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RESEARCH PAPER

Legume intercropping for sustainable management of fall armyworm (*Spodoptera frugiperda*) in maize in the north-eastern Himalayas, India

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Abstract: Maize (*Zea mays* L.) is an essential crop in northeast India, widely cultivated for food, fodder, and industrial purposes. However, maize cultivation in this region faces significant challenges, including poor soil fertility, pest infestations, and a lack of access to modern inputs. The 2018 invasion of the fall armyworm (FAW) (*Spodoptera frugiperda*) has further threatened maize production, leading to substantial yield losses. In northeast India, where smallholder farmers rely on rainfed, low-input farming systems, there is an urgent need for sustainable pest management strategies. Intercropping, particularly maize-legume systems, offers a potential solution by enhancing soil fertility through nitrogen fixation and providing ecological pest control benefits. This study was conducted in Manipur, a key maize-growing state in northeast India, to evaluate the effectiveness of maize-legume intercropping in managing FAW infestations and improving maize productivity. Field experiments were conducted over two years (2020 in experimental field and 2021 in farmers field), using a randomized block design (RBD) with treatments including sole maize and maize intercropped with legumes such as soybean, groundnut, green gram, and cowpea in different row ratios. The study assessed grain yield, stover yield, maize equivalent yield, and pest infestation levels. The results showed that maize-legume intercropping significantly reduced FAW infestation compared to sole maize. The maize-groundnut intercropping system recorded the highest grain yield (5869 kg/ha in 2020 and 3430 kg/ha in 2021) and the lowest pest infestation. Additionally, intercropped exhibited higher economic returns, making this practice both agronomically and economically viable for smallholder farmers in the region.

Keywords: Maize • Legume • Intercropping • Fall armyworm

Introduction

Maize (*Zea mays* L.) is a critical cereal crop for food security and economic development worldwide, particularly in India. The diverse agro-climatic conditions in north eastern India, characterized by hilly landscapes and abundant rainfall, make maize an ideal crop for rainfed agricultural systems (Das *et al.,* 2020). However, maize cultivation in this region faces several challenges, notably soil fertility issues, poor infrastructure, and the emergence of invasive pests such as the fall armyworm (FAW) (*Spodoptera frugiperda*).

Insect and pests can cause yield losses of 20% to 60%, especially in regions like the NER, where farmers have limited access to pest control resources (Day *et al.,* 2017). FAW, first detected in India in 2018, has spread rapidly across the country, posing a serious threat to maize production. This pest is particularly devastating to rainfed, low-input agricultural systems, which are prevalent in the NER, and the high cost and environmental impact of chemical pesticides make them impractical for smallholder farmers (Meena *et al.,* 2020). Therefore,

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alternative, sustainable pest management strategies are urgently needed.

Intercropping, a traditional agricultural practice in northeast India, offers a promising solution to these challenges. Intercropping involves growing two or more crops together in the same field, often with complementary characteristics that enhances resource use efficiency by optimizing light, water, and nutrient uptake, particularly in the marginal, hilly environments (Lithourgidis *et al.,* 2011). In addition to its agronomic benefits, intercropping offers significant ecological advantages, particularly for pest management. By diversifying the cropping system, intercropping disrupts pest lifecycles and reduces the likelihood of severe infestations. This is especially important for managing the FAW, which predominantly affects monocultures of maize (Poveda *et al.,* 2008). Maize-legume systems help smallholder farmers maximize the use of limited land resources by producing multiple crops simultaneously, thus enhancing food security and household income. Legumes contribute to soil health and reduce soil erosion, which is a critical concern in the region (Ghosh *et al.,* 2006). The presence of legumes alters the microclimate, reduces the attractiveness of maize to pests, and promotes the presence of natural enemies that prey on pests like FAW (Khan *et al.,* 2014). Legumes like cowpea and groundnut, in particular, can attract beneficial insects, contributing to the "push-pull" mechanism in which pests are repelled from the main crop while beneficial insects are attracted to control pest populations (Khan *et al.,* 2014). This approach aligns well with the ecological needs of the NER, where farmers rely on environmentally friendly practices due to the region's fragile ecosystems and limited access to agrochemicals (Das *et al.,* 2020).

This study was conducted to evaluate the effects of maize-legume intercropping on maize yield and FAW severity. The findings will provide valuable insights into sustainable pest management strategies and contribute to improving maize production systems in northeast India.

Materials and methods

The experiments were conducted in two distinct phases: the first in the 2020 *kharif* season at research farm, Central Agricultural University, Imphal, and the second in the 2021 *kharif* season in farmers' fields at Andro Machengpat village, Imphal east district, Manipur in total area of 2 ha. The soil characteristics at the research farm indicated a pH of 5.7, an organic carbon content of 0.89%, and available nitrogen, phosphorus, and potassium levels of 278, 19.5, and 215 kg/ha, respectively. In contrast, the soil in the farmers' field had a pH of 5.3, an organic carbon content of 0.62%, and nutrient levels of 216 kg/ha for nitrogen (N), 17.3 kg/ha for phosphorus (P_2O_5), and 189 kg/ha for potassium (K_2O). During the growing period in 2020, a total rainfall of 673 mm was recorded, with minimum and maximum temperatures of 19°C and 37°C, respectively. Similarly, the growing period in 2021 experienced a total rainfall of 527 mm, along with a minimum temperature of 18°C and a maximum temperature of 34°C. A randomized block design (RBD) was used for both field trials, with four replications. In the 2020 trial, nine treatments were tested, consisting of sole maize and different maize-legume (soybean, groundnut, green gram and cowpea) combination in 1:1 and 2:2 row ratios. In 2021, five treatments were evaluated in farmers' fields with sole maize and maize-legume combinations in a 1:1 row ratio. Maize (variety HQPM-1), soybean (JS 335), groundnut (ICJS 76), green gram (MH 921) and cowpea (Cowpea Ali 265) were sown in July keeping 60 x 25 m^2 spacing for maize and intercropping in additive series. Recommended doses of fertilizer off maize as 120:60:60 kg/ha $N:P_2O_5:K_2O$. Nitrogen were applied in three split doses while P and K were applied once at basal. Similar practice was followed at the farmer's field. Crop growth parameters, yield, and FAW infestation were recorded following standard protocols. Pest severity was assessed using the Davis scale method (Davis *et al.,* 1992) at three growth stages (knee-high, tasseling, and maturity). Infestation percentage was calculated by counting damaged plants. Economic analysis, including net returns and benefit-cost ratios, was based on the prevailing market prices of maize and legumes. The data were analyzed using ANOVA, and means were compared using critical difference (CD) values at a 5% significance level, following Gomez and Gomez (2010).

Results and discussion

Fall armyworm severity and infestation

The data indicate that sole maize experiences the highest levels of infestation, with severity reaching 5.0, 5.7, and

3.6, and the percentage of infestation reaching 31.4%, 24.7%, and 15.8% at the knee-high, tasseling, and maturity stages, respectively. In contrast, intercropping maize with legumes significantly reduces infestation. Among the intercropped systems, maize + groundnut (1:1) shows the lowest infestation, with severity dropping to 2.6 at knee-high and only 6.4% infestation at maturity. The effectiveness of intercropping varies, with the 1:1 row ratio generally providing better protection than the 2:2 ratio. Maize intercropped with soybean, green gram, and cowpea also shows reduced infestation, though not as pronounced as groundnut. Similar trends were observed in farmers' fields, with sole maize having the highest severity (4.3) and infestation (18.8% at maturity), while maize-groundnut had the lowest severity (2.7) and infestation (2.3%) (Table 2). Intercropping reduces the severity and incidence of FAW due to increased biodiversity, which disrupts the pest's ability to locate its host plant. The presence of legumes creates a more complex environment that interferes with the olfactory and visual cues that FAW uses to locate maize. This finding is consistent with the research by Poveda *et al.* (2008), who found that intercropping can reduce pest pressure by enhancing biological control. Moreover, the legumes themselves may harbour natural enemies of the FAW, further contributing to pest control (Khan *et al.,* 2014).

Growth and yield of maize

The sole maize treatment exhibited the longest duration for both tasseling (56.0 days) and silking (59.7 days). Conversely, the 1:1 intercropping ratio with groundnut showed the shortest duration for both tasseling (51.7 days) and silking (54.0 days). Among the 2:2 ratios, the maize + soybean combination resulted in tasseling at 55.0 days and silking at 58.3 days (Figure 1). The variance in days to tasseling and silking across treatments was statistically significant, with critical differences of 1.8 days for tasseling and 1.3 days for silking. The reduced

Table 1. Severity and percentage of infestation of fall armyworm as influence by intercropping of legumes in different row ratios

Treatments	Severity of infestation			Percentage of infestation		
	At knee high	At tasseling	At maturity	At knee high	At tasseling	At maturity
Sole Maize	5.0	5.7	3.6	31.4	24.7	15.8
Maize + Soybean (1:1)	3.8	4.8	2.5	20.3	13.7	9.7
Maize + Groundnut (1:1)	2.6	3.1	1.4	17.5	11.7	6.4
Maize + Green gram (1:1)	3.0	3.4	1.4	18.9	12.2	6.9
Maize + Cowpea (1:1)	3.3	3.9	2.0	19.0	13.7	7.9
Maize + Soybean (2:2)	3.5	4.8	3.0	23.3	19.8	12.2
Maize + Groundnut (2:2)	2.7	3.7	1.7	20.9	14.0	9.4
Maize + Green gram (2:2)	2.9	3.9	1.5	21.4	15.1	9.0
Maize + Cowpea	3.0	4.0	1.7	20.5	15.9	9.8
SEm (±)	0.3	0.3	0.2	1.4	0.9	0.9
CD	0.8	0.9	0.6	4.3	2.6	2.7

Table 2. Severity and Percentage of infestation of fall armyworm as influence by intercropping of legumes at farmer's field

Treatments	Severity of infestation			Percentage of infestation		
	At knee high	At tasseling	At maturity	At knee high	At tasseling	At maturity
Sole maize	4.3	6.1	4.5	18.7	27.9	18.8
Maize + Soybean	3.9	5.3	2.2	9.5	16.7	7.8
Maize + Groundnut	2.7	3.0	1.5	7.4	13.0	2.3
Maize + Green gram	3.2	3.4	2.1	7.6	12.8	4.6
Maize + Cowpea	3.3	3.7	1.8	8.2	13.3	5.8
SEm (±)	0.2	0.3	0.2	0.7	1.3	1.4
CD	0.5	0.8	0.6	2.1	4.1	4.3

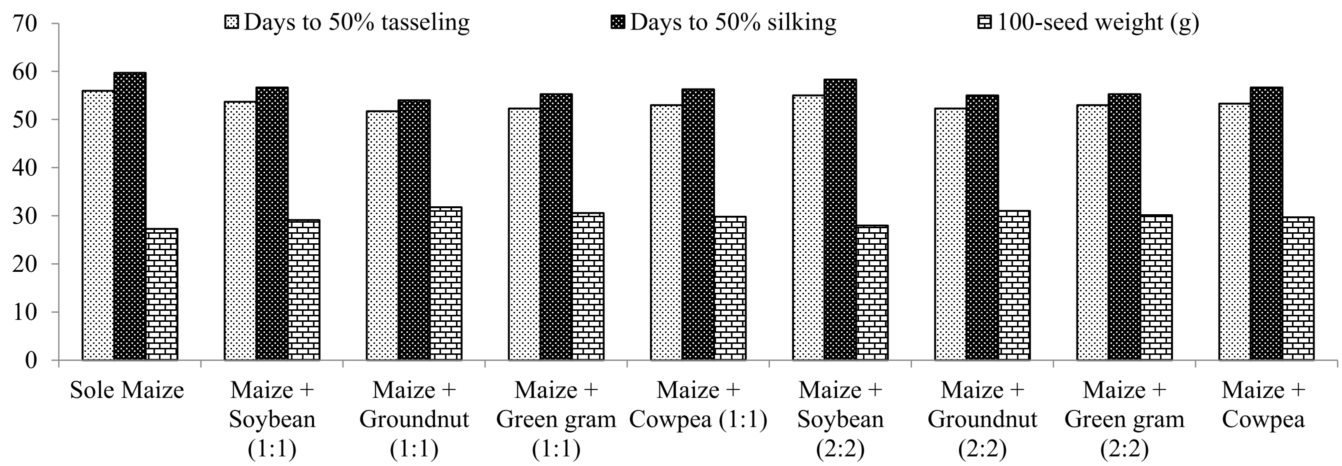

Figure 1. Number of days to 50% tasseling, silking and 100 seed weight of maize as influence by intercropping with legumes

Table 3. Yield and economics of maize as influence by intercropping with legumes in different row ratios at experimental field

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Maize equivalent yield (kg/ha)	Net return (Rs./ha)	B:C ratio
Sole Maize	4461	9833	4461	46536	2.09
Maize + Soybean (1:1)	4779	10222	6483	70625	2.46
Maize + Groundnut (1:1)	5869	13965	8308	109161	3.20
Maize + Green gram (1:1)	5457	12520	7947	101362	3.13
Maize + Cowpea (1:1)	5182	11799	7545	80640	2.67
Maize + Soybean (2:2)	4354	9740	5358	52148	2.08
Maize + Groundnut (2:2)	5554	11928	7543	91823	2.85
Maize + Green gram (2:2)	5249	10516	7501	93040	2.96
Maize + Cowpea	5022	10096	6976	72237	2.50
SEm (±)	304	802	355	6216	0.13
CD	912	2403	1065	18627	0.39

time to tasseling and silking in legume intercropping treatments, particularly with groundnut, suggests that legumes may enhance nutrient availability or improve soil health, leading to earlier maturation (Srinivas and Reddy, 2018). This is consistent with earlier studies that demonstrated how intercropping can optimize light and nutrient use, thus promoting faster growth rates (Ofori and Stern, 1987). The highest 100-seed weight was observed in the 1:1 maize + groundnut treatment (31.8 g), while sole maize produced the lowest weight (27.3 g). Likewise, in the farmers' fields, a similar trend was observed, with reduced durations to 50% silking and tasseling, as well as heavier seed weights, in the intercropping with groundnut at a 1:1 ratio (Figure 2). The increase in 100-seed weight in intercropped treatments, especially with groundnut, can be attributed to improved resource competition and potentially better moisture retention and nutrient cycling within the intercropped systems (Yin *et al.,* 2021). These results align with the findings of Khaliq *et al.* (2016), who reported similar enhancements in seed quality when legumes were intercropped with cereals.

Grain yield was significantly influenced by intercropping with legumes. The highest grain yield was recorded in the maize-groundnut intercrop (5869 kg/ha) in a 1:1 ratio, followed by maize-green gram (5457 kg/ha), whereas sole maize produced the lowest grain yield (4461 kg/ha) (Table 3). The 2:2 row ratio treatments resulted in slightly lower yields than the 1:1 row ratio treatments, indicating that closer planting might enhance competitive advantage for maize in intercropped systems. This is consistent with the findings of Mohan *et al.* (2016); Lithourgidis *et al.* (2011); Sahu (2006), who reported that intercropping systems generally result in

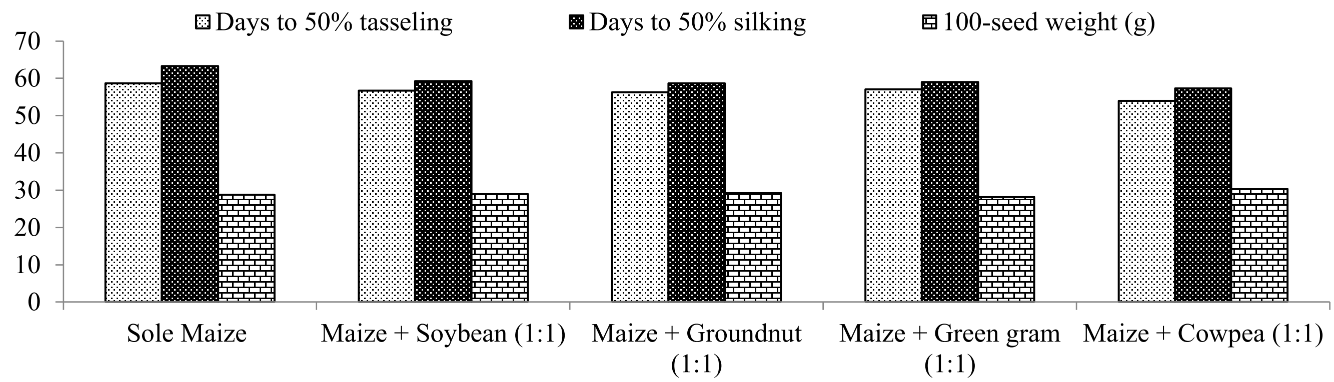

Figure 2. Number of days to 50% tasseling, silking and 100 seed weight of maize as influence by intercropping with legumes at farmer's field

higher yields due to complementation. In the farmers' field trials, similar trends were observed. The maize-groundnut system recorded the highest grain yield (3430 kg/ha), while sole maize produced the lowest yield (3061 kg/ha) (Table 4). The relatively lower yield in farmers' fields compared to the experimental plots may be attributed to variations in management practices, soil fertility, and environmental factors, as also noted by Rao and Willey (1980). Previous studies, including those by Agegnehu *et al.* (2006), support the idea that legume intercrops can increase maize yields by improving soil fertility. Furthermore, the competitive interaction between maize and legumes in a 1:1 ratio allows for efficient utilization of the available resources, explaining the higher yields in this system (Ijoyah and Jimba, 2012).

Stover yield followed a similar pattern to grain yield, with the maize-groundnut system again producing the highest stover yield (13,965 kg/ha), followed by maize-green gram (12,520 kg/ha). Sole maize produced the lowest stover yield (9,833 kg/ha). This increase in stover yield can be attributed to better growth of maize when intercropped with legumes, as legume root exudates can stimulate maize root growth, improving nutrient uptake (Sanginga *et al.,* 2003). The stover yield was highest in the maize-groundnut intercrop (10,657 kg/ha) and lowest in sole maize (7,852 kg/ha) (Table 3). While yields were generally lower in the farmers' fields compared to the experimental plots, the trend of intercropping increasing biomass remained consistent. This finding aligns with the work of Li *et al.* (2015), who reported that intercropping can lead to higher biomass production, particularly in legume-based systems.

Economic analysis

Maize equivalent yield (MEY) considers the yield of both maize and intercrop legumes, adjusted to their economic value. The maize-groundnut intercrop had the highest MEY (8,308 kg/ha), followed by maize-green gram (7,947 kg/ha). Sole maize yielded only 4,461 kg/ha in MEY, reflecting the economic advantage of intercropping (Table 4). In the farmers' field, maize-groundnut had the highest MEY (5,164 kg/ha), and sole maize had the lowest (3,061 kg/ha) (Table 3). This highlights the economic benefit of intercropping, as observed in previous studies (Singh *et al.,* 2023; Lithourgidis *et al.,* 2011; Zhang *et al.,* 2007).

Table 4. Yield and economics of maize intercropping with legumes at the farmer's field

Treatments	Maize grain yield (kg/ha)	Maize stover yield (kg/ha)	Maize equivalent yield (kg/ha)	Net return (Rs./ha)	B:C ratio
Sole maize	3061	7852	3061	25119	1.77
Maize + Soybean (1:1)	3101	9292	4325	40469	2.04
Maize + Groundnut (1:1)	3430	10657	5164	58714	2.53
Maize + Green gram (1:1)	3409	9806	4534	51974	2.33
Maize + Cowpea (1:1)	3201	9205	5138	52141	2.29
SEm (±)	65	627	139	1681	0.05
CD	201	1932	427	5182	0.14

The increase in MEY demonstrates the significant economic benefits of intercropping maize with legumes. These results align with earlier findings from Waktola *et al.* (2019), who reported higher MEY in maize-legume intercropping systems compared to monocropping. The complementary nature of the two crops ensures that the overall productivity is higher than sole cropping, thus maximizing the returns per unit area.

Net returns were significantly higher in intercropping systems. The maize-groundnut intercrop generated the highest net return (Rs. 109,161/ha) and benefit-cost ratio (B:C ratio) of 3.20, while sole maize had the lowest net return (Rs. 46,536/ha) and B:C ratio of 2.09 (Table 3). In the farmers' field, the maize-groundnut system had the highest net return (Rs. 58,714/ha) and a B:C ratio of 2.53. Sole maize had the lowest economic returns with a net return of Rs. 25,119/ha and a B:C ratio of 1.77 (Table 4). The higher economic returns and B:C ratio in intercropped systems suggest that legume intercropping is more profitable than sole maize cultivation. This is due to the combined yields of maize and legumes, the reduction in pest damage, and the improved soil fertility brought about by legume nitrogen fixation. These results align with studies by Alabi *et al.* (2006) and Adetiloye *et al.* (1983), who reported higher economic returns in intercropping systems compared to monocropping due to efficient resource use and reduced input costs.

The results of both experimental and farmers' field trials consistently demonstrate the agronomic and economic benefits of maize-legume intercropping. Intercropping not only increases maize grain and stover yield but also reduces the severity of FAW infestation. The economic advantage of intercropping, evidenced by higher MEY, net returns, and B:C ratios, highlights the potential of this system to improve the sustainability and profitability of maize cultivation in regions prone to FAW infestation. Given the region's reliance on small-scale, rainfed agriculture, maize-legume intercropping offers a practical, low-cost solution for improving both productivity and pest management. By reducing pest infestations, and minimizing reliance on chemical inputs, this practice can contribute to long-term agricultural sustainability in the NER.

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Conflict of Interest

The authors declare that there is no conflict of interest in the publication of this manuscript.

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