

Maize-legume intercropping for Fall armyworm management

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1. Introduction

Fall armyworm (*Spodoptera frugiperda* J.E. Smith) is one of the most destructive insect pests of maize globally, posing a serious threat to food security in sub-Saharan Africa, South Asia, and parts of Latin America (Goergen et al., 2016). Native to the Americas, the pest has rapidly expanded its geographical range and successfully adapted to diverse agro-ecological conditions, resulting in substantial yield losses and economic damage in maize-based farming systems worldwide (Montezano et al., 2018). Its high reproductive capacity, migratory behaviour, and ability to attack maize at multiple growth stages have made fall armyworm particularly difficult to manage.

In Bhutan, maize is a major staple crop and an important source of food and income for smallholder farmers. However, maize production is increasingly constrained by fall armyworm infestations, which damage plants from the seedling stage through to ear formation, leading to defoliation, reduced grain yield, and increased expenditure on pest control (Mahat et al., 2021). These challenges highlight the urgent need for management strategies that can effectively suppress fall armyworm while maintaining maize productivity and safeguarding farmer livelihoods.

Chemical insecticides remain the primary method used to control fall armyworm (Yang et al., 2021). Nonetheless, the frequent and often indiscriminate use of pesticides has resulted in insecticide resistance, environmental contamination, and adverse effects on non-target organisms, including natural enemies and beneficial insects (Diez-Rodriguez & Omoto, 2001; Meagher et al., 2016). As a result, attention has increasingly shifted toward agroecological pest management approaches that are environmentally sustainable and economically feasible.

Intercropping, defined as the simultaneous cultivation of two or more crop species within the same field, has emerged as a promising strategy for reducing insect pest pressure and enhancing agroecosystem resilience (Assefa, 2018; Kasoma et al., 2021). By increasing plant diversity, intercropping can interfere with pest host-finding through disruption of visual and chemical cues (Poveda et al., 2008), while certain intercrop species release bioactive compounds that deter herbivorous insects (Bakthavatsalam, 2016). In addition, diversified cropping systems provide floral resources, alternative prey, and shelter that support predators and parasitoids, thereby strengthening natural biological control (Mailafiya, 2011).

Maize–legume intercropping has shown particular potential for managing fall armyworm, with several studies reporting reductions in infestation levels and damage when maize is intercropped with legumes such as common bean, cowpea, and soybean (Hailu et al., 2018; Tanyi et al., 2020; Udayakumar et al., 2021; Jalloh et al., 2023). The inclusion of legumes can enhance the abundance of natural enemies and contribute to the ecological regulation of fall armyworm populations (Kebede et al., 2018; Matova et al., 2020). However, the effectiveness of maize–legume intercropping in suppressing fall armyworm, its influence on natural enemy populations, and its effects on maize yield and farm profitability are highly context-dependent and remain insufficiently documented under Bhutanese agro-ecological conditions.

Therefore, this study evaluates maize–legume intercropping as a sustainable and integrated approach to fall armyworm management by comparing intercropped systems with conventional maize monocropping. Specifically, the study examines the extent to which maize–legume intercropping reduces fall armyworm infestation and damage, enhances the abundance of natural enemies associated with fall armyworm, and influences maize grain yield performance. In addition, the economic viability of maize–legume intercropping is assessed through cost–benefit analysis using indicators such as profitability, benefit–cost ratio, and return on investment.

By addressing these interrelated ecological and economic dimensions, the study aims to generate evidence-based recommendations on whether maize–legume intercropping can serve as a practical, environmentally sound, and economically viable strategy for fall armyworm management and maize production in Bhutan. The trial is a deposit work in collaboration with Entomology Program of National Plant Protection Center and Plant Protection Unit of ARDC, Bajo.

2. Materials and Methods

2.1 Study site and design

The trial was conducted at Rilangthang under Sergithang gewog in Tsirang Dzongkhag from March– July 2026. The trial was carried out in same area one was set up in dry land (27°7'4" N, 90°4'15" E, 550 masl). The experiment trial was laid out using a Randomised Complete Block Design (RCBD), consisting of four treatments with three replications at each site. The treatments were: (i) maize monocrop (control), (ii) maize intercropped with grey pole bean (an indeterminate climbing legume), (iii) maize intercropped with Borlotto bean (a determinate

bushy legume), and (iv) maize intercropped with soybean ('Khangma Lebi 1', a determinate legume). The total experimental area measured 273 m² (21 m × 13 m) and was divided into twelve plots of 12 m² each (4 m × 3 m), arranged in four rows and three columns. Each plot was separated by a 1 m-wide alley and surrounded by a 1 m border to minimise edge effects and facilitate access for data collection.

To improve soil fertility, well-decomposed farmyard manure (FYM) was incorporated into the soil during land preparation. At planting, Suphala (NPK 15:15:15) and muriate of potash (MoP; 60% K₂O) were applied as basal fertilisers. Urea (46% N) was split-applied, with half the dose given at the V5 stage (35–40 days after sowing) and the remaining half at the V9 stage (60–70 DAS). The line sowing of maize seeds was done to maintain uniform numbers of plants per plot.

Each plot contained five rows of maize, sown with a row spacing of 0.7 m and 0.3 m spacing between plants, resulting in a total of 45 maize hills per plot. Legume rows were alternated with the maize rows, with six rows of legumes spaced 0.7 m apart and 0.15 m between plants, yielding 102 legume hills per plot. For both maize and legumes, three seeds were sown per hill. At the V2 growth stage, only the most vigorous seedling in each hill was retained to ensure a uniform plant stand and minimise intraspecific competition. Yangtsepa maize seeds and the three legume species —grey pole bean, Borlotto bean, and soybean ('Khangma Lebi 1') — were sown simultaneously to ensure synchronized growth stages for accurate comparison in pest management effectiveness.

2.2 Data collection

For data collection, 14 plants were randomly selected and tagged from each plot. Data were collected fortnightly monitoring all the leaves on these plants, recording the number of live larvae, egg masses and record the number of natural enemies observed on each leaf. Data were collected at different stage of the plants: V2 (7 days after sowing), V5 (21 days after sowing), V9 (35 days after sowing), V14 (49 days after sowing), and R1 (63 days after sowing). For the damage severity, at the end of the vegetative stage (V12), all leaves on 14 tagged plants were examined for signs of damaged using the Leaf Damage Index method described by Toepfer et al. (2021).

3. Result and Discussion

3.1 Effect of treatments on fall armyworm larval abundance.

Negative binomial regression analysis revealed a highly significant effect of treatment on fall armyworm (FAW) larval abundance ($\chi^2 = 33.49$, $df = 3$, $p < 0.001$). Relative to Treatment 1, larval counts were significantly reduced in Treatment 2 ($\beta = -0.908$, $p < 0.001$), Treatment 3 ($\beta = -1.090$, $p < 0.001$), and Treatment 4 ($\beta = -1.116$, $p < 0.001$). The largest reductions in larval abundance were observed in Treatments 3 and 4.

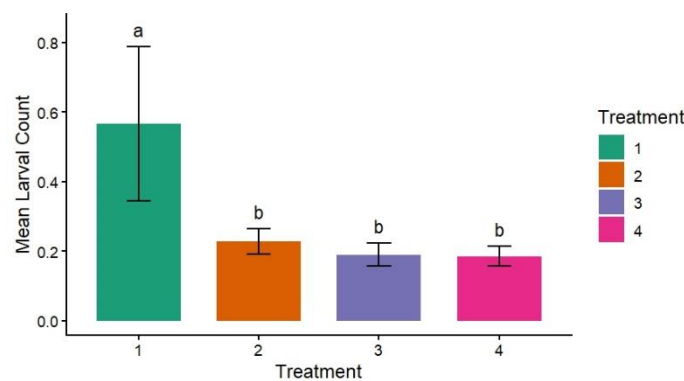


Figure 1. Showing mean fall armyworm larval counts under different treatments. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to pairwise comparisons from the negative binomial regression model ($P < 0.05$).

The significant reduction in larval abundance observed in Treatments 2, 3, and 4 indicates that these management strategies were effective in suppressing FAW populations. The higher larval counts recorded in Treatment 1 suggest that this treatment provided comparatively less protection against infestation. Reduced larval abundance in the remaining treatments may be attributed to mechanisms such as disruption of host location, modification of the crop environment, or enhanced activity of natural enemies.

These findings support the resource concentration hypothesis, which proposes that herbivorous insects are more likely to locate and remain in habitats where host plants occur in concentrated and uniform stands (Root, 1973). Increased plant diversity through intercropping or other ecological management practices can interfere with pest host-finding behaviour and reduce pest establishment.

The comparable performance of Treatments 2, 3, and 4 suggests that all three management options provided a similar level of suppression. Similar reductions in FAW populations under

diversified cropping systems have been reported by Harrison et al. (2019), who noted that agroecological approaches can contribute substantially to FAW management through ecological regulation of pest populations. Furthermore, diversified systems may support greater abundance and diversity of natural enemies, thereby strengthening biological control services (Landis et al., 2000).

3.2 Effect of maize growth stage on fall armyworm larval abundance.

Maize growth stage had a highly significant effect on FAW larval abundance ($\chi^2 = 79.25$, $df = 4$, $p < 0.001$). Pairwise comparisons revealed that larval abundance at the V2 stage was significantly lower than at V5 ($p < 0.001$), V9 ($p < 0.001$), V14 ($p = 0.002$), and R1 ($p = 0.002$). In contrast, no significant differences were observed among V5, V9, V14, and R1 stages ($p > 0.05$).

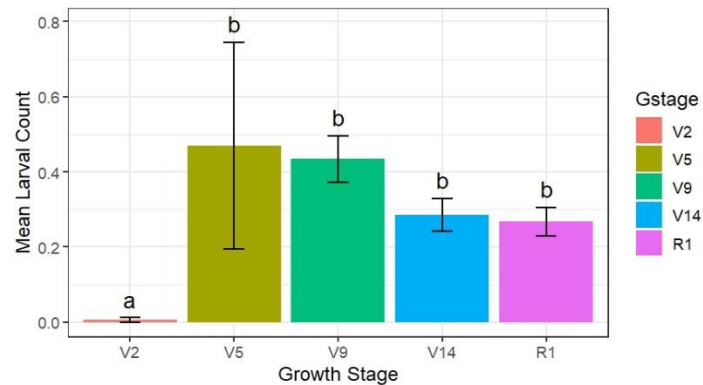


Figure 2. Mean fall armyworm larval counts at different maize growth stages. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to pairwise comparisons from the negative binomial regression model ($P < 0.05$).

The significant influence of crop growth stage on FAW abundance highlights the importance of plant phenology in determining pest infestation patterns. The low larval abundance observed at the V2 stage suggests that young maize plants were less attractive or less suitable for oviposition and larval establishment than older plants. As maize developed from V5 onwards, larval populations increased significantly, indicating greater suitability of the crop for feeding and development.

Several studies have reported that FAW infestation generally increases as maize plants produce greater leaf biomass and develop a more complex canopy structure, which provides favourable feeding sites and shelter for larvae (Prasanna et al., 2018). The whorl stage of maize

is particularly vulnerable because it offers protected feeding habitats that reduce exposure to environmental stress and natural enemies.

The absence of significant differences among V5, V9, V14, and R1 suggests that once FAW populations become established, larval abundance remains relatively stable throughout subsequent developmental stages. Similar infestation patterns have been reported in maize-growing regions worldwide, where FAW populations increase rapidly after crop establishment and persist until reproductive stages (Day et al., 2017).

These findings indicate that monitoring and management interventions should be implemented during the early vegetative stages of crop development to prevent population buildup and subsequent damage.

3.3 Effect of Intercropping Treatments on Fall Armyworm Severity

The severity of fall armyworm (FAW) damage differed significantly among treatments (Kruskal–Wallis test, $P < 0.05$). Mean severity scores ranged from 0.388 to 0.855 across treatments (Figure X). Treatment 1 recorded the highest mean severity score (0.855 ± 0.041), whereas Treatments 2 and 4 exhibited the lowest severity scores, with means of 0.397 ± 0.031 and 0.388 ± 0.029 , respectively.

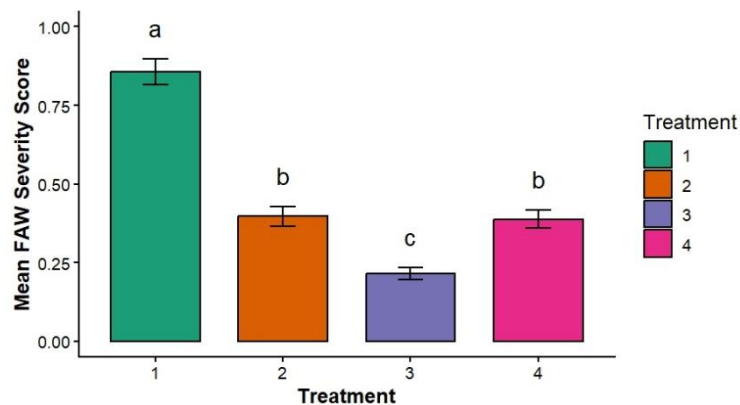


Figure 3. Showing Mean fall armyworm severity scores under different intercropping treatments. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to Dunn's test (Bonferroni-adjusted, $P < 0.05$).

The significant differences in FAW severity among treatments suggest that intercropping influenced the extent of pest damage in maize. The lower severity scores observed in Treatments 2 and 4 indicate that these intercrop combinations may have created conditions that were less favourable for FAW infestation and feeding. Intercropping systems are known to reduce pest pressure through increased plant diversity, disruption of host-location behaviour, modification of the crop microclimate, and enhancement of natural enemy activity (Altieri & Nicholls, 2004).

The higher severity recorded in Treatment 1 suggests that this treatment provided comparatively less protection against FAW damage. The ability of diversified cropping systems to interfere with insect host-finding behaviour has been widely reported and is consistent with the resource concentration hypothesis, which proposes that herbivorous insects are more likely to locate and remain on host plants when they occur in dense and uniform stands (Root, 1973). In contrast, intercrops can mask host cues and reduce pest colonization.

The reduced severity observed in Treatments 2 and 4 may also be associated with greater biological control activity. Diverse cropping systems frequently support higher populations of predators and parasitoids by providing alternative food sources, shelter, and favourable microhabitats (Landis et al., 2000). Enhanced natural enemy abundance has been reported to contribute significantly to the suppression of FAW populations in agroecosystems.

Although severity scores were generally low across all treatments, the significant differences detected indicate that intercropping can influence FAW damage levels even under relatively low pest pressure. Similar reductions in FAW infestation and crop damage have been reported in maize-based intercropping systems where companion crops disrupted pest establishment and improved ecological regulation of insect populations (Harrison et al., 2019).

4. Conclusion

The present study demonstrates that maize–legume intercropping can play a meaningful role in the sustainable management of fall armyworm (FAW) under Bhutanese agro-ecological conditions. Although differences in live FAW populations were site-specific, with significant treatment effects observed only at one location, FAW damage was consistently lower in intercropped systems compared to maize monocropping at both sites. This indicates that intercropping does not necessarily eliminate FAW infestations but effectively reduces damage severity, likely through disruption of host-finding behaviour, increased habitat complexity, and enhanced biological control. These findings reinforce the ecological disadvantages of maize monocropping in FAW-prone environments and highlight intercropping as a viable agroecological strategy for pest suppression.

The trial is on-going and we are yet to collect yield data and do economic analysis.

5. References

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