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# Long-term Impact of Cotton Insecticide Resistance Management Programme: A Case Study from Punjab, India

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***Abstract***: An Insecticide Resistance Management (IRM) based Integrated Pest Management (IPM) programme was launched in 10 cotton-growing states of India in 2002, coinciding with the commercialization of Bt cotton in western and southern regions of the country. In Punjab, the IRM programme for rationalizing insecticide use was implemented from 2002 to 2013.A field study with IRM intervention and without IRM intervention was employed to compare the differences between IRM and non-IRM farmers in 2016, and a modified quasi-experimental difference-in-differences (DD) research design was used to compare changes between IRM and non-IRM farmers between 2004 and 2016 to account for biases over time due to seasonality and the widespread adoption of Bt cotton since 2004. In 2004, the IRM farmers' insecticide use (a.i.) in cotton area was less than 30% compared to non-IRM farmers. However, the difference in mean insecticide use (a.i.) per hectare farm per farmer between IRM and non-IRM farmers was only 10.3%, which was not significant. IRM farmers' mean number of insecticide applications was15% less than non-IRM farmers and the difference was significant but without any significant difference in yield compared to the non-IRM farmers. We revisited the study area of 2003–2004 in 2016 to find out the impact of the programme after the IRM intervention was withdrawn. We observed a significant reduction in insecticide use by volume and the number of applications both among the IRM trained and other farmers over time, but unlike in 2004, the differences between IRM and non-IRM farmers had not only flattened over time but also the non-IRM farmers had applied lesser number and volume of insecticides (a.i.) without any significant difference. The reduction in insecticide applications and active ingredients among both IRM and non-IRM can be attributed to the widespread adoption of Bt cotton and *Helicoverpa armigera* no longer being a key pest of cotton.

***Keywords***: Adoption, Environmental impact, Impact evaluation, Insecticide resistance management, Integrated pest management, Pesticide use

India is the world's leading cotton cultivating country. Cotton is cultivated on 13.3 million ha with a total production of 35.2 million bales (1 bale=170kg), but the productivity (491kg/ha; CCI 2022) is lower than the world average (772 kg/ha; USDA 2022). The major reasons for low productivity are both biotic and abiotic stresses. Prior to the commercialization of Bt cotton in 2002, the insecticide use in cotton accounted for 50% of the total pesticide use in Indian agriculture (Peshin et al 2014). The cotton insect pest management posed many challenges to cotton growers and entomologists. Despite heavy insecticide use, the cotton crop was ravaged by insect pest outbreaks, mainly bollworms, leading to the failure of the cotton crop. The cotton bollworm, *Helicoverpa armigera* (Hubner), a key pest of cotton, exhibited widespread resistance to cypermethrin, endosulfan, and chlorpyriphos (Kranthi et al 2002). To ameliorate this problem, the Insecticide Resistance Management (IRM) based Integrated Pest Management (IPM) programme was launched by the Central Institute for Cotton Research (CICR) under the cotton Mini Mission in 10 major cotton producing states in 2002. These 10 states accounted for 80% of the insecticide use in cotton (Russell, 2004). There have been studies reporting positive impacts of the IRM programme on reduction in insecticide use active ingredients (a.i.) and applications, saving on insecticide expenditure (ICAR 2007, Peshin et al 2009, Kumar et al 2012, Kranthi et al 2019). But these studies have measured immediate outcomes (short-term impacts), before the withdrawal of IRM programme intervention. Punjab-specific IRM module was validated by the Punjab Agricultural University (PAU), Ludhiana, India and is a part of its recommendation for cotton cultivation in Punjab. Peshin et al (2009) conducted a field study in 2003 and 2004 to find out the immediate outcome of the IRM programme in Punjab during the programme intervention. Peshin et al (2009) reported that the IRM programme implementation resulted in lesser insecticide use by weight (a.i.) and applications by the IRM farmers compared to non-IRM farmers. However, long- -

term impact evaluations are necessary to assess whether benefits are indeed sustained over time. Therefore, what has been the long-term impact of the IRM programme; we conducted an empirical field study in Punjab, India. The study area was revisited in 2016 and the comparison was made with 2004 data.

## MATERIAL AND METHODS

**Study area:** Under the IRM project, Bathinda (30.2110° N, 74.9455° E), Mansa (29.9995° N, 75.3937° E), and Fazilka (30.4036° N, 74.0280° E) districts, covering 72% of cotton-growing areas, were selected for the field study in 2003 and 2004 for finding the immediate outcomes of the IRM programme in cotton. The study area was revisited in 2016 for conducting the field study

**Sampling plan:** A sample of 150 cotton farmers trained under the IRM programme and a control group of 60 cotton farmers were surveyed and the results were published in a peer-reviewed journal (Peshin et al 2009). For assessing the long-term impact of the IRM programme, the sampled farmers were revisited in 2016–2017.Because of sample attrition, only 172 of them could be contacted, and of the total contacted farmers, only 121 were cultivating cotton (IRM 92 and non-IRM 29) and the rest had shifted from cotton to rice cultivation and a few had given up farming and leased out their farms. An additional sample of 83 cotton farmers was drawn from six villages from the list of IRM and non-IRM cotton farmers prepared in 2003 and 2004. The new additions were from the same test and control farmers as in 2003–2004.The sample size comprised 27 villages and 204 farmers.

**Empirical framework:** Treatment and control groups with/without (Eq.1) and modified quasi-experimental difference-in-differences (DD) design were used to compare the differences between IRM and non-IRM cotton farmers and the changes between 2004 and 2016 (Eq.2). DD is a quasi-experimental design that makes use of longitudinal data from treatment and control groups to estimate a causal effect. DD was used to account for biases over time due to seasonality and the widespread adoption of Bt cotton since 2004.

$$\Delta Y = Y_t - Y_c \quad (1)$$

Here, $Y$ is the impact of IRM programmes, $Y_t$ denotes the observations in the treatment group with IRM intervention, and $Y_c$ denotes the observations in the control group without IRM intervention.

$$\Delta\Delta Y = (Y_{t2} - Y_{t1}) - (Y_{c2} - Y_{c1}) \quad (2)$$

Here, $Y$ represents the difference-in-differences between IRM and non-IRM cotton farmers, $Y_{t1}$ and $Y_{t2}$ denote the observations in the treatment group in 2004 and 2016, respectively, and $Y_{c1}$ and $Y_{c2}$ indicate the observations in the control group in 2004 and 2016, respectively.

**Impact evaluation indicators:** The following were the impact evaluation indicators of the IRM programmes:

**Extent of adoption**: It was measured as percent of farmers adopting a particular pest management practice. A score of "1"was for adoption and "0" otherwise.

**Pesticide use by weight**: Pesticide use by weight (a.i.) kg/ha was calculated by summing up the different pesticides applied by farmers and dividing it by the total area under cotton crop and mean pesticide (a.i.) applied/farmer/ha of farm.

**Pesticide applications**: It was the average treatment frequency of pesticides (herbicides, fungicides, insecticides, and bio-pesticides) applied to the cotton crop.

**Proportion of pesticides (a.i.)**: The proportion of pesticides applied belonging to different hazard categories was measured by using the World Health Organization classification (Ia: extremely hazardous, Ib: highly hazardous, II: moderately hazardous, III: slightly hazardous, U: unlikely to present an acute hazard) (WHO 2020), and the proportion of probable and possible carcinogenic pesticides (a.i.) applied was determined based on the U.S. Environmental Protection Agency categorization (EPA 2018).

**Field use environmental impact quotient (FEIQ) of pesticides**: The methodology of Kovach et al (1992) was employed to measure the FEIQ of pesticides on consumers, workers, and ecology for comparing the pesticide use. The Cornell University reference EIQs were used for the calculation of FEIQ. The FEIQ was calculated by the formula of Kovach et al (1992).

$$\text{FEIQ} = \text{EIQ of a pesticide} \times \%\ \text{active ingredient} \times \text{dosage rate per ha} \quad (3)$$

FEIQ was calculated by summing over the FEIQ of each active ingredient applied per ha.

**Data collection:** The structured interview schedule was developed for data collection from cotton farmers in face-to-face interviews in 2016 and 2017.

**Statistical analysis:** The data on differences between IPM and non-IPM farmers were analyzed with the help of two sampled *t*-test and *z*-test of proportions. Heckman (1979) two-step model was employed for identifying the sample bias and variables affecting pesticide applications. IBM SPSS 25 and Stata 12 were used for the analysis of the data.

**Heckman's two-step selection model**: Linear regression model does not account for endogeneity and sample selection bias. Many approaches to address endogeneity and self-selection of farmers, such as progressive/active farmers volunteering for training (Peshin et al 2009, Knook et al 2018), difference-in-differences, propensity score matching, and the Heckman correction model (Heckman 1979), are employed. We employed both the modified difference-in-differences to compare the differences between IRM and non-IRM cotton farmers between 2004 and 2016 and Heckman's two-step model to address the issue of sample selection bias.

The dependent variables in Heckman's two-step estimation model were farmers having participated in the IRM programme and the number of pesticide applications. The probability of participation in the IRM programme was estimated by using a probit model (Eq 4).

$P_i = \beta_0 + \beta_1 X_1 + ... + \beta_{15} X_{15} + \mu_1 > 0$ ........ (4)

Here, $P_i$ is the probability of participation of a farmer in the IRM programme ("1" for participation in IRM and "0" otherwise), $\beta_0$ is the intercept, and $x_1$ to $x_{15}$ are explanatory variables. The explanatory variables entered in the selection model were age, education, family size, farming experience, farm size, the area under cotton crop, land leased-in, household members associated with farming, households having non-farm income, and distances of households to the nearest market, seed store, fertilizer store, pesticide shop, and agriculture office. The measurement of the variables is given in Table 1. $\beta_1$ to $\beta_{15}$ are vectors of explanatory variables estimated. $\mu_1$ is the normally distributed error term. From Eq. 4, we obtain the inverse Mills ratio ($\lambda$), which is used as a control in the outcome equation for correction of the sample selection bias, yielding estimates of the predictor of the outcome (Rejesus et al 2009).

$Y_i = \beta_0 + \beta_1 X_1 + ... + \beta_{14} X_{14} + \mu_1$ ........ (5)

In Eq. 5, $Y_i$ is the dependent variable (the number of pesticide applications in cotton crop) of the outcome equation, $\beta_0$ is the intercept, $\mu_1$ is the error term, and $x_1$ to $x_{14}$ represent predictors of the outcome equation, namely, age, education, family size, households with non-farm income, land leased-in, the area under cotton, total landholding, the distance of a household from the nearest pesticide store, purchase of a pesticide on credit, and sources of information about pesticides such as pesticide agents, package of practices of PAU, farmer's own experience, fellow farmers, and mass media. The measurements of these predictor variables are given in Table 1. $\beta_1$ to $\beta_{14}$ are vectors of explanatory variables $x_1$ to $x_{14}$. The default value of a 5% significance level was adopted. The regression equations were run using Stata 12 software.

**Binary logistic regression**: Binary logistic regression model was applied to identify the independent variables influencing the dependent variables where the dependent variables were dichotomous (adoption of selected IPM practices). The result of this type of regression can be expressed as follows:

$$Ln\left[\frac{p}{1-p}\right] = b_0 + b_1x_1 + b_2x_2 + b_3x_3 ...... b_kx_k \qquad (6)$$

Here, $p$ is the probability of an outcome, $\ln[p/(1-p)]$ is the log odds ratio or logit, $b_0$ is the $y$-intercept, $b_1$ to $b_k$ represent the predictors in the equation. $x_1$ to $x_k$ represent the independent variables given in Table 1.

## RESULTS AND DISCUSSION

**Descriptive statistics:** There were no significant differences between the sampled IRM and non-IRM farmers with respect to their operational landholdings, age, literacy

**Table 1.** List of independent variables and their measurement

| Independent variable | Measurement |
|---|---|
| Age | No. of years |
| Literacy | "1" for literate and "0" for illiterate |
| Education | No. of formal schooling years |
| Family size | No. of family members |
| Family members associated with farming | No. |
| Operational landholding | Ha |
| Owned landholding | Ha |
| Leased-in landholding | Ha |
| Leased-out landholding | Ha |
| Area under cotton | Ha |
| Farming experience | Number of years |
| Non-farm economic activity | "1" for non-farm and "0" for otherwise |
| Sources of information about pesticides | "1" for a particular source of information and "0" for not using that particular source of information |
| Bt and non-Bt | "1" for Bt and "0" for non-Bt |
| IRM training | "1" for IRM farmers and "0" for non-IRM farmers |

rate, average formal schooling years completed, and possession of mobile phones (Table 2). The samples of IRM and non-IRM farmers matched on biophysical and personality variables.

**Adoption of IPM practices:** IPM practices adopted by the farmers were the cultivation of PAU-recommended Bt-cotton hybrids and other varieties resistant to sucking pests and cotton leaf curl virus (CLCV), which accounted for more than 50% of the total adoption (Table 3). Timely sowing, from April 1 to May 15,was done by more than 70% of the cotton growers, which resulted in the prevention of insect pest attack and diseases and thereby a better yield (PAU 2016). Cleaning of bunds to destroy the alternative host of cotton leaf curl virus and whitefly was done by 91% and 76% of the IRM

**Table 2.** Descriptive statistics for the IRM (treatment) and non-IRM (control) farmers

| Parameter | IRM (n=141) | Non-IRM (n=63) | Difference |
|---|---|---|---|
| Average age of the respondent farmers (years) | 43.8±0.95 | 44.1±1.65 | 0.3 |
| Literate (%) | 93 | 83 | 10 |
| Average formal schooling (years) | 9.2±0.31 | 8.7±0.78 | 0.5 |
| Mobil phone (%) | 93 | 86 | 7 |
| Average family members of a household (No.) | 6.7±0.21 | 6.8±0.32 | 0.1 |
| Farm families exclusively dependent on on-farm income (%) | 69 | 62 | 7 |
| Farm families having non-farm income (%) | 31 | 38 | 7 |
| Average family members associated with farming (No.) | 1.8±0.06 | 1.9±0.11 | 0.1 |
| Average farming experience of respondents (years) | 24.5±0.93 | 25.3±1.56 | 0.8 |
| Average operational landholding | 6.1±0.21 | 7.0±0.62 | 0.9 |
| I. Owned (ha) | 5.3±0.37 | 6.1±0.61 | 0.8 |
| I. Leased-in (ha) | 1.2±0.17 | 1.3±0.27 | 0.1 |
| ii. Leased-out (ha) | 0.4±0.22 | 0.4±0.10 | 0 |
| Average area under cotton (ha) | 2.01 | 2.37 | |
| % area under cotton | 32.95 | 33.86 | 0.91 |
| Farm size[a] (% farms) | | | |
| I. Marginal(<1ha) | 6 | 3 | 3 |
| I. Small (1–2 ha) | 12 | 20 | 8 |
| ii. Semi-medium (2–4 ha) | 29 | 16 | 13 |
| iii. Medium (4–10 ha) | 38 | 37 | 1 |
| iv. Large (>10 ha) | 15 | 24 | 9 |
| Sources of irrigation (% farms) | | | |
| I. Canal | 98 | 97 | 1 |
| I. Diesel pumps | 67 | 71 | 4 |
| ii. Electric pumps | 51 | 49 | 2 |
| Permanent hired labour (% farms) | 41 | 43 | 2 |
| Average distance from (km) | | | |
| Department of Agriculture office | 13.3±0.420 | 19.8±1.184 | 6.5*±1.004 |
| Seed retailer | 11.7±0.513 | 16.0±1.128 | 4.3*±1.076 |
| Fertilizer store | 6.4±0.556 | 7.3±0.780 | 0.9±0.994 |
| Pesticide retailer | 12.1±0.413 | 15.6±1.071 | 2.7*±0.984 |
| Nearest cotton sale point | 12.9±0.413 | 12.9±0.413 | 1 2.7*±0.984 |
| Commission agent | 14.0±0.363 | 14.5±1.005 | 0.5±0.859 |
| Cooperative store | 3.3±0.345 | 3.9±0.671 | 0.9±0.686 |
| Farm households cultivating cotton in 2016 | 79 | 83 | 3 |

Significant at $p<0.05$. ± Std. mean error
[a]Categorization of landholding as per the Government of India classification of farmers

and the non-IRM farmers, respectively. The recommendation not to grow okra, green gram, pigeon pea, castor, and *Sesbania bispinosa* in and around the cotton fields to reduce the build up of insect pests and diseases, especially tobacco caterpillar (*Spodoptera litura*), did not differ among IRM and non-IRM farmers. The surveillance to monitor insect pests such as jassids (*Amrasca biguttula*) and whitefly (*Bemisia tabaci*) was widely adopted. In case of jassids, the adoption of PAU-recommended ETL, along with farmers' own modifications of thresholds, was around 21% and 14% in the IPM and non-IPM villages. This was on the higher side in 2016, as the PAU and Department of Agriculture had employed scouts in 2016 to combat the whitefly infestation that devastated the crop in 2015. A small percentage of farmers had applied synthetic pyrethroids after September 15, 2016. Following the PAU recommendation, about 65% and 84% of the IRM and non-IRM farmers, respectively, did not apply synthetic pyrethroids after September 15 to minimize a resurgence of whitefly (PAU 2022). The sowing of non-Bt varieties/hybrids as a refuge to manage resistance to Bt toxins in bollworms over time was zero.

**Factors affecting adoption of non-pesticide IPM practices:** The socioeconomic and biophysical variables impacting the adoption of non-pesticide IPM practices were analyzed by running a binary logistic regression model. There was no uniformity in the predictors of adoption of different non-pesticide IPM practices (Table 4). In case of adoption of the PAU-recommended hybrids, the drivers of adoption were the area under cotton, family members associated with farming, and farmers trained under the IRM programme. Surprisingly, the IRM training was negatively impacting the cultivation of the PAU-recommended varieties/hybrids (Table 4).

**Impact on pesticide use**: Contrary to our hypotheses that IRM implementation would have had a long-term impact on the reduction of pesticide use by weight and applications, the results show otherwise. There is not much to differentiate between the IRM and the non-IRM cotton farmers. In cotton, the IRM farmers on average had applied more insecticide applications in Bt cotton hybrids, non-Bt varieties, and *desi* cotton and the difference was significant only in Bt cotton (t=2.486; p=0.014), which was cultivated by 95% of farmers on 92% acreage. The other cultivars were cultivated by a mere 5% of farmers. In non-Bt varieties, the non-IRM farmers had applied more fungicide applications and the difference was not significant (Table 5).

In cotton, the key pests reported were whitefly (*B. tabaci*), jassids (*Amrasca biguttula*), thrips (*Thrips tabaci*), wilt (caused by *Fusarium oxysporum* f. sp. *vasinfectum*), and Anthracnose (caused by *Colletotrichum lindemuthianum*). Pesticide use by weight (a.i.) among IRM farmers was marginally higher than non-IPM farmers by about 13%. The insecticide contributed 70% of the total pesticide use in cotton (Fig. 1). The impact of IRM on the environment and human health was estimated by FEIQ of pesticides applied by the IRM and non-IRM farmers and the use of the riskiest pesticides that have been reported to be probable and possible carcinogenic by the Environmental Protection Agency (EPA) of the United States (EPA, 2018). In cotton, insecticides contributed more than 75% of the total FEIQ in both the IRM and non-IRM villages, and organophosphates contributed around 66% and 61% in the IRM and non-IRM villages, respectively (Table 6). In the IRM and non-IRM villages, the contribution of probable (B) and possible (C) carcinogenic pesticides to the total pesticide use was 23.5%. However, FEIQ of pesticide use was more in the case of the IRM farmers.

**Pesticide expenditure:** In 2004, pesticide costs with regard to cotton accounted for 31% and 27%of the total cost of

**Table 3.** Adoption of IPM practices in cotton

| Practice | IRM (n=141) | Non-IRM (n=63) | Difference |
|---|---|---|---|
| Cultivation of recommended Bt/hybrids resistant to sucking pests and CLCV | 69 | 51 | 18 |
| Timely sowing (April to May 15)[#] | 72 | 77 | –5 |
| Cleaning of bunds to destroy alternate hosts of CLCV and whitefly | 91 | 76 | 15 |
| Bt cotton | 94 | 94 | 0 |
| Avoiding cultivation of alternate host crops of tobacco caterpillar | 29 | 35 | -6 |
| Surveillance for monitoring insect pests | 96 | 100 | –4 |
| Regular field visit | 99 | 100 | –1 |
| Farmers' own thresholds for taking pesticide use decision | 89 | 90 | –1 |
| Adoption of a threshold concept for Jassids | 21 | 14 | 7 |
| No synthetic pyrethroids applied after September 15 | 65 | 84 | 19 |

CLCV, cotton leaf curl virus

[#]Timely and late sowing (April to May): Cotton farmers who started sowing their cotton crop in April and completed sowing after May 15

**Table 4.** Factors affecting the adoption of non-chemical IPM practices in cotton

| Practice | Coefficient (β) | SE | Wald | p value | Model summary |
|---|---|---|---|---|---|
| Cultivation of PAU-recommended hybrids/Bt | | | | | |
| Constant | 0.923 | 0.449 | 4.220 | 0.040 | –2 log likelihood 244.792<br>Nagelkerke'sR$^2$ = 0.149<br>$\chi^2$= 5.402<br>df = 8<br>p = 0.714<br>Predicted percentage = 63.2 |
| Family members associated with farming | –0.383 | 0.189 | 4.079 | 0.043 | |
| Area under cotton | 0.272 | 0.091 | 8.923 | 0.003 | |
| IRM farmers | –0.853 | 0.329 | 6.718 | 0.010 | |
| Timely date of sowing (upto 15th of May) | | | | | |
| Constant | 2.219 | 0.400 | 30.742 | 0.000 | –2 log likelihood 212.770<br>Nagelkerke's $R^2$ = 0.140<br>$\chi^2$= 10.164<br>df = 8<br>p = 0.254<br>Predicted percentage = 73.9 |
| Area under cotton | –0.124 | 0.059 | 4.479 | 0.034 | |
| Distance from the seed store | 0.052 | 0.026 | 4.154 | 0.042 | |
| Distance from market/mandi | –0.102 | 0.031 | 11.078 | 0.001 | |
| Timely and late sowing | | | | | |
| Constant | 0.859 | 1.050 | 0.669 | 0.413 | –2 log likelihood 132.762<br>Nagelkerke'sR$^2$ = 0.199<br>$\chi^2$= 5.149,df = 8<br>p = 0.742<br>Predicted percentage = 87.3 |
| Family members associated with farming | –0.795 | 0.315 | 6.370 | 0.012 | |
| Area under cotton | 0.216 | 0.064 | 11.271 | 0.001 | |
| Age of the respondent | –0.051 | 0.021 | 5.711 | 0.017 | |
| Late sowing (after 15th May) | | | | | |
| Constant | –3.628 | 0.587 | 38.256 | 0.000 | –2 log likelihood 138.64<br>Nagelkerke'sR$^2$ = 0.119<br>$\chi^2$= 11.695,df = 7<br>p = 0.111<br>Predicted percentage = 87.7 |
| Distance from the cotton mandi | 0.102 | 0.030 | 11.929 | 0.001 | |
| Cleaning/weeding of bunds | | | | | |
| Constant | 3.334 | 0.554 | | 36.165 | –2 log likelihood 144.260<br>Nagelkerke'sR$^2$ = 0.095<br>$\chi^2$= 10.572,df = 1<br>p = 0.001<br>Predicted percentage = 87 |
| Distance from the pesticide store | –0.089 | 0.029 | | 9.747 | |
| Avoiding cultivation of crops that are alternate hosts of insect pests around cotton crop | | | | | |
| Constant | –2.032 | 0.410 | 24.550 | 0.000 | –2 log likelihood 217.772<br>Nagelkerke'sR$^2$ = 0.208<br>$\chi^2$= 32.200,df = 3<br>p = 0.000<br>Predicted %age = 76.60 |
| Operational land holdings | 0.07 | 0.031 | 5.392 | 0.020 | |
| Distance from the nearest agricultural market | –0.099 | 0.037 | 7.220 | 0.007 | |
| Distance from the nearest pesticide retailer | 0.154 | 0.039 | 15.972 | 0.000 | |

**Cont...**

**Table 4.** Factors affecting the adoption of non-chemical IPM practices in cotton

| Practice | Coefficient (β) | SE | Wald | p value | Model summary |
|---|---|---|---|---|---|
| Pest surveillance and monitoring | | | | | |
| Constant | 0.335 | 0.895 | 0.140 | 0.708 | –2 log likelihood 40.980<br>Nagelkerke'sR$^2$ = 0.266<br>$\chi^2$= 12.978,df = 2<br>p = 0.002<br>Predicted percentage = 97 |
| Distance from Commission agent | 0.245 | 0.089 | 7.603 | 0.006 | |
| IRM farmer | 18.502 | 1.009 | 0.160 | 0.002 | |
| Not using synthetic pyrethroids after 15th September | | | | | |
| Constant | –2.027 | 0.537 | 14.235 | 0.000 | –2 log likelihood 228.216<br>Nagelkerke'sR$^2$ = 0.114<br>$\chi^2$= 16.841,df = 3<br>p = 0.001<br>Predicted percentage = 74.10 |
| IRM trained farmer | –1.038 | 0.412 | 6.337 | 0.012 | |
| Commission agent | 0.050 | 0.026 | 3.789 | 0.052 | |
| Farming experience | 0.878 | 0.412 | 4.525 | 0.033 | |

**Table 5.** Average number of pesticide applications in cotton

| Pesticide/crop | IRM farmers (n=141) | Non-IRM farmers (n=63) | Difference |
|---|---|---|---|
| *Gossypium hirsutum* L. | | | |
| Bt cotton hybrids | n=133 | n=60 | |
| Insecticides | 8.46±0.279 | 7.37±0.339 | +1.09* (14.8) |
| Fungicides[1] | 0.79±0.091 | 0.83±0.168 | -0.04 (4.8) |
| Herbicides[1] | 0.42±0.050 | 0.53±0.080 | -0.11 (20.1) |
| All pesticides | 9.67 | 8.73 | +0.94(10.8) |
| Non-Bt cotton varieties | n=9 | n=6 | |
| Insecticide | 8.56±0.818 | 7.17±1.447 | +1.39(19.4) |
| Fungicides[1] | 0.11±0.111 | 0.67±0.333 | -0.56*(83.6) |
| Herbicides[1] | 0.56±0.176 | 0.50±0.341 | +0.056 (11.2) |
| All pesticides | 9.23 | 8.34 | +0.89 (10.7) |
| *G. arboreum* L. | | | |
| *Desi* cotton | n=21 | n=13 | |
| Insecticide | 7.14± 0.741 | 6.92±0.916 | +0.22 (3.2) |
| Fungicides[1] | 0.29±0.171 | 0.38±0.241 | -0.09 (23.7) |
| Herbicides[1] | 0.30±0.105 | 0.54±0.183 | -0.24 (44.4) |
| All pesticides | 7.73 | 7.84 | -0.11 (1.4) |

**Notes**: [1] Herbicides and fungicides were not components of the IRM programme but the data included to workout insecticide contribution to the total pesticide use in cotton. ± Std. mean error. *n* is the number of farmers out of a sample of 204 who had cultivated different cotton cultivars. Figures in the parentheses are the % differences with non-IRM farmers. *Significant at $p$<0.05.

cultivation in the IRM and non-IRM villages, respectively (Peshin et al 2009); this had come down to around 20% in 2016–2017, owing to reduction in pesticide applications since the commercialization of Bt cotton.

**Sources of information:** IRM cotton farmers were less dependent on pesticide retailers/pesticide industry sale agents compared to those in the non-IRM villages (Table 7). Although farmers have vast hands-on experience, they consult different sources for pest- and pesticide-related advice. The pesticide industry has a greater influence on farmers' pesticide use decisions compared to public sector extension agencies.

**Factors affecting pesticide applications: Heckman's two-step model:** The independent variable that determined the participation of farmers in the IRM programme was the distance of the household from the nearest market, whereas the distance of a village from pesticide stores negatively affected the participation in the IRM programme (Table 8). The variables causing a positive variation in pesticide use in the cotton were (i) area under cotton crop and (ii) influence of neighbour/fellow cotton farmers in pesticide use decision. There was no sample selection bias as the inverse Mills ratio was not significant (–0.682, $p$ = 0.663), confirming that the estimates of impacts on pesticide applications are free of sample selection bias (Table 8). The other variables that caused variation in the pesticide applications at $p \leq 0.10$ were land leased-in and farm size.

**Difference-in-differences between 2004 and 2016:** Modified difference-in-differences (DD) model (Ashenfelter and Card 1985) was used to determine the change in pesticide use frequency between 2004 and 2016and to eliminate the seasonal effect and impact of Bt cotton cultivation over time. In 2004, none of the farmers had applied fungicides to cotton (Peshin 2005, Peshin et al 2009), but in 2016 the average fungicide use frequency was 0.79 and 0.83 in the IRM and non-IRM villages, respectively (Table

**Table 6.** Insecticide use by weight (a.i.) and FEIQ in cotton in 2016 (Cotton insect pests)

| Pesticides applied to cotton | Insecticide use (a.i.) (kg/ha) | | FEIQ/ha | |
|---|---|---|---|---|
| | IRM | Non-IRM | IRM | Non-IRM |
| Insecticides | | | | |
| Acephate[C] | 0.127 | 0.065 | 3.15 | 1.63 |
| Alphamethrin[C] | 0.005 | 0.003 | NA | NA |
| Chlorpyriphos | 0.000 | 0.014 | 0.00 | 0.36 |
| Clothianidin | 0.003 | 0.002 | 0.08 | 0.07 |
| Cypermethrin[C] | 0.000 | 0.001 | 0.00 | 0.05 |
| Diafenthiuron | 0.206 | 0.139 | 6.57 | 4.43 |
| Dichlorvos | 0.016 | 0.000 | 0.84 | 0.02 |
| Dimethoate[C] | 0.058 | 0.053 | 1.94 | 1.78 |
| Dinotefuran | 0.008 | 0.000 | 0.18 | 0.00 |
| Ethion | 0.423 | 0.472 | 18.28 | 20.41 |
| Fenvalerate | 0.015 | 0.002 | 0.61 | 0.07 |
| Fipronil[C] | 0.003 | 0.010 | 0.32 | 0.91 |
| Flonicamid | 0.051 | 0.056 | 0.45 | 0.49 |
| Imidacloprid | 0.073 | 0.172 | 2.69 | 6.31 |
| Indoxacarb | 0.001 | 0.000 | 0.02 | 0.01 |
| Lambda-cyhalothrin | 0.000 | 0.000 | 0.01 | 0.00 |
| Monocrotophos | 0.157 | 0.160 | 6.95 | 7.07 |
| Pyriproxyfen | 0.045 | 0.050 | 0.66 | 0.74 |
| Quinalphos | 0.000 | 0.003 | 0.00 | 0.12 |
| Spinosad | 0.006 | 0.002 | 0.09 | 0.04 |
| Spiromesifen | 0.021 | 0.001 | 0.59 | 0.04 |
| Thiodicarb[B] | 0.000 | 0.002 | 0.00 | 0.05 |
| Thiamethoxam | 0.123 | 0.093 | 4.10 | 3.09 |
| Triazophos | 0.614 | 0.426 | 21.87 | 15.17 |
| β-Cyfluthrin | 0.001 | 0.001 | 0.05 | 0.03 |
| Insect growth regulator | | | | |
| Chlorantraniliprole | 0.005 | 0.003 | 0.09 | 0.05 |
| Novaluron | 0.000 | 0.011 | 0.00 | 0.15 |
| Emamectin benzoate | 0.001 | 0.007 | 0.02 | 0.19 |
| Total | 1.962 | 1.748 | 69.56 | 63.28 |

**Notes**: The superscripts "B" and "C" denote probable and possible carcinogenic pesticides, respectively. FEIQs do not include alphamethrin and *P. fluorescens* as their reference EIQs are not available. The total insecticide use does not include *P. fluorescens and neem based* formulations

**Table 7.** Sources of information about pesticide use (% farmers)[a]

| Source | IRM | Non-IRM | Difference |
|---|---|---|---|
| Department of Agriculture | 26 | 14 | 12 |
| PAU | 06 | 06 | 00 |
| KVKs of PAU | 04 | 02 | 02 |
| Pesticide retailer/company | 38 | 65 | 27 |
| Package of practices of PAU | 05 | 02 | 03 |
| Commission agents | 05 | 06 | 01 |
| Own experience of the farmers | 78 | 62 | 08 |
| Progressive farmers | 47 | 62 | 15 |
| Newspaper | 01 | 02 | 01 |
| Radio | 01 | 02 | 01 |
| Television | 00 | 02 | 02 |
| Scouts of the PAU | 06 | 02 | 04 |
| Others | 00 | 00 | 00 |

[a]Multiple sources of information: KVK, Krishi Vigyan Kendras; PAU, Punjab Agricultural University

6). A change was also observed in the use of botanical or biological pesticides. In 2004, none of the farmers had applied botanical or biological pesticides (Peshin 2005), but in 2016 the average use frequency of these pesticides was 0.20 and 0.22 in the IRM and non-IRM villages, respectively, though not recommended under IRM (Table 8). The farmers had applied these for multiple sucking pests.

In 2003, there was no significant difference between the mean frequency of pesticide use between IRM and non-IRM farmers, and after the intervention of the IRM programme, the IRM farmers reduced the use of insecticide applications by 2.36 in 2004 (Peshin 2005). In 2004, the average number of insecticide applications in the IRM villages was 13.1 compared to 15.1 in non-IRM villages, with a significant difference of 15.3% ($t$ =2.1, $p \leq 0.05$). The pesticide use by weight (a.i.) applied by in the IRM and non-IRM villages was 5.602 and 8.032 kg/ha, respectively, with a difference of 30.25%. However, the mean insecticide applied per ha per farm by the IRM and non-IRM farmers was 5.455 and 6.083kg, respectively (Table 10). After the withdrawal of IRM intervention, the difference in insecticide use frequency between these two groups in 2016 was 0.9, which was not significant (Table 10). Besides, there were no significant differences in seed cotton yield and active ingredients of pesticides applied by the IRM and non-IRM farmers. But if we analyze the data using the modified DD model, the differences in pesticide applications and active ingredients of pesticides applied are found to be 2.9 applications and 0.746kg/ha, respectively. After the withdrawal of the IRM intervention, if we analyze the data using the DD methodology, the difference in mean pesticide applications is 2.9, which is significant.

Overall pesticide use has decreased since 2004, but that can be attributed to Bt cotton cultivation (Peshin 2005, Peshin et al 2007, Peshin et al 2021). The cultural pest management practices, such as timely sowing of the cotton crop having a high adoptability index (Peshin 2013) to avoid late season insect pest infestation, using seeds treated with chemicals, not applying or reducing the use of synthetic pyrethroids to avoid whitefly resurgence, were widely and equally adopted by both the IRM and non-IRM farmers in 2004 and 2016.Bt cotton has reached a 95% rate of adoption, yet pesticide use has consistently increased in Bt cotton since 2004, especially fungicides from zero (Peshin et al 2007, 2009) to 15% of total pesticides. The impact of the IRM programme at the national level, based on the project reports, is the reduction in insecticide use per hectare, which resulted in the saving of US$84/ha (US$1=Rs. 44 at 2005 rates) during 2002–2006 (ICAR, 2007; Peshin et al., 2009), US$46/ha (US$1=Rs. 50 at 2011 rates) during 2007–2011, and US$143/ha during 2012–2015 (US$1=Rs. 66 at 2015 rates) (Kranthi et al 2019). In a study commissioned by the Ministry of Agriculture and Farmers' Welfare, Government of India, the IRM programme resulted in saving on insecticides by US$44/ha at 2005 rates of US$1=Rs.44 (2002–2008), owing to a reduction in insecticide use by 30% and insecticide applications by 15% compared to farmers not covered under the IRM-based IPM programme (AFC 2010). The reduction in pesticide use and the increase in yields are estimated to have resulted in economic benefits of Rs. 968 million (US$16 million at Rs. 65=US$1) and Rs. 1983 million (US$33 million), respectively (AFC 2010). Similar trends of reduction in pesticide use from 31.2% to 26.8% were reported during the implantation phase of the IRM programme in Haryana (Kumar et al 2012). A peer-reviewed impact study of this programme by Peshin et al (2009) reported that 2 years of the IRM programme implementation (i.e., 2003 and 2004) resulted in 15% lesser insecticide applications and 30% lesser by weight (a.i.) by the IRM farmers compared to the

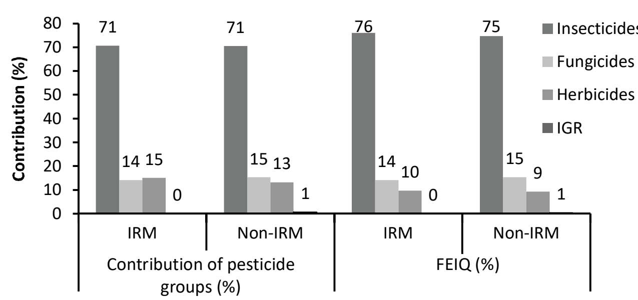


**Fig. 1.** Contribution of different groups of pesticides by weight and FEIQ

non-IRM farmers. This resulted in the benefit of US$24.05/ha (at 2005 rates: US$1 = Rs. 45), which is less than that reported by the CICR, the implementing agency of the IRM-based IPM programme in cotton. Our results show that the benefits have not sustained after the withdrawal of IRM intervention.

**Table 8.** Heckman's two-step estimates for sample bias and the factors affecting the pesticide use in cotton (Regression model with sample selection)

| Variable | Coefficient | Standard error | *z* value | *p*>\|*z*\| |
|---|---|---|---|---|
| Pesticide application regression model | | | | |
| Constant | 8.840* | 2.288 | 3.860 | 0.000 |
| Age | –0.035 | 0.026 | –1.350 | 0.176 |
| Education | –0.095 | 0.083 | –1.140 | 0.253 |
| Family size | 0.148 | 0.130 | 1.140 | 0.253 |
| Households with non-farm income | 0.960 | 0.734 | 1.310 | 0.191 |
| Land leased-in | –0.259 | 0.147 | –1.760 | 0.078 |
| Area under cotton | 0.491* | 0.149 | 3.300 | 0.001 |
| Total landholding | –0.138 | 0.076 | –1.810 | 0.070 |
| Distance of a household from the nearest pesticide store | 0.062 | 0.050 | 1.240 | 0.215 |
| Purchase of pesticides on credit | 0.087 | 0.418 | 0.210 | 0.835 |
| Sources of information about pesticides: | | | | |
| Source pesticide agents | 0.052 | 0.588 | 0.090 | 0.929 |
| Package of practices of PAU | 0.986 | 1.563 | 0.630 | 0.528 |
| Own experience | 0.145 | 0.745 | 0.190 | 0.846 |
| Fellow farmers | 1.171* | 0.589 | 1.990 | 0.047 |
| Mass media | –1.302 | 1.113 | –1.170 | 0.242 |
| IRM/non-IRM sample selection model | | | | |
| Constant | 1.055 | 0.680 | 1.550 | 0.121 |
| Age | 0.012 | 0.015 | 0.840 | 0.399 |
| Education | 0.040 | 0.021 | 1.900 | 0.057 |
| Family size | 0.000 | 0.058 | 0.000 | 0.999 |
| Family members associated with farming | –0.006 | 0.161 | –0.040 | 0.969 |
| Land leased-in | –0.020 | 0.047 | –0.420 | 0.675 |
| Total landholding | –0.021 | 0.028 | –0.760 | 0.447 |
| Area under cotton | 0.022 | 0.051 | 0.430 | 0.667 |
| Farming experience | –0.016 | 0.014 | –1.100 | 0.270 |
| Households with non-farm income | –0.427 | 0.246 | –1.740 | 0.082 |
| Distance of farm household from: | | | | |
| Seed store | –0.007 | 0.020 | –0.370 | 0.709 |
| Fertilizer store | 0.030 | 0.021 | 1.480 | 0.138 |
| Pesticide store | –0.300* | 0.151 | –1.980 | 0.048 |
| Nearest market | 0.293* | 0.131 | 2.240 | 0.025 |
| Agriculture office | –0.055 | 0.029 | –1.920 | 0.055 |
| Inverse Mills ratio | –0.682 | 1.566 | –0.440 | 0.663 |
| Rho | –0.211 | | | |
| Sigma | 3.233 | | | |

**Notes:**
1. Heckman's two-step model summary: The number of observations = 192; Wald $\chi^2(13)$ =31.34; $p>\chi^2$=0.005; IRM and non-IRM omitted because of collinearity.
2. Probit regression model summary: The number of observations = 192, LR $\chi^2$ (14) = 58.33;$p>\chi^2$ = 0.000; loglikelihood = –92.340; pseudo $R^2$ = 0.24.
*Significant at $p \leq 0.05$.

The IRM farmers using more pesticides was mainly driven by more outliers present among the IRM farmers compared to the non-IRM group. Peshin et al (2009) have highlighted that more active farmers having more landholding and better extension contacts were selected or volunteered in the IRM training programme in 2004. There were more outliers among the IRM farmers with respect to farm size and the number of pesticide applications. Besides, insecticides, for example, acephate and monocrotophos, were used for reducing boll shedding and as plant growth regulators. However, IRM farmers' use of the riskiest pesticide and dependence on pesticide retailers for pesticide advice was less compared to the non-IRM farmers. Many studies have shown that farmers acquire pesticide information and other technological information mainly through local contact (Koul and Cuperous 2007, Peshin 2005, Peshin et al 2009, Sharma et al 2015, Sharma and Peshin 2016). Dissemination and adoption are constrained by complexities, be it the use of pesticides according to good agricultural practices or cultivation of refuge requirements for Bt cotton; our results show that adoption was low in the case of the former and zero in the case of the latter.

## CONCLUSION

The results confirm that bollworms, especially American bollworms, are no longer key pests of cotton in Punjab. This has resulted in a reduction of insecticide use in cotton, but on the other hand fungicide use has increased. The use of more insecticides by IRM farmers than non-IRM confirms that IPM programmes have a short-term positive impact on

**Table 9.** Mean frequency of pesticide applications against different pests of cotton in 2004 and 2016 (With sample attrition)

| Pest | IRM | | | Non-IRM | | | DD |
|---|---|---|---|---|---|---|---|
| | 2004 (*n*=147) | 2016 (*n*=141) | Difference | 2004 (*n*=60) | 2016 (*n*=63) | Difference | |
| Cotton bollworm complex (main Bt target pests) | 8.50 | 0.26 | -8.24 | 11.15 | 0.25 | -10.90 | 2.66 |
| Tobacco caterpillar | 1.55 | 0.00 | -1.55 | 1.23 | 0.00 | -1.23 | -0.32 |
| Whitefly/jassid | 2.93 | 7.17 | +4.24 | 3.01 | 6.08 | +3.07 | 1.17 |
| Thrips | 0.00 | 0.36 | +0.36 | 0.00 | 0.33 | +0.33 | 0.03 |
| Aphid | 0.00 | 0.08 | +0.08 | 0.00 | 0.15 | +0.15 | -0.07 |
| Mite | 0.00 | 0.17 | +0.17 | 0.00 | 0.10 | +0.10 | 0.07 |
| Insecticides for growth | 0.05 | 0.11 | +0.06 | 0.02 | 0.13 | +0.11 | -0.05 |
| Other insect pests | 0.05 | 0.11 | +0.06 | 0.00 | 0.11 | +0.11 | -0.05 |
| Wilt | 0.00 | 0.24 | +0.24 | 0.00 | 0.13 | +0.13 | 0.11 |
| Anthracnose | 0.00 | 0.20 | +0.20 | 0.00 | 0.09 | +0.09 | 0.11 |
| Multiple sucking insect pests (botanical pesticides[a]) | 0.00 | 0.20 | +0.20 | 0.00 | 0.22 | +0.22 | -0.02 |
| Fungicide used for growth, flowering, and controlling fruit shedding | 0.00 | 0.35 | +0.35 | 0.00 | 0.58 | +0.58 | -0.23 |
| All cotton pests | 13.08 | 9.25 | -3.83 | 15.41 | 8.17 | -7.24 | 3.41 |

DD=Difference-in-differences.
[a]Organic and natural pesticides that are derived from plants and minerals

**Table 10.** Difference-in-differences impact of IRM programme (with sample attrition)

| Parameter | 2004 | | | 2016 | | | DD |
|---|---|---|---|---|---|---|---|
| | IRM | Non-IRM | Difference | IRM | Non-IRM | Difference | |
| Mean pesticide applications (No.) | 13.1 (6.58) | 15.1 (6.55) | –2.0* | 9.2 (3.57) | 8.3 (2.95) | 0.9 | 2.9* |
| Mean pesticide use by weight (a.i.) | 5.455 (3.08) | 6.083 (3.42) | –0.628 | 1.863 (1.06) | 1.745 (1.04) | 0.118 | 0.746 |
| Yield (kg/ha) | 2243 (849.1) | 2296 (636.6) | –53 | 2099 (25.2) | 1922 (578.4) | 177 | 230 |
| % area under Bt cotton | 34.7 | 25.2 | 9.5 | 91.2 | 96.8 | –5.6 | 15.1 |

*Significant at $p \leq 0.05$.
**Note**: Figures in the parentheses are standard deviations. DD, difference-in-differences

reducing pesticide use and these benefits are not sustained on a long-term basis. Both IRM and non-IRM farmers had cultivated Bt cotton on more than 92% and 95% cotton acreage, respectively, and had applied more pesticides on Bt cotton compared to *desi* and not Bt cotton, which is paradoxical. Glorified host-plant resistance that Bt cotton provides has not become a component of IRM/IPM strategies, unlike in a few countries such as the United States where it has become part of IPM to eradicate pink bollworm (Frisvold 2009). Thus, farmers are caught in "pesticide and genetic treadmill." IPM/IRM programming has to be a continuous process and not project or mini-mission-based projects implemented by the public sector and private sector.

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