Artificial Intelligence & Nature Based Solution in Agriculture — BT Cotton Pest Management Case in India

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Abstract

Artificial intelligence (AI) based pest management advisory based on integrated pest management (IPM) to cotton farmers on smartphone by resulted in pest attack reduction & up to 22% higher income in the 1 year-2020-21 in Ranebennur, Karnataka & Wardha, Maharashtra states. However, no significant benefit was seen in multi-state experiment 2022-22 due unusually high rainfall, resulting in lower pest attack. The artificial intelligence was used in pest detection & counting insect numbers in the pheromone trap to decide if threshold numbers are reached for pesticide spraying decision. This was 1-2 weeks in advance of mass pest emergence and could control it to reduce the crop damage. It required manual trap checking by the farmers on weekly basis, that many farmers disliked. Artificial intelligence coupled to remote sensing, GIS and/or farm sensors can benefit the farmers to cut cost, increase yield & cleaner production. Lower environmental pollution, less risk to the farmers and consumers are co-benefits of AI-IPM package. However, mating disruption technology is its competitor includes, which puts 4-6 pheromone traps per acre for mass capture of the moths. It is organic compatible and another competitor is the mechanical growing degree day (GDD) based IPM advisory such as by the startup “Fasal”. These are unintelligent, mechanical but very effective algorithms. Thus, a cautious, logical and gradual approach is needed in promoting AI in agriculture also keeping in mind its impact on labour displacement.

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Introduction
Climate change, farm viability, economically and sustainability, in environmental terms are top agricultural challenges in the new millennium, due to the rising costs mainly by the costly chemical pesticides and their impacts on the health of soil, and water, farmer and consumers. Artificial intelligence (AI) is being deployed in all fields such as healthcare, governance, finance, logistics and manufacturing. Agriculture is no exception & various applications ranging from drones in pesticide spraying to smartphone based weather or marketing advisory to drones are emerging rapidly. Here we describe an example of a successful case of cotton pest management in India by Wadhwani Institute of Artificial Intelligence, Mumbai including its benefits and limitations. We also enlist some other successful/ emerging technologies and their likely impact on agriculture economics, labour demand and environment, in this short research communication.

Pests cause up to 30-50% yield loss in many crops including cotton that accounts for nearly 50% of the insecticides used in India and its cost constitutes 40% of its total farming cost [1]. About 6 million farmers sustain on growing Cotton- among the top cash crops in India and also a leading farmer’s suicide crop, due to the rising insecticide cost [2]. The States Andhra Telangana, Maharashtra are leading cotton growing states constituting majority of the produce while the rest comes form Gujarat, Punjab, Haryana, M. P., Karnataka & Tamilnadu.

Pink Bollworm (PBW, *Pectinophora gossypiella*) is the most destructive of the cotton pests, causing most of the above damage. It is widespread globally and across India, destroying the crop aged 100 to 180 days from sowing. However, its infestation has started much earlier recently, from 50th day!

Pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) is most economically damaging insect pest of cotton globally, especially the American variety (*Gossypium hirsutum*) that is widely grown globally today, but to lesser extent the Indian, tree type Cotton (*G. arboretum*). This pest, a moth, has recently become a serious menace on transgenic Bt cotton in India, causing widespread damage and approximate yield losses to the tune of 20-30% [3] and its damage resurfaced in the last decade after successful reduction in it & pesticide sprays during 2000 to 2010 triggering the development of newer versions of BT-Cotton to cover over 95% Indian cotton fields [4]. The crop resistance to the pest is due to the toxic protein that the worms cannot digest and die. The gene responsible for producing the protein was inserted from the soil microbe BT (*Bacillus thuringensis*). But over 1.5 decades, the worm evolved resistance to the BT gene & thus started devastating the cotton Crop again, similar to the mosquitos that developed resistance to the DDT few decades ago. Gossypol, the natural plant chemical in Cotton that resisted pest attack is 50% less in Bt-Cotton than the natural, indigenous Cotton variety [5].

**Box 1.** Pink Bollworm Biology & life cycle, threshold for pesticide spray
It is a moth with 2 cm wide wings & dull, grey-brown in colour with a life of 2 weeks. After mating & fertilization, the female moths deposit eggs soon on emergence on or near the cotton bolls during the flowering period. Young larvae emerge after 3-5 days, entering the cotton bolls shortly after emergence for internal feeding in the pod. They also make a small hole to the exterior to allow air to penetrate. Larvae then pass through 4 instars & emerge from the top of the boll & fall on the ground where they pupate, about 50 mm below the surface and adults emerge after about 9 days. Adults are nocturnal and normally, the life cycle is completed in 25-30 days. There may be 4 to 6 generations per year. In dry winter, the larvae may undergo diapause in a small cocoon in partially opened bolls in cotton lint, stored seed or in the soil. They emerge generally when conditions are more favourable (late March or early April). Growing degree day (GDD) model is developed to predict pink bollworm emergence timing & intensity, based on number of days from sowing & the temperature. Eggs require temperatures between 10 and 37.5°C to hatch. There is no use of spraying pesticides on the moths but its lethal for the worms, that roam on the crop few days from emergence i.e. during 5-10 days from egg laying, before they pupate. This period is estimated when the number of moths caught in the pheromone trap crosses the threshold of 8 months/ night/ trap. For, after crossing this threshold, mass emergence of worms is likely in the next week and if no pesticides are sprayed, numerous moths emerge in the field 2 weeks later, further intensifying the attack. Spraying before this window of 4-5 days from the threshold is also ineffective as majority of the worms are in cocoon stage, unaffected by the spray. Only the soft skinned, slow moving, elongated worm stage is susceptible to the pesticides (skin contact mode). The PBW attack typically starts after 100 days & lasts upto 180th days since crop germination (October-January) in the 210-225 day long Cotton crop cycle that include many harvest cycles, every 15-20 days.

Pest damage, climatic risk and population monitoring threshold

The farmers conduct reckless spray pesticides that has no effect on the pests due to the wrong timing/ growth phase such as eggs or moth unlike at the larvae stge. The insecticides have grown costlier over decades and comprise over 50% of the farming cost often running into Rs. 1 lakh/ ha/ year. Around the year 2,000 farmers got 4-5 quintal of dryland Cotton yield & 10-15 quintal of irrigated Cotton productivity and with Rs. 3,000/- per quintal price, earned Rs. 15,000/- to 45,000/- per acre and earned handsome profit farming operations expenses being 30-40% of it. But the 20-30% or more crop damage by the PBW made them bankrupt both by lower returns and higher spraying cost. This led to increasing farmers’ suicides that number nearly 0.3 million from 1990s to 2017. Climate change has risked the temperature rise of over 2 °C by the end of the century predicted due to potential climate change that could make PBW more devastating and new pest/ disease may also emerge enhancing the farmer’s vulnerability. In USA, the PBW was controlled and eradicated during 2006 to 2013 by genetically modified organisms (GMO) technique (Box 1) but it is not permitted in India so smart, innovative technology solutions are needed.

Economic Threshold Limit (ETL), is the pest infestation level beyond which the crop loss exceed the pesticide spraying cost so it is necessary to avoid damage. This avoids wastage & loss by too early or extra effort on the costly chemical insecticides. It is monitored by laying insect traps in the field and counting the insect trap per night specified for different species separately by the agri-scientists.

Box 2. The male sterile moth GMO based eradication in the USA

Genetically modified male months were released in millions across the USA during 2006 to 2013 causing emergence of sterile next generation implying little moth population emerged in the 3rd generation and virtually nil thereafter. Few pockets may have escaped this mass extinction but repeated such release over the years finally ended the PBW menace and occurrence after a century of this exotic insect in the USA. Simultaneous release of BT-Cotton across the farms in USA ensured that any emergent larvae died. This is impressive but GMOs are prohibited in India as observed in the case of refusal to the permission of BT-Brinjal crop by 2010 with BT-Cotton being the only exception Brinjal productivity & production grew by over 1% in the following decade. BT Brinjal thus appears redundant. However, there are reports of illegal, herbicide tolerant BT0Cotton cultivation in India is scattered places which must be curtailed.

With the motto of “AI for social good”, the Wadhwani Institute of Artificial Intelligence (WIA) with the motto of “AI for social good”, the Wadhwani Institute of Artificial Intelligence (WIA) www.wadhwaniai.org, Mumbai developed an AI based imaging app to named “cottonace” during 2019-20 to identify the PBW correctly caught in
the pheromone traps at night and count the number of insects per trap. For this, 1-2 traps/acre were installed in the farms of 2-3 farmers/village called as ‘lead farmers’ who monitored the traps on weekly basis and photographed the contents by their mobile app. This image was then processed by the app and the threshold was exceeded, pesticide spray advisory was issued to all the farmers in the group of the lead farmer in that village. A lower threshold of 4 moths/trap was assigned in this experiment in consultation with Raichur agriculture university considering delays in pesticide procurement or spray due to ignorance, festivities, guests or other incidental causes.

The pilots in Karnataka Summer Cotton

The cottonace app was piloted in Ranebennur block (14.62 N, 75.62 E), Haveri district, Karnataka state with 100 farmers in the summer cotton crop (March- August 2020). They are all irrigated and belong to 13 villages and grow cotton during March to August. Karnataka is one of the few states besides erstwhile Andhra Pradesh & Tamilnadu that grow Summer Cotton due to salubrious climate, with temperatures not exceeding 40°C which is detrimental to the cotton growth. Table 1 enlists the chemical and organic pesticides recommended based on CICR recommendations \[1\].

<table>
<thead>
<tr>
<th>No. of days</th>
<th>CHEMICAL</th>
<th>ORGANIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-70</td>
<td>Profenophos 50 EC @ 20 ml*</td>
<td>Use the Tricogramma cards 35 Days After Sowing @ 6 card per acre.</td>
</tr>
<tr>
<td>71-90</td>
<td>Thiodicarb 75 WP @ 20 g per 10 litres of water if rosette flowers/bolls with live larvae observed</td>
<td>Spray Beauveria @ 2 kg/acre OR Metarhyzeum @ 2 kg/acre OR Dashparni Ark (10 bitter leaves extract) or Brahmastra @ 6 lit/acre.</td>
</tr>
<tr>
<td>91-150</td>
<td>Profenophos 50 EC @ 2.0 ml/litre OR Lamda Cyalothrin 5 EC @ 0.5 ml/litre OR Fenvelerate 20% EC 0.5 ml/litre OR Cypermethrin 10% EC 0.5 ml/litre of water.</td>
<td>Microbial cultures 2 sprays in 5 days intervals- Biocontrol agentsBeauveria basiana OR Metarrhizium anisoplie, Verticilium lecanii (7% each) - with Neem extract singularly or in combination OR distribute 6 trichocards (20,000 eggs each)/acre OR Install PBW Pheromone traps @ 10/acre for mass trapping &amp; destroying.</td>
</tr>
</tbody>
</table>

*- Check 10% flowers are rosette/bolls have live larvae/ hole infested i.e. 2 out of 20 flowers/bolls

**- Do not repeat the use of same chemical in a season nor mix 2 chemicals as it builds resistance.

There were no organic farmer here but it helped later in Maharashtra cluster at Wardha (Welspun co.) & Chhindwada, Madhya Pradesh state (Srijan NGO in 2021).

In all, 38 farmers adopted the advisory as recommended by the app on their mobile phone about pesticide spray and had 3 sprays on an average costing Rs. 3,500/- acre each including labour. The 43 “control” farmers who did not adopt the app conducted 2 sprays on average based on general knowledge/media advice/word of mouth etc. & incurred Rs. 1,600/- cost/acre each.

The app “adopter” farmers got 2.2 quintal (16%) higher yield of seed cotton (15.3 quintal/acre) while the non-adopters got only 13.1 quintal/acre yield. The adopter farmers got Rs. 5,326/- per quintal price due to white, clean, smooth fibre (i.e. Rs. 343 extra, equal to 7%) while the non-adopters got Rs. 4,982/- per quintal price, as the fibre is brownish, unclean, rough.
The adopters had Rs. 81,462/- gross income/acre while the non-adopters had it Rs. 65,385/-, so the former had 20% more gross income. About 19 farmers neither adopted the recommendations nor had proper information on yield and pesticide sprays or cost, so their data were not considered here. Thus the AI based app improves the crop yield by 17%, quality by 7% and profitability by 24%. Later, experts from Agriculture University, Dharwad re-visited the farmers and confirmed these findings triggering the validation study in monsoon (June-December 2020) in Maharashtra state. The lower pesticide sprays by the control -adapter farmers here was unusual and may be explained by the different season (summer) of Cotton harvest, than usual crop (winter spraying).

<table>
<thead>
<tr>
<th>Category</th>
<th>Sample size (n)</th>
<th>Area</th>
<th>Avg. Yield Q/acre</th>
<th>Avg. Price Rs./Q</th>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. AI Adopters</td>
<td>38</td>
<td>1.27</td>
<td>15.3</td>
<td>5326</td>
<td>81462</td>
</tr>
<tr>
<td>2. Control</td>
<td>41</td>
<td>1.45</td>
<td>13.1</td>
<td>4982</td>
<td>65385</td>
</tr>
<tr>
<td>Margin (A-B)</td>
<td>-0.18</td>
<td>2.2</td>
<td>343.2</td>
<td>16076</td>
<td></td>
</tr>
<tr>
<td>TOTAL/ premium as % of B</td>
<td>-14</td>
<td>16.6</td>
<td>6.9</td>
<td>24.6</td>
<td></td>
</tr>
</tbody>
</table>

The results (yield) are found significantly different (p< 5%) using student’s t test.

The Maharashtra Experiment

Similar experiment was then repeated with 100 farmers in Wardha block & district of Maharashtra state immediately for validation in the monsoon (June-October 2020) in collaboration with farmers in contract with the Welspun company as part of the better Cotton initiative (BCI, https://bettercotton.org/) who advise responsible sprays and crop management for cost cutting and better yield for better yield and health of the farmer. Here, the app user farmers were all from the village Pulai (latitude- 20° 49' 59" N, longitude- 78° 30' 17" E) & the control from the village Narsula (20° 50' 31" N, 78° 30' 36" E) but the 2 villages had similar geography (soil, water, topography). The app user farmers got 4.7 quintal/acre yield while non users for only 31. Quintal/ acre yield i.e. 33% less yield to only BCI farmers who got 6% less yield than the control group (table 1). The later was surprising and unexpected, possibly due to some soil or water issues as the cropping practices are similar. The 50% extra yield of 2021 in the model farmers is reduced to half (25%) as the real, incremental yield due to the app usage, using standard scientific “double difference” method (current- past difference) as these farmers had 25% yield in excess of the BCI farmers last 3 years average yield also (Table 2).

Table 3. Productivity data for maharashtra farmers
No. of pesticide sprays were 25% higher the app user farmers (2.5 average) than the no users (2 average) implying about Rs. 1,000/- extra cost/ acre. But they received dividend of 1.5 quintal/ acre i.e. Rs. 7,500/- per acre, and Rs. 2,750/- by deducting the extra pesticide spray cost.

Table 4 represents the double difference (DD) method of re-computation where past yield of both category of farmers is deducted from their current yield. Then the difference of the app no users is deducted from the app users to get the residual/ incremental benefit.

<table>
<thead>
<tr>
<th>Table 4. Yield change by double difference method</th>
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<tbody>
<tr>
<td>Past yield quintal/acreavg. (3 years)</td>
</tr>
<tr>
<td>Yield Change- 2021-past quintal/acre avg.</td>
</tr>
<tr>
<td>Past Yield difference (3 years avg.)</td>
</tr>
<tr>
<td>quintal/acre</td>
</tr>
<tr>
<td>Current - Past yield difference quintal/acre avg.</td>
</tr>
<tr>
<td>Double difference (DD) yield benefit</td>
</tr>
<tr>
<td>DD yield increment % over past yield difference</td>
</tr>
</tbody>
</table>

The farmers lost about 25% of the crop yield on average in 2021 on average due to excessively heavy rains- 50% over the long term annual average level. However, the app user farmers showed least inter-annual variation (4%) while BCI only farmers suffered 14% yield loss! The app based alert & advisory focuses on the correct spray timing to check the pest population growth and reduce the future damage, unlike the calendar based advisory that is same for all the farmers.

There is 25% additional yield to the app user farmers than the no users by DD method (table 3). Soil nutrient status was similar in the 2 villages (Table 4) to check if it did not influence the yield and overall results.
### Other related studies & Competing technologies

The results reported here are further confirmed by larger multistate (7 states) upscaling experiment by WIAI during 2021 ([www.wadhwaniai.org/cottonace_k21](http://www.wadhwaniai.org/cottonace_k21)). Several other studies have also reported the benefit of integrated pest management strategy [1][2][4] and particularly the latest one in Andhra Pradesh[11]. AI may add to it and benefit farmers, environment and consumer health. These benefits are well capitalized by the agri-startup like Fasal ([https://fasal.co](https://fasal.co)) who reported 42% reduction in pesticide use in the homepage itself.

Other innovative techniques are being promoted by others too- refugia (Box 3) & Mating disruption technique (Box 4). These are “Nature based Solutions” i.e. replicating natural processes and are eco-friendly. But since GMO is not permitted under organic methodology, and chemical pesticides are used, Bt-Cotton farm with refugia defy organic standards.

#### Box 3. Refugia of non-GM crop as pest resistance management strategy

Bt-cotton technology experts and Government suggested farmers to plant a refugia of non-BT Cotton crop in a corner of the farm where the Pink Bollworm can feed and not attack the BT-crop [12]. This will avoid emergence of resistance of the pest to the BT-gene, it was postulated. But in ignorance or the greed of maximum production, the farmers did not adhere to this technique. This lead to emergence of resistance of the pest to BT-gene and pest damage started increasing by 2010 leading to 2nd generation of Bt-Cotton varieties with 2 pest resistant genes and costlier seeds. So the Government mandated the seed companies to mix some non-Bt-Cotton crop seeds in the BT-Cotton seeds packet. This is continuing for the last few years though questioned in terms of seed quality.

The above question escapes the pheromone traps method as it is synthetic but akin to the natural fragrance exuded by the female moths but does not leave any chemical residue on the food/ crop so not toxic to humans/ other animals. The fragrance is very species specific so the lure for PBW does not attract even its cousin, the pre-millennium major pest of Cotton farming in India- American bollworm (*Helicoverpa armigera*, f).

#### Box 4. Pest control by mass trapping & mating disruption technology- NBS
Pheromone Lure trap is effective way capture male moths to reduce the mating in the farm and thus reduce future generation population. Here up to 20 pheromone traps are place per acre at cost of Rs. 2,000/- per acre, which 20% of the pesticide cost. University of Agriculture Science, Dharwad tested this at Kurudi village, Manvi taluk, Raichur district, Karnataka during Kharif 2017 [13]. It revealed that rosette flower, green boll and locule damage of 6.4, 7 and 12 % @ 500 g per acre compared to farmers’ practice at 16, 19.4 and 41% respectively 500 g per acre. The cotton yield was 46.25 quintal/ ha and B:C ratio of 2.48 with mass trapping, but only 24.55 q/ha and 1.23 resp. in farmers’ practice. It also avoids pesticide harm to the environment, farmer’s health & pro-organic.

To address the PBW problem, an innovative strategy developed by the Telangana Agriculture University is to develop short duration, single flush Cotton variety [14]. If successful, such innovative technologies may both end the menace and application scope for AI. In fact, the same applies to Biotechnology also where UK scientists question the lack of benefit of GMO technology such as BT cotton as the profits that rose initially have been lost today & losses are rising [15] as also questioned by other in U. K. [4].

Cost, Labour issues

The cost of the Wadhwani AAI experiment to the farmer was nil as it was financed by MNCs like Google. But if farmers start paying for the AI then it could be significant, though more than compensated by the extra benefit it brings. For instance, the farm sensor tool of Fasal co. costs Rs. 50,000/- (fifty thousand) which is equal to normal per ha cultivation cost of 1 cropping cycle or season of. It is large for a smallholder farmer (<2 ha) but not for a large farmer (> 5 ha). Similarly, food crop farmer may find it hard to buy who earn that much per acre but not cash crop farmer like Sugarcane or Cotton that earn 2-3 times this. In a success story narrated by Fasal sales manager Mr. Amarinder Singh told (pers. Comm.) in January 2024 meeting that Sugarcane farmers near Pune city who spent Rs. 2-3 lakh (0.2-0.3 million, $ 1 = Rs. 82/-) ha/ year on farm expense could save the senor cost after installing it to match the extra expense. Moreover, his yield has increased by over 50%, earning him Rs. 5-6/- lakh/ ha i.e. 15-20% extra. Thus, the total additional benefit of Rs. 1.5-2 lakh/ ha is 2 times the AI tool fixed cost and the variable cost is not significant- only the digital communication cost i.e. sim card & user fee. Maintenance is negligible and life span of the sensor is 5 years, implying its low per year average.

AI will benefit the farmer, through reducing cost & improving yield & quality its likely[16] and while there are questions about labour impact of AI, companies such as Mahindra have launched driver-less tractor indicating labour shortage in farming sector. Its thus argued that AI will improve the quality of labour & their income through proper training. Its possible that manual labour jobs such as sowing, weeding, harvesting, post harvest management may remain or lose out to mechanisation, but not much to AI. But decision making jobs like irrigation, fertilizer inputs, pesticide spray can be monopolized by AI such as drones for pesticide spraying as of today. Drip irrigation is already mechanized with little AI input today & low labour demand.

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Footnotes

1 Villages Ankalaspur, Aremallapur, Eladahalli, Guttal, Hiladahalli, Hirebidari, Konanatambigi, Medleri, Rahutanakatti, Rajeev Nagar, Timmapur, Udagatti, Yakalaspur


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