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Impact of Invasive Fall Army Worm on Maize Yield and Return Pattern in India: A Comprehensive Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted from 2018 to 2022 to investigate the impact of fall armyworm (FAW) invasion on maize cultivation in Karnataka, India. The financial implications and determinants of maize productivity were also determined. Following FAW invasion, cost of cultivation rose significantly to Rs. 69,747 compared to previous year cost of cultivation Rs.63,283 in absence of FAW, attributed to increased expenses on plant protection chemicals, labor, and fertilizer. Plant protection costs at Rs. 3,450 skyrocketed post FAW invasion compared to Rs. 329 before invasion. Whereas non managed fields had a total cost of Rs 61,760. The findings revealed that FAW

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caused substantial significant yield reduction of 4.14 q/ha in managed fields and 21.74 q/ha in non-managed fields when compared with yield of 49.54 q/ha prior to invasion. The cost of production found to be substantially high (Rs.2,222/q) after FAW invasion in non-managed fields and managed fields (Rs.1,536/q) when compared to prior FAW (Rs.1,277/q). The farmers in study area could able to realize higher returns per rupee of expenditure (1.54) prior to FAW when compared with after FAW invasion with management (1.28) and without management (0.89). The net profit margin of maize cultivation in the study area prior to FAW invasion stood at 35.19 per cent compared to 22.06 per cent after Fall Armyworm invasion with management and -11.71 per cent, without management practices, respectively. The results also revealed net financial impact of FAW invasion on maize cultivation, at Rs. -13,472/ha post invasion even after employing management practices and positive net financial impact of Rs. 26,987.50/ha for implementing FAW management measures when compared with non-managed fields post invasion. The relation between rainfall and productivity was statistically significant at one per cent level of probability with co-efficient value of 1.72. The coefficient value associated with the infestation event (-406.81) was found to be high, indicating a potentially strong relationship between productivity and infestation event.

Keywords: FAW; maize; invasive; economics; management.

1. INTRODUCTION

Maize (*Zea mays* L) being one of the versatile emerging crop with wider adaptability under different agro-climatic environment conditions. It is a vital crop for millions of people in the form of food, fodder, feed and industrial raw material. Globally, around 1147.7 million metric tonnes of maize is produced from 193.7 million hectares with an average yield of 5.75 t/ha in 170 countries [1] with a diverse range of soil, climate, biodiversity, and management approaches, accounting for 36 per cent of world grain production. Maize plays a crucial role in India, being the third most significant food crop after rice and wheat. India, ranking fourth in area and seventh in production, has witnessed a remarkable increase in maize production from 1.73 mt in 1950-51 to 31.51 mt in 2020-21. This growth is attributed to 5.42 times increase in average productivity and a threefold expansion in the maize cultivation area to 9.9 m. ha [2].

Amid the success of maize cultivation, a new challenge has emerged in the form of the invasive alien species, Fall Armyworm (*Spodoptera frugiperda*) and has become major production risk in cultivation of maize after its invasion [3]. First reported in Karnataka during August 2018, this pest has since spread to other maize-growing regions of the state and whole country with incidence ranging from 9 to 62.5 percent [4]. Invasive pests cause a significant reduction in crop yield and quality, imposing a great effect on the livelihoods of smallholders, besides economic, ecological, and societal impacts [5, 6] in Africa this pest damage ranging from 11 to 58 per cent has caused US$9.4 billion annual revenue to farmers since its introduction in 2016 [7]. In India Fall Armyworm has inflicted severe damage to maize crops, causing substantial grain yield of maize up to 44 per cent.

Authors have tried to measure economic losses from invasive alien species (IAS) nationally, but these studies overlook the specific effects on rural communities [8, 9]. Hence, there's an urgent need to fill this knowledge gap. This study has attempted to bridge that gap by analyzing the farm level data and impacts of FAW on individuals in maize cultivation.

2. MATERIALS AND METHODS

Structured schedule was prepared and pretested before it was administered to the respondent farmers. The schedule covered general information on maize farmers, their asset position and details of maize crop production in terms of input usage, costs, income, production risk associated and damage caused by Fall Armyworm etc. For assessing the production risk associated and yield loss, the purposive sampling was employed in selection of districts and random sampling technique was employed in the selection of sample farmers. Based on area, production, productivity and Fall Armyworm incidence on maize, four major maize growing districts viz., Davanagere, Haveri, Hassan and Chikkaballapur in Karnataka were selected for the study. The ultimate sample of farmers numbering 50 from each district was chosen randomly from the cluster of villages to form overall sample size of 200 maize farmers.

2.1 Analytical Tools and Techniques Used

The data was analyzed using the following statistical methods in order to meet the study's specific goals.

1. Descriptive analysis
2. Cost and return analysis
3. Paired t test
4. 4.Partial budgeting

2.2 Cost Concepts

Cost A1: All actual expenses in cash and kind incurred in production by the owner-operator.

Cost A2: Cost A1 + rent paid for lease in the land.

Cost B1: Cost A2 + interest on the value of owned fixed capital assets (excluding land)

Cost B2: Cost B1 + rental value of owned land + rent paid for lease in the land.

Cost C1: Cost B1 + imputed value of family labour.

Cost C2: Cost B2 + imputed value of family labour.

Estimation of cost ratios

yield and By product: (q/ha)

Total cost: Total cost (Rs./ha)

Estimation of income measures

1. Gross income (Rs/ha) = (quantity of main product x price
2. per unit) + (quantity of by-product x price per unit)
3. Net returns (Rs/ha) = Gross income – Cost C2
4. Benefit Cost ratio: Gross income/Cost
5. C2Cost of production (Rs/q): Total cost / Total output
6. Return over variable cost = Gross income – Total variable cost
7. Net profit margin = Net returns / Gross income *100

2.3 Paired t-test

The paired t-test was carried out to compare the mean yield, plant protection sprays, expenditure before and after the invasion of Fall Armyworm. It was also employed to compare the mean yield of IPM and non-IPM farmers after Fall Armyworm invasion.

The study involved 200 farms maize farmers across four districts as described in source of data where Fall Armyworm invasion was observed. Yield data (in q/ha), expenditure on plant protection chemicals and sprays taken (in Rs./ha and No. of sprays/farmer) were collected from these farms both before and after the invasion of Fall Armyworm.

2.4 Variables

- **Yield**: The yield of crops per hectare.
- **Plant protection expenditure**: The expenditure on plant protection measures such as pesticides, insecticides, etc.
- **Sprays**: Number of sprays per farmer per crop

2.5 Statistical Analysis

The paired t-test was employed to compare the mean yield and plant protection expenditure before and after the invasion of Fall Armyworm. The paired t-test formula is as follows:

$$t = \frac{\acute{d}}{S_d/\sqrt{n}}$$

Where:

- $\acute{d}$ is the mean of the differences between before and after invasion measurements.
- Sd is the standard deviation of the differences.
- n is the number of pairs (or observations).

The null hypothesis (H0) states that there is no significant difference in yield and plant protection expenditure before and after the invasion of Fall Armyworm. The alternative hypothesis (H1) suggests that there is a significant difference.

2.6 Interpretation

If the calculated t-value is greater than the critical t-value at the chosen level of significance (e.g., α = 0.05), then the null hypothesis is rejected, indicating a significant difference between the means of yield and plant protection expenditure and sprays before and after the invasion.

List 1. Partial budgeting

Debit	Credit
A. . Added cost.	B. Reduced cost.
C. Reduced returns.	D. Increased returns.
Total = A+B	**Total** = C+D
Net gain / loss=Credit-Debit	

3. RESULTS AND DISCUSSION

3.1 Cost of Cultivation under Different Maize Cultivation Scenarios in Study Area

Table 1 provides a comprehensive comparison of per ha costs and returns associated with maize cultivation under different scenarios *viz*. before and after the invasion of Fall Armyworm and after invasion of Fall Armyworm with and without management practices.

Respondents incurred a total cost of Rs. 40,552, Rs. 46,856 and 39,105 in the cultivation of maize prior to invasion of Fall Armyworm, after invasion of Fall Armyworm with and without management practices employed, respectively. The cost of cultivation was higher after Fall Armyworm invasion with management mainly attributable to higher expenses on plant protection chemicals, labour usage and fertilizer for upkeep of good plant growth. Proportion of working expenses was relatively more than fixed costs in the cultivation of maize in all the three scenarios, which accounted for 64.08, 67.17 and 63.31 per cent, respectively.

Among the different items of cost, the cost of human labour (Rs.14,800/ha) and machine hours (Rs.8,660/ha) increased slightly after Fall Armyworm invasion with management practices, possibly due to increased labour requirements for pest control and management. Fertilizer cost was relatively higher especially after Fall Armyworm invasion where management practices were employed (Rs.5,880/ha), compared to Rs.4,775/ha and Rs. 4,620/ha before Fall Armyworm invasion and after its invasion without management practices, consecutively. This could be attributed to increased fertilization needs to support crop recovery. The cost of seed material before Fall Armyworm invasion was lower (Rs.3,650/ha) as compared to after Fall Armyworm invasion (Rs.3,811/ha). This higher seed cost was due to the use of more quantity of seed material after Fall Armyworm invasion to maintain the plant population in case of crop damage at early stages. The plant protection cost at Rs. 3,450 skyrockets after Fall Armyworm invasion, especially with management practices, indicating the expense associated with pest control efforts. The same cost was merely Rs.329 before Fall Armyworm invasion. Miscellaneous cost was found to be the prominent item of cost at Rs.965 and Rs.750 after Fall Armyworm invasion in with and without management practices respectively potentially due to various unforeseen expenses.

From the above results, it is evident that there was significant negative impact of Fall Armyworm invasion on maize cultivation. The costs of cultivation rise across various aspects, with higher expenses for plant protection, labour, machinery, fertilizers and seeds.

3.2 Production and Returns from Maize Cultivation

The information on yield and returns in maize cultivation is shown in Table 2. The per hectare yield realized by the respondents was higher prior to Fall Armyworm invasion (49.54 q/ha) compared to (45.40 q/ha) after invasion even after employing management practices. Moreover, the quantity of the main product (maize) decreased significantly after Fall Armyworm invasion without management practices to 27.8 quintals per hectare. A huge yield difference of 21.74 (43.90 %) quintals per hectare and 4.14 (8.36 %) quintals per hectare was noticed in non-managed and managed fields compared to maize cultivation prior to Fall Armyworm invasion (Table 2). In the Figs. 1 and 2 the outliers in the gross return, net return, yield and cost of production after invasion of Fall armyworm indicate the extreme variation due to unawareness and inexperience in management of the pest resulting in low yield and returns. Gross returns decrease substantially after Fall Armyworm invasion (Rs.54, 822) resulting in negative net returns (Rs. -6,938) in the scenario of without management practices. Whereas the gross returns were Rs.89,490 in Fall Armyworm managed fields after invasion was lower compared to prior Fall Armyworm invasion which was at Rs. 97,651 mainly because decrease in

maize yield after Fall Armyworm invasion due to crop damage. The impact of Fall Armyworm is clearly visible from the point of cost of production per quintal, which was substantially high (Rs.2,222/q) after Fall Armyworm invasion in non-managed fields and managed fields (Rs.1,536/q) when compared to prior Fall Armyworm invasion (Rs.1,277/q). A negative net return (Rs. -6,938) in non-managed fields after invasion of Fall Armyworm signifies the severity of Fall Armyworm's impact on profitability (Figs 3 and 4).

Table 1. The comparative cost of cultivation in the study area in the context of a normal maize cultivation characterized by the absence of FAW and after FAW invasion with and without management practices. (*per ha*)

Sl. No.	Particulars	Qty	Before FAW (Rs.) (n=200)	Qty	After FAW with Management (Rs.) (n=193)	Qty	After FAW without Management (Rs.) (n=07)
I	**Variable costs (Rs.)**						
1	Man days	34.31	13800 (21.81)	36.45	14800 (21.22)	33.24	13500 (21.86)
3	Machine (hrs)	8.52	8520 (13.46)	8.66	8660 (12.42)	7.8	7800 (12.63)
4	Seed (kg)	8.97	3650 (5.77)	9.36	3811 (5.46)	9.15	3792 (6.14)
5	FYM (tractor load)	1.91	4775 (7.55)	1.94	4850 (6.95)	1.84	4620 (7.48)
6	Fertilizer (Rs.)		4845 (7.66)		5880 (8.43)		4685 (7.59)
7	Plant Protection Chemicals (Rs.)		329 (0.52)		3450 (4.95)		200 (0.32)
8	Marketingcost (Rs.)		1500 (2.37)		1375 (1.97)		1200 (1.94)
9	Miscellaneous		480 (0.76)		965 (1.38)		750 (1.21)
10	Interest on working capital @7%		2653 (4.19)		3065 (4.39)		2558 (4.41)
	Total variable cost		40552 (64.08)		46856 (67.18)		39105 (63.23)
II	**Fixed costs (Rs.)**						
1	Depreciation		1135 (1.79)		1280 (1.84)		1065 (1.72)
2	Land revenue		30 (0.05)		30 (0.04)		30 (0.05)
3	Rental value of land		19500 (30.81)		19500 (27.96)		19500 (31.57)
4	Interest on fixed capital @10 %		2067 (3.27)		2081 (2.98)		2060 (3.34)
	Total fixed cost		22732 (35.29)		22891 (32.82)		22654.5 (36.68)
III	**Total costs**		63283 (100)		69747 (100)		61760 (100)

Figures in the parentheses indicate per cent to total cost

Table 2. Production and return pattern in the context of a normal maize cultivation characterized by the absence of FAW and after FAW invasion with and without management practices (*per ha*)

Sl. No.	Particulars	Before FAW invasion	After FAW invasion with Management	After FAW invasion without management
1	Main product (q)	49.54	45.4	27.8
	a) Returns from main product (Rs.1850/q)	91649	83990	51430
	b) Returns from by product 110 qt (@Rs. 100 /q)	6002	5500	3392
2	Gross returns (Rs.)	97651	89490	54822
3	Net returns (Rs.)	34368	19743	-6938
4	Returns per rupee of expenditure	1.54	1.28	0.89
5	Cost of production (Rs. /q)	1277	1536	2222
6	Return over variable cost (Rs.)	57099	42634	15716
7	Net profit margin (%)	35.19	22.06	-12.73
8	Reduction in yield (q)		4.14 (8.36 %) *	21.74 (43.9 %) *

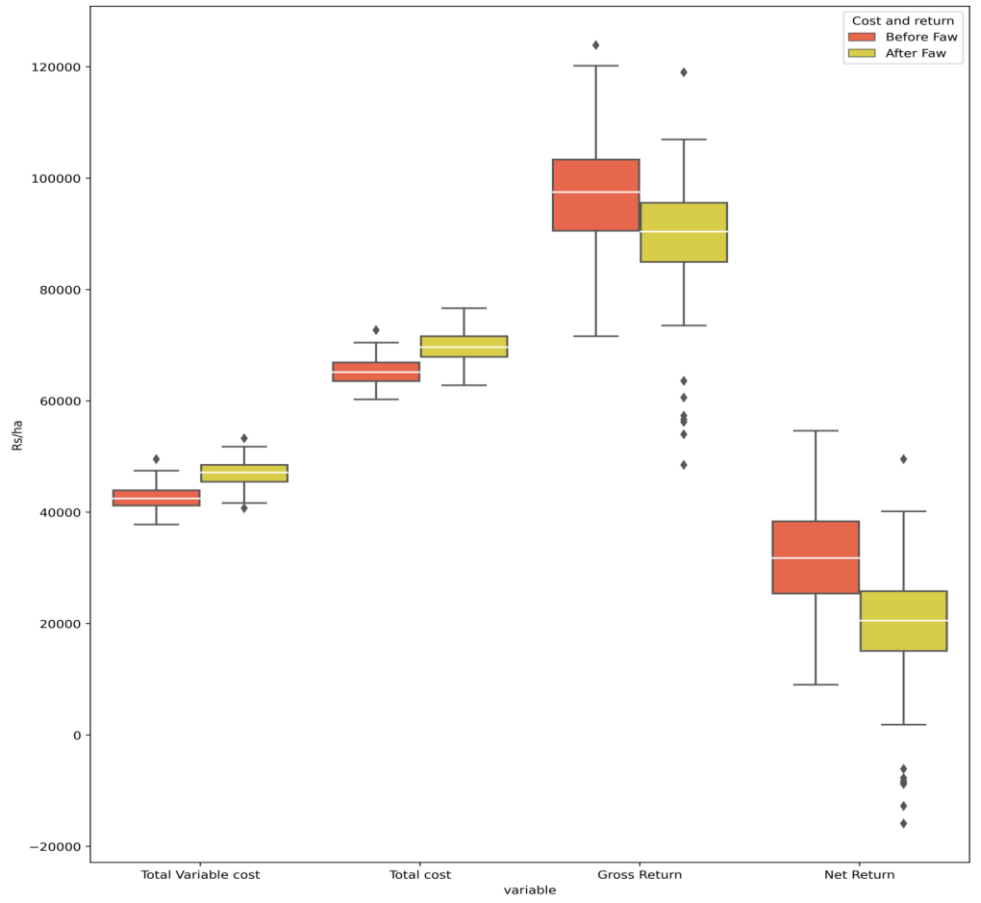

Fig. 1. Comparative cost and returns pattern (1) in study area before and after FAW invasion in Maize

Accordingly, the farmers in study area could able to realize higher returns per rupee of expenditure (1.54) prior to Fall Armyworm invasion when compared with after Fall Armyworm invasion with management (1.28) and without management (0.89). The net profit margin of maize cultivation in the study area prior to Fall Armyworm invasion stood at 35.19 per cent compared to 22.06 per cent after Fall Armyworm invasion with management and -12.73 per cent, without management practices, respectively. The respondents in study area incurred loss of 8.36 per cent maize yield with management practices whereas respondents with non-managed farms incurred huge yield loss to the tune of 43.9 per cent when compared to prior Fall Armyworm invasion yield levels. The results underscore the urgent need for strategies to combat the challenges posed by Fall Armyworm. Integrated pest management practices and other preventive measures can help minimize the negative financial impact on maize cultivation, ensuring sustainable profitability for farmers.The findings are in line with the study conducted by the Kofi and Mohammed [10] which investigates the effects of Fall Armyworm (*Spodoptera frugiperda*) infestation on maize (*Zea mays* L.) growth, yield, and economic returns in northern Ghana and found Fall Armyworm infestation significantly reduced maize yield by 44 per cent in 2018 and 37 per cent in 2019 in the absence of management.

3.3 Financial Impact of FAW Invasion on Profitability of Maize Cultivation

Table 3 reveals critical challenges and changes in profitability providing insights into the overall financial implications of Fall Armyworm invasion. The invasion of Fall Armyworm imposed substantial added costs on maize cultivation. These expenses primarily came from mitigating the damage caused by this pest and ensuring the continuation of cultivation despite the infestation. The added costs include seed costs (Rs.161/ha), human labor (Rs.1,000/ha), machinery (Rs. 140/ha), fertilizers (Rs.1,010/ha), plant protection chemicals (Rs. 3,121/ha), and training and

extension costs (Rs. 3.5/ha). In addition, the invasion of FAW lead to reduced returns from reduced yield (Rs. 7,659/ha) and by product (Rs.502/ha) from maize cultivation. The total added cost amounted to Rs. 13,597 per hectare. The reduced cost was only seen in miscellaneous expenses (Rs. 125/ha). The net financial impact of FAW invasion on maize cultivation stands at Rs. -13,472/ha [11-13]. This negative financial impact underscores the severity of FAW infestation on the profitability of maize cultivation (Table 3).

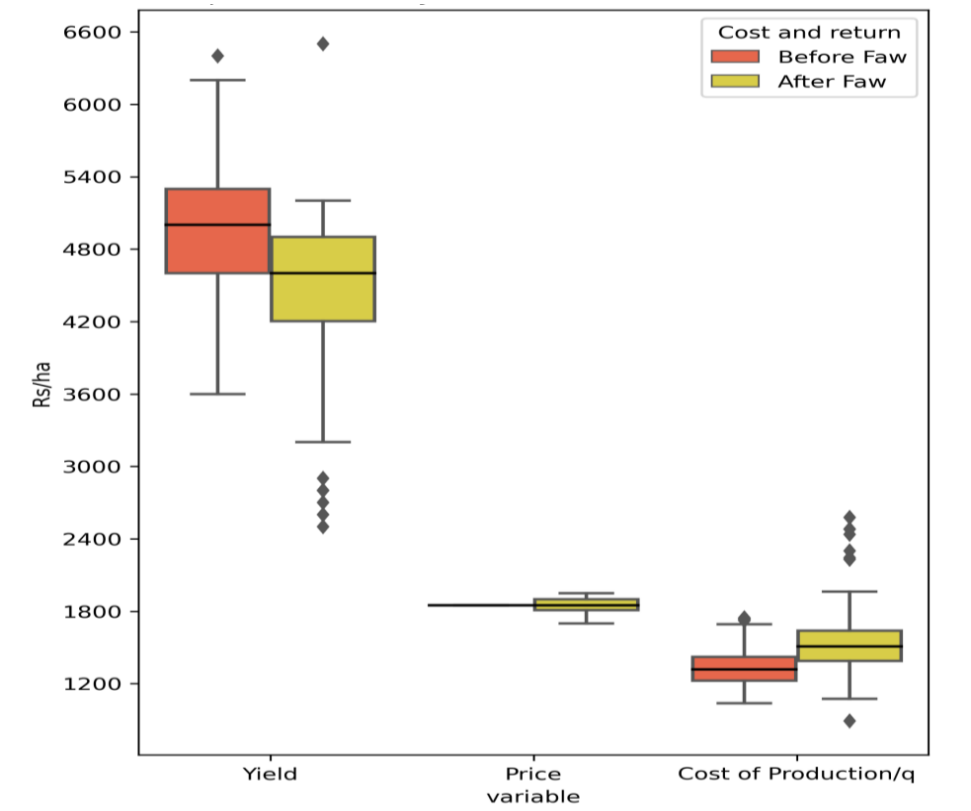

Fig. 2. Comparative cost and returns pattern (2) in study area before and after FAW invasion in Maize

Table 3. Financial impact of FAW invasion on profitability of maize cultivation (*Rs/ha*)

	Debit	Amount (Rs)		Credit	Amount (Rs)
A	**Added cost**		**C**	**Reduced cost**	
i	Seed cost	161	i	Seed cost	0
ii	Human labour	1000	ii	Human labour	0
iii	Machine	140	iii	Machine	0
iv	FYM and fertilizer	1010	iv	FYM and fertilizer	0
v	Plant protection chemicals	3121	v	Plant protection chemicals	0
vi	Miscellaneous	0	vi	Miscellaneous	125
vii	Training and extension costs	3.5	vii	Training and extension costs	0
B	**Reduced returns**		**D**	**Increased returns**	
i)	Output lost (main product) (4.14 q*1850 rupees)	7659	i)	Main product	0
ii)	Byproduct	502	ii)	By product saved	0
	Total reduced income and additional cost (A)	13597		Total additional income and reduced cost (B)	125
	Net financial impact of Fall Armyworm invasion in Maize (B-A) = Rs. -13472				

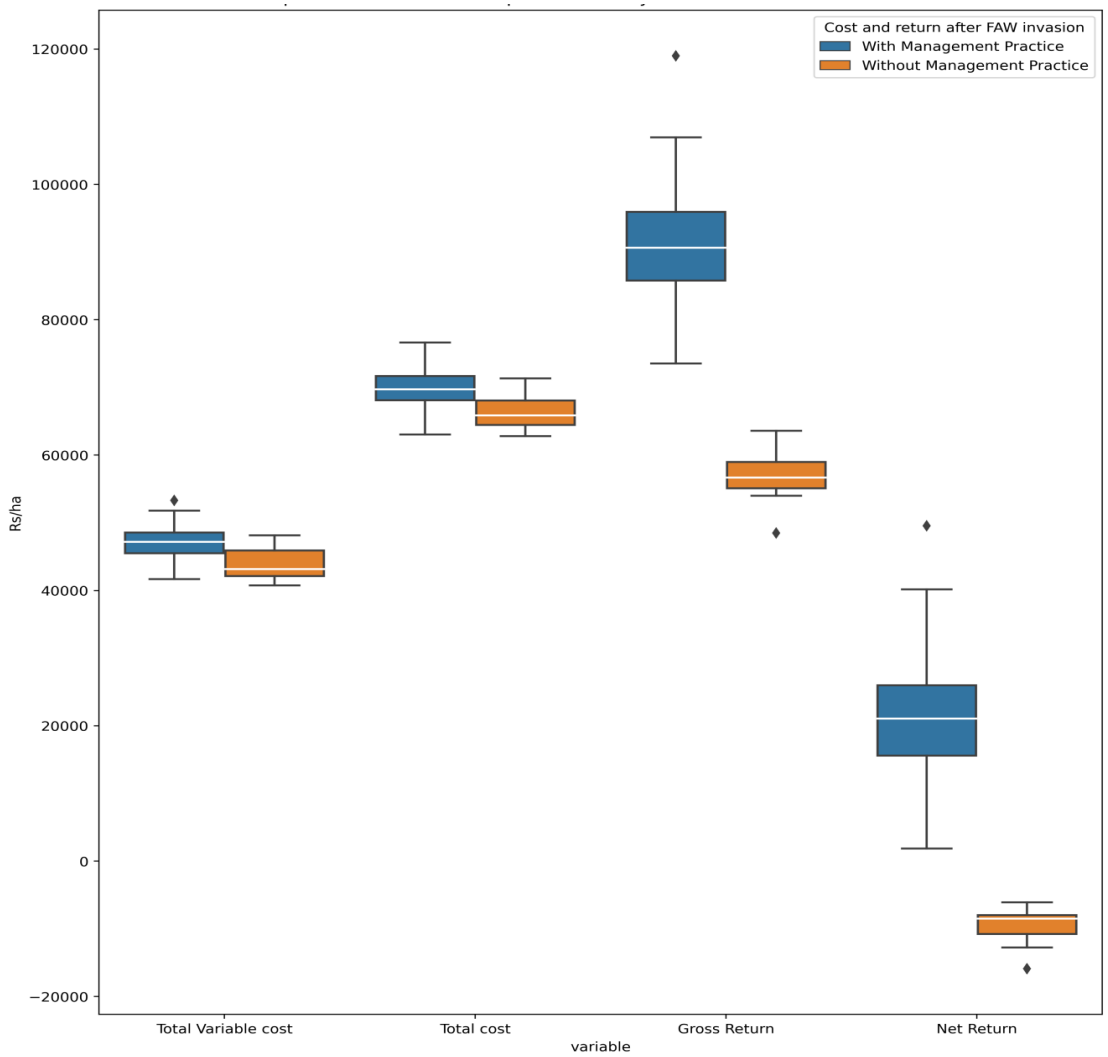

Fig. 3. Comparative cost and returns pattern (1) in study area with and without management practices after FAW invasion in Maize

3.4 Additional Benefit Derived from Adoption of Management Practices in Maize Cultivation after Fall Armyworm Invasion

Invasion of Fall Armyworm on maize in Karnataka is causing substantial yield losses to the maize growing farmers. In order to reduce yield losses and manage Fall Armyworm adoption of management practices is mandatory in maize cultivation. The partial budgeting analysis presented in Table 4 indicates that relative benefit of implementing plant protection management measures for Fall Armyworm in maize cultivation has a positive financial impact of Rs.27,420.50/ha. The additional income generated from adopting these measures outweighs the additional costs mentioned in left hand side of table (Rs.7,247.50/ha) associated with fertilizers, plant protection chemicals, human labour, machine hours and training/extension activities *etc*. The positive net financial impact of Rs. 27,420.50/ha demonstrates the economic benefits of implementing Fall Armyworm management measures (Table 4). Without these measures, the damaging effects of Fall Armyworm infestation would lead to a significant reduction in maize yield, amounting to 17.60 q/ha. This reduction represents a substantial 39 per cent decrease in yield caused by Fall Armyworm (Balla *et al.,* 2019). Therefore, implementing effective Fall Armyworm management strategies is crucial to mitigate yield losses in order to protect the economic viability of maize cultivation.

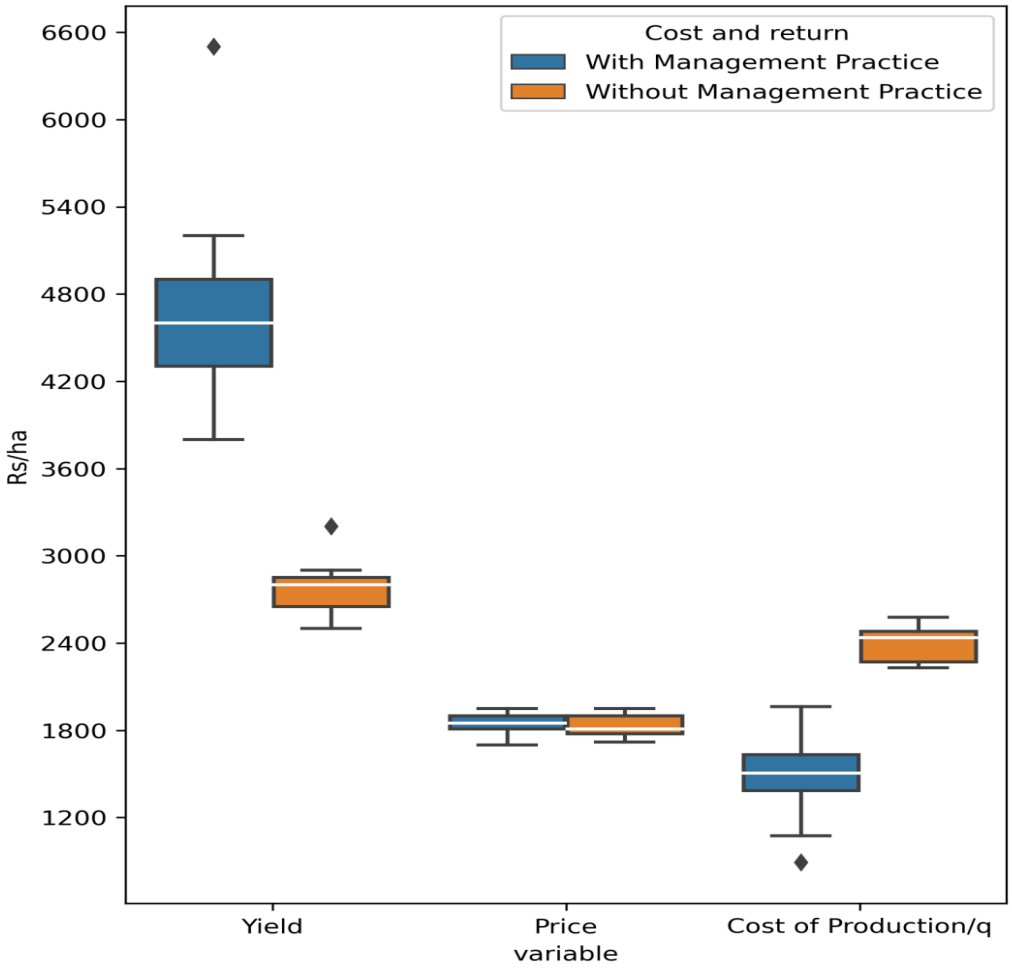

Fig. 4. Comparative cost and returns pattern (2) in study area with and without management practices after FAW invasion in Maize

Table 4. Relative benefit of adopting FAW management after invasion in maize cultivation

	Debit	**Amount (Rs)**		**Credit**	**Amount (Rs)**
A	**Added cost due to FAW management**		**C**	**Reduced cost due to FAW management**	
i	Seed cost	19	i	Seed cost	0.00
ii	Human labour	1300	ii	Human labour	0.00
iii	Machine	860	iii	Machine	0.00
iv	FYM and fertilizer	1425	iv	FYM and fertilizer	0.00
v	Plant protection chemicals	3250	v	Plant protection chemicals	0.00
vi	Marketing and miscellaneous	390	vi	Marketing and miscellaneous	0.00
vii	Training and extension costs	03.50	vii	Training and extension costs	0.00
B	**Reduced returns due to FAW management**		**D**	**Increased returns due to FAW management**	
i)	Main product	0.00	i)	Output saved main product (17.6 q*1850 rupees)	32560
ii)	Byproduct	0.00	ii)	By product saved	2108
	Total reduced income and additional cost(A)	7247.50		Total additional income and reduced cost(B)	34668
	Net financial impact for adoption of FAW Management practices (B-A) = Rs. 27420.50				

4. CONCLUSION

The study conducted on the impact of fall armyworm (FAW) invasion on maize cultivation in Karnataka, India, revealed significant financial implications and productivity challenges. The invasion led to a considerable rise in the cost of cultivation and a substantial reduction in maize yield. Despite implementing management practices, the net profit margins declined significantly after FAW invasion, indicating the severity of the pest's impact on maize cultivation. The study underscores the urgent need for effective pest management strategies and support mechanisms to mitigate the economic losses caused by FAW invasion and ensure the sustainability of maize cultivation in India. the study underscores implementing robust biosecurity protocols, including early detection, monitoring, and quarantine measures, coupled with integrated pest management strategies to prevent and mitigate the impact of invasive pests like FAW on agricultural crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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