Artificial Intelligence & Nature-Based Solutions in Agriculture: A BT Cotton Pest Management Case Study in India

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Abstract

Artificial intelligence (AI)-based pest management advisory, based on integrated pest management (IPM), provided to cotton farmers on smartphones, resulted in a reduction in pest attacks & up to 22% higher income in the 1 year 2020-21 in Ranebennur, Karnataka, and Wardha, Maharashtra states. However, no significant benefit was seen in a multi-state experiment in 2021-22 due to unusually high rainfall, resulting in lower pest attacks. The artificial intelligence was used in pest detection & counting insect numbers in the pheromone trap to decide if threshold numbers were reached for pesticide spraying decisions. This was 1-2 weeks in advance of mass pest emergence and could control it to reduce crop damage. It required manual trap checking by the farmers on a weekly basis, which many farmers disliked. Artificial intelligence coupled to remote sensing, GIS, and/or farm sensors can benefit the farmers by cutting costs, increasing yield, and enabling cleaner production. Lower environmental pollution and less risk to farmers and consumers are co-benefits of the AI-IPM package. However, mating disruption technology, a competitor, includes putting 4-6 pheromone traps per acre for the mass capture of moths. It is organic-compatible, and another competitor is the mechanical growing degree day (GDD)-based IPM advisory, such as that provided 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, economic 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, water, farmers, 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 the 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, which 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 of Andhra Pradesh, Telangana, and Maharashtra are leading cotton-growing states, constituting the majority of the produce, while the rest comes from Gujarat, Punjab, Haryana, M. P., Karnataka, & Tamil Nadu.

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 the 50th day!

Pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) is the most economically damaging insect pest of cotton globally, especially the American variety (*Gossypium hirsutum*), which is widely grown globally today, but to a 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 pesticide sprays during 2000 to 2010, triggering the development of newer versions of BT-Cotton to cover over 95% of Indian cotton fields [4]. The crop's 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 thuringiensis*). But over 1.5 decades, the worm evolved resistance to the BT gene & thus started devastating the cotton crop again, similar to the mosquitoes that developed resistance to DDT a few decades ago. Gossypol, the natural plant chemical in cotton that resisted pest attack, is 50% less in Bt cotton than in 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 after 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 [6]. There may be 4 to 6 generations per year. In dry winters, the larvae may undergo diapause in a small cocoon in partially opened bolls in cotton lint, stored seed, or in the soil. The larvae emerge generally when conditions are more favourable (late March or early April). A growing degree day (GDD) model is developed to predict pink bollworm emergence timing & intensity, based on the number of days from sowing & the temperature [3]. Eggs require temperatures between 10 and 37.5°C to hatch. There is no use in spraying pesticides on the moths, but it's lethal for the worms that roam on the crop a 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 moths/night/trap [1]. 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 the majority of the worms are in the 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 up to the 180th day since crop germination (October-January) in the 210-225 day-long cotton crop cycle that includes many harvest cycles, every 15-20 days.

Pest Damage, Climatic Risk, and Population Monitoring Threshold

The farmers conduct reckless spray pesticide applications that have no effect on the pests due to the wrong timing/growth phase, such as eggs or moths, unlike at the larvae stage. 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 quintals of dryland cotton yield & 10-15 quintals of irrigated cotton productivity and, with a Rs. 3,000/- per quintal price, earned Rs. 15,000/- to 45,000/- per acre, with handsome profits, farming operations expenses being 30-40% of it. But the 20-30% or more crop damage by the PBW made them bankrupt, both from lower returns and higher spraying costs. This led to increasing farmers' suicides, which numbered nearly 0.3 million from the 1990s to 2017 [7]. Climate change has risked a temperature rise of over 2 °C by the end of the century, predicted due to potential climate change that could make PBW more devastating [1], and new pests/diseases may also emerge, enhancing the farmers' vulnerability. In the USA, the PBW was controlled and eradicated during 2006 to 2013 by the genetically modified organisms (GMO) technique (Box 1), but it is not permitted in India, so smart, innovative technology solutions are needed.

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

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

Genetically modified male moths were released in millions across the USA during 2006 to 2013, causing the emergence of sterile next generation, implying that little moth population emerged in the 3rd generation and virtually none thereafter. Few pockets may have escaped this mass extinction, but repeated such releases over the years finally ended the PBW menace and led to the occurrence after a century of this exotic insect in the USA [8]. Simultaneous release of BT-Cotton across the farms in the USA ensured that any emergent larvae died. This is impressive, but GMOs are prohibited in India, as observed in the case of refusal to grant permission for the BT-Brinjal crop by 2010 [9], with BT-Cotton being the only exception. Brinjal productivity & production grew by over 1% in the following decade [10]. BT Brinjal thus appears redundant. However, there are reports of illegal, herbicide-tolerant BT-Cotton cultivation in India in scattered places, which must be curtailed [9].

With the motto of "AI for social good," the Wadhwani Institute of Artificial Intelligence (WIAIwww.wadhwaniai.org), Mumbai, developed an AI-based imaging app 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 per acre were installed in the farms of 2-3 farmers per village, called “lead farmers,” who monitored the traps on a weekly basis and emptied them on a paper and photographed the contents with their mobile app. This image was then processed by the app, and if the threshold was exceeded, a 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 per 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 & Tamil Nadu, that grows Summer Cotton due to the salubrious climate, with temperatures not exceeding 40 ^{0}C, which is detrimental to cotton growth. Table 1 enlists the chemical and organic pesticides recommended based on CICR recommendations [1].

Table 1. Pesticide advisory by crop age & type

No. of days	CHEMICAL	ORGANIC
50-70	Profenophos 50 EC @ 20 ml*	Use the Tricogramma cards 35 Days After Sowing @ 6 cards per acre.
71-90	Thiodicarb 75 WP @ 20 g per10 litres of water if rosette flowers **or bolls with live larvae** observed	Spray *Beauveria* @ 2 kg/ acre OR *Metarhyzeum* @ 2 kg/ acre OR Dashparni Ark (10 bitter leaves extract) or Brahmastra @ 6 lit/acre.
91-150	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.	Microbial cultures 2 sprays in 5 days intervals- Biocontrol agents*Beauveria basiana OR Metarrhizium anisoplie, Verticilium lecani*i (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 & destroying.*

**- 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 the same chemical in a season nor mix 2 chemicals as it builds resistance.*

There were no organic farmers here, but it helped later in the Maharashtra cluster at Wardha (Welspun Co.) & Chhindwara, Madhya Pradesh state (Srijan NGO in 2021).

In all, 38 farmers adopted the advisory as recommended by the app on their mobile phones about pesticide spray and had 3 sprays on average, costing Rs. 3,500/- per 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 quintals (16%) higher yield of seed cotton (15.3 quintals/acre) while the non-adopters got only 13.1 quintals/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. 4982/- 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, 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 the monsoon (June-December 2020) in Maharashtra state. The lower pesticide sprays by the control-adopter farmers here were unusual and may be explained by the different season (summer) of cotton harvest than the usual crop (winter spraying).

Table 2. Yield and income data

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

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

The Maharashtra Experiment

Similar experiments were then repeated with 100 farmers in the Wardha block and district of Maharashtra state immediately for validation in the monsoon (June-October 2020), in collaboration with farmers under contract with the Welspun company as part of the Better Cotton Initiative (BCI, https://bettercotton.org/), who advise on responsible sprays and crop management for cost cutting and better yield for the 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), and the control group was from the village Narsula (20° 50' 31" N, 78° 30' 36" E), but the two villages had similar geography (soil, water, topography). The app user farmers got a 4.7 quintal/acre yield while non-users got only 3.1 quintals/acre, i.e., 33% less yield. The BCI farmers got 6% less yield than the control group (Table 1). The latter 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 the 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

VILLAGE	Pulai	Narsula
Treatment	App	Control
Yield quintal/ acre	4.7	3.1
Incremental yield quintal/ acre	1.5	-0.2
Incremental yield %	50%	-6%
No. of Sprays	2.5	2
Farm area acre	5.1	4.1

The number of pesticide sprays was 25% higher for the app user farmers (2.5 on average) than for the non-users (2 on average), implying about Rs. 1,000/- extra cost per acre. But they received a dividend of 1.5 quintals/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 recomputation, where the past yield of both categories of farmers is deducted from their current yield. Then the difference of the app non-users is deducted from the app users to get the residual/incremental benefit.

Table 4. Yield change by double difference method

Past yield quintal/acreavg. (3 years)	4.9	3.6
Yield Change- 2021-past quintal/acre avg.	-0.2	-0.5
Past Yield difference (3 years avg.) quintal/acre	1.3	-
Current - Past yield difference quintal/acre avg.	1.6-1.3	
Double difference (DD) yield benefit	0.3	
DD yield increment % over past yield difference	25%	

The farmers lost about 25% of the crop yield on average in 2021 due to excessively heavy rains—50% over the long-term annual average level. However, the app user farmers showed the least inter-annual variation (4%), while BCI-only farmers suffered a 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 the same for all farmers. There is 25% additional yield for the app user farmers than for the non-users by the DD method (Table 3). Soil nutrient status was similar in the two villages (Table 4) to check if it did not influence the yield and overall results.

Table 5. Soil nutrient status

PARAMETER/VILLAGE	Pulai	Narsula
pH	7.6	7.8
EC#	0.4	0.5
O.C. (%)	0.49	0.56
N (Kg/Ha)	196	193
P (Kg/Ha)	31	32
K (Kg/Ha)	466	489

#- Difference >10%

Other related studies & Competing technologies

The results reported here are further confirmed by a larger multistate (7 states) upscaling experiment by WIAI during 2021 (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, the environment, and consumer health. These benefits are well capitalized on by agri-startups like Fasal (https://fasal.co) , who reported a 42% reduction in pesticide use on 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 GMOs are not permitted under organic methodology, and chemical pesticides are used, Bt-Cotton farms with refugia defy organic standards.

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

Bt-cotton technology experts and the government suggested farmers 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 for maximum production, the farmers did not adhere to this technique. This led to emergence of resistance of the pest to the Bt gene, and pest damage started increasing by 2010, leading to the 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 has been 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 it does not leave any chemical residue on the food/crop, so it is not toxic to humans or 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, the American bollworm (*Helicoverpa armigera, 1*).

Box 4. Pest control by mass trapping & mating disruption technology- NBS

Pheromone lure traps are an effective way to capture male moths to reduce mating in the farm and thus reduce the future generation population. Here, up to 20 pheromone traps are placed per acre at a cost of Rs. 2,000/- per acre, which is 20% of the pesticide cost. The 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 was 6.4, 7, and 12% @ 500 g per acre compared to farmers' practice at 16, 19.4, and 41%, respectively, at 500 g per acre. The cotton yield was 46.25 quintals/ha, and the B:C ratio was 2.48 with mass trapping, but only 24.55 q/ha and 1.23, respectively, in farmers' practice. It also avoids pesticide harm to the environment, farmers' health, & pro-organic.

To address the PBW problem, an innovative strategy developed by Telangana Agriculture University is to develop a short-duration, single-flush cotton variety [14]. If successful, such innovative technologies may both end the menace and reduce the application scope for AI. In fact, the same applies to biotechnology, 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 others in the 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 the normal per ha cultivation cost of one cropping cycle or season. It is large for a smallholder farmer (<2 ha) but not for a large farmer (> 5 ha). Similarly, food crop farmers may find it hard to buy, especially those who earn that much per acre, but not cash crop farmers like Sugarcane or Cotton that earn 2-3 times this. In a success story narrated by Fasal sales manager Mr. Amarinder Singh (pers. Comm.) in a January 2024 meeting, Sugarcane farmers near Pune city who spent Rs. 2-3 lakh (0.2-0.3 million, $ 1= Rs. 82/-) per ha/ year on farm expenses could save the sensor cost after installing it to match the extra expense. Moreover, their yield has increased by over 50%, earning them 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 the life span of the sensor is 5 years, implying its low per year average.

AI will benefit the farmer through reducing costs & improving yield & quality; it's likely[16] and while there are questions about the labour impact of AI, companies such as Mahindra have launched driver-less tractors, indicating a labour shortage in the farming sector. It's thus argued that AI will improve the quality of labour & their income through proper training. It's 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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