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Economic analysis of pesticide expenditure for managing the invasive fall armyworm, *Spodoptera frugiperda* (J.E. Smith) by maize farmers in Karnataka, India

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The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), invaded India for the first time in May 2018 in Karnataka state and since then has threatened maize production in the country. In this study, during 2017 to 2020, a total of 150 smallholder maize farms were randomly selected and surveyed from three major maize growing districts in Karnataka for the pesticide usage patterns, pesticide cost, and yield in important maize-growing districts. During 2020, FAW infestation level was recorded at 2.15 larvae per 100 plants with an overall Davis damage score of 3.80. Maize farmers used on an average 2.12 pesticide sprays per season for FAW management in the surveyed districts in 2020. Maize yields per hectare were

4.46, 3.76, 4.06 and 4.18 tonnes per hectare (t/ha) in 2017, 2018, 2019 and 2020, respectively, while the average cost on pesticides spent by farmers per 100 kg maize grain during the same years were US$ 0.124, US$ 2.04, US$ 1.68 and US$ 1.39, respectively. The study highlights the effect of FAW invasion on pest management regime on the maize crop in Karnataka. Integrated pest management (IPM) is the need of the hour to reduce the environmental impact of synthetic pesticide use and protect the incomes and livelihoods of the smallholders.

Keywords: Fall armyworm, pesticides, fall armyworm infestation, pesticide expenditure, maize farmers, yield

In India, maize is the third most important cereal crop grown after rice and wheat. The crop was grown on an area of 9.20 million hectares with a production of 27.82 million metric tonnes (MMT) in 2019[1]. The area under maize in Karnataka was 1.34 M ha with a production of 3.73 MMT and average yield of 2.77 metric tonnes per hectare (t/ha)[2]. Davanagere, Shivamogga and Chitradurga are the major maize growing districts in Karnataka covering an area of 0.30 M ha[3].Various factors affect maize production and productivity in the tropical maize-growing areas in India, insect pests being one among them.

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a pest native to the Americas[4,5]. FAW is highly migratory in nature, has high fecundity, and has a voracious feeding behaviour, without diapause. These characteristics make this pest one of the most destructive insect-pests of crops. Outside Americas, FAW was first reported in West Africa in January 2016[6] and has spread to more than 40 countries across Africa [7,8].

During May 2018, FAW was noticed for the first time in India on the maize crop in the Karnataka state[9], and subsequently reported in various states within the country, as well as various countries across the Asia-Pacific[10,11]. The total duration of FAW life cycle ranges from 32-46 days[12]. The pest was reported to have even displaced the native stem borers in some areas[13]. FAW feeds extensively on maize foliage; however, most of the economic damage is caused by the late instar larvae that bore into the maize ears[8]. Since its invasion in 2018, FAW has rapidly spread across India[14-16]. The damage on maize crops during July 2018 to February 2019 varied between 20 to 80 per cent[17]. This was estimated to have resulted in a reduction in total maize output by 37,000–75,000 tonnes[18].

In Africa, farmers in several countries responded to the FAW invasion by resorting to excessive application of chemical insecticides[8]. This has resulted in an increase in the use of highly dangerous or restricted-use pesticides by smallholder farmers in the region, many of whom are completely unaware of proper pesticide handling procedures[19]. According to integrated pest management (IPM) guidelines, synthetic pesticides can only be used as a last resort, that too after proper field-level monitoring of the pest using appropriate pheromone traps. In Karnataka, IPM-based practices for FAW control were widely disseminated to the farmers since the invasion of the pest in mid-2018. However, no studies were conducted on the economic analysis of pesticide expenditure for managing FAW. In this study, we analysed (1) the effect of FAW invasion on the pest management practices (e.g., pesticide usage, number of applications) by the maize farmers in Davanagere, Shivamogga and Chitradurga districts of Karnataka, a major maize-growing state in India; and (2) the cost of pesticide expenditure to the maize farmers for controlling FAW.

Materials and methods

Study area

Field visits and farmer surveys were conducted during June-July 2020 in Davanagere, Shivamogga and Chitradurga districts of Karnataka, India. In these three districts, majority of the farmers cultivate maize during the *kharif* (monsoon) season. Farmers also grow maize in the *Rabi* (winter) season and in the summer season, depending on the availability of irrigation. In the three districts, the surveyed maize fields ranged from 0.5 ha to 8 ha in size (average size of around 1.2 ha). In June 2018, FAW occurred for the first time in these three districts at high population densities.

Pest occurrence and prevailing pest management regime

Field surveys were carried out to assess the relative abundance of FAW larvae in the maize fields during June 15 to July 30, 2020 in the three districts. Data were recorded from a total of 150 individual farms through household (face-to-face) surveys/interviews. In most of the fields, farmers planted the commercial maize hybrids (CP 818, NK6240, S6668 plus, P3550 and TATA Dhanya). The growth stages of the crop varied from V2–V8 (i.e., 2–8 leaves with visible leaf collars). The seed rate used by the surveyed farmers was 18 kg per ha. In each field, observations were recorded by walking in a "W" shape with recording done in five spots (20 plants per spot). A total of 100 plants were screened per field to record observations on the number of FAW larvae, per cent damaged plants, and the level of leaf damage caused by the FAW on the Davis 0-9 scale[20].

In addition to the above-mentioned surveys in farmer-managed fields, in 2020, two experimental plots (1000 m^2 each) were established in Agricultural and Horticultural Research Station, Kattalagere, Davanagere district, and Zonal Agricultural and Horticultural Research Station, Shivamogga, to assess the pest infestation levels in the absence of pesticide use. A commercial maize hybrid CP 818 (CP Seeds Pvt. India Limited, Mumbai) was planted in the second week of June 2020 with a spacing of 60 cm row-to-row and 20 cm plant-to-plant. Observations were recorded at 30 days after planting on the mean number of FAW larvae, per cent damaged plants, and the level of leaf damage (based on Davis scale). For the surveyed fields in 2020, the farmer in each surveyed field was interviewed about the pest management practice, using a questionnaire with open-ended choice questions. Each farmer was asked to freely list the type of pesticide that was used during the cropping season and the number of applications. In case of products about which the farmer knew only the trade name, pesticide packages were photographed and the local pesticide dealers were contacted to get information on the active ingredients.

Temporal trends in pesticide use

Pesticide application data were gathered for the maize crop seasons (*kharif*) of 2017, 2018, 2019 and 2020. A total of 150 farmers were interviewed in the December month of 2018, 2019, and 2020. In 2018, the data for 2017 was also collected from the surveyed farmers on the pesticides used and the number of applications. In addition, interviews were conducted with 10 agro-dealers to confirm the details regarding local pesticide application regimes during 2017–2020. Each questionnaire covered the type of pesticides that were used for FAW management, their respective costs, application frequency, and any other IPM practices that were implemented by the farmers. Further, yearly pricing information for the main pesticides from 2018 to 2020 was obtained from 15 local pesticide dealers, while the pricing data of harvested maize were provided by the Davanagere maize merchants. Other data, as obtained through household surveys and farmer recalls, could be subject to error and interviewer bias; this was taken into account when interpreting or extrapolating the findings from the study.

Data analysis

The pesticide application frequency and the cost of pesticides were compared between the study years (i.e., 2017–2020). Households applying the pesticide were determined and the data, expressed in percentage, were compared over the years. Data on the number of pesticide sprays per crop, pesticide expenditure, maize grain yield and the pesticide expenditure (US$/100 kg of maize grain production) were subjected to analysis of variance (ANOVA) and mean values were compared by Tukey's HSD test.

Results and discussion

Pest occurrence and pest management regime

During 2020, FAW was the dominant herbivore in the farmers' maize fields in the surveyed districts, with infestation levels occurring at 2.15 ± 0.16 (Mean ± SE) larvae per 100 plants (range 0–71 larvae per 100 plants). Across the surveyed fields, 23.71 ± 0.70% plants exhibited leaf or whorl damage and the overall Davis damage score was low (i.e., 3.80 ± 0.12 on a 0–9 numerical scale). In the experimental plots without pesticide use, FAW infestation was significantly higher with 156 ± 10.25 larvae per 100 plants, 80.00 ± 0.04% damage incidence and a Davis damage score of 5.73 ± 0.19 (30 days after planting). Within a given field, an average of 1.2 ± 0.80 active ingredients were used to control FAW. Emamectin benzoate was applied in 93% fields, while other synthetic pesticides were less common; no farmer had reported to have used biopesticides.

Temporal shifts in pesticide use

Before the invasion of FAW in India, three pesticide active ingredients (lambda-cyhalothrin, carbofuron and phorate) were used by farmers in Karnataka for the management of stem borers in the maize fields. Since 2018, when FAW invasion occurred, the pattern of pesticides usage appeared to have changed; the most common active ingredients used was emamectin benzoate (76.67 %) (Figure 1). In 2019 and 2020, nearly 84% and 91.67% households applied emamectin benzoate against FAW (Figure 1). In 2020, majority of the farmers sprayed emamectin benzoate twice during the maize crop season as compared to other insecticides because of its lower price as compared to other pesticides. Farmers used only sole application of the pesticides like novaluron plus emamectin benzoate, chlorantraniliprole and spinetoram. Farmers chose pesticides based on information obtained from pesticide dealers, State Agricultural Universities, State Department of Agriculture, and neighbouring farmers.

Pesticide application frequency differed markedly between successive years ($F3, 596 = 648.303$, $P < 0.001$). While the farmers reportedly applied pesticide at a low level (0.10 ± 0.02 per season) in 2017, the application frequencies reached 2.85, 2.25 and 2.12 sprays per season in 2018, 2019 and 2020, respectively (Figure 2). Over the course of a single cropping season, the cost of chemical pesticide used on maize crops averaged US$ 5.56 per hectare in 2017. However, in 2018 the cost of crop protection by using pesticides in maize increased to US$ 71.23 per hectare ($F3,596 = 1.352$, $P < 0.001$) in 2018 and US$ 64.48 per hectare in 2019. In 2020, there was a decrease in the cost of plant protection (US$ 56.01 per hectare) (Figure 2). Prices of the main pesticides largely remained unchanged over 2017–2020 except emamectin benzoate, where the price reduced up to 33.72 and 36.60 per cent in 2019 and 2020, respectively. Maize yield per hectare was 4.47 ± 0.95, 3.76 ± 0.78, 4.06 ± 0.79 and 4.18 ± 0.67 tons/ha ($F3, 596 = 13.049$, $P < 0.001$) in 2018, 2019 and 2020, respectively (Figure 3) and the pesticide expenditure to produce 100 kg grains raised from

US$ 0.124 in 2017 to US$ 1.39 in 2020 (Figure 3). There was a 12 times increase in the crop protection cost to manage FAW in the maize fields in the surveyed districts.

Among the farmers surveyed, only 6.66% farmers used conventional insecticides (carbofuron, phorate, and lambda cyhalothrin) to combat the maize stem borers before the FAW invasion in India. When FAW invaded the Karnataka state in India in 2018, maize farmers began using new-generation insecticides including emamectin benzoate and novaluron plus emamectin benzoate in their, in addition to chlorantraniliprole and spinetoram.

The Directorate of Plant Protection, Quarantine and Storage (DPPQS), Faridabad, India, endorsed the use of azadirachtin based insecticides, *Bacillus thuringiensis* (Bt) and other biopesticides for FAW management. However, farmers largely favoured synthetic pesticide application, and chose emamectin benzoate and emamectin benzoate plus novaluron, possibly due to their relatively lower price as compared to chlorantraniliprole or spinetoram, though the latter are new-generation insecticides and are highly effective against FAW.

Farmers' pesticide application frequency increased significantly over the three year period, with 0.10 pesticide sprays per season in 2017 to 2.10 applications in 2020 but in China pesticide application increased from 2.1 in 2018 to 6.4 in 2020[21]. In the present study, FAW was observed mainly feeding on foliage and did not damage the maize ears but in September 2019 and 2020 when the crop was at silk stage, greater mortality of all the larval stages was observed due to *Metarrhizium rileyi* infection. This appears to have prevented FAW larvae from entering inside the ears and causing damage. These results conform with the findings of Mallapur *et al*. [22] and Sharanabasappa *et al*. [23], wherein, higher disease incidence of *Metarrhizium* was noticed in September month.

In India, there is a need for developing economic threshold for FAW management. Between 2017 (i.e., pre-invasion) and 2020 (i.e., post-invasion), Karnataka maize farmers spent an additional US$ 49.32 per hectare (average of 4 years) on pesticides for FAW control. These additional costs are considerable for resource-constrained smallholders. The maize yields during 2020 were largely at par with those in the year 2017, but the cost of plant protection increased 10 times in 2020. The increase in yield is mainly due to mass awareness programmes conducted by the State Department of Agriculture and State Agricultural Universities to take up IPM-based management strategies at the right time, including conservation biological control of FAW. Many awareness programmes were conducted by the State Agricultural Universities, national institutions (e.g., ICAR-IIMR, Ludhiana; NBAIR, Bengaluru), international organisations (CIMMYT, CABI, ICRISAT) and NGOs (SABC, New Delhi) to extension workers, scientists, pesticide dealers and farmers, soon after the FAW pest outbreak in 2018. In 2020, during COVID-19 pandemic, the Karnataka State Department of Agriculture and the State Agricultural Universities made intensive efforts in organising virtual FAW management campaigns in local language (before the planting and 15 days after the planting), besides print media and Radio.

The use of biopesticides, such as *Bt* sprays, entomopathogenic nematodes, applications of *Metarhizium anisopliae* and the use of FAW pheromone lures for monitoring or mating disruption are being actively promoted by various agencies. Identification and use of native natural enemies is an important component of IPM. Several studies reported natural enemies on FAW in India [24,25,26]. The inundative/augmentative release of well-validated biological enemies against FAW, especially egg parasitoids like *Trichogramma* sp. and *Telenomus* sp., should be taken up as a priority by both public and private sector institutions in India. In addition to biological control agents, biorational pesticides could also be potentially incorporated into the IPM-based strategies[24]. Studies by Udayakumar *et al.* [27] and Varshney *et al.* [28] showed that legume-based intercropping and biointensive management could help in reducing the incidence of FAW on maize. The DPPQS, India, made an ad-hoc recommendation of different insecticides for FAW management[29]. Chlorantraniliprole, emamectin benzoate and spinetoram were found to be suitable insecticides for managing FAW [30,31].

In the present study, we relied upon field observations in comparatively small areas and the data on pest management decision making were gathered through household surveys or farmer recalls. While the study has some limitations on sample size, the data can be effectively combined with population monitoring, participatory validation of IPM technology packages and farmer awareness-raising for further understanding the patterns of FAW pest management regimes followed in major maize growing areas in states like Karnataka in India. This will enable design and deployment of relevant IPM based strategies for sustainable management of FAW.

Conclusion

The present study demonstrates how the fall armyworm (FAW) invasion on maize crop has altered the pest management regimes over the last four years in Karnataka, India, highlighting the heavy dependence of the smallholder farmers at present on synthetic pesticides. In 2020, maize growers in the three surveyed districts in Karnataka applied 3-fold higher levels of synthetic pesticides as compared to 2017. However, farmers' dependency on high-risk pesticides appeared to have decreased over the years, while more selective compounds, such as emamectin benzoate, are now more widely used. Given the adverse environmental impacts of chemical-based pest control, a transition towards more sustainable integrated pest management is urgently needed in the smallholders' maize cropping systems in India. Intensive research is required for developing appropriate economic thresholds, and intensify FAW monitoring and surveillance. Environmentally sustainable FAW management requires effective integration of various approaches, including good agronomic practices, host plant resistance, biological control, environmentally safer pesticides, and agro-ecological management.

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Conflict of Interest

The authors declare that they have no known competing financial or other conflicts of interest that influence the work reported in this paper.

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Ethics approval and consent to participate

We agree to all concerned regulations.

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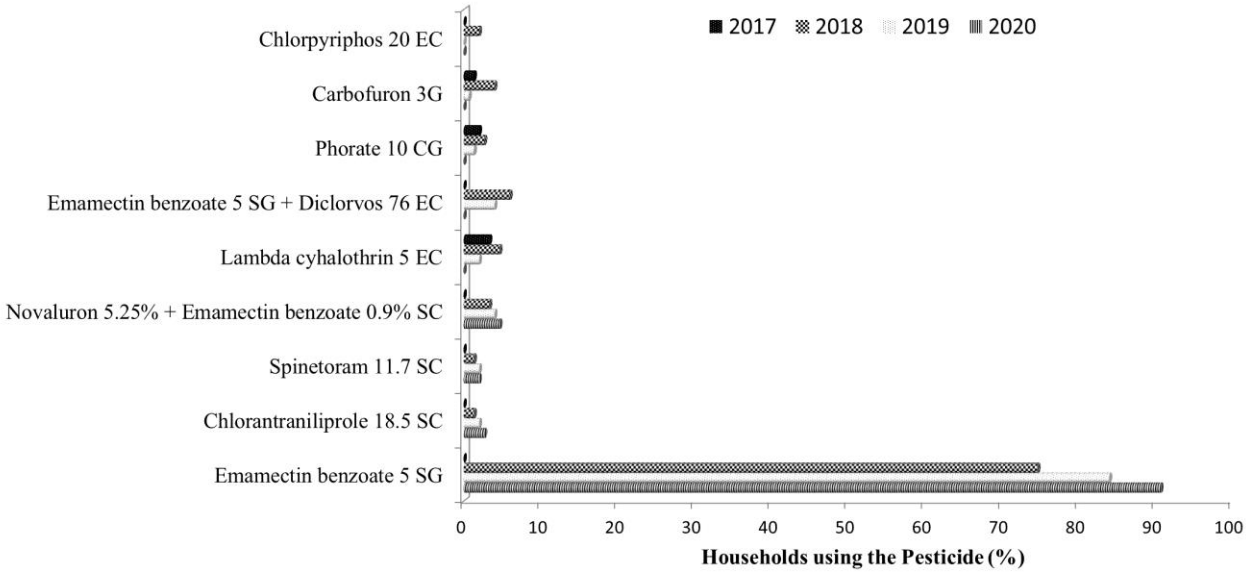

Figure 1. Synthetic pesticides used by the farmers for FAW management in maize fields during 2018 to 2020 in Karnataka.

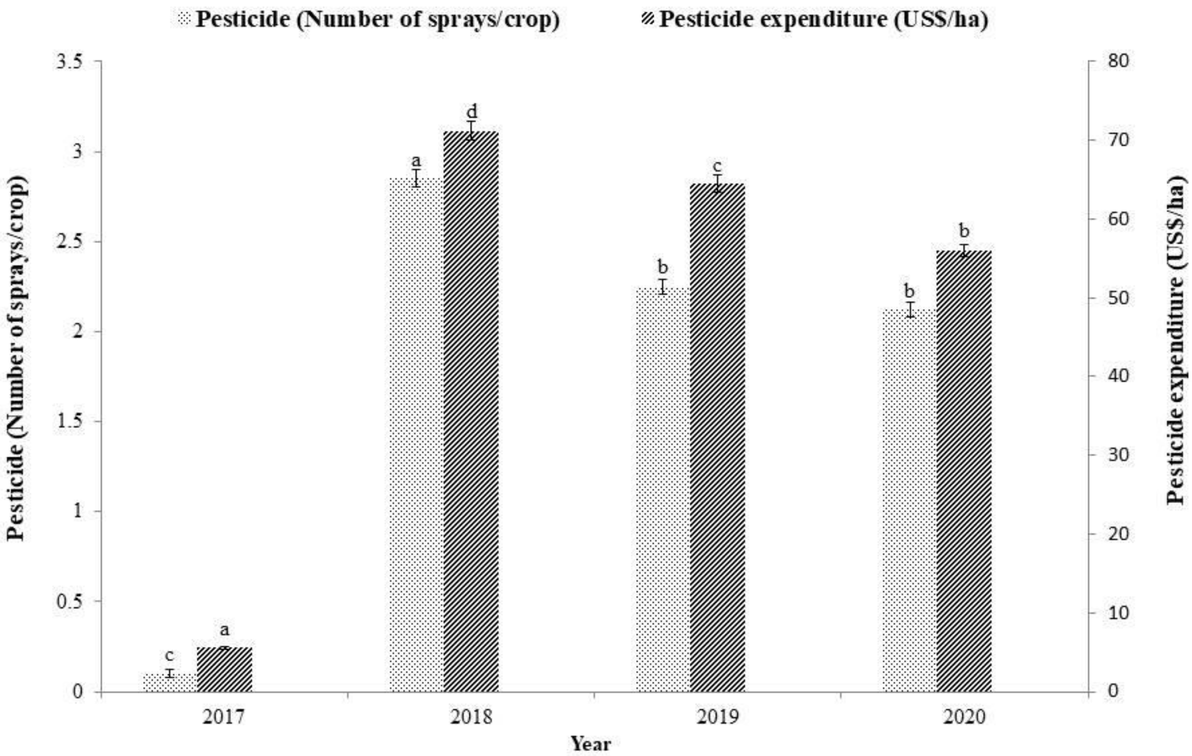

Figure 2. Number of pesticide sprays and pesticide expenditure for FAW management on maize crop from 2018 to 2020.

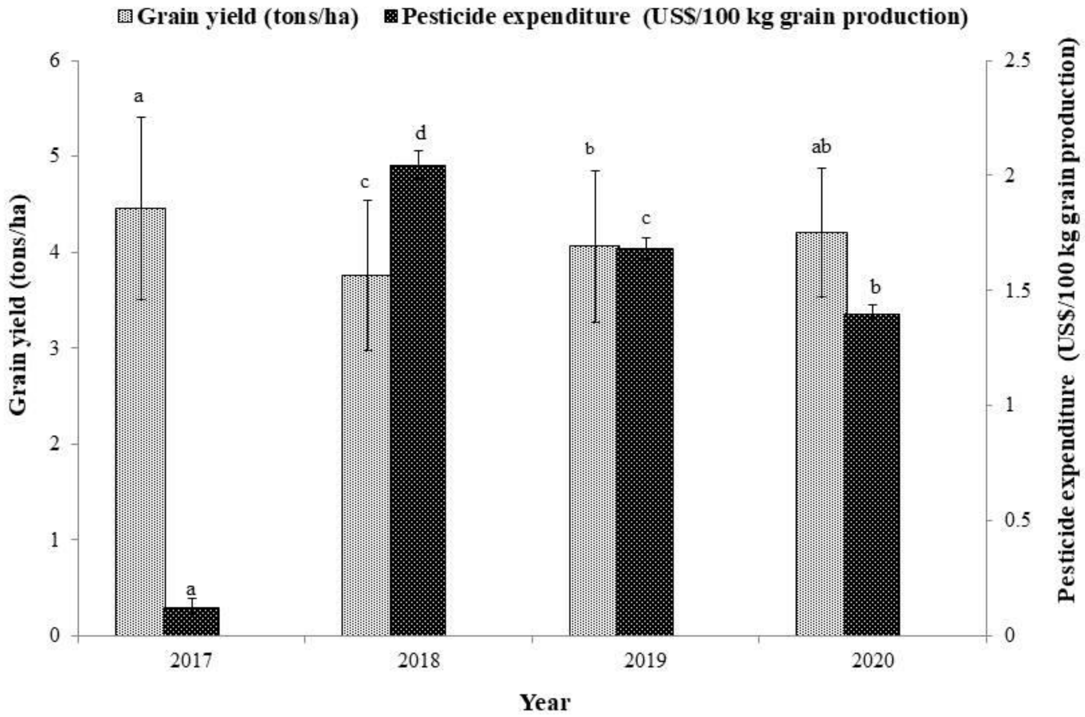

Figure 3. Maize grain yield and pesticide expenditure for FAW management on maize crop from 2018 to 2020.