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Table 3 Summary Table of Means for Sorghum Midge Infestation of Sorghum as Influenced by Farming Practices Interactions During Season 2015B

Sorghum midge infestation (flies/head)		
Barrier status X Variety status interaction		
	AS21 (midge mod. resistant)	**GA010/010 (midge susceptible)**
Without maize barrier	119.1	111.0
With maize barrier	87.6	88.2
Fpr	0.518	
CV (%)	10.4	
Barrier X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	121.7	108.3
Sorghum with maize barrier	80.3	95.4
Fpr	0.015	
Variety X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum variety AS21 (midge mod. resistant)	91.9	89.00
Sorghum variety GA010/010 (midge susceptible)	110.2	114.80
Fpr	0.001	

Barrier X Variety X Cropping pattern interaction			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety AS21 (midge mod. resistant)	115.6	122.6
	Sorghum variety GA010/010 (midge susceptible)	127.9	94.1
Sorghum with maize barrier	Sorghum variety AS21 (midge mod. resistant)	68.2	107.0
	Sorghum variety GA010/010 (midge susceptible)	92.4	83.9
	Fpr	0.732	
	CV (%)	11.1	

Table 4 Summary Table of Means for Sorghum Midge Infestation of Sorghum as Influenced by Farming Practices Interactions During Season 2016A

Sorghum midge infestation (flies / head)		
Barrier status X Variety status interaction		
	AS21 (Resistant sorghum)	**GA010/010 (susceptible sorghum)**
Without maize barrier	40.00	50.00
With maize barrier	152.10	80.40
Fpr	0.002	
CV (%)	11.8	
Barrier status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	94.70	137.80
Sorghum with maize barrier	48.70	41.20
Fpr	0.001	
Variety status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum variety AS21 (midge mod. resistant)	59.60	70.70

Sorghum variety GA010/010 (midge susceptible)	83.80	108.30
Fpr	0.058	

Barrier status X Variety status X Cropping pattern interaction			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety AS21 (midge mod. resistant)	40.70	39.30
	Sorghum variety GA010/010 (midge susceptible)	56.80	43.20
Sorghum with maize barrier	Sorghum variety AS21 (midge mod. resistant)	126.90	177.20
	Sorghum variety GA010/010 (midge susceptible)	62.50	98.30
	Fpr	0.857	
	CV (%)	9.2	

Table 5 Summary Table of Means for Sorghum Midge Damage of Sorghum as Influenced by Farming Practices Interactions During Season 2016A

Sorghum midge severity of damage (scores)		
Barrier status X Variety status interaction		
	AS21 (midge mod. resistant)	**GA010/010 (midge susceptible)**
Without maize barrier	4.18	7.75
With maize barrier	3.98	7.67
Fpr	0.915	
CV (%)	15.30	
Barrier status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	5.43	6.50
Sorghum with maize barrier	5.02	6.63
Fpr	0.282	
Variety status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum variety AS21 (midge mod. resistant)	3.37	4.80
Sorghum variety GA010/010 (midge susceptible)	7.08	8.33
Fpr	0.714	

Barrier status X Variety status X Cropping pattern interaction			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety AS21 (midge mod. resistant)	3.04	5.33
	Sorghum variety GA010/010 (midge susceptible)	7.83	7.67
Sorghum with maize barrier	Sorghum variety AS21 (midge mod. resistant)	3.70	4.27
	Sorghum variety GA010/010 (midge susceptible)	6.33	9.00
	Fpr	0.001	
	CV (%)	9.9	

Table 6 Summary Table of Means for Sorghum Midge Damage of Sorghum as Influenced by Farming Practices Interactions During Season 2017A

Sorghum midge severity of damage (scores)			
Barrier status X Variety status interaction			
	IESV25009SH (midge resistant)	**GA010/010 (midge susceptible)**	
Without maize barrier	4.67	4.88	
With maize barrier	3.92	3.71	
Fpr	0.596		
CV (%)	14.90		
Barrier status X Cropping pattern interaction			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum without maize barrier	5.22	4.33	
Sorghum with maize barrier	3.46	4.17	
Fpr	0.12		
Variety status X Cropping pattern interaction			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum variety IESV25009SH (midge resistant)	3.80	3.71	
Sorghum variety GA010/010 (midge susceptible)	4.88	4.79	
Fpr	0.046		
Barrier status X Variety status interaction X Cropping pattern interaction			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety IESV25009SH (midge resistant)	4.77	3.67
	Sorghum variety GA010/010 (midge susceptible)	5.67	5.00
Sorghum with maize barrier	Sorghum variety IESV25009SH (midge resistant)	2.83	3.75
	Sorghum variety GA010/010 (midge susceptible)	4.08	4.58
	Fpr	0.937	
	CV (%)	26.00	

Table 7 Summary Table of Means for Sorghum Yield Loss as Influenced by Farming Practices Interactions During Season 2016A

Sorghum yield loss (%)		
Barrier status X Variety status interaction		
	AS21 (midge mod. resistant)	**GA010/010 (midge susceptible)**
Without maize barrier	49.96	77.40
With maize barrier	52.11	80.92
Fpr	0.716	
CV (%)	4.7	
Barrier status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	54.10	73.25
Sorghum with maize barrier	59.56	73.46
Fpr	0.105	
Variety status X Cropping pattern interaction		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum variety AS21 (midge mod. resistant)	40.74	61.32
Sorghum variety GA010/010 (midge	72.92	85.39

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susceptible)		
Fpr	0.022	
Barrier status X Variety status X Cropping pattern interaction		

	Variety	Cropping Pattern	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety AS21 (midge mod. resistant)	46.83	65.26
	Sorghum variety GA010/010 (midge susceptible)	34.65	81.24
Sorghum with maize barrier	Sorghum variety AS21 (midge mod. resistant)	46.83	57.38
	Sorghum variety GA010/010 (midge susceptible)	72.29	89.54
	Fpr	0.001	
	CV (%)	5.40	

Table 8 Summary Table of Means for Sorghum Yield Loss as Influenced by Farming Practices Interactions During Season 2017A

Sorghum yield loss (%)		
Barrier status X Variety status		
	IESV25009SH (midge resistant)	**GA010/010 (midge susceptible)**
Without maize barrier	65.92	72.53
With maize barrier	53.95	48.68
Fpr	0.004	
CV (%)	3.30	
Barrier X Cropping pattern		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	66.03	72.42
Sorghum with maize barrier	35.13	65.51
Fpr	0.001	
Variety X Cropping pattern		
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum variety IESV25009SH (midge resistant)	44.00	62.72
Sorghum variety GA010/010 (midge susceptible)	57.15	72.21
Fpr	0.01	

Barrier X Variety X Cropping pattern			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety IESV25009SH (midge resistant)	15.12	52.77
	Sorghum variety GA010/010 (midge susceptible)	55.14	78.25
Sorghum with maize barrier	Sorghum variety IESV25009SH (midge resistant)	59.17	72.17
	Sorghum variety GA010/010 (midge susceptible)	72.89	72.67
	Fpr	0.001	
	CV (%)	7.3	

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Table 9 ANOVA Summary for Effects of Farming Techniques on the Abundance of Sorghum Midge Natural Enemies - Seasons 2016A and 2017A

Season 2016A		**Assassin bugs**				**Lace wings**				**Spiders (complex)**				**Eupelmid and Eulophid wasps**			
Source of Variation	**df**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**
Block stratum	2	5.69	2.85	0.78		0.041	0.02	1.14		0.021	0.01	0.04		0.616	0.31	0.34	
a). Barrier status	1	1.76	1.76	0.48	0.560	0.002	0.002	0.09	0.789	0.037	0.037	0.13	0.753	4.92	4.92	5.37	0.146
Residual	2	7.33	3.67	1.63		0.036	0.018	0.37		0.57	0.28	3.84		1.83	0.92	0.12	
b). Variety status	1	0.68	0.68	0.30	0.612	0.06	0.06	1.24	0.328	0.11	0.11	1.44	0.296	5.54	5.54	0.74	0.438
c). Cropping pattern	1	0.19	0.19	0.23	0.648	0.007	0.007	0.21	0.661	0.16	0.16	4.26	0.073	1.57	1.57	0.48	0.508
d). Barrier status X Variety	1	0.82	0.82	0.36	0.579	0.027	0.027	0.55	0.499	0.005	0.005	0.07	0.811	0.125	0.125	0.02	0.904
Residual	4	9.01	2.25	2.6		0.19	0.05	1.51		0.29	0.07	2.01		29.96	7.49	2.29	
e). Barrier status X Cropping pattern	1	4.54	4.54	5.26	0.051	0.00	0.00	0.00	1.00	0.06	0.06	1.63	0.238	1.59	1.59	0.49	0.504
f). Variety X Cropping pattern	1	0.104	0.104	0.12	0.740	0.015	0.015	0.47	0.513	0.191	0.191	5.18	0.052	1.74	1.74	0.53	0.486
g).Barrier X Variety X Cropping pattern	1	0.16	0.16	0.19	0.675	0.042	0.042	1.30	0.287	0.002	0.002	0.05	0.837	0.58	0.58	0.18	0.685
Residual	8	6.91	0.86			0.257	0.03			0.29	0.037			26.15	3.29		
Total	23	37.21				0.678				1.736				74.64			
Season 2017A		**Assassin bugs**				**Lace wings**				**Spiders (complex)**				**Eupelmid and Eulophid wasps**			
Source of Variation	df	ss	ms	vr	Fpr	ss	ms	vr	Fpr	ss	ms	vr	Fpr	ss	ms	vr	Fpr
Block stratum	2	0.75	0.375	9.00		0.08	0.042	0.04		0.58	0.29	0.33		3.25	1.63	4.33	
a).	1	12.04	12.0	289.0	0.00	2.67	2.67	2.5	0.25	9.38	9.38	10.7	0.08	0.38	0.38	1.00	0.42

Barrier status			4	0	3			6				1	2				
Residual	2	0.08	0.042	0.03		2.08	1.042	5.00		1.75	0.88	5.25		0.75	0.38	0.90	
a). Variety status	1	2.42	2.42	1.58	0.28	0.17	0.17	0.80	0.42	0.04	0.04	0.25	0.64	0.04	0.04	0.10	0.77
b). Cropping pattern	1	0.38	0.38	0.24	0.64	0.17	0.17	0.31	0.59	0.04	0.04	0.09	0.77	0.04	0.04	0.06	0.81
c). Barrier X Variety	1	0.04	0.04	0.03	0.87	0.00	0.00	0.00	1.00	0.04	0.04	0.25	0.64	7.04	7.04	16.9	0.015
Residual	4	5.167	1.29	0.82		0.83	0.21	0.38		0.67	0.167	0.36		1.67	0.42	0.59	
d). Barrier X Cropping pattern	1	0.04	0.04	0.03	0.88	0.67	0.67	0.31	0.59	0.38	0.38	0.82	0.39	7.04	7.04	9.94	0.014
e). Variety X Cropping pattern	1	1.04	1.04	0.66	0.44	0.17	0.17	0.31	0.59	0.38	0.38	0.82	0.39	9.38	9.38	13.24	0.007
f). Barrier X Variety X Cropping pattern	1	0.38	0.38	0.24	0.64	0.67	0.67	1.23	0.29	0.04	0.04	0.09	0.77	0.38	0.38	0.58	0.488
Residual	8	12.67	1.58			4.33	0.54			3.667	0.46			5.67	0.71		
Total	23	34.625				11.83				16.96				35.63			

Table 10 ANOVA Summary for Effects of Farming Techniques on the Abundance of Sorghum Midge Natural Enemies – Season 2017A *cont'd*

Season 2017A Continued		**Pirate bugs**				**Coccinellids**			
Source of Variation	**df**	**ss**	**ms**	**vr**	**Fpr**	**ss**	**ms**	**vr**	**Fpr**
Block stratum	2	0.25	0.125	0.16		0.083	0.042	0.08	
a). Barrier status	1	0.17	0.17	0.21	0.69	0.042	0.042	0.08	0.808
Residual	2	1.58	0.79	0.54		1.083	0.542	2.60	
a). Variety status	1	0.17	0.17	0.11	0.75	0.380	0.380	1.80	0.251
b). Cropping pattern	1	0.00	0.00	0.00	1.00	0.042	0.042	0.17	0.694
c). Barrier X Variety	1	1.50	1.50	1.03	0.37	0.042	0.042	0.20	0.678
Residual	4	5.83	1.46	7.00		0.833	0.208	0.83	
d). Barrier X Cropping pattern	1	0.00	0.00	0.00	1.00	0.380	0.380	1.50	0.256
e). Variety X Cropping pattern	1	0.67	0.67	3.20	0.11	0.042	0.042	0.17	0.694
f). Barrier X Variety X Cropping pattern	1	0.67	0.67	3.20	0.11	0.042	0.042	0.17	0.694
Residual	8	1.67	0.21			2.000	0.250		
Total	23	12.50				4.958			

Table 11 Summary Table of Means for Sorghum Midge Natural Enemy Occurrence on Sorghum Influenced by Maize Barrier Status During Seasons 2016A and 2017A

	Sorghum growing season 2016A					
	Assassin bugs	**Spiders**	**Wasps**	**Lacewings**	**Pirate bugs *Orius spp.***	**Coccinellids**
Sorghum plots without maize barrier	1.88	0.17	0.66	0.10	-	-
Sorghum plots with maize barrier	2.42	0.25	1.57	0.08	-	-
Fpr	0.56	0.75	1.46	0.79	-	-
CV (%)	44.5	127.9	42.9	73.0	-	-
			Sorghum growing season 2017A			
	Assassin bugs	**Spiders**	**Wasps**	**Lacewings**	**Pirate bugs *Orius spp.***	**Coccinellids**
Sorghum plots without maize barrier	2.17	1.33	1.52	0.75	0.83	0.33
Sorghum plots with maize barrier	3.58	2.58	1.75	1.42	0.67	0.25
Fpr	0.03	0.082	0.075	0.25	0.69	0.81
CV (%)	3.5	23.9	18.8	47.1	59.3	126.2

Table 12 Summary Table of Means for Assassin Bugs Infestation on Sorghum as Midge Natural Enemies Under the Influence Farming Practices 2017A

Assassin bugs / sorghum panicle			
Sorghum plots without maize barrier	2.17		
Sorghum plots with maize barrier	3.58		
Fpr	0.03		
CV (%)	3.5		
Sorghum variety IESV25009SH (midge resistant)	3.17		
Sorghum variety GA010/010 (midge susceptible)	2.58		
Fpr	0.277		
Sole sorghum plot	3.00		
Sorghum – cowpea intercrop	2.75		
Fpr	0.64		
Barrier status X Variety status			
	IESV25009SH (midge resistant)	**GA010/010 (midge susceptible)**	
Without maize barrier	2.50	1.83	
With maize barrier	3.83	3.33	
Fpr	0.866		
CV (%)	28.0		
Barrier X Cropping pattern			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum without maize barrier	2.33	2.00	
Sorghum with maize barrier	3.67	3.50	
Fpr	0.875		
Variety X Cropping pattern			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum variety IESV25009SH(midge resistant)	3.50	2.83	
Sorghum variety GA010/010 (midge susceptible)	2.50	2.67	
Fpr	0.441		
Barrier X Variety X Cropping pattern			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety IESV25009SH	3.00	2.00

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	(midge resistant)		
	Sorghum variety GA010/010 (midge susceptible)	1.67	2.00
Sorghum with maize barrier	Sorghum variety IESV25009SH (midge resistant)	4.00	3.67
	Sorghum variety GA010/010 (midge susceptible)	3.33	3.33
	Fpr	0.64	
	CV (%)	43.8	

Table 13 Summary Table of Means for Assassin Bugs Infestation on Sorghum as Midge Natural Enemies Under the Influence Farming Practices 2016A

Assassin bugs / sorghum head			
Sorghum plots without maize barrier	1.88		
Sorghum plots with maize barrier	2.42		
Fpr	0.56		
CV (%)	44.5		
Sorghum variety AS21 (midge mod. resistant)	2.32		
Sorghum variety GA010/010 (midge susceptible)	1.98		
Fpr	0.612		
Sole sorghum plot	2.24		
Sorghum – cowpea intercrop	2.06		
Fpr	0.648		
Barrier status X Variety status			
	AS21 (midge mod. resistant)	**GA010/010 (midge susceptible)**	
Without maize barrier	1.86	1.90	
With maize barrier	2.77	2.07	
Fpr	0.579		
CV (%)	49.40		
Barrier X Cropping pattern			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum without maize barrier	1.53	2.22	
Sorghum with maize barrier	2.95	1.90	
Fpr	0.051		
Variety X Cropping pattern			
	Sole sorghum plots	**Sorghum – Cowpea Intercrop**	
Sorghum variety AS21 (midge resistant)	2.47	2.16	
Sorghum variety GA010/010 (midge susceptible)	2.00	1.96	
Fpr	0.739		
Barrier X Variety X Cropping pattern			
	Variety	**Cropping Pattern**	
		Sole sorghum plots	**Sorghum – Cowpea Intercrop**
Sorghum without maize barrier	Sorghum variety AS21 (midge mod resistant)	1.50	2.22
	Sorghum variety GA010/010 (midge susceptible)	1.50	2.22
Sorghum with maize barrier	Sorghum variety AS21 (midge resistant)	3.45	2.10
	Sorghum variety GA010/010 (midge susceptible)	2.44	1.69
	Fpr	0.675	
	CV (%)	43.2	

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