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WADHWANI AI

Pest Management in Cotton

Learnings from deploying CottonAce in India

KHARIF 2021

Pest Management in Cotton

LEARNINGS FROM DEPLOYING COTTONACE IN INDIA

TABLE OF CONTENTS

Glossary

Alerts (Green, Yellow, Red)

The CottonAce app offers users three distinct color-coded alerts. They are:

Green Alerts, which indicate the absence of PBW or ABW moths.
Yellow Alerts, which indicate a moderate incidence of PBW or ABW moths, and the possibility of a moderate-level infestation in the future.
Red Alerts, which indicate a large number of PBW or ABW moths, and the possibility of a high-level infestation in the future.

American Bollworm (ABW) and Pink Bollworm (PBW)

American Bollworm: The American bollworm (Helicoverpa armigera, a.k.a. corn earworm or sorghum head worm or tomato fruit borer) is a pest in cotton growing areas which feeds on squares (buds), flowers, and bolls of cotton.
Pink Bollworm: A small dark brown moth (Pectinophora gossypiella), whose pinkish larva bores into the flowers and bolls of cotton. It is a destructive pest in most cotton-growing regions.

Bt cotton

Bt cotton is a genetically modified, pest-resistant cotton crop variety, which produces an insecticide to combat bollworms. Not only does Bt cotton cost four times as much as non-GMO (genetically modified organism) cotton, it also requires irrigation (traditionally, cotton farms in India have been largely rainfed) as well as greater quantities of pesticide and fertilizer.

Control or Cascade Farmer

Cotton farmers who do not directly use the CottonAce app, but may benefit from the advisories generated by the app, conveyed through lead farmers.

CottonAce

CottonAce is an AI-powered early warning system developed by Wadhwani AI, available through an app on Android smartphones. It helps farmers protect their crops by determining the right time to spray pesticides through immediate and localized advice. The AI technology analyzes photos of pests caught in traps which are uploaded by farmers and agriculture program workers, and classifies and counts the number of PBW or ABW found.

Cotton boll

The cotton fruit. It consists of burrs (the shell), fibers and seeds.

Economic Threshold Level (ETL)

The ETL provides an estimate of the pest population at which control measures need to be initiated to prevent economic loss.

Kharif Season

In India, the Kharif cropping season takes place between the months of June and October. Kharif crops are usually sown at the beginning of the first rains of the south-west monsoon season, and are harvested between October–November, at the end of the season. The Kharif season varies by crop and region, starting at the earliest in May and ending at the latest in January.

Lead Farmer (LF)

Cotton farmers who own an Android smartphone and are users of the CottonAce app.

Larvae

The stage of growth of insects before they develop into adulthood through metamorphosis

Lures

Lures are chemical attractants or pheromones that may attract only a specific sex of an insect population.

Pesticide

Pesticides are chemical substances that farmers apply to their crops, often in the form of sprays, with the purpose of preventing, destroying, repelling, controlling, or mitigating pests.

Rosette Flower

The pink bollworm larvae feed on flowers and buds, boring into cotton bolls. They feed on the developing anthers and styles, and occasionally on ovaries. When these larvae bore through flowers, the flowers do not open as they usually do and instead give a rosette-like appearance.

Traps

Insect traps are used to monitor or directly reduce populations of insects or other arthropods, by trapping individual insects and killing them. Traps typically use food, visual lures, chemical attractants and pheromones as bait and are installed so that they do not injure other animals or humans or result in residues in food or animal feed. Visual lures use light, bright colors, and shapes to attract pests. ■

Acronyms

ABW	American bollworm
AEO	Agricultural Extension Officers, employed by the state government
AI	Artificial intelligence
CIB & RC	Central Insecticide Board and Registration Committee
CSIR	Council of Scientific and Industrial Research
CSIR-IICT	CSIR - Indian Institute of Chemical Technology
ETL	Economic Threshold Level
FF	Field Facilitators, employed by the partner organization
ICAR-CICR	Indian Council of Agricultural Research - Central Institute For Cotton Research
MEL	Measurement, evaluation, and learning
MoU	Memorandum of Understanding
MSP	Minimum Support Price
NDA	Non-Disclosure Agreement
OTP	One-Time Password
PBW	Pink bollworm
WIAI	Wadhwani Institute for Artificial Intelligence

Introduction

In India, pest traps form the basis of a pest management system that relies on recommendations from a local agricultural agency. When farmers send information regarding their trap catch to the most accessible expert or organization, they receive advice anywhere between a few days and a few weeks. Unfortunately, pests do not wait that long to inflict damage, which is why reducing the timeline for decision-making from a few days or weeks to a few minutes is the point of intervention for our solution. Creating awareness also significantly impacts adoption and usage. The first few steps are very important in the journey of astute technology adoption, and we are at that stage.

CottonAce is a part of the larger intervention to reduce costs and the burden on the environment, increase yield, and over a period of time, improve the lives of farmers. In this report, in addition to assessing impact, we also outline our understanding of the challenges present in the implementation of an AI-powered pest management intervention in one of the most complex agricultural ecosystems in the world.

Our technology is being introduced into an environment that is new to technology, and so we designed for accessibility—our solution is multilingual, voice-enabled, visually rich, and simple to use. One of our successes lies in the fact that there are over 1,000 farmers who have downloaded our app or got in touch with us without any outreach on our part. We have also received very positive feedback for introducing such advanced technology at the ground level addressing a problem that directly impacts the farmer's well being.

Our mission—impact, and impact alone—is one we share with the central and state governments, and private partners, for whose support we are extremely grateful. We continue our work with the hope that one day, we may impact six million farmers in cotton. This is only the beginning: based on our learnings and the data gathered so far, we are now exploring the idea of applying our work to other pests and crops, and have now identified 20 pest-crop combinations. Done well, we can aspire to create the first standard in the world to scientifically manage pest infestation in agriculture at the scale and diversity of India.

— SHEKAR SIVASUBRAMANIAN
CEO, Wadhwani AI

Preface

Innovative technology such as artificial intelligence (AI) and machine learning can play an important role in providing solutions to make agriculture more sustainable. India is among the largest producers of cotton and grows 26% of the world's demand. As a result, the local economy and many small-holder farmers depend on it: India approximately has 6 million cotton farmers, with more than 50 million people engaged in related activities such as cotton processing and trade. This makes it pertinent to find innovative solutions to protect against potentially adverse effects on crop productivity, such as climate change, plant diseases and weeds.

Cotton is particularly vulnerable to pests which gives rise to intensive use of pesticide for cotton. Nonetheless pest attacks result in loss of up to 30% of crops every year. Bollworms are estimated to cause 70% of all pest damage to cotton. Especially, the pink bollworm is considered to be the most damaging pest for cotton crops, and it has recently developed a resistance to Bt-cotton.

Existing approaches to counter pests have several limitations: They require manual data collection (physical counting of pests found in farms), analysis, and advisory dissemination, they tend to be error-prone, unverifiable, and difficult to scale. There is also a lack of awareness among farmers about which countermeasures work for specific pests and what frequency of spraying is adequate. This results in indiscriminate pesticide use that fails to protect crops and is both damaging to the environment and farmers' health.

The CottonAce application was developed by Wadhwani AI to address this challenge. It is an AI-powered early warning system widely available on Android smartphones. It is already being implemented in ten states in India and it helps farmers protect their crops by determining the right time to spray pesticides through immediate, localized advice. We support this mission through our project "FAIR Forward – Artificial Intelligence for all" which is implemented by GIZ on behalf of the German Ministry for Economic Cooperation and Development (BMZ). Together with Wadhwani AI, we make CottonAce an open-source application and digital public good that supports Indian cotton farmers and the local AI ecosystem alike. Ultimately, this assists the progress of scaling the implementation in the coming years to reach an even greater number of farmers. This will help transition cotton farming to more agroecological practices with all round positive impacts on ecology, farmers, and consumers.

— **RAJEEV AHAL**
Director, Natural Resource Management and Agroecology (NRMAe), GIZ-India

Acknowledgments

Wadhwani AI would like to thank the Ministry of Agriculture & Farmers' Welfare, NITI Aayog and all of our state government partners for encouraging and supporting us to deploy CottonAce on the ground to improve pest management methods practised by farmers in India. We are immensely grateful for continuing to receive this opportunity to work closely in collaboration with the government towards achieving large-scale and positive social impact.

Wadhwani AI would like to thank Google.org for believing in our mission to improve farmers' lives by supporting and funding our pest management project twice. We are immensely thankful for having had the support of two Google.org Fellows work with us enthusiastically towards making our vision a success.

Wadhwani AI is grateful for the extensive support received from GIZ towards the sustained implementation of this project.

The deployment of the CottonAce solution would not have been possible without our implementation partners, and the cooperation and enthusiastic support of thousands of farmers across 10 cotton-growing states in India, who have adopted the solution. We are grateful for their support and look forward to growing the solution with them.

01

Executive summary

One enduring challenge to the six million cotton farmers in India is the pink bollworm (PBW). In this report, we describe the context in which our AI/ML solution and the CottonAce smartphone application were introduced, as well as the implementation of the solution through various field partners, our learnings, and our recommendations.

The report also explores the effects of CottonAce on various factors such as pesticide use, damage due to PBW, and cotton yield. The CottonAce mobile application can be used on Android smartphones. It has been developed by the Wadhwani Institute for Artificial Intelligence—Wadhwani AI—via a quasi-experimental two-arm field trial in 17 districts, in five states of India, during Kharif 2021. A limited amount of data is currently available to support a complete impact analysis as the focus was more on the adoption of the technology and program implementation than on formal measurement and evaluation. Impact analysis will be a more central part of our efforts in future cotton harvesting seasons.

There are multiple factors affecting bollworm infestation in cotton crops, such as the temperature, amount of rainfall, humidity, the sowing dates of the crop, duration of the crop cycle, and its overlap with the peak infestation period (October–December) of the Pink bollworms. These factors are all vital to understanding the actual impact of the CottonAce application. At the time of writing this report, we did not have access to this data.

Going forward, we will continue to build on a formal data collection mechanism to support greater rigor in the impact evaluation of the application. Our plan is to design and implement data collection and measurement protocols to address these gaps in subsequent Kharif seasons. ■

02

Problem statement

> Up to 30% of cotton crops are lost every year due to the damage caused by sucking pests, and about 70% of these losses are caused by only two species of cotton bollworms

India's estimated six million cotton farmers can largely be found in 10 states, with Gujarat, Maharashtra, and Telangana being the top contenders in terms of land used for growing cotton. And yet, the average cotton yield in India is estimated to be 487 kg/ ha, which is significantly lower than the global average of 768 kg/ ha. There are a number of reasons that may explain this gap; more than 75% of these farmers own less than two hectares of land and it is likely that most of these farmers depend on the monsoon rainfall. One of the enduring challenges to cotton farmers, which we are concerned with is crop damage caused by pests—up to 30% of cotton crops are lost every year due to the damage caused by sucking pests, and about 70% of these losses are caused by only two species of cotton bollworms (Sharma et al., 2017).

The pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), is a monophagous pest with hybrid cotton as its primary host (Naik et al., 2020; Najork et al., 2021) and the American bollworm (ABW), *Helicoverpa armigera* (Hübner), causes significant losses in non-Bt and organic cotton. PBW is one of the most destructive pests attacking cotton crops across a majority of states and districts (Deore et al., 2010; Devi & Reddy, 2012). In 2017-18, an increase in farmer suicides was attributed to heavy crop loss caused by PBW (Gutierrez et al., 2015; Gutierrez et al., 2020).

Crop losses can be reduced by adopting various physical, biological, and chemical measures. However, the over-utilization of pesticides for cotton crops has led to negative downstream effects: unnecessary expenses incurred by farmers, farmer deaths due to pesticide poisoning (Newsclick, 2020; Varghese & Erickson, 2022), and contamination of soil and water, making the land unfit for cultivation. Farmers will usually seek help by reaching out to local agricultural agencies such as Krishi Vigyan Kendras (KVK) for the advice. This is a time-consuming process, and farmers often don't receive timely preventive advice or corrective measures, leading to a loss of crops due to damage caused by pests. ■

03

Objectives of the AI/ML solution

Short-term objectives

- The timely and accurate identification of PBW pests
- The timely and appropriate use of the appropriate pesticide(s)

Long-term objectives

- Improvement in crop yields and farmer incomes
- A reduction in unnecessary and indiscriminate pesticide use

04

Description of the solution

TOPICS COVERED IN THIS SECTION

- The CottonAce application
- Prerequisites for using the CottonAce application
- Steps to use the application

The CottonAce application

CottonAce is currently available in 9 languages—English, Hindi, Marathi, Gujarati, Telugu, Kannada, Tamil, Odia, and Punjabi.

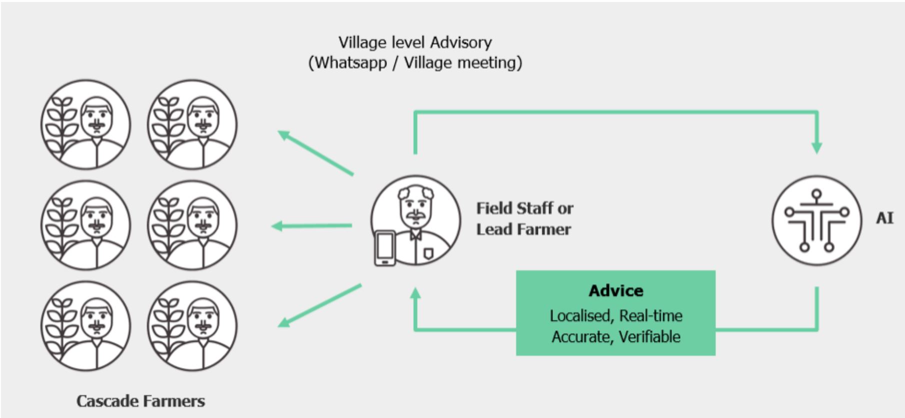
Wadhwani AI developed an AI-based early pest warning system to identify PBW infestation, delivered through an Android application—CottonAce. The AI/ ML solution was trained and validated on 18,396 images of pests obtained from farms in 2018-19. The CottonAce app is used by farmers to capture images of the pests caught in the pheromone traps installed at their farms.

The AI model at the heart of the CottonAce app identifies and counts PBW pests from the uploaded images. Based on the number of PBW pests, the app provides the farmer with an appropriate rule-based advisory (based on the ETL) in the form of a recommendation for the type and dosage of pesticide. The app also collects other information provided by farmers, including the date of sowing. CottonAce is currently available in 9 languages—English, Hindi, Marathi, Gujarati, Telugu, Kannada, Tamil, Odia, and Punjabi.

Prerequisites for using the CottonAce application

The CottonAce app is to be used by lead farmers, who must own **at least one acre of land (0.4 ha)**. Farmers with less than one acre of land are termed as cascade farmers, who may receive information from lead farmers about the advisories disseminated by CottonAce, but do not use the application themselves (Figure 1).

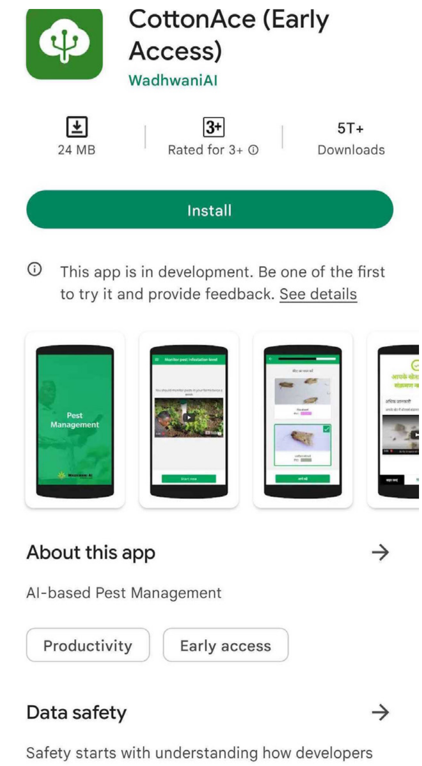
Figure 1: **CottonAce workflow and farmer engagement**



The solution requires two traps to be set up in a central one-acre area of the farm. The traps are to be placed one foot above the canopy of the plant (the height needs to be adjusted frequently by farmers so that it stays one foot above the growing canopy; see Annexure 2). The traps should be set up at a distance of 50 feet inside from the farm boundary with a distance of 100 feet between two traps to ensure a higher chance of capturing PBW moths from a wider area. Traps should be installed and used from the 45^{th} day of sowing to the end of the season (ICAR-CICR, 2019; Vennila et al., 2016). A lure, consisting of **a synthetic chemical that attracts male moths**, is added to the traps and replaced on a regular basis based on its date of expiry or validity (expiry can be a few months or years away; once a lure is opened, however, it must be replaced after 15–120 days, as per manufacturer advice—this is its validity).

After a moth enters a trap containing an active lure, it is unable to escape it, and doesn't remain alive for more than a few hours afterwards. It should be noted that **continuous rain may reduce the ability of the trap to attract the moths**, thus affecting the performance of the solution.

Figure 1: **CottonAce's app listing on the Google Play Store**



Steps to use the application

The CottonAce app is available as a free application that can be downloaded and installed from the Google Play Store and registered farmers can **login using an OTP** sent to their registered mobile number.

Once the application is installed, farmers are required to complete a short registration process. As per the instructions provided by the app, farmers **empty the pest traps** installed at their farm and distribute the moths collected evenly on a white sheet of paper. They then capture an image of the moths on the sheet using the CottonAce app. Farmers must ensure that none of the moths they place on the sheet of paper are alive.

Once good-quality images from each of the pest traps have been captured under good lighting conditions and uploaded, the **app displays an alert—green, yellow, or red**. The relevant advisory is also generated (for yellow and red alerts), with recommendations for the use of pesticides.

Images should be captured and uploaded at least once every seven days, irrespective of the type of alert that is received. The lead farmer relays this advisory to cascade farmers. Screenshots of these steps are shown in Annexure 3. ■

05

Implementation of the solution

TOPICS COVERED IN THIS SECTION

- Takeaways from the evaluation in 2020
- Objective of the current evaluation (Kharif 2021)
- Measurement Approaches
- Design of evaluation

Planning

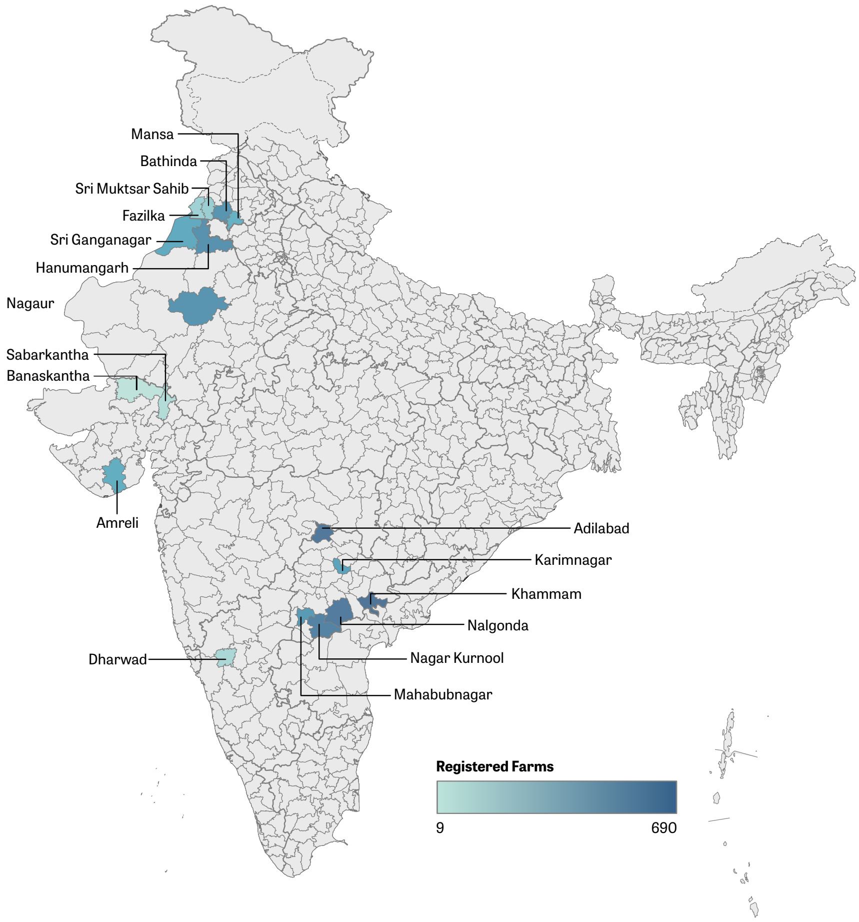
Implementation partners for CottonAce were identified during March and April 2021. MoUs and NDAs were signed to begin the engagement. These partners were consulted to decide on the following:

- Implementation locations
- Implementation protocols
- Roles and responsibilities of all parties involved, including Wadhwani AI
- ETL definitions, by location
- The nature of advisories for each alert type
- Monitoring mechanisms
- Design and implementation of evaluation

Current state of implementation: Geographies and duration

The solution was implemented during Kharif 2021 (June–December 2021) in 60 districts within 10 states of India—Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, and Telangana.

Figure 2: **District-wise distribution of farms in India registered as part of the Kharif 2021 deployment of CottonAce**



We had the help of **12 partners** (ten from the non-profit sector, and two state governments). In Punjab, the implementation began in August 2021, due to delays in procurement logistics (traps and lures) from partners.

Table 1 in the next page summarizes the geographies where the project was implemented, and shows the details of registered farmers and farmers who used the application, i.e., uploaded an image using CottonAce, at least once.

Table 1:
Implementation coverage

NO.	STATE	DISTRICT/s	NO. OF FARMERS REGISTERED	NO. OF FARMERS THAT USED THE APP	% USE (OUT OF REGISTERED)
1	Andhra Pradesh	Kurnool, Guntur, Kadapa, Prakasham, Krishna, Ananatpur	91	4	4%
2	Gujarat	Amreli, Gir Somnath, Junagarh, Bhavnagar, Sabarkantha, Banaskantha, Kutch	1,169	1,293**	111%
3	Karnataka	Dharwad, Bagalkot, Hubli, Raichur, Bellary, Haveri	69	53	77%
4	Madhya Pradesh	Chhindwara	85	2	2%
5	Maharashtra	Chandrapur, Nagpur, Wardha, Hinganghat, Akola, Amravati, Yavatmal, Jalna, Nanded, Dhule, Nandurbar	2,649	1,215	46%
6	Odisha	Kalahandi, Rayagada	43	1	2%
7	Punjab	Mansa, Bhatinda, Fazilka, Muktsar Sahib	913	741	81%
8	Rajasthan	Hanumangarh, Sri Ganganagar, Nagore	1,464	962	66%
9	Tamil Nadu	Kallakurichi, Salem, Cuddalore, Peramblur, Erode, Ariyalur, Thanjavur, Mayiladudu-rai, Thiruvavur, Virudhunagar, Tenkasi, Tirunelveli, Kallakurichi, Madurai	21	0	0%
10	Telangana	Khammam, Adilabad, Nagar Kurnool, Karimnagar, Mahbub Nagar, Nalgonda	3,105	2,013	65%
	Combined*		**9,609**	**6,284**	**65%**

*Values computed by combining data of all mentioned states
**These farmers were not registered with the implementation partners, but they installed and used the app.

The role of Wadhwani AI

The staff at Wadhwani AI **conducted training sessions for the extension officers** (officials from the agricultural department of state government) and field facilitators (officials from partner organizations responsible for agricultural programs). These training sessions were carried out virtually during the second wave of the COVID-19 pandemic, but were later conducted on-site.

Field visits were also conducted between July–August 2021 to oversee the implementation of the solution, to understand the experience of the end-users (lead farmers), and to obtain feedback for improvements in user experience. Wadhwani AI staff also conducted need-based retraining and troubleshooting sessions.

Partners and extension officers were provided access to the district dashboard, which showed an overview of farming practices, based on the data generated by CottonAce. **Fortnightly review meetings** were conducted with the partners to review the implementation, identify challenges, and troubleshoot.

The role of the partners

The partners **trained lead farmers to correctly install and use the CottonAce app, as well as the requisite pest traps and lures**. They procured and supplied pest traps and lures to the farmers, free of cost, and guided them to carefully and safely install these traps at appropriate places at their farms, as per the established guidelines. They collected data from farmers that was relevant for registration on the application, as well as for evaluation, and provided this data to Wadhwani AI (see Annexure 1).

It was also emphasized that **lead farmers should monitor the traps using CottonAce every week** and act as per the advisory generated. A mechanism was established for cascade farmers (who did not directly use CottonAce) to receive CottonAce-generated information on pest management from the lead farmers (app users) in their villages, based on the advisories generated by the application.

During field visits, partners provided continued guidance to farmers on how to use the application, interpret the advisories once they were generated by the app, change the location and height of traps when needed, and replace expired lures, among other matters.

Findings

A session is defined as a continuous interaction of a user with the app. In other words, whenever a farmer opens the CottonAce app, a session is said to be created. In a given time frame, if 10 users opened the app, 10 sessions are said to be created in that time frame. The session duration is the time interval between opening and closing of the app by the user. The app allows users to upload multiple images during a single session. If valid images are uploaded, alerts and corresponding advisories (for yellow and red alerts) are generated in that session.

Out of the 9,609 farmers registered during Kharif 2021, 6,284 farmers (>65%) used the app at least once. During a total of 11,379 sessions, 22,340 images were uploaded, resulting in 9,619 alerts. Out of these, 5,029 (52%) were green alerts, 1,966 (20%) were yellow alerts, and 2,624 (27%) were red alerts. The data generated through the use of CottonAce was used for analysis. The overall analysis of this data has been presented in
Annexure 6.

Field challenges

The following field challenges were faced by farmers during the implementation:

1. There were **delays in supplying the requisite pest traps** and lures to farmers due to their unavailability in the market.
2. During each picking, **farmers may choose not to pick cotton from the damaged bolls**. Picking the cotton that is damaged along with the cotton that is undamaged may lead to contamination while the undamaged cotton is in storage. Therefore, damaged cotton bolls are left on the plant until the farmer decides what to do with them. The continued presence of infected cotton bolls on the plant leads to persistent infestation, which may affect the crop in subsequent pickings or subsequent seasons. Due to resource constraints, we were not always able to verify if the installation and maintenance of traps were carried out as per the guidelines.
3. Farmers **could not always use the application** once every week, as recommended (see Annexure 5 for reasons).

The following challenges were faced by farmers due to pest infestation:

1. Some farmers **continued to harvest from their cotton plants beyond December**, which led to greater PBW infestation during winter and consequently to a poorer yield.
2. There is a **lack of regulatory provisions** (by competent authorities such as the CIB&RC) for standards pertaining to the quality of pest lures for manufacturers. This leads to the proliferation of substandard lures in the market. Farmers are not always able to ensure that the lures they procure are of good quality.
3. In several cases, the **farmers have been unable to adhere to the guidelines** pertaining to the correct quantities of the lures to be used or to their timely replacement (as suggested by the manufacturer).

Recommendations

The following recommendations were made by farmers and implementation partners for further improvements to the overall solution:

1. The **accuracy of pest counts, and their identification needs to improve** so that the application does not generate alerts for images which do not contain pests; farmers must be guided to upload only those images which contain pests, and not any others.
2. The **findings** presented in the monitoring dashboards used by the implementation partners (which contain a village- and district-level overview of the data generated by CottonAce) **should be available to export as Microsoft Excel files**, for additional analysis and customized monitoring.
3. In addition to an application for PBW management, **a holistic solution may be provided to the farmer**, from sowing to harvesting. This may include the selection of seeds and fertilizers (based on type of soil and weather), irrigation schedules, management of other pests, diseases and nutrition deficiencies affecting the cotton plant, ideal dates for harvesting, guidance for storage, and market linkages. ■

06

Evaluation of the solution

TOPICS COVERED IN THIS SECTION

- Planning
- Geographies and duration
- The role of Wadhwani AI
- The role of the partners
- Findings
- Field challenges
- Recommendations

Takeaways from the 2020 evaluation

In the summer of 2020, the first impact assessment by the University of Agricultural Sciences, Dharwad, confirmed a statistically significant increase in income levels among farmers who adopted the advisories generated by CottonAce.

An **independent impact assessment** was conducted by an external agency during Kharif 2020. The assessment analyzed yields, costs of pesticides, selling prices, and net gains, as reported by CottonAce adopters.

Farmers were surveyed across four districts in Maharashtra, Gujarat, and Telangana. The resulting report observed an increase in net profits for the farmers and a better quality of yield.

Objective of the current evaluation (Kharif 2021)

To assess differences in crop damage, crop yield, and pesticide usage among app users and control farmers.

MEASUREMENT APPROACHES

Image 1: **Photograph of a PBW infestation**

1. **Crop damage**

   a. **Damage to flowers:** Observe twenty randomly selected flowers and count the flowers showing a rosette-like appearance due to pink bollworm damage.

   b. **Damage to bolls:** Observe twenty randomly selected bolls and count bolls that contain live pink bollworm larvae.

   c. **Damage to locules:** Twenty randomly selected bolls are broken and opened to count the total number of locules (compartments). Out of them, the number of damaged locules are counted. A damaged locule is black and contains larvae; a healthy locule is typically white and devoid of any larvae.
2. **Crop yield:** Self-reported by farmers and expressed as quintal per acre of farmland.
3. **Pesticide use:** As it was difficult to measure the quantity of the spray used, only frequency of spraying was considered for analysis. The type, quality or brand of the spray could not be considered for analysis.

Design of evaluation

A quasi-experimental two-arm field trial (non-randomized) was planned with the 17 implementation partners in all 60 districts, across 10 states in India, from June to December 2021.

One arm had 30 lead farmers (50 in the state of Telangana, as per the suggestion of the state government), who used the app as per the established guidelines, and acted on the advisories generated. They are referred to as "app users". The other arm had 30 farmers without access to the app. They are referred to as "control farmers".

Considering the ground challenges and the monitoring capacity of the partners, a sample size of 30 was decided for each group, per district.

The farmers were selected by the implementation partners after considering matters such as the geography they themselves operate in and are able to monitor, the willingness of the farmer, and the availability of smartphones.

For each app user, one control farmer was selected from the same village so that environmental conditions affecting pests and yields would remain reasonably similar. Other factors that could affect the yield (access to water from wells or other irrigation facilities, type of fertilizer used, frequency of fertilizer used, type and time of seed sowing, etc.) could not be matched.

Each farmer was interviewed by a trained staff member of the implementation partner every fortnight to assess app usage, advisories generated, and actions taken on advisories, including the type and frequency of pesticides sprayed. The staff member also checked for damages caused by PBW to flowers, bolls, and locules at fortnightly intervals. Relevant information pertaining to fertilizer and irrigation facilities was also collected. At the end of the season, information on total costs and yields was collected. A structured study instrument is shown in Annexure 4.

Implementation

The field trial, involving 1,056 farmers from 17 districts of 5 states, was conducted between June and December 2021 (see Table 2 below). Data from the remaining geographies could not be made available by implementation partners or had quality issues which could not be reconciled. The details of farmers who could continue to use the application and provide data during the evaluation are given in the table below.

Table 2: **Farmers considered for evaluation**

STATES	NO. OF PARTNERS	DISTRICT/s	NO. OF CONTROL FARMERS	NUMBER OF APP USERS
Gujarat	2	Amreli	30	30
		Banaskantha	13	13
		Sabarkantha	17	17
		State Total	**60**	**60**
Karnataka	1	Dharwad	30	30
		State Total	**30**	**30**
Punjab	1	Bathinda	25	28
		Fazilka	9	18
		Mansa	13	25
		Sri Muktsar Sahib	11	11
		State Total	**58**	**82**
Rajasthan	1	Hanumangarh	12	30
		Nagaur	30	30
		Sri Ganganagar	10	30
		State Total	**52**	**90**
Telangana	3	Adilabad	55	52
		Karimnagar	46	52
		Kammam	28	39
		Mahabubnagar	21	28
		Nagar Kurnool	57	71
		Nalgonda	72	71
		State Total	**279**	**315**
Combined*	**8**	**17**	**479**	**577**

*Values computed by combining data of all mentioned states

Each app user was required to follow the steps mentioned in Section 1.1. However, as there were several farmers who could not follow these steps (from the app user group) or withdrew their consent (from both groups), this led to an unequal number of app users and control farmers in the final analysis.

The implementation during Kharif 2021 was affected by the second wave of COVID-19. It led to delays in on-ground monitoring and support efforts. Regular checks regarding data quality and adherence to the protocol could not be conducted.

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Distribution of boll damage, number of sprays and yield in each of the app users and control groups are described in various box whisker plots below, along with tables that test for difference in mean observations for above mentioned parameters across states and whether they are statistically significant.

Due to various data related issues, many outliers are present. In the box whisker plots, "Combined" refers to all five states combined.

Table 3: **Findings of the evaluation for proportion of bolls damaged.** Statistical significance of differences between user and control groups were assessed using a chi-square test for difference in proportions

STATES	BOLL DAMAGE % (USER)	BOLL DAMAGE % (CONTROL)	CHI SQUARE VALUE	P-VALUE	SAMPLE SIZE (NO. OF BOLLS)
Gujarat	14.6	12.7	1.863	0.1724	2400
Karnataka	5.4	7.1	1.577	0.2095	1140
Punjab	39.8	38.2	0.7554	0.3848	2800
Telangana	2.3	3.2	9.175	**0.00245**	11880
Combined*	**10.3**	**9.6**	**2.875**	**0.09001**	**18220**

Figure 3: **Distribution of boll damage** The adjacent box whisker plots show the extent of boll damage for control and app users from various states during the Kharif season of 2021. "All" refers to all five states combined where evaluation was carried out.

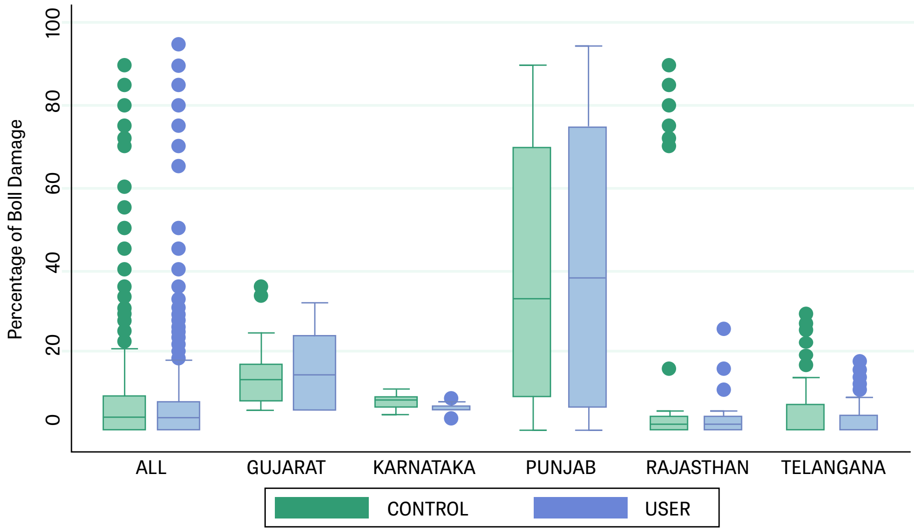


Table 4: **Findings of the evaluation for number of sprays (PBW)** Statistical significance of differences between user and control groups were assessed using a t-test for difference in means

STATES	DIFFERENCE IN NO. OF SPRAYS (USER-CONTROL)	MEAN SPRAYS (USER)	MEAN SPRAYS (CONTROL)	STD. ERROR (MEAN)	P-VALUE	SAMPLE SIZE (NO. OF FARMERS)
Gujarat	-0.95	2.6	3.55	0.3641	**0.0102**	120
Karnataka	0.5333	2.8667	2.3333	0.638	0.4066	60
Punjab	0.3207	1.7	1.3793	0.2839	0.2606	138
Rajasthan	0.0571	0.2148	0.1577	0.0798	0.4755	142
Telangana	0.0722	0.4743	0.4021	0.0529	0.173	594
Combined*	**-0.1399**	**0.9113**	**1.0512**	**0.0952**	**0.142**	**1054**

*Values computed by combining data of all mentioned states

Figure 4: **Distribution of number of pesticide sprays** The adjacent box whisker plots show the average no. of pesticide spray for control and app users from various states during the Kharif season of 2021. "All" refers to all five states combined where evaluation was carried out.

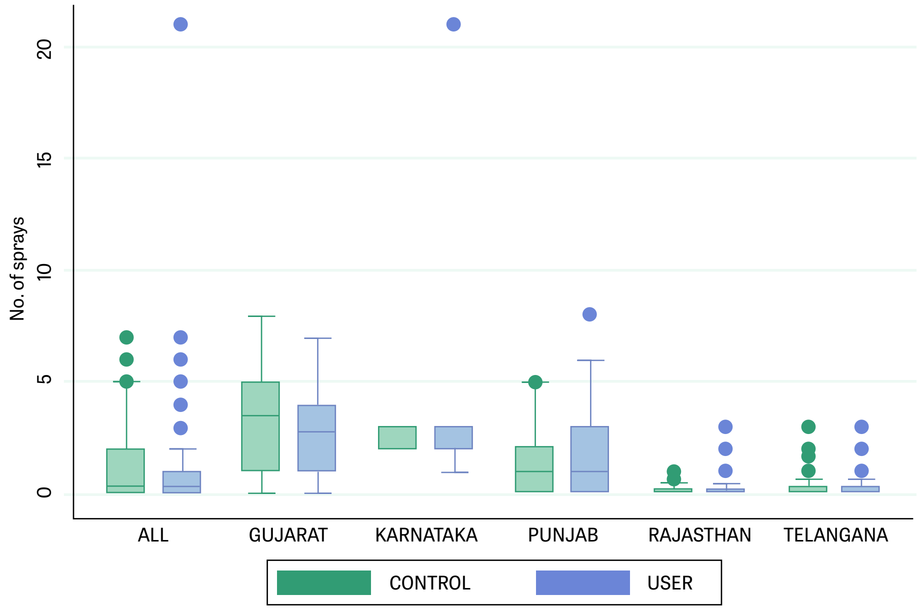
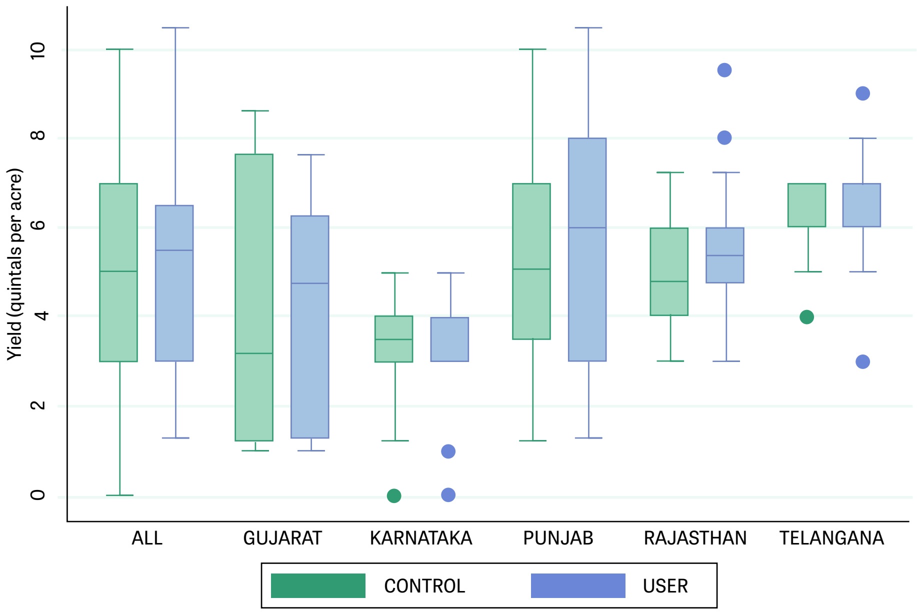


Table 5: **Findings of the evaluation for crop yield (quintals per acre)** Statistical significance of differences between user and control groups were assessed using a t-test for difference in means

STATES	DIFFERENCE IN YIELD (USER-CONTROL)	MEAN YIELD (USER)	MEAN YIELD (CONTROL)	STD. ERROR (MEAN)	P-VALUE	SAMPLE SIZE (NO. OF FARMERS)
Gujarat	-0.4692	3.8553	4.3045	0.5266	0.3748	120
Karnataka	0.0667	3.5667	3.5	0.2884	0.818	60
Punjab	0.445	5.6993	5.2543	0.4183	0.2893	140
Rajasthan	0.5113	5.3908	4.8795	0.3	0.0922	82
Telangana	0.61	6.6	5.99	0.2723	**0.0289**	60
Combined*	**0.2854**	**5.0607**	**4.7754**	**0.2164**	**0.1879**	**462**

Figure 5: **Distribution of yield**
The box whisker plots adjacent show the average yield in quintals per acre of farm for control and app users from various states during the Kharif season of 2021. "All" refers to all five states combined where evaluation was carried out.



*Values computed by combining data of all mentioned states

It can be seen from the tables above that there are variations in the findings observed across states. Statistically significant differences between app users and control farmers are observed in the following cases:

1. The proportion of bolls damaged was lower among app users in Telangana.
2. The average number of PBW sprays was lower among app users in Gujarat.
3. The crop yield was greater among app users in Telangana.

It is important to note that wherever the differences between app users and control farmers are statistically significant, the use of the CottonAce app has resulted in improved pest management.

Limitations

The evaluation could not be implemented in each of the geographies planned, thus the findings may be carefully interpreted and extrapolated. Given different priorities and limited resources, it was challenging for us to ensure fortnightly data collection schedules, use of the same versions of the data collection tools, and data quality assessment and appropriate actions to improve it.

The limited bandwidth for supervision made it difficult to ensure standardization in the implementation of the study instrument of the evaluation. This led to an inability to use all the available data for analysis. Due to non-adherence to the fortnightly interview schedule, we have averaged the values for each of the three indicators so that they are comparable across both groups. Due to lack of clarity from implementation partners, the missing values for these three variables were replaced with zero, which may not be a correct assumption. ■

07

Conclusions and the way forward

> We are preparing to onboard more Monitoring, Evaluation and Learning (MEL) experts and expose them to the agriculture domain.

Despite the challenges present during the second wave of the COVID-19 pandemic, we were able to roll out the CottonAce solution to include more than 6,000 farmers, with the help of a number of implementation partners from various parts of the country. Wherever there were statistically significant differences, we observed better yields, lower boll damage, and lower pesticide use among app user groups as compared to control groups.

There were quite a few data- and measurement-related challenges, which also provided us with insights for future work. To accurately measure the impact of the intervention in the next season, we are preparing to onboard more Monitoring, Evaluation and Learning (MEL) experts and expose them to the agriculture domain, as well as train domain experts in MEL methodologies before designing a framework. We are also in the process of preparing a study protocol, study instrument, and training and assessment plans for Kharif 2022. Robust data entry and data quality control mechanisms are being put into place, and there will be fortnightly data analyses conducted to regularly review progress, with regard to both implementation and assessment.

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Annexures

Annexure 1: **Data requirements for registration on the app**

The format below was filled by implementing partners after consulting with farmers and shared with Wadhwani AI, so that registered farmers could log in to CottonAce using their registered mobile number.

Name:
Phone Number:
Country:
State:
District:
Taluka:
Village:
Sowing Date:
Farm Type:
Extension Worker Phone Number:

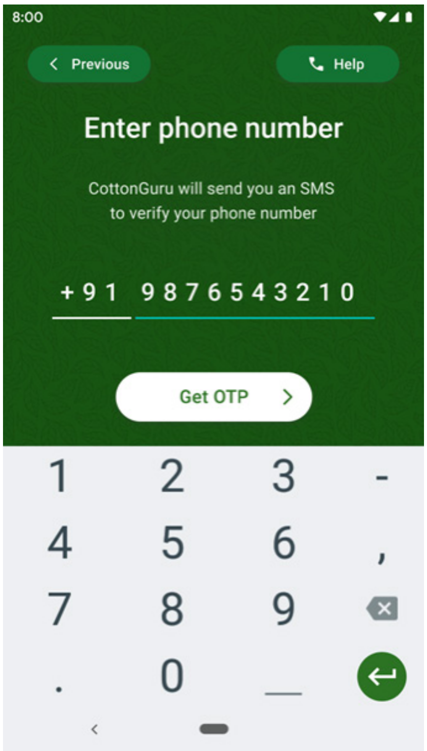
Annexure 2: **The pheromone trap**

The trap is affixed to a wooden stick and gradually moved upwards along the stick so that it maintains a one-foot distance from the canopy of the cotton plant.

The lure (rubber septa containing the pheromone) should be attached inside the trap.

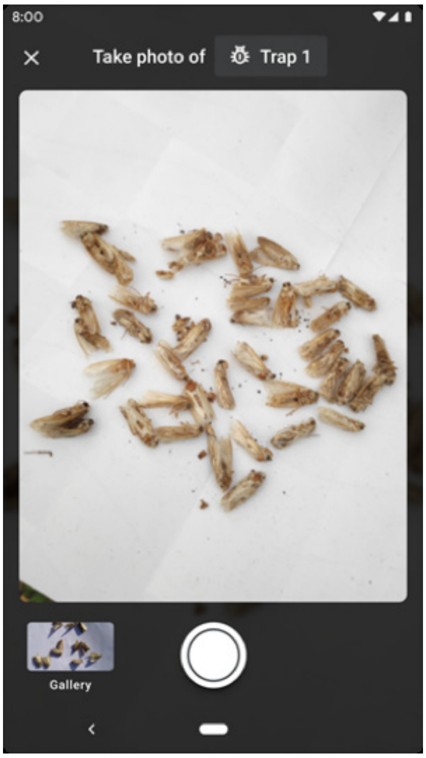
Annexure 3: **App workflow**

1. Home page

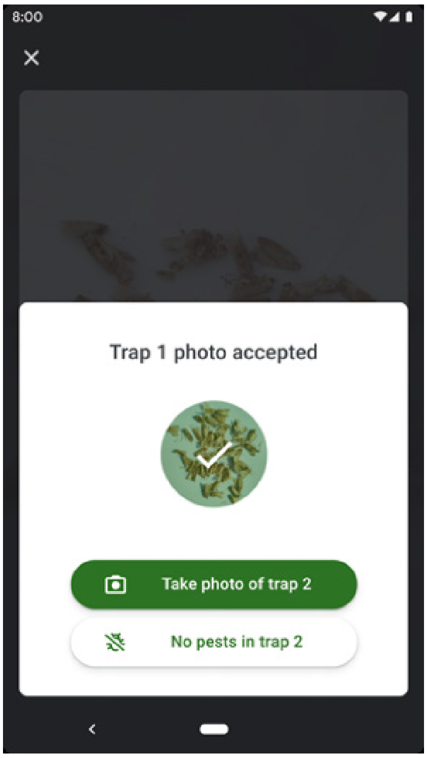


2. Login page

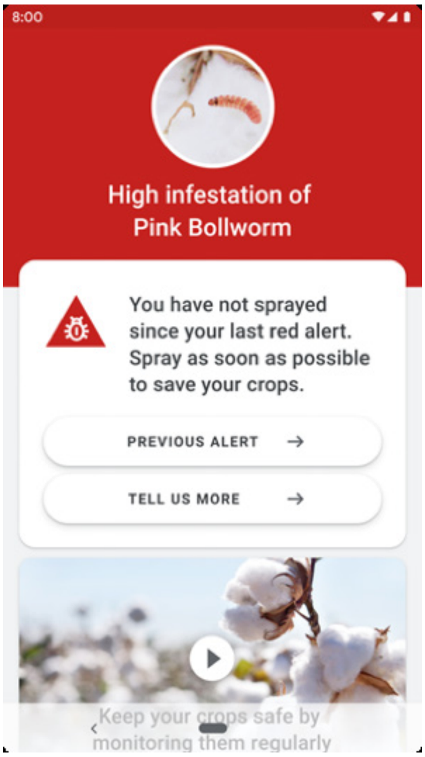
3. Farmer emptying the trap



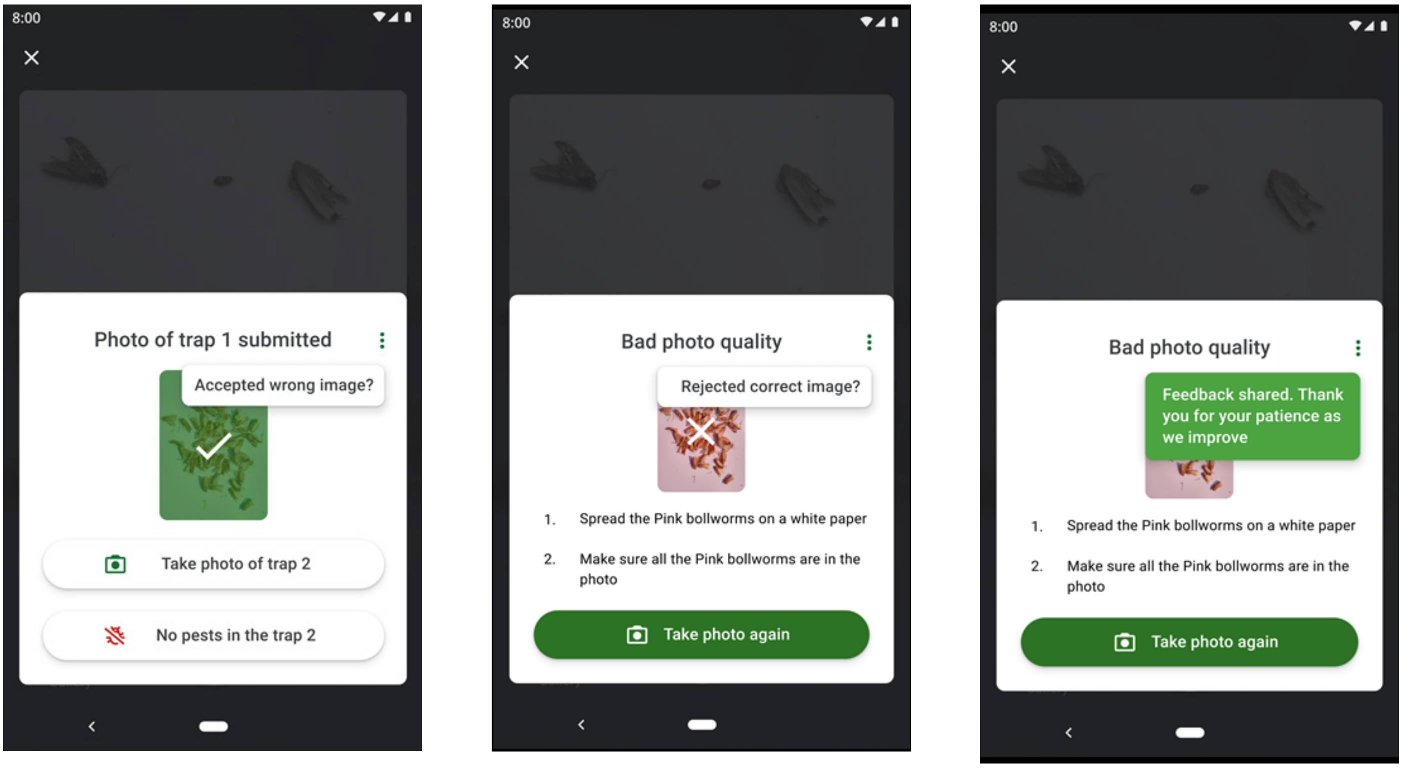
4. Image taken from smartphone



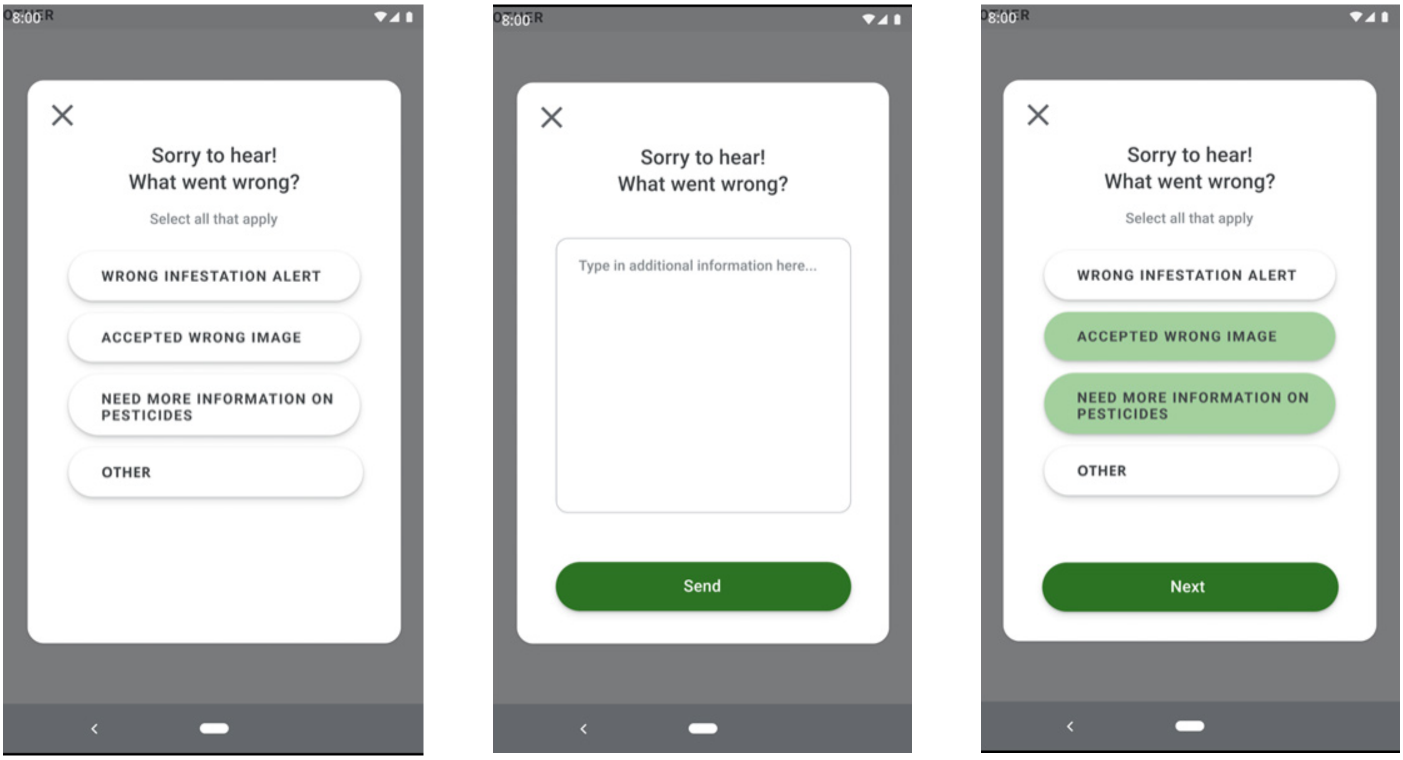
5. Submission



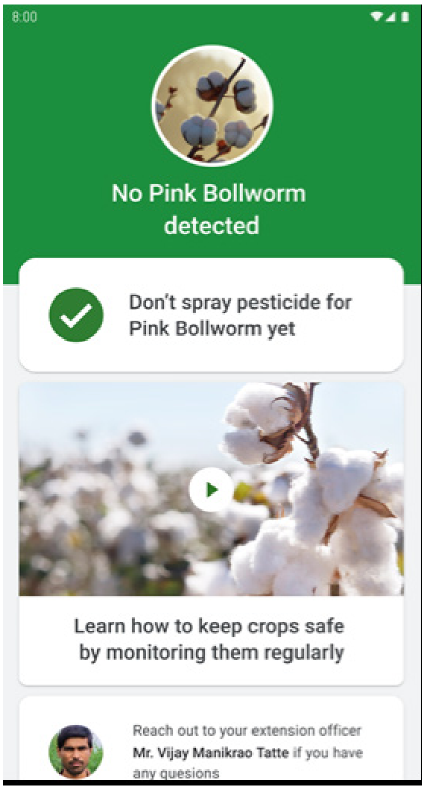
6. Alert



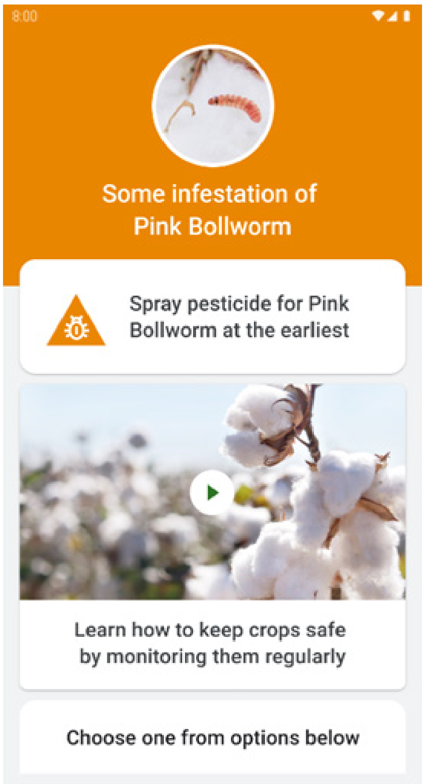
7-9: Report options while uploading pest images



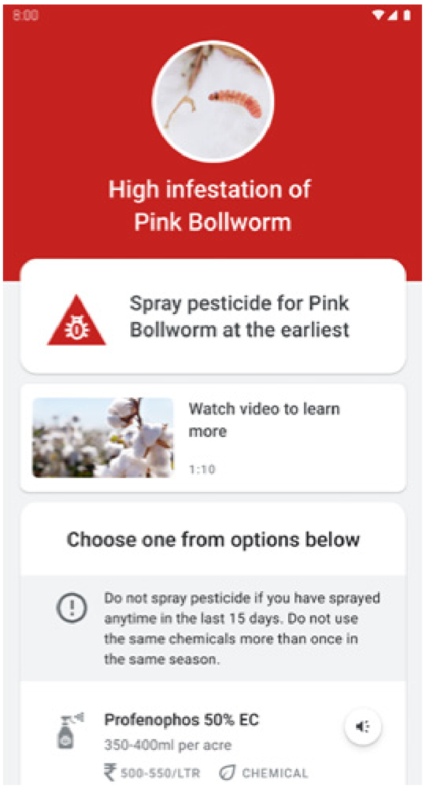
10-12: Report options after issuing advisory



13: Green alert



14: Yellow alert



15: Red alert

Annexure 4: **CottonAce solution evaluation form, Kharif 2021**

A. Baseline questions (to fill once per farmer)

Partner agency name:	District:
Date:	Surveyor name:

	PARAMETERS	FARMER			
1	Farmer name:				
2	Farmer type:	User/control			
3	Sowing date:				
4	Age (years):				
5	Education (years):				
6	Land area (acres):				
7	Irrigation (yes/no/partial):				
8	Vehicle (2/4 wheeler or kuccha house):				
9	Village name:				
10	Block & district names:				
11	Mobile no.:				
12	Growing cotton since (no. of) years:				
13	Any intercrops grown (names):				
14	Yield 2020 (Q/acre)[1] & (Price Rs./Q)[2]:				
15	Yield 2019 (Q/acre) & (Price Rs./Q):				
16	Yield 2018 (Q/acre) & (Price Rs./Q):				
17	Soil fertility status and source (Ref: soil health card for current sampling)[3]	N- EC-	P- pH-	K- Any other value-	OC-

B. SEASONAL/ VARIABLE REPLY QUESTIONS (to repeat twice every month; Sept.-Dec.)

Partner agency name:	District:
Date:	Surveyor name:

	PARAMETERS	FARMER
17	Survey date:	
18	Surveyor name:	
19	Number and type (red/yellow/green) of alerts in the last 15 days:	
20	Frequency of PBW sprays when app generated alert in the last 15 days:	

1. Yield Q/acre -Yield in Quintal/acre for the year 2018, 2019, 2020;
2. Price Rs./Q- Price in Rupees/Quintal for the year 2018, 2019, 2020;
3. Soil health card status is desirable for all farmers and sample 3-5 each of user and control types

21	Frequency of PBW sprays in the last 15 days, if any, without generation of alert by CottonAce:
22	Name of PBW sprays applied in last 15 days, if any, without generation of alert by CottonAce:
23	PBW pesticide drug nos. cost Rs./acre (till date, avoid labor cost):
24	Total Yield Quintal (Q/acre):
25	Picking 1, (Q/acre) & Date:
26	Picking 2, (Q/acre) & Date:
27	Picking 3, (Q/acre) & Date:
28	Picking 4, (Q/acre) & Date:
29	Average selling price of cotton received by farmer during the season for all the pickings in Rs./Quintal (If any documentary proof is available, mention its name and no.):
30	Cotton farming input cost- Rs./acre (incl. paid labor) total so far:
31	Bolls % PBW infested now[4]:
32	Rosette flowers %[5]:
33	Remark (any major causes of damage, % etc.):
34	If no adoption (of advisory), its reason[6]:
35	Fertilizer inputs cumulative so far- N, P, K, kg/ acre, please also specify if any micronutrients added, name, quantity:
36	Biomass inputs (farmyard manure- FYM/ vermi/ compost/ Amrut pani/ Jeevamrut, etc. please specify quantity- quintal/ acre and type, no. of doses total):
37	Number of irrigations provided, if any (this may be done by few during long dry spell):
38	Any other relevant information:
39	No. of Fellow Farmers:
40	Red alerted- No. of Fellow farmers:
41	No. of Fellow farmers sprayed- Chemicals
42	No. of Fellow farmers sprayed- Neem etc.
43	Do fellow farmers report any benefit of advisory adoption in time?

4. Measured by breaking 20 bolls selected at random and the number of locules (compartments) in the bolls that are infested

5. Measured by counting the (infested) rosette flower % in 20 randomly selected cotton flowers.

6. 1) PBW not considered important, 2) Barrier- Rains/ guests/ festival etc., 3) Pesticide (brand) not available, 4) Finance issue to buy pesticide, 5) No trust on solution (due to past experience etc.), 6) Any other reason

Reasons for not using CottonAce app on weekly basis for farmers

- The lead farmers mobiles are being utilised by their children for education purposes
- Continuous rains are leading to non monitoring
- Farmers did not prefer to monitor or spray
- Educational levels of the farmers
- Login issues, app feature related issues etc.
- Farmers will not give any inputs/use any pesticides after first picking as the maximum number of bolls are already open and a few late formed bolls will be in the boll formation stage. It was observed that most of the farmers did not monitor their farms after first picking as they opined that if they conduct spraying in cotton during picking, the ready to harvest cotton gets wet and secondary infection of black fungus is developed on the harvested cotton in storage and its quality gets affected, hence farmers did not prefer to monitor or spray after first picking is over.

Reasons for non-adherence to the advisory generated by the app

- Farmer unable to understand the advisory as it was given in chemical component form (No trade names were mentioned)
- Non availability of recommended pesticides in the local market
- Financial issues and timely availability of labor
- Suitable weather for spraying

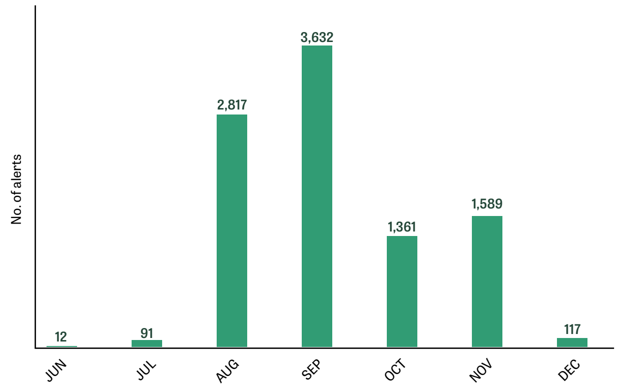


FIGURE 6: Monthwise alert generation during Kharif 2021

The figure adjacent shows the number of alerts generated using the CottonAce application by over 6000 farmers across all geographies. Through the interactions with the implementation partners, it was known that the majority of the farmers harvested cotton by Diwali (October 2021) and reduced pesticide spraying.

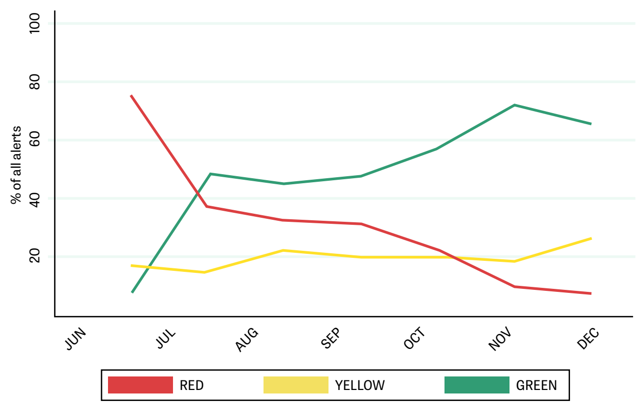


FIGURE 7: Monthwise alert generation during Kharif 2021

The figure adjacent shows the proportion of green, yellow and red alerts from all alerts generated using the CottonAce application by over 6000 farmers across all geographies. It indicates a gradually increasing proportion of green alerts during the Kharif season of 2021 (June to December).

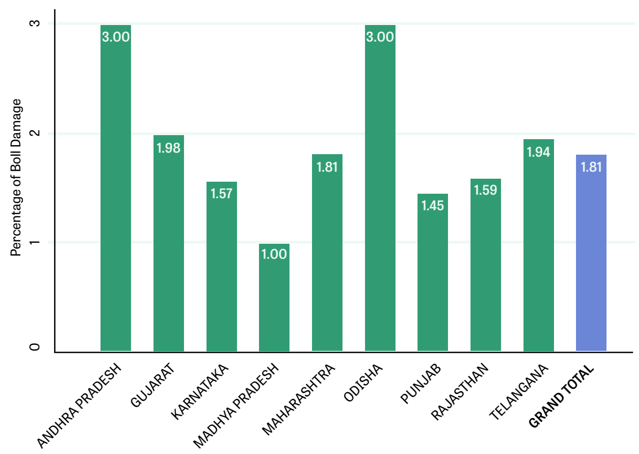


FIGURE 8: App usage

The figure adjacent shows the average number of sessions per farmer from various states during the Kharif season of 2021. The app usage was far lower in each of the states as it was recommended to use the app once a week. Reasons for low usage are mentioned in Annexure 5.

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