Research Article

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Genetically modified crops in India: Experiments with Bt Cotton to explore the road ahead

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Abstract: The success of genetically modified crops (GMCs), claimed to hold solution to impending environmental problems, depends on land holdings, agroclimatic and geoclimatic conditions, food preferences and sociocultural factors. The direct and indirect impacts of these crops on human health, ecology and environment have not been evaluated on long-term basis. In India, with rich background of farming, GMCs remain a minor change. Introduction of first GMC, Bt Cotton (BC), showed varied response throughout the country. New GMCs like Bt Brinjal and GM Mustard approved for open-field trials in the country were marred under contentious debate and were never approved for commercial cultivation. The current research article aims to study the ecological implications of only GMC available for experimentation in India, BC. A three-phase study carried out as field survey, glass dome experiments and open-field trials compared the BC and conventional cotton (CC) plants with extensive experimentation of ecological parameters including vegetation diversity, insect diversity, plant morphology and infestation intensity. Results highlighted the better morphological characteristics of BC over CC, while infestation studies showed 40% survival rate of insect pest on BC for which it is genetically modified. High electrical conductivity and low organic matter content in the BC soil samples as compared to CC soil samples were indicative of impact of Bt toxins in soil but need further in-depth soil studies to reach scientifically valid results. The current research article substantiates the environmental concerns raised against GMCs especially BC in the country. Its objective is to trigger more research in this direction, so that the technology of GMCs is utilized for the benefit of humankind.

Keywords: agriculture, genetically modified crops, Bt cotton, India, conventional cotton

1 Introduction

Genetically modified crops (GMCs) entered Indian agricultural system at a time when farmers were distraught with declining crop yields, increased chemical inputs leading to loan debts, depleted water table and degraded soils. These ecological, social and economic issues weighed down to the national catastrophe of farmer suicides. Misuse and overadoption of tools of Green Revolution left a deleterious impact on agroecosystem. Thus, GMCs claiming to hold solution to these impending agricultural, environmental and economic problems entered Indian agriculture with great hope (Qaim 2009). But these crops soon got embroiled in controversy. Effect of these crops on ecology, environment, health, ethics, economy and society as whole has led to perplexing debate (Smith 2009). Further, lack of factual scientific data, post-commercial cultivation monitoring, misrepresented data, wrongful interpretation and modification of existing information together generated massive asymmetrical knowledge base.

GMC is not an isolated biotechnological innovation with universal appeal. Its adoption and impact will vary with land holdings, agroclimatic and geoclimatic conditions, food preferences and sociocultural factors (Kaur et al. 2013a, 2013b). It is an expensive technology as 80% of the research and development of commercial GMCs is held by the private groups and few by the public sector (Kaur et al. 2012). GMCs do bring economic benefits but such benefits do not extend to all segments of the society (Gupta and Chandak 2005). In India, Bt Cotton (BC), an insect-resistant transgenic Gossypium hirsutum is the only commercially grown GMC. Approved for commercial cultivation in March 2002, there were varied reports of its performance throughout the country along with reports of pest resistance, secondary pest attacks and allergic reactions to farmers. Impetus to research in the field of
GMCs in the country with no substantial outcome has raised questions on their real efficacy and the government policy supporting these crops with no biosafety regulation, post-cultivation monitoring and multi-department control. Therefore, a research study to analyse the ecological impact of the only GMC grown in the country, by drawing a comparative account of transgenically modified *Gossypium hirsutum* popularly known as BC with *Gossypium hirsutum* commonly called conventional cotton (CC), was conducted over three kharif (summer crop) seasons. The extensive field and lab studies were carried out in three phases (field survey, glass dome and open field) to understand and observe its implications on environment so as to devise a plan for future of GMCs in India.

## 2 Materials and methods

Cotton is a summer crop, which grows well in warm and humid climate and sandy loam to loamy soil with low water requirement of about 700–1,000 mm (CICR 2005). Of the 11.4 mha of land under cotton plantations in India, 10.8 mha is under BC (CICR 2018; James 2018). It was the only GMC available for ecological analysis and experimentation. An ecological study was carried out in three phases of experimentation done over BC and CC plants as explained in following sections.

### 2.1 Phase I field survey

Field surveys were carried out on 10 randomly selected BC and CC fields at three different sites repeatedly for three seasons. The field survey was conducted at three sites: Site A – Village Rupana, District Mukatsar, Punjab, India (Latitude – 30°25′11″N; Longitude – 74°32′00″E); Site B – Village Muradwala, District Abohar, Punjab, India (Latitude – 30°17′30″N; Longitude – 74°17′06″E); Site C – Village Fatuhi, District Ganaganagar, Rajasthan, India (Latitude – 30°02′46″N; Longitude – 73°52′11″E). Fields were ploughed in conventional manner, followed by manual sowing of seeds. Record of quantity and frequency of fertilizer use, pesticide spray and irrigation in the fields was maintained and was found to be similar.

At every field, on-site vegetation analysis was done using the quadrat method. The minimum quadrat size was determined for every field. Fifteen quadrats were laid in the vicinity of every field for determining the presence of vegetation other than the crop. The net-sweep method was used to analyse insect diversity. Eight sweeps each at randomly selected three different locations on the every field were done. All the readings were taken in the morning time 1,000 h. Data so collected was analysed to infer the insect diversity of that area using the Shannon Weaver index ($H'$).

The plant morphology including height, number of leaves per plant, leaf surface area, stem surface area and root volume were calculated on-site for the fresh biomass and statistically analysed by taking mean values with standard error. Soil sampling at every field was done in triplicate at three depths, 0–15 cm, 15–30 cm and below 30 cm, and tested for the presence of macro and micronutrients and the physiochemical characteristics. The potentiometric determination of pH and electrical conductivity (EC) was done using the digital analysis kit. Organic carbon (OC) of the samples was analysed using the titration method. Approximate value of nitrogen was estimated from the amount of OC. The percent OC was first converted to percent organic matter (OM) using the Van Bemmelen factor as following:

$$\%\text{OC} \times 1.724 = \%\text{OM}$$

Nitrogen constitutes about 5% of the soil OM by weight (Wells et al. 1997). Thus, an approximate value of percent nitrogen for every sample was deduced as 5% of OM. Available phosphorus in the given sample was determined by using a spectrophotometer. Flame photometer was used to determine the content of potassium in the given soil sample. Atomic absorption spectroscopy was used to determine the quantity of micronutrients (zinc, iron, manganese, copper) in the given soil samples.

### 2.2 Phase II Glass Dome

Phase II glass dome experiments were conducted on sample size of 100 BC and CC plants for three seasons in Botanical Garden of the Panjab University Campus. The plants were grown without any fertilization and pesticide sprays on virgin soil with irrigation frequency similar for BC and CC plants. Height, number of leaves per plant, stem surface area and surface area of leaf for 10 plants of each type in three replicates were measured and recorded.

Infestation studies on major insect pest of cotton in this region, *Pectinophora gossypiella*, commonly called pink bollworm (PB), was conducted as BC is genetically...
modified to resist this pest attack. To study the extent of PB infestation, number of worms per plant, number of worms per leaf, number of leaves infested and surface area of leaf infested were measured and recorded taking 10 as the sample size in three replicates. To analyse the effect and efficacy of BC resistance to PB infestation, an experiment of forced infestation was formulated and exercised. Under this experiment, PBs which had infested CC plants were collected from these plants and put in a fibre bag. This fibre bag was then tied on to the leaf of a BC plant in the glass dome. The experiment was repeated thrice on 10 different BC plants with 20 living worms in each bag. The bag was opened after 72 h and number of living worms recorded.

After aborting the experiment, soil sampling of rhizosphere soil from the beds growing two different varieties was done. The analysis for macro and micro-nutrients was conducted as explained in Section 2.1. A control soil sample was also taken from nearby soil in the glass dome with no plantation.

2.3 Phase III open field

Phase III open-field trials were done on field of 0.1 acre approximately for three seasons at Village Tasauli, District Mohali, Punjab, India (Latitude 30°70’46″N, Longitude 76°71’79″E). The land was ploughed, prepared and divided in two equal halves. The seeds were sown at approximately 20 cm row-to-row and seed-to-seed distance. The soil temperature and pH were recorded. Daily observation of the field and record of temperature were maintained. Record of irrigation, fertilizer used and pesticides sprayed was maintained. The cotton yield of both the varieties was recorded and experimentation was done on plant growth, cotton yield and rhizosphere soil physiochemical parameters and micro-macronutrients as explained in Section 2.1. All the results were statistically analysed using both parametric tests, one-way ANOVA and t-test, and non-parametric tests, Kruskal–Wallis and Mann–Whitney tests, on SPSS 18 software to deduce their significance.

3 Results

At various levels of experimentation, comparison was drawn between BC and CC varieties. The results of ecological analysis are discussed phasewise below.

3.1 Phase I field survey

First level of the study aimed at gaining grass-roots level data on cotton plantations in the North Western belt of India by extensive comparative field surveys of BC and CC fields of Punjab and Rajasthan. Vegetation analysis of weeds growing in vicinity of the fields was variable in relative density for various species at all the three sites. At site A, Eleusine indica was the densest species in both BC and CC fields with relative density of 31% and 27%, respectively. Similarly, at site C, E. indica recorded highest relative density of all the species with 22% higher relative density in CC fields. At site B, Dactyloctenium aegyptium was the densest species in BC fields and Digeria muricata of CC fields. Relative frequency of all weeds at the three sites was recorded nearly same for both BC and CC fields with exception of Dactyloctenium aegyptium which recorded four times higher frequency in the CC fields of site A (Rupana). It was also the most dominant species of site A at CC fields while Physalis minima was the most dominant species of BC fields of the same site. The comparative analysis of BC and CC grown fields for three survey sites highlighted that the change in vegetation diversity was not governed by genetically modified characteristic but due to changing agroclimatic conditions of three survey sites. These results were in assertion with earlier studies as reported by Raju (2010).

The study of flying insect diversity using the net sweep method generated raw data. The data when analysed on Shannon index measured low insect diversity in the BC fields as compared to CC fields at all three survey sites. High values of divergence were observed for BC field which entailed to low biodiversity (Table 1). Thus, the efficacy of systemic transgenic toxin produced in BC plants could be doubted for its specificity. Further, the use of broad-spectrum insecticides as observed during field survey in the BC fields negatively affects insect diversity. The results so obtained are supported by a Chinese research study carried out over four academic institutions. It included

| Table 1: Shannon diversity index of flying insects in the BC and CC fields |
|---|---|---|---|---|---|---|
| Factors | Site A | Site B | Site C |
| | Bt Cotton | CC | BC | CC | BC | CC |
| No. of species | 2 | 3 | 3 | 3 | 2 | 3 |
| N (no. of all individuals) | 10 | 11 | 13 | 8 | 4 | 4 |
| $H$ | 0.881 | 1.49 | 1.29 | 1.406 | 0.811 | 1.5 |
| $H_{\text{max}}$ | 1 | 1.58 | 1.58 | 1.585 | 1 | 1.58 |
| $D$ | 0.11 | 0.09 | 0.29 | 0.18 | 0.19 | 0.08 |
laboratory experimentation and field research (Xue 2002; Xue et al. 2005). The study reported that the stability of insect community in BC fields was much lesser than in CC fields, increasing the possibility of outbreaks of secondary pests in BC fields.

Comparison of plant morphological characteristics of BC and CC plants depicted improved morphological features of BC over CC plants as the GM seeds are developed by inserting the transgene in best of the conventional variants available (Barwale et al. 2004). BC transgene releases a toxin in the plant which harms the insect only, whereas expectedly the success of this genetic manipulation would be if the plant characteristics do not change. However, the results showed that there was a significant increase of 40–70 cm in the height for BC plants at all the three sites. The number of leaves was on an average double in the BC plants than the CC plants. The surface area of leaf was significantly higher for BC plants while the stem surface area showed no significant difference between the two cotton varieties studied. Root volume was recorded similar for both BC and CC plants at all three sites. The close examination of the morphological features recorded improved features for BC plants over CC plants.

Soil samples were collected from every field at three depths and analysed for physiochemical characteristics, macro and micronutrients. Soil analysis of all the fields surveyed depicted normalcy in most of the macro and micronutrients. Soil samples of all the fields at three survey sites measured alkaline in pH (Table 2). The EC of soil samples from all the BC fields was higher than the respective CC fields. Higher EC of the soil samples of BC fields hinted towards the possible presence of more chemicals in ionic form. It affects the integrity of the cell membrane in the rhizosphere aiding the process further. Earlier research studies have determined the release of toxins from Bt corn, yet there is no available evidence for the BC plants (Saxena et al. 1999; Saxena and Stotzky 2003). Low OC of BC soil samples inferred into lower nitrogen concentration. It hinted towards possible impact of Bt toxin on the soil microbiota responsible for maintaining the organic content of soil. These results were in contrast to the findings of Wang et al. (2008) who reported adsorption of the Cry1Ab protein on soils to be positively related to the soil OM content.

### 3.2 Phase II Glass Dome

In the second phase of experimentation, CC and BC plants were grown in a glass dome consecutively for three seasons to draw comparative account of plant growth and worm infestation. Morphological characteristics like height, number of leaves, stem surface area and leaf surface area were observed to be higher in the BC plants than CC plants. Both height and number of leaves of the plant were nearly double for BC plants than the CC plants (Table 3). These characteristics were found to be statistically significant using parametric and non-parametric tests. This competitive advantage of the BC plants has been reported in earlier studies as well (Barwale et al. 2004; Karihaloo and Kumar 2009). On comparing the plant growth data as measured in the dome conditions with the field survey conditions, it was found that it was statistically more significant at the dome conditions. This could be attributed to the controlled conditions during the dome experiments.

The infestation study of the two varieties of cotton plants was analysed on un-augmented soil without any pesticide sprays. CC was heavily infested as compared to BC. Degree of infestation was measured on the basis of number of leaves infested, number of worms per plant, number of worms per leaf and infested surface area of leaf. On an average, around 23 leaves per plant were infested in CC (Table 4a). Around 2–3 worms were found

### Table 2: Comparative soil analysis at three survey sites

| Characteristic | Site A | Site B | Site C |
|---------------|--------|--------|--------|
|               | BC     | CC     | BC     | CC     |
| **Ph**        | 8.6 ± 0.2 | 9.2 ± 0.1 | 8.8 ± 0.0 | 8.4 ± 0.0 | 8.6 ± 0.1 | 8.5 ± 0.2 |
| **EC (siemens/cm)** | 0.41 ± 0.04 | 0.15 ± 0.03 | 0.34 ± 0.01 | 0.24 ± 0.01 | 0.33 ± 0.00 | 0.17 ± 0.0 |
| **Org. C (%)** | **0.21 ± 0.01** | 0.34 ± 0.09 | **0.27 ± 0.03** | 0.60 ± 0.09 | **0.18 ± 0.02** | 0.51 ± 0.1 |
| **Nitrogen (%)** | 0.018 ± 0.004 | 0.029 ± 0.01 | 0.023 ± 0.01 | 0.0517 ± 0.00 | 0.015 ± 0.00 | 0.044 ± 0.0 |
| **P (kg/ha)** | 2.35 ± 0.21 | 0.44 ± 0.02 | 0.44 ± 0.04 | 0.44 ± 0.07 | 0.77 ± 0.01 | 0.44 ± 0.0 |
| **K (kg/ha)** | 12.41 ± 2.03 | 26.71 ± 5.3 | 64.35 ± 4.32 | 38.85 ± 3.74 | 63.13 ± 5.48 | 75.27 ± 3.21 |

Note: Bold values show low organic carbon and high electrical conductivity values, significant to soil analysis result, highlighting anomaly in Bt cotton soil samples.
on every leaf in case of conventional plants and 33 worms per plant. Leaves of BC, transgenically modified to resist PB, were observed with minimal infestation which was found to be statistically significant (Table 4b). These findings were in sync with earlier reported studies (Betz et al. 2000; Roh et al. 2007) which highlight the advantage of BC to worm infestation.

Incidentally, the BC plants were not observed to be 100% resistant to pest attack as minimal degree of bollworm infestation was recorded on BC leaves. To assess the efficacy of the BC plant to insect resistance, forced infestation studies were also done. The survival rate of PBs forced to feed on BC leaves was noted to be around 40%. This depicted the actual efficiency of BC plants and the possible fast and strong evolution of PB to the Bt toxin. Thus, it proves that pest resistance in BC plants was not permanent and the possibility of development of resistance by the pest on subsequent plantations. Other research studies also support this result (Pray et al. 2002; Tabashnik et al. 2008; Tabashnik et al. 2013).

Moreover, during glass dome studies the ball formation occurred in case of BC plants as conventional variety was heavily infested. But these balls failed to open till late winters and experiment was eventually aborted. The pattern repeated in all the three seasons. The observation suggests that BC crop is not 100% pest free and pesticide use free. It does require pesticide sprays for better yield. The pesticide sprayed may not be against bollworms but other insects.

Rhizosphere soil samples of BC and CC plants were taken at the end of the experiment and analysed as

### Table 3: Mean values ± SD for plant characteristics at glass dome

| Plant variety | Height (cm) | No. of leaves/plant (cm) | Surface area of leaf (cm²) | Surface area of stem (mm²) |
|---------------|-------------|--------------------------|--------------------------|--------------------------|
| CC            | 102.1 ± 8.46| 31.67 ± 2.19             | 66.47 ± 9.57             | 1175.90 ± 213.64         |
| BC            | 160.6 ± 16.12| 88.63 ± 24.63            | 88.63 ± 24.75            | 1622.64 ± 167.99         |

### Table 4: (a) Mean values ± standard deviation on worm infestation. (b) Significance of infestation characteristics under one-way ANOVA analysis

| (a) Plant variety | No. of leaves infested | Infested leaf surface area (cm²) | No. of worms per leaf | No. of worms per plant |
|-------------------|------------------------|----------------------------------|----------------------|------------------------|
| CC                | 23.40 ± 9.97           | 44.38 ± 23.29                   | 2.23 ± 0.09          | 33.3 ± 6.58            |
| BC                | 4.90 ± 0.623           | 8.33 ± 1.05                     | 0.1 ± 0.03           | 0.1 ± 0.06             |
| (b) One-way ANOVA |                        |                                  |                      |                        |
| F value           | 47.495                 | 23.442                           | 84.972               | 75.123                 |
| Significance      | 0.000                  | 0.000                            | 0.000                | 0.000                  |

### Table 5: Analysis of physiochemical, macro and micronutrients of rhizosphere soil samples

| Characteristic | CC             | BC             | Control         |
|---------------|----------------|----------------|----------------|
| Physiochemical characteristics |                 |                 |                 |
| pH            | 8.0 ± 0.1      | 8.0 ± 0.1      | 8.0 ± 0.1      |
| EC (siemens/cm) | 0.10 ± 0.03    | 0.20 ± 0.01    | 0.080 ± 0.03   |
| Org. C (%)    | 0.930 ± 0.60   | 0.900 ± 0.76   | 0.360 ± 0.09   |
| Macroelements |                 |                 |                 |
| Nitrogen (%)  | 0.088 ± 0.06   | 0.0801 ± 0.02  | 0.031 ± 0.007  |
| P (kg/ha)     | 4.937 ± 0.42   | 4.937 ± 0.26   | 0.649 ± 0.9    |
| K (kg/ha)     | 74.347 ± 5.63  | 71.632 ± 4.57  | 49.373 ± 3.01  |
| Microelements |                 |                 |                 |
| Zn (kg/ha)    | 1.165 ± 0.38   | 1.271 ± 0.54   | 0.842 ± 0.11   |
| Fe (kg/ha)    | 3.804 ± 1.5    | 11.874 ± 1.09  | 5.051 ± 0.13   |
| Mn (kg/ha)    | 3.545 ± 0.93   | 4.274 ± 1.07   | 4.120 ± 0.07   |
| Cu (kg/ha)    | 0.534 ± 0.009  | 0.810 ± 0.07   | 0.437 ± 0.03   |
explained in Section 2.1. A control sample was also taken as explained in Section 2.2 and analysed. All the soil samples had close to neutral pH and fell in normal category requiring no treatment and suitable for all crops (Bates 1954). The EC of all rhizosphere samples fell in higher category and was abnormally high for BC plant (Jackson 1967).

The results so obtained followed similar trend as reported in the field survey analysis. Low organic content and high EC of Bt soil samples as compared to CC samples supported the earlier field survey results (Table 5). These findings were relatable to the research studies of Saxena et al. (1999). Saxena and Stotzky (2003) determined the release of toxins in soil from the Bt corn plants. None of the soil samples were found to be deficient in any of the micronutrients (Lindsay and Norvell 1978).

3.3 Phase III open field

Third phase of the study involved an open-field trial on 0.1 acre arable land in village Tasauli of District Mohali, Punjab, India. BC and CC plants were grown on two equal halves of the field maintained by a farmer practicing routine farming methods as explained in Section 2.3.

Comparative study of the morphological features to assess their ecological significance was performed. Comparative study of plant morphology showed statistically significant results (Tables 6a–c). A 40% increase in height, number of leaves per plant and stem surface area was noted for BC plants as compared to CC plants. This difference in morphological features among BC and CC cotton plants was observed to be lesser during the open-field trial than the glass dome studies. The BC plants had better morphological features as well as double the number of cotton balls than the CC plants. Therefore, the total biomass of BC plants was 50% higher than the CC plants. These characteristics when inferred on ecological basis showed increased water demand of BC plants than conventional because of more transpiration pull due to its higher leaf surface area, number of leaves and height (Nobel 1991). The higher biomass of the BC plants was directly relatable to double the number of cotton balls on it. Total cotton yield recorded from the two portions of the field was found to be marginally higher by 10 kg for BC plants than CC plants. The significantly better plant characteristics including increased number of cotton balls did not correspond to

| Table 6: (a) Mean values ± standard deviation on plant characteristics in open field. (b) Results of t-test on plant characteristics in open field. (c) Results of Mann-Whitney test on plant characteristics in open field. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | Height (cm)     | No. of leaves   | Surface area of leaf (cm²) | Stem surface area (cm²) | Plant biomass (g) | No. of cotton balls | Moisture content of cotton balls (%) |
| (a) Plant variety | CC 100.76 ± 9.9 | 118.00 ± 12.0  | 2.27 ± 0.00 | 96.54 ± 96.54 | 82.42 ± 21.37 | 1849.7 ± 196.1 | 82.48 ± 1.92 |
| (b)               | BC 173.53 ± 2.72| 191.95 ± 34.38| 2.31 ± 0.00| 98.57 ± 98.57| 74.12 ± 21.37 | 1849.7 ± 196.1 | 84.62 ± 1.44 |
| (c)               | t-value        | Z-value        | Sig.      | t-value        | Z-value        | Sig.      | t-value        | Z-value        | Sig.      |
|                  | −11.975        | −8.465         | 0.000     | −11.975        | −8.465         | 0.000     | −11.975        | −8.465         | 0.000     |
|                  | −3.977         | 0.000          | 0.000     | −3.977         | 0.000          | 0.000     | −3.977         | 0.000          | 0.000     |
|                  | −11.975        | −8.465         | 0.000     | −11.975        | −8.465         | 0.000     | −11.975        | −8.465         | 0.000     |
|                  | −10.410        | −7.910         | 0.000     | −10.410        | −7.910         | 0.000     | −10.410        | −7.910         | 0.000     |
|                  | −9.124         | −6.624         | 0.000     | −9.124         | −6.624         | 0.000     | −9.124         | −6.624         | 0.000     |
|                  | −1.700         | −1.210         | 0.000     | −1.700         | −1.210         | 0.000     | −1.700         | −1.210         | 0.000     |
|                  | −1.278         | −0.788         | 0.000     | −1.278         | −0.788         | 0.000     | −1.278         | −0.788         | 0.000     |
|                  | −1.278         | −0.788         | 0.000     | −1.278         | −0.788         | 0.000     | −1.278         | −0.788         | 0.000     |
Table 7: Analysis of physiochemical, macro and micronutrients of rhizosphere soil samples in open field

| Characteristic | CC     | BC     | Control |
|---------------|--------|--------|---------|
| **Physiochemical characteristics** |        |        |         |
| Ph            | 8.6 ± 0.0 | 8.6 ± 0.1 | 8.1 ± 0.1 |
| EC (siemens/cm) | 0.09 ± 0.02 | 0.23 ± 0.01 | 0.06 ± 0.03 |
| Org. C (%)    | 0.900 ± 0.010 | 0.615 ± 0.015 | 0.399 ± 0.024 |
| **Macronutrients** |        |        |         |
| Nitrogen (%)  | 0.077 ± 0.023 | 0.0788 ± 0.031 | 0.0257 ± 0.010 |
| P (kg/hectare) | 3.425 ± 1.02 | 4.135 ± 0.97 | 1.963 ± 1.03 |
| K (kg/hectare) | 66.337 ± 13.64 | 72.628 ± 10.71 | 56.324 ± 11.40 |
| **Micronutrients** |        |        |         |
| Zn (kg/hectare) | 1.076 ± 0.012 | 1.609 ± 0.009 | 1.091 ± 0.012 |
| Fe (kg/hectare) | 4.438 ± 0.013 | 7.651 ± 0.032 | 1.093 ± 0.017 |
| Mn (kg/hectare) | 3.173 ± 0.015 | 3.964 ± 0.15  | 3.421 ± 0.41  |
| Cu (kg/hectare) | 0.458 ± 0.007 | 0.630 ± 0.011 | 0.472 ± 0.029 |

equal increase in yield. These results were in complete contrast to claims of highly increased yields as depicted in many research studies (Qaim and Zilberman 2003; Qaim 2009). While other earlier studies support the current findings and report the increased yield of BC plants as a short-term gain (Pray et al. 2002).

After aborting the experiment, soil analysis was performed for both portions of the field as explained in Section 2.1. The pH of all the samples was alkaline (Table 7). The presence of increased electrolytes in BC soils was clear from the high EC values for all BC samples which was nearly double to that of CC soil samples due to release of chemicals in ionic form. But this could not be inferred for the presence of Bt toxins. The current findings hint but do not confirm the presence of Bt toxins in soil due to short-term nature of experiment done over single planting season. Although the presence of these toxins as root exudates has been determined earlier (Saxena and Stotzky 2003) but the process of leaching of root exudates and their adsorption is not fully understood. Further identification of the ions in the soil was beyond the scope of the study.

Repetitive of the results found at the glass dome level, the decreased OC of BC soil samples hints towards its inhibiting role in the formation and accumulation of OM soil. But the process of adsorption of soil OM remains doubtful; no clear-cut evidence could be deduced necessitating further detailed experimentation. Macronutrients like phosphorus and potassium fell under low category for samples (Mervin and Pech 1950; Olsen et al. 1954). Micronutrient analysis depicted no anomaly as they fell within normal category (Lindsay and Norvell 1978). The results so drawn were indicative of impact of Bt toxins on the soil physiochemical properties but not validated scientifically because of the short-term nature of the experiment.

4 Discussion

Ecological evaluation of the only GMC being grown in the country substantiated the environmental concerns raised against these crops. Field surveys of BC and CC fields of North-Western India pointed out low insect diversity of the BC fields as compared to the CC fields questioning the specificity of the transgenic toxin being produced by BC plants and its effect on non-target insects. The same two varieties grown and compared for morphological features highlighted the significantly better characteristics of BC plants than the CC plants. The open-field trial carried out for BC and CC reaffirmed the significantly better plant characteristics of BC that did not correspond to an equal increase in the yield. This change in the plant morphology when inferred on ecological perspective could increase the stress on the ecosystem.

Infestation studies done over the two varieties were clearly depictive of the competitive advantage of the BC transgenically modified to resist insect pest attack. But another experiment of forced infestation of BC plants with PBs showed that it was not completely resistant to it with 40% survival rate of PBs on BC plants. Soil analysis of the BC and CC at all three phases recorded higher values of EC and low OC in BC fields, due to increased concentration of chemicals in ionic form in the BC soil samples.

In the overall context of the extensive and rich background of farming in India, GMCs specifically BC remain a minor change. But such monoculture threatens the homogenization of agriculture in the country. Thus,
these crops appear to be a complete misfit in Indian agricultural system requiring large landholdings while 80% of the farmers in India have small to marginal landholdings on which multiple cropping is practiced. Moreover, these crops have already lead to new ecological problems like development of superweeds and emergence of secondary pests (Nandula et al. 2005; Xue et al. 2005; Dorhout and Rice 2010; Brookes and Barfoot 2017). Pest profile of the GMC-growing fields has changed drastically with negative impact on the insect community. Mealy bug infestation of BC in India and China gave early warning signals on the changing insect pest profile in the fields (Fischer 2016). Recent white fly outbreak in BC fields of Punjab badly affected its yield (Kulkarni 2013).

Consequently, GMCs do not appear to be providing the solution we are looking for. Therefore, they necessitate the need for thorough scientific analysis and logical scrutiny before adopting them and formulating a policy for posterity. In the event otherwise, we are fraught with altering evolution process and biodiversity pool.

Abbreviations

| Abbreviation | Definition                  |
|--------------|-----------------------------|
| BC           | Bt cotton                   |
| CC           | conventional cotton         |
| EC           | electrical conductivity     |
| GMC          | genetically modified crops  |
| OC           | organic carbon              |
| OM           | organic matter              |
| PB           | pink bollworm               |

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