EFFICACY OF PUSH AND PULL STRATEGY AGAINST FALL ARMYWORM {*SPODOPTERA FRUGIPERDA* (J.E. SMITH)} IN MAIZE IN BHAIRAHAWA, NEPAL

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ABSTRACT

Fall Armyworm (FAW), Spodoptera frugiperda (J.E. Smith), a voracious sporadic pest, had been major problem in maize causing significant yield loss and challenging food security around the world. It was first recorded in Nepal on 9th May, 2019 and is distributed in most part of the maize farming regions. Farming system such as maize-legume intercropping has been reported to reduce Fall Armyworm infestation significantly. The experiment for effective management of Fall Armyworm in maize as push and pull strategy was carried at horticulture farm of Institute of Agriculture and Animal Science, Paklihawa Campus, Bhairahawa. Seven treatments including the control were applied in Randomized Complete Block Design. Maize (var. Rampur Hybrid-10) was the main crop, with Napier (var. Super Napier) used as a border crop. All the treatments were replicated three times. The treatments deployed were: Desmodium {Desmodium oojeinese (Roxb) H.Ohashi}, cowpea (Sampada), blackgram (U-99), greengram (local var.), common bean (Italy 38), soyabean (local var.) and control. On an average, the research showed that Desmodium had the highest resistance to fall armyworm with lowest leaf damage score (4.90), being superior to Soyabean (5.61), Green gram (5.79), Black gram (5.90), Cowpea (6.45), Common bean (6.85), and Control (7.31). The average number of infested plant and infested leaf were least in plot where Desmodium was intercropped, having the highest yield of 8.86 tons/ha. From this experiment, we concluded that Desmodium was the most effective legume among other treatments. However, crops like soyabean and green gram can also be suggested as a next best alternative for ecofriendly management of fall armyworm.

Keywords: Desmodium, Infestation, Leaf-score, Management

INTRODUCTION

Maize (*Zea mays* L.), known as the 'queen of cereals' (Thumar et al., 2020), holds significant genetic potential and is a crucial crop in Nepal. With an annual production of 3,106,397 tons (MoALD, 2023), it is the second major cereal crop in the country (Durbar, 2016). Maize is cultivated in diverse regions, including sloping lands in hills and low-lying basin areas, both under rainfed and irrigated conditions (Timsina et al., 2016). Nepal exhibits the highest per capita maize consumption in South Asia (Ranum et al., 2014), with 86% of production in mid-hills consumed by humans and 80% of Terai production used for animal and poultry feed. Despite its importance, the current farm-level maize yield in Nepal, at 2.45 tons/ha, falls short of its attainable yield of 5.7 tons/ha (Ghimire et al., 2018).

Fall armyworm (FAW) [*Spodoptera frugiperda* (J.E Smith)], a member of the Noctuidae family in the lepidopteran order, is an invasive pest that invades multiple plant species, can damage a broad range of hosts, have the ability to grow quickly and are highly mobile in nature (Naharki et al., 2020a). The initial reports of FAW were made in West Africa around the end of 2016 (Goergen et al., 2016) and on May 9, 2019, the pest was first observed in Nepal in the Nawalparasi district (N 27°42'16.67" E 084°22'50.61") (Bajracharya et al., 2019). Being a noctuid moth pest, FAW can wipe out a number of crop varieties if allowed to proliferate (Adhikari et al., 2020; Robert L. Meagher et al., 2013). The optimum temperature for FAW growth and development is 20°C-30°C (Naharki et al., 2020b). It can result in significant yield losses in maize and other important staple cereal crops, endangering the lives of hundreds of millions of smallholder farmers and consumers as well as food security. Being the second most consumed staple food in Nepal, equally crucial for both human and animal, continuity of prevailing infestation of FAW could show prominent effect on security of food and subsistence, leading to both quantitative and qualitative damage.

It was revealed that the yield loss of 20-25% maize was due to fall armyworm (Pradhan, 2020). Yield loss of 17% of maize in Nepal has also been reported when 20-100% of maize was infested at whorl stage (Bhusal & Chapagain, 2020). Infestation rates of maize ranges from 26.4% and 55.9%, resulting in 11.57% reduction on yield due to fall armyworm as per the report (Baudron et al., 2019). Similarly, other researchers have also documented the damage level on leaf, silk and tassel which lies in between 25 to 50% and about 58% decrement in yield (Chimweta et al., 2020). The full-fledge potential of maize production has still not been met due to the infestation of insects and pests. Holes that do appear in tissue are a usual sign of occurrence of pest because early instars feed on the leaf tissue (Sisay et al., 2019). Midega (2018) demonstrated that mature instars have the capacity to defoliate whole plants, leaving only skeletal structures and stalks, thereby inducing a ragged or shredded look which may lead to considerable detrimental effect. The damage brought by young larvae by consuming the tender leaf clusters, ear and tassel sometimes results in complete harvest loss (Sarmento et al., 2002).

As a result of additional investigations, it became evident that the young maize plants were damaged completely, and relying solely on chemical pesticides would not be effective in controlling the infestation of FAW (Khanal et al., 2024), as these pests have developed resistance to the chemicals being used. The ability to undergo multiple generations, migrate and feed on various range of host plant makes FAW most challenging to manage as a pest. The farmer's current strategy for handling the FAW infestation is not proving to be very successful. Although various methods for managing FAW are available, inadequate dissemination of knowledge and techniques has left many farmers unaware, particularly in most regions, contributing to reduced maize production as well. They also lack a clear understanding of locally available leguminous crops which can help to control these pests when intercropped with maize. Some leguminous crops contain substances that can repel FAW naturally (Scheidegger et al., 2021). Therefore, instead of relying solely on chemical pesticides, which can harm the environment, it's crucial for farmers to adopt integrated management techniques that are environmentally friendly. Utilization of climate-adjusted push-pull technology, a highly efficient method for controlling FAW pioneered by the International Centre of Insect Physiology and Ecology (ICIPE), may be one of the most effective ways to control the FAW as the country's development is still limited and the majority of farmers lack access to markets and chemical pesticides (Bhusal & Bhattarai, 2019). Along with that, small-scale farmers in Nepal rarely use chemical pesticides as a pest management strategy, mostly because of poor information, unavailability of suitable and efficient products, and expensive costs.

Using 'stimulo deterrent diversion' tactic, push-pull strategy involves repelling of FAW female moths from the maize plots by legumes intercropping and at the same time luring it to Napier grass (*Pennisetum purpureum* Schumach) as a trap crop. It is still unknown how edible legumes and push-pull companion plants affect host preference of FAW, consumption behaviour, physical condition and egg-laying directly. The improvement and endurance of agroecological maize farming systems, such as push-pull and legume intercropping, against FAW depend substantially on this kind of comprehension. The primary goal of the study is to assess the effectiveness of different leguminous crops for fall armyworm control along with repelling and attracting behaviour of legumes and napier respectively, when it is intercropped with maize. It will also assess the level of farmers adoption of effective management practices against the fall armyworm influencing their production trend. Similarly, it will also encompass the barriers in the maize production and study the feasibility of management strategy against fall armyworm. Therefore, this study was conducted with the aim of evaluating the efficiency of push (maize-legume intercrop) and pull (napier as a border crop) strategy for the management of fall armyworm in maize field.

MATERIALS AND METHODS

Study site

The research was conducted in the Rupandehi district of Nepal (*Figure 1*), situated in the inner Terai region, approximately 3 kilometers from the Bhairahawa, within the Lumbini Province of Nepal. The climate in this area is tropical, and the elevation is 120 meters above sea level. The average temperature ranges from 8.75°C to 42.4°C. The yearly average rainfall recorded is 1174 mm, with the monsoon season accounting for 80% of the total precipitation (Singh et al., 2011).

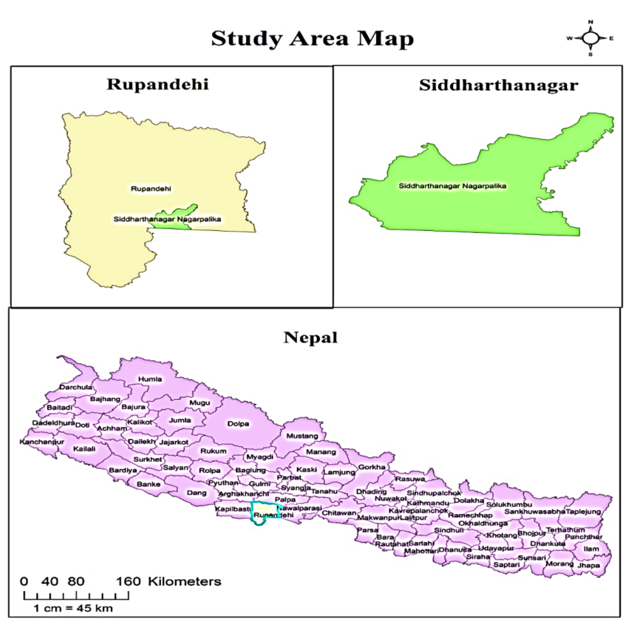

Figure 1: Map of research site

Treatments and experimental design

A Randomized Complete Block Design (RCBD) was used to arrange the combinations of maize and legumes and replicated three times. The treatments deployed in the experiment were; T1: Control, T2: Desmodium {*Desmodium oojeinese* (Roxb) H.Ohashi}, T3: Cowpea {*Vigna unguiculata* (L.) Walp., variety Sampada}, T4: Greengram (*Vigna radiata* (L.) R.Wilczek, variety-Local), T5: Common Bean (*Phaseolus vulgaris* (L.), variety Italy 38), T6: Soyabean (*Glycine max* (L.) Merr, variety local), and T7: Blackgram (*Vigna mungo* (L.) Hepper, variety- U-99). The test maize (*Zea mays L.*, var Rampur -Hybrid 10) with single row was intercropped with a single row of leguminous crop. Napier and Desmodium were used as a border and intercrop respectively which were planted a month earlier than maize and other intercrops. The varieties for intercrops were collected from the local farmers and agrovets. Seeds were subjected to priming for about 12-24 hours depending on the seed types.

Maize along with other leguminous seeds were sown in the first week of May. The dimensions of the experimental plots were 3 m long and 3 m wide. Both plots and replications were separated by 1m paths. Maize was sown 60cm row-row and 20 cm plant-plant. Seeding density of the legumes varied with species. Legume was sown at 1.5 cm depth, whereas maize was sown 2–5 cm deep. Seedlings of Desmodium were planted for the early establishment of crop. Each plots received 15 Kg of well rotten FYM, 117.99 gm diammonium phosphate (DAP), 60 gram potash and ½ (75 g) of urea before sowing of seeds and remaining Urea were applied in two split doses, six weeks after sowing and 2 weeks before flowering. Data were collected from May to August, 2022 where the temperature ranged from 23°C-35°C with an average precipitation of 5.695 mm/hg and relative humidity 75% (*Figure 2*). Earthing up was carried out after 20 days of emergence and weeding was done after 20 and 35 days of sowing. Yield of maize in each treatment was considered as the major parameter to measure FAW infestation.

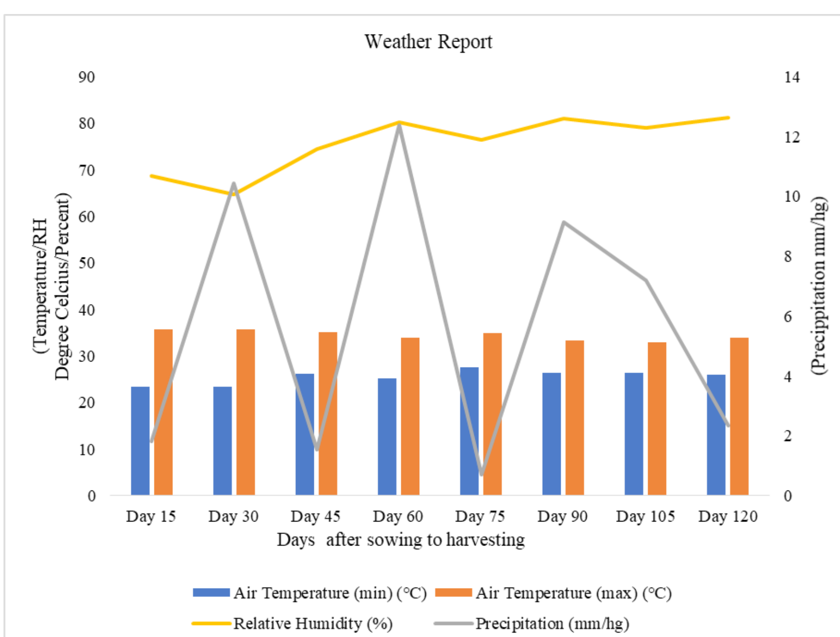

Figure 2: Weather report of the research site

Source: National Wheat Research Program (NWRP), Bhairahawa, Rupandehi

Data collection

Fall armyworm outbreak was graded and ranked based on assessments of yield, infested plants, tassel damage, and leaf damage. The Davis scale was used to assess the scores (*Table 1*). As per this scale, score 1 represents high resistivity and score 9 represents high susceptibility (*Figure 3*) (Davis et al., 1992). Five randomly chosen plants from the middle two rows were used for sampling.

Table 1: Scale for evaluating maize leaf damage caused by fall armyworm (*S. frugiperda*)

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage to leaf
3	Small elongated lesions (5-10 mm) on 1-3 leaves
4	Mid-sized lesions (10-30 mm) on 4-7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3-5 leaves
7	Elongated lesions (>30 cm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70 % of leaves
9	Most leaves with long lesions and complete defoliation observed

Source: Davis et al., 1992

Data on infested plant, infested leaves and tassel were visually recorded and the yield data was calculated on the basis of test weight. Using a ruler, the heights of five randomly chosen plants, infested in the middle two rows of each plot were measured, recording the height from bottom to the tip of the tassel at blooming.

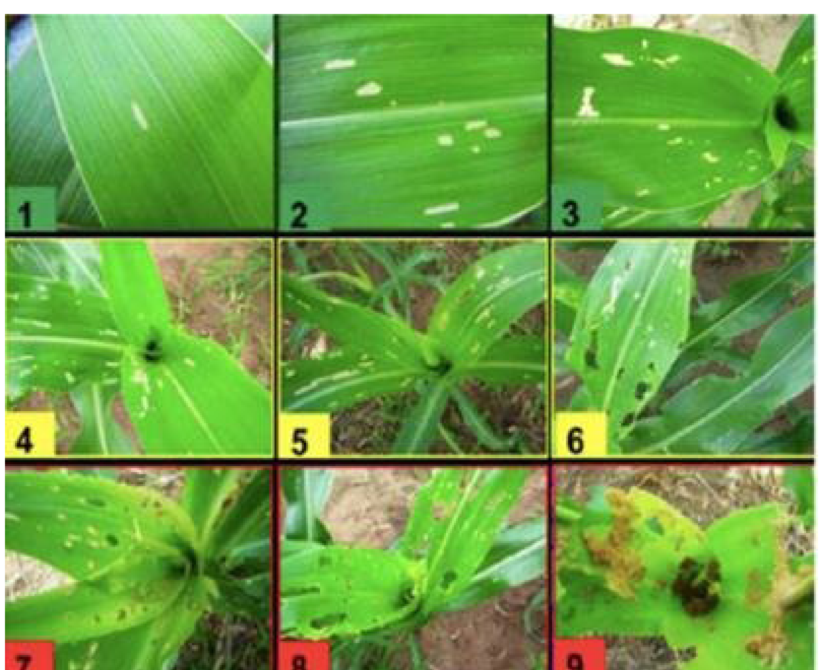

Figure 3:Maize plants rated according to leaf damage by FAW

Source: Supartha et al., 2021

Data analysis

Data entry was performed using Microsoft Excel. The mean percentage mortality of FAW larvae was analyzed using a one-way Analysis of Variance (ANOVA). Mean differences were evaluated with the Duncan Multiple Range Test (DMRT) using the agricolae package in R (version 4.0.0) at a 5% significance level.

RESULTS

Average number of maize plants infested by fall armyworm

The incidence of FAW ranged from high to low among the treatments used. After 14 days of sowing date, the highest damage was recorded in case of control plot (18.33±0.33) followed by cowpea (17.33±0.88), common bean (16.67±0.33), green gram (15.67±1.20), black gram (15.33±1.20), soyabean (14.67±0.35) and least damage in the plot of Desmodium (12.67±0.33), respectively. Similar sequence was observed at 21DAS, 28DAS, 35DAS, 42DAS and 49DAS with highest mean value at 49DAS as maximum damage was recorded in control plot (mono cropped) and least damage was recorded in Desmodium plot (18 ±0.57) (*Figure 4*).

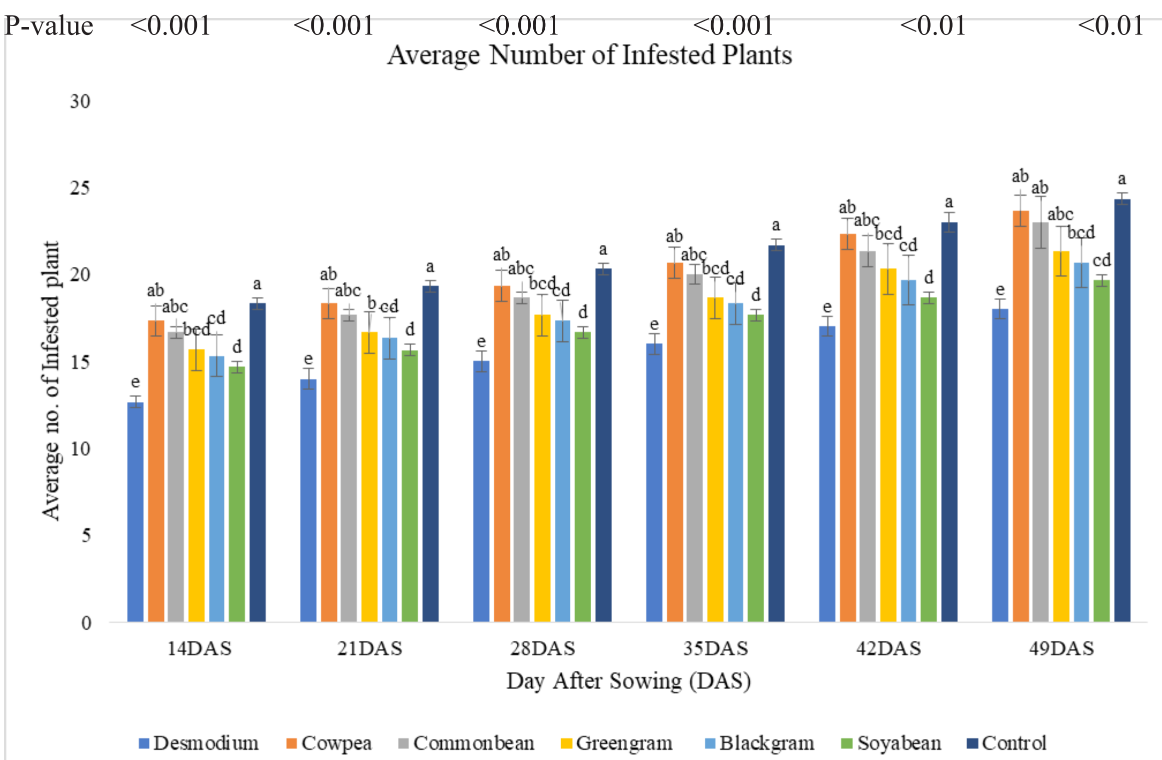

Figure 4:Average number of infested plants by fall armyworm

Average number of maize leaves infested by fall armyworm

Fourteen days after sowing, the average number of infested leaves was lowest in plots intercropped with Desmodium (6.40±0.79), followed by soybean (7.40±0.66), cowpea (7.93±0.38), black gram (8.60±0.58), green gram (9.16±0.60), common bean (10.00±0.28), and the control (10.66±0.16). Over subsequent observations, the average number of infested leaves gradually increased. However, the control and common bean plots consistently showed a greater number of infested leaves during later stages. Once the crop entered the reproductive phase, the number of infested leaves stabilized and remained nearly constant (*Figure 5*).

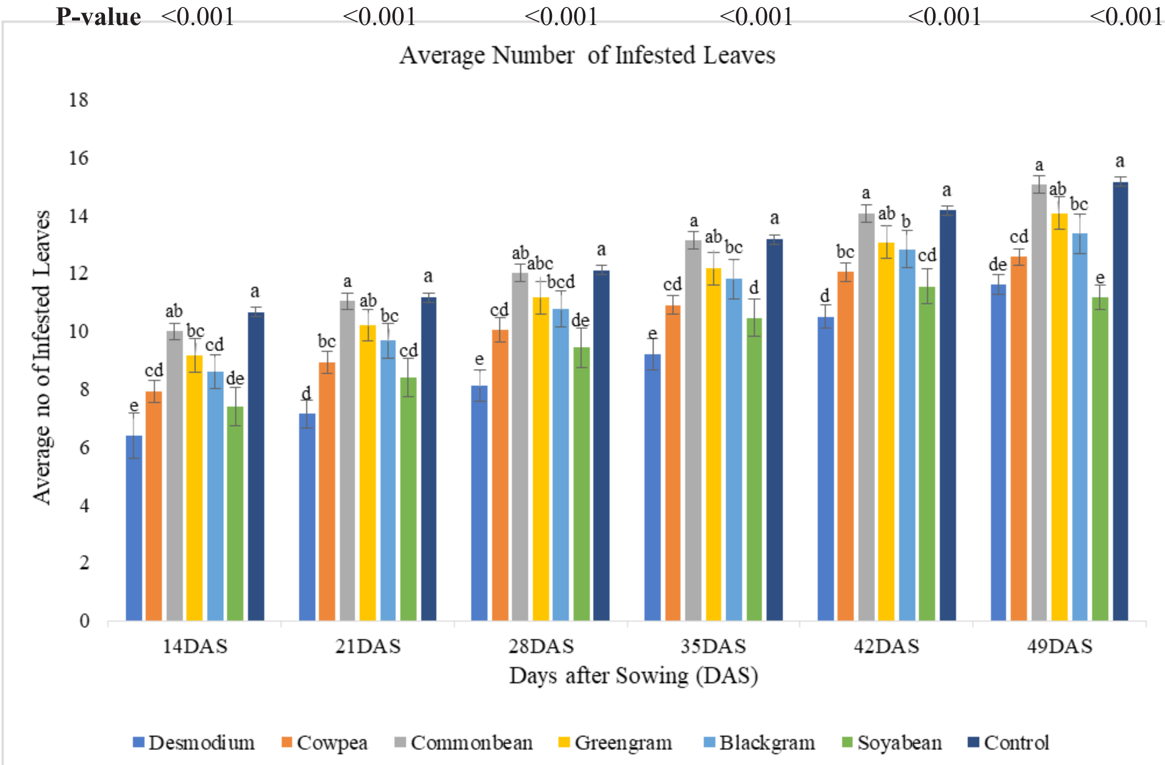

Figure 5: Average number of infested leaves

Maize leaves damage score

Based on Davis leaf score chart, intercropping legumes with maize significantly affected leaf damage scores caused by Fall Armyworm. Fourteen days after sowing, plots intercropped with Desmodium had the lowest average leaf damage score (3.00±0.28). In contrast, the highest foliage damage was observed in the control plot (5.83±0.16), followed by common bean (5.06±0.06), cowpea (4.66±0.16), black gram (4.33±0.16), green gram (4.00±0.28), and soybean (3.66±0.16). A similar pattern was seen 21 days after sowing, with the control plot showing the highest damage rating and Desmodium the lowest. This trend persisted at 28, 35, and 42 days after sowing, except for black gram and green gram, which exhibited less significant differences at 35 days after sowing (*Figure 6*).

P-value	<0.001	<0.001	<0.001	<0.01	<0.01

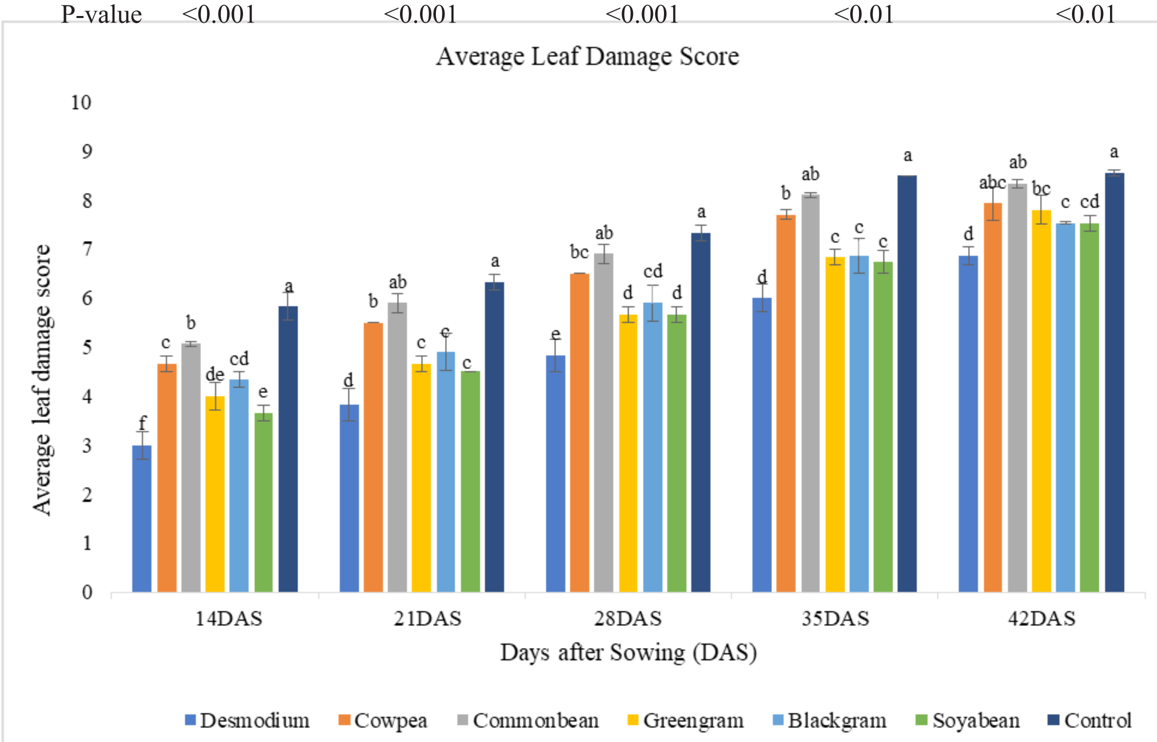

Figure 6:Average leaf damage score by fall armyworm

Average number maize tassels infested by fall armyworm

The relationship between treatments and average number of tassels infested during period of time from 7DAT to 35DAT was also notable. The highest damage was recorded in case of control plot (10.67±0.33) followed by common bean (9.33±0.33), cowpea (8.67±0.33), green gram (8.33±0.66), black gram (7.33±0.66), soyabean (7.33±0.33) and least infection in plot of Desmodium (5.67±0.33), respectively when observed after a week of tasselling. The pattern of damage scale observed at 14DAT, 21DAT, 28DAT and 35DAT was also alike with highest mean value at 35DAT as maximum damage was recorded in control plot (mono cropped) and least damage was recorded in Desmodium plot (9.67±0.33) (*Figure 7*).

P-value <0.001 <0.001 <0.001 <0.001 <0.001

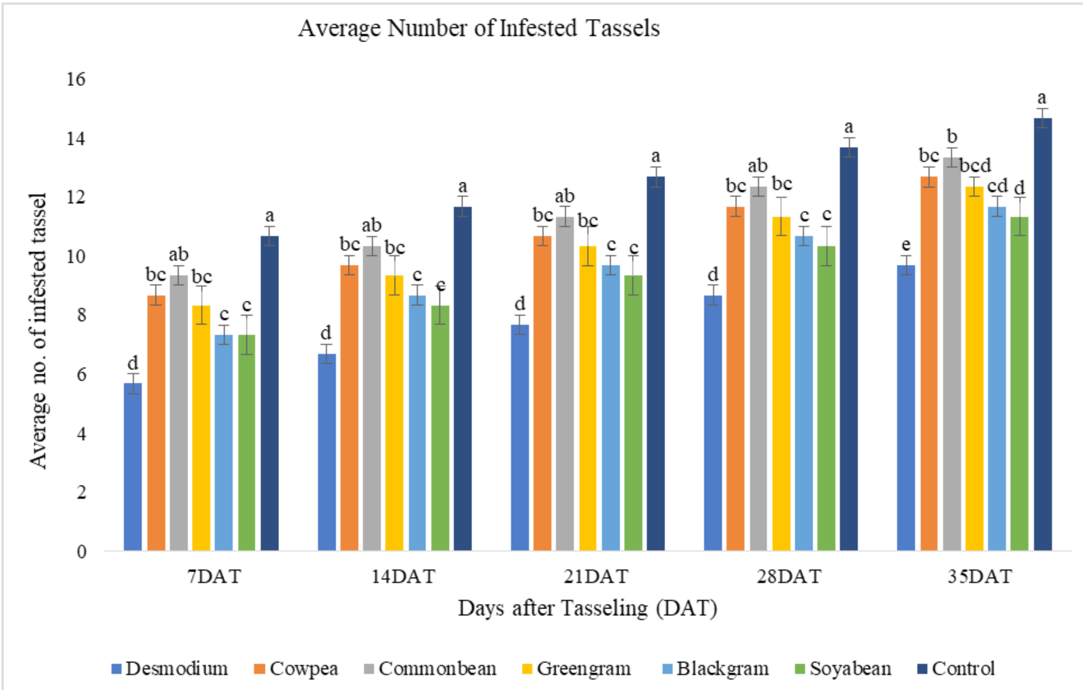

Figure 7: Average number of maize tassels infested by fall armyworm

Effect of treatments on maize yield

The correlation between treatments and average yield obtained from the plot at the day of harvesting also had major significance. The yield of maize intercropped with Desmodium was observed to be the highest (8.86±0.23) (tons/ha) among maize intercropped with other legumes. The second highest yield was observed from the soyabean treated plot (8.26±0.11) (tons/ha), followed by green gram (7.66±0.16) (tons/ha), black gram (7.16±0.16) (tons/ha), cowpea (6.7±0.15) (tons/ha), common bean (6.66±0.14) (tons/ha) and lastly least harvest was obtained in control plot (mono cropped) (*Figure 8*).

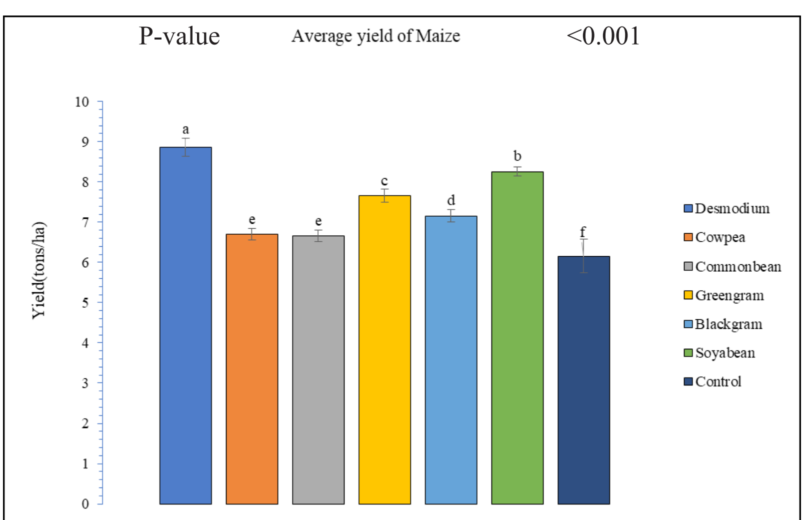

Figure 8: Average yield of maize

DISCUSSION

Number of FAW affected maize plants observed under different scale basis (7 days interval) as influenced by intercropping system of Desmodium, black gram, green gram, chickpea, common bean and cowpea with maize was evaluated. Almost all the treatments exhibited effective results as compared to the control plot.

During the scotophase, napier grass produces noticeably stronger volatile chemicals that attracts FAW females for oviposition (Scheidegger et al., 2021). When compared to eggs deposited on border crops used, as double the size of maize, a significant number of eggs were deposited on grass types like napier and brachiaria species, indicating that these types of grass could serve as pull-plants if they reach a minimum of double the size of maize (Cheruiyot et al., 2021). Nevertheless, as Napier grass is an unsuitable plant for their development, roughly 80% of larvae die; consequently, the grass being an appropriate trap plants for the pest. When early larval stages pierce the grass, it emits a sticky material that hinders the growth of the larvae (Khan et al., 1997).

Particularly hairy or sticky, *Desmodium uncinatum* (Jacq.) DC. can catch larvae that scatter throughout plants and rows (Antixenosis) and also repel the female ovipositing armyworms. Desmodium produces volatile repellent {(E)- *β*- ocimene and (E)-4,8-dimethyl -1,3,7-nonatriene} that repel the pests (Antibiosis) but may vary in different agro-climatic zones (Tumlinson et al., 1986). The effects of antixenosis and antibiosis also have been recorded in other legumes species like beans and, as trichome-based plant defense mechanisms have also been discovered in some legume plants, it may potentially function as physical barriers as well (Scheidegger et al., 2021). Legumes like beans, peas, and vetch contain quinolizidine alkaloids, which contribute to their allelopathic effects on FAW within maize fields (Peter Lual, 2022). Compared to maize mono-crops, where 95% infestation was observed, infestations indices in sustainable and conventional Push-Pull technology systems were 36% and 38%, respectively (Hailu et al., 2018). Intercropping rows of beans, soybeans, cowpeas, and pigeon peas was found to serve as trap crops for various pests like leaf hoppers, leaf beetles, *Helicoverpa* sp, stalk borers, and fall armyworms (Mapuranga et al., 2015). The decrease in fall armyworm population resulting from combining maize with cowpea, soybean, common bean, black gram or green gram in this research could also be attributed to the increase in natural enemies facilitated by the cultivation of diverse plant species together. Previous findings suggest that plant diversity influences pest populations by emitting olfactory cues and disrupting the spatial cycle of pests (Ratnadass et al., 2012). These mechanisms may also have resulted in comparable effects on reducing FAW infestations in maize by intercropping with legumes in this study.

The least amount of FAW infestation was observed in maize plants intercropped with Desmodium, according to all observations recorded using the Davis scale. This could be attributed to the expansive nature of desmodium, which created barriers to the movement of FAW between rows of maize. Additionally, the scent emitted by desmodium may have been unfavorable to FAW. Intercrops such as desmodium, soybeans, black gram, green gram, common beans, and cowpeas were found to be increasingly effective in deterring FAW, with desmodium showing the highest effectiveness compared to other treatments. Lual (2022) also showed the superiority of Desmodium, Beans and Cowpea for cultural FAW control in maize crop on comparison with other leguminous crops. Hailu (2018) suggested that intercropping maize with leguminous crops such as soybeans, groundnuts, and beans offer protection against fall armyworm compared to monocropping, aligning well with the findings of the study. Harrison (2019) refers that fall armyworm can be managed sustainably through effective soil management, intercropping with carefully chosen companion plants, and diversifying the agricultural environment.

Incorporating additional species into the mixture diminishes the insect pest's capacity to locate susceptible host plants for feeding, consequently lowering migrating populations (Meagher et al., 2004). It is possible that FAW might avoid laying eggs on main host maize and prefer alternative legumes that is intercropped with the maize because of confusion, thereby diminishing its impact on maize plants. These perplexing mechanisms could have also been responsible for the comparable decrease in pest larvae observed in the maize intercropped plots with various types of leguminous plants in this study.

Among the treatments (mungbean, sesame and cowpea), the maize+cowpea combination showed the least number of FAW-infested plants whereas sole maize cropping showed maximum infestations (Bhagat et al., 2022). However, this statement does not agree with the findings of our cowpea results. The efficacy of cowpea in our research plot could have been masked by the poor quality of seeds and at the same time, the choice and number of treatments used may have also differed the results. Critical variations were seen between push-pull technology and mono-cropped maize while scoring the FAW infestation during the early to tasseling growth phases (Hailu et al., 2018). The use of legume and maize intercrop resulted in plant damage levels that were all higher than those of the chemical treatment but lower than those of the maize-only treatment (Kalama & Makila, 2022).

The enhanced yields, however, are due to a combination of variables, including the parasitic weed's management and increase in soil health brought about by legumes' nitrogen-fixing ability. These reasons cannot be entirely credited to the technology's successful control of fall armyworm. Though, pest attract-repel technique using napier and legumes plays a major role in FAW management, it also contributes to creating suitable environment for plant growth and natural enemies. It is advised to integrate legumes instead of chemical treatment because legumes fix nitrogen, enhance organic matter, soil biota, carbon sequestration, moisture retention, and soil fertility while halting further soil degradation. The technology's ability to control such a destructive pest along with the smallholder farmers' favorable opinions of it, where it has already been used to control striga and stemborers, demonstrate its reliability and adaptability and indicate that it is an environmentally sound and socially acceptable method of managing pests (Midega et al., 2018). From this study, we concluded that, as an ultimate option for controlling this pest we can rely on the legumes intercropping that repels the pest from the main plot. Firake (2019) and Khatri (2020) also reported analogous finding.

CONCLUSION

Among legumes intercropped, Desmodium had the lowest infested plant count, followed by soyabean, black gram, green gram, common bean, and cowpea, while maximum infestation was observed in monocropping. Additionally, the yield in Desmodium and soyabean intercropped plots was higher than that in the control plot, rendering these treatments superior in effectiveness. However, a prominent effect of other legume intercropping was also observed in terms of having the lower infested plants, infested leaves, scores, and infested tassels. Other edible and non-edible legumes can also be included as treatments for further study. Planting napier grass and desmodium a month earlier than maize was found to be productive. Further research on a multi-seasonal and multi-locational basis can be conducted for more precise results.

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