

Cropping Systems of Haryana - Challenges and Opportunities

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List of acronyms and abbreviations

BEDF	Basmati Export Development Foundation
CCS	Chaudhary Charan Singh
CSISA	Cereal Systems Initiative for South Asia
CIMMYT	International Maize and Wheat Improvement Center
CLCuD	Cotton leaf curl virus disease
CWCS	cotton–wheat cropping system
DAP	diammonium phosphate
DOA	Department of Agriculture
DSR	direct seeded rice
FYM	farmyard manure
GEAC	Genetic Engineering Approval Committee
GL	Group Leader
GPS	geographical positioning system
HAU	Haryana Agriculture University
HH	household
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research Institute
IFPRI	International Food Policy Research Institute
INR	Indian rupees
IPM	integrated pest management
IRRI	International Rice Research Institute
KVK	Krishi Vigyan Kendra
LDS	landscape diagnostic survey
LSWV	late sown wheat variety
MDRH	medium duration rice hybrid
MDRV	medium duration rice variety
MEL	monitoring, evaluation and learning
OBC	Other Backward Classes
ODK	Open Data Kit
PAU	Punjab Agricultural University
PBW	pink bollworm
PMCS	pearl millet–mustard cropping system
PPS	probability proportionate to size
RAWE	Rural Agricultural Work Experience
RWCS	rice–wheat cropping system
SAU	state agricultural university
SDRH	short duration rice hybrid
SSP	single superphosphate
SOM	soil organic matter
TSWV	timely sown wheat variety
USA	United States of America
USD	United States dollars



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Foreword

State Agricultural Universities (SAUs) are mandated to carry out the triple functions of education, research, and extension education. There are already statutory provisions like Academic Councils in each State Agricultural University (SAU) for monitoring and implementing plans for technical infrastructure for agricultural education in India. The Internship Program in Agriculture (IAP) as part of the B.Sc. (Hons.) Ag. degree was initiated during Eighth five year plan on the initiative taken by the Indian Council of Agricultural Research (ICAR). The IAP was taken up in the course curriculum for the undergraduate program from 1992-93 academic year. In December 1999, the ICAR decided to introduce Rural Agricultural Work Experience (RAWE) program as part of the B.Sc. (Hons.) Ag. 4-year programme at the national level. After successfully pushing IAP in 1992-93 and then RAWE program in 1999, it is now time to review it and add one more practical element that includes assessment of what students have learned in theory. The success of this programme will depend on: a) understanding field problems, b) finding their solutions, c) whether these solutions meet the farmers expectations, d) how technologies are adopted by farmers, and e) whether emphasis is given to the needs of farmers and consumers. Krishi Vigyan Kendra (KVK) system created by ICAR is contributing towards RAWE program to make the students understand how they can help in the transformation of agriculture and how teaching, research, and extension are integral parts of education. The capacity building through RAWE was conceptualised by developing a framework that helps students understand serious challenges by seeing and observing the adoption process of technologies under actual field situation and under farmers' perspectives rather than the perspective of what we want to see.

DDG (Agricultural Extension) has initiated a Monitoring, Evaluation and Learning (MEL) system by generating data base on how technologies are adopted by farmers. Here the capacity building also includes the development of an instrument like Landscape Diagnostic Surveys (LDS), which holds the promise of making the research and extension management more evidence-based, accountable, and transformative.

The National Research and Education System also needs further scaling up of the land grant model with a strong interface of teaching, research and extension in Indian Agriculture. There will be a need for big data as we go along. It has put a spotlight on setting research and extension priorities based on the needs of farmers. It will cater to the needs of the farmers to bridge the technological and adoption gaps. The survey design of different cropping systems has shown how farmers are adopting new technologies, how to set priorities, how to bridge the yield gaps, technology gaps between states and within states, where we are and where we want to go. Students will be exposed to the process of formulating demand-driven, problem-oriented, and location-specific programmes. It also helps teachers for reorienting course curricula and pedagogy to meet future needs. The university will strive hard to successfully add value to farmers' limited resources by speeding up changes that make farming more sustainable and stable.

The primary objective of this publication "Cropping Systems of Haryana – Challenges and Opportunities" is to increase the capacities of students and help them understand the process of a proper feedback on what they have learned and how their learning is implemented at the ground level. Once this concept is introduced, it will create trained human resource to meet the need of new challenges in the field of agriculture and allied sciences.



(R.C. Agrawal)

Preface

Haryana is bounded by the Shivalik Hills to the north, the Aravali Hills to the south, the Yamuna River to the east and the Thar desert to the west. The land slope is from north to south. The average topographic elevation is in the range of 700 to 950 feet above sea level. The state covers 1.4% (4.4 million hectares) of the country's total geographical area.

Nearly 70% of the population is engaged in agriculture. Haryana state, with its strategic fertile land, has a rich legacy of sustainable agricultural development, despite encountering many human-made and natural calamities over its long history. Its farmers have increased food grain production from 2.6 m tons in 1966–67 to 18.3 m tons in 2020–21. Increases in wheat and rice production during this period were eleven and sixteen-fold, respectively. Today, Haryana is self-sufficient in food production and the second largest contributor of food grains to the nation's food basket.

The predominant cropping systems practiced within the three ecologies of the state are the cotton–wheat cropping system (CWCS), pearl millet–mustard (PMCS) and rice–wheat (RWCS). In 2022, a landscape diagnostic survey (LDS) in parts of Sirsa and Hisar districts (for CWCS), Rewari and Mahendergarh districts (for PMCS) and Panipat, Yamunanagar and Kurukshetra districts (for RWCS) was initiated under the Rural Agricultural Work Experience (RAWE) programme. The twin objectives of this collaborative initiative were to (1) gain an understanding of the existing challenges and opportunities for these cropping systems in the region through a bottom-up approach, and (2) prepare students for a future career in agriculture by building their practical skills in digital agriculture and big data management. This publication documents the success of both these objectives to a large extent.

Data were collected from farming households by RAWE students using questionnaires, and thoroughly analysed using different analytical tools and techniques. Important data points about the region's three crucial cropping systems have been recorded, using real-time data sourced directly from the farmers. Some of the data collected indicated conditions beyond expectations, while some supported views on emerging trends, and a few on the need for judicious system intervention.

The survey has helped build student capacity to design and understand data collection methods and data analysis and management, combined with actual field exposure. Further, the qualitative data-gathering experience enabled student understanding of farmers' perspectives when adopting or rejecting a particular technology or recommendation.

This publication provides material for teaching, research, and extension. Many of the messages and lessons learned can be shared with research and extension streams in agricultural universities, with government extension divisions and Krishi Vigyan Kendras (KVKs) centres, and with the private sector. In the long run, this type of systems approach to building student capacity will encourage fieldwork and studies which support the development of solutions to tomorrow's problems. Alongside this, the survey also marked GPS (geographical positioning system) coordinates which can be cross verified in future studies. In the short term, this publication will hopefully facilitate research and extension activities that address the concerns and desires of farming households, reflected in the discussions and conclusions sections of this publication.

The entire design of this survey was based on farmers' participatory engagement and the cropping system framework. The commitment of Haryana Agriculture University (HAU) to implementing a strong RAWE programme under the technical guidance of Cereal Systems Initiative for South Asia (CSISA), with support from district KVKs and student participation, has made this publication a powerful endorsement of and reference for similar RAWE programmes across the India's states and central universities.

This publication is based on contributions from Shudhanshu Singh, Cynthia Carmona Reyes, Prakashan Chellattan Veetil, Sonam Sherpa, Arindam Samaddar, Ashok Kumar, Anurag Ajay, Harshit Rajan, Umesh Singh Yadav, Nima Chodon, Ajay Kumar, Shishpal Poonia, Anurag Kumar, Madhulika Singh, Pankaj Kumar, Deepak Kumar Singh, Moben Ignatius, Sugandha Munshi, Peramaiyan Panneerselvam, Wasim Iftikar, Bidhan Mohapatra, Bhavani Pinjarla and Narayan Chandra Banik and other colleagues from CSISA. Principal Investigators and Co-Principal Investigators of participating KVKs conducted the surveys and analyzed the data. Directors of Extension and Principals of Colleges helped provide facilities. Other members of the RAWE faculty who provided support include S. K. Thakral, A. K. Dhaka, Bhagat Singh, R. D. Jat, Praveen Kumar, Dalip Kumar Bishnoi, Sanjay Bhyan, J. K. Bhatia, Joginder Malik, Bharat Singh Ghanghas, Rati Mukteshwar, Karmal Malik, Rajbir Garg, O. P. Lathwal, Ramesh Yadav, Pratap Panwar, Amarjeet Nibhoria,

Rakesh Sangwan, Navish Kamboj, Parveen Rohilla, Aradhana Bali, Sarita, R., S Gadhwal, RC Verma, Navin Kumar, Amit Sodhi, Naresh Kaushik, Ashish Siwran, Sardool Maan, S. K. Singh and Vijay Kaushik.

The survey was conducted by RAWE students: Ravi Sharma, Aadesh Kaushik, Aashish, Manish Kumar, Pardeep, Ankit, Naveen, Shubham, Yogesh Kumar, Sachin Dagar, Raj Kumar, Mohit, Vikas, Navdeep Kumar, Lovepreet Singh, Chand Kumar, Devender Yadav, Rohit, Rohit, Ujjwal, Neeraj, Ajay Kumar, Pardeep, Somveer, Deepak Pahal, Sagar Saroha, Sahil, Anurag, Tejas Malik, Dhruv, Nisha, Neha Yadav, Tanu, Sunita, Yamini, Monika, Kajal, Supriya, Rashmi, Krishna, Preeti, Meenakshi, Chetan, Pooja, Yashpal (Group Leader), Akhilesh Attri, Aryan, Parvesh Kumar, Prateek, Sahil, Ankit Yadav, Ravinder, Vikas Saini, Mitul, Pulkit Chahar, Surender, Rahul, Vijay Kumar, Praveen, Sachin, Naseeb Singh, Dhruv Saharan, Deepak, Manish, Parveen, Sachin, Shiv Kumar, Yash Sindhu, Keatsav Sharan (Group Leader), Anaam Ahmad, Bheem Singh, Mohit Kumar, Mosim, Sanjeev Kumar, Ajay Kumar, Ajay, Ankit Kumar, Rajat, Sahil, Vinit Kumar, Ankit, Rohit, Naveen Kumar, Gaurav Dangi, Dinesh, Satender, Ajay, Sahil, Karan Singh, Ravinder Singh, Nitish, Chasin, Manish, Mahesh, Shubham, Sanjay Kumar, Vikas, Amit, Nakul, Sachin, Sunil, Vishal, Yash Kamboj, Harsh, Deepak, Lovish, Akshay, Nilanchal, Sourav Singal, Sumit, Luxmi (GL), Deepak Yadav, Mamta, Manju, Chelsi (GL), Anju, Dipti Yadav, Neha, Sakshi Goyat, Muskan (GL), Monika, Nandini, Nidhi, Rimpi, Simran, Nitika, Devanshi, Kriti, Ritu Yadav, Ruchika, Priya Kundu, Priya (GL), Kriti, Urvashi, Jyoti, Nishtha, Kartiki Sharma (GL), Ankita Chauhan, Divya Sharma, Manisha, Mansi Bishnoi, Vaishali, Pooja (GL), Divya, Himanshi, Jyoti Rani, Renu Kumari, Ankit Tiwari (GL), Aayushi, Anjeeta, Avishi, Chetna, Pooja Berwal (GL), Nisha Yadav, Priyanka Devi, Ritika, Sucheta Kumari, Tinnu, Romita Sharma, Aditi, Akansha, Kajal, Komal, Ritika, Sangeeta, Kiran, Shiksha Rani, Manjubala, Jyotikhatkar, Alka, Yogita, Neha, Pratibha, Mahima, Suman, Sunaina, Ishika, Sakshi Nimbale, Alkhil (GL), Abhinav, Aditya Dagar, Aman Kumar, Dhenanjay Yadav, Ravinder, Rajiv (GL), Abhishek, Ajay Kumar, Rammehar, Tapanshu, Manish (GL), Abhilekh, Anuj, Karan Singh, Mojit Kumar, Gourav, Deepak Soni, Sachin Narwal, Deepak, Kamaldeep (GL), Chirag Gehlot, Lalit Mohan, Ritik Duhan, Suraj, Rohit Kumar, Suman Baidya, Himanshu, Jaswant Singh, Manjeet and Parveen.

Editors

1. Method applied for the random selection of farmers in the landscape diagnostic survey conducted by students of Chaudhary Charan Singh Haryana Agriculture University, Hisar during the Rural Agricultural Work Experience (RAWE) programme, Haryana

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The selection of a subset of individuals from a population to collect data is called sampling. In large surveys, sampling is typically done in such away as to estimate characteristics of the whole population. The random sampling method is the most appropriate approach when survey results are to be generalized for a larger population. In this approach, every item of the population has an equal chance (probability) of being selected. Random sampling techniques are divided into four different types: simple, systematic, stratified and cluster sampling, with the most suitable method being selected according to the purpose of the study being conducted. The landscape diagnostic survey (LDS) conducted under the rural agricultural work experience (RAWE) programme applied the cluster sampling method, with one district considered the 'universe' from which the farmers to be surveyed were selected. The same sampling process was applied separately for each district. First, a predetermined number of villages were selected and farmers were selected from these villages; 'village' referred to one cluster of dwellings (Wooldridge, 2003). Farmers were then randomly selected from each cluster/village. This approach of cluster-based random sampling is referred to as 'single stage cluster sampling'.

To apply any random sampling method, a prerequisite is to construct a sampling frame and then use a method (in this case, a computer program) to generate random numbers to pick the selected item (Taherdoost, 2016). A sampling frame is the list of all sampling units available for selection, and population refers to the aggregate of all the elements defined prior to the construction of the sampling frame. With the LDS, sampling units were first 'village', then 'household'.

(i) Probability-proportionate-to-size (PPS)

A probability-proportionate-to-size (PPS) approach is considered accurate in a sampling process where the size of cluster within the universe varies. PPS assigns probability of selection based on the size of the unit. As part of this LDS, PPS was used to obtain the desired number of villages in a district. As the size of village can be very small to very large based on the number of households, PPS provided better accuracy by assigning probabilities proportionate to village size. In this way, larger villages had a higher chance of being selected and smaller villages a smaller chance. At the same time, PPS ensured that none of the villages was assigned zero probability in the selection process.

(ii) Sample size

A larger sample size generally means more precise estimates for the whole population; however, the marginal gain in the accuracy of results reduces after a certain size of sample (Dell et al., 2002). With the LDS, sample size was also decided by taking into consideration the time and resources available to the RAWES students who would be collecting the data. It was decided to conduct the survey in 30 villages from each district and to interview seven farmers in each village. Samples were to be distributed across the 30 villages, meaning that variations between villages would be adequately captured.

$$\text{Sample size/district} = 30 \text{ villages} \times 7 \text{ households} = 210 \text{ households}$$

(iii) Sampling frame for village selection

A sampling frame for village selection was constructed by processing 2011 district-level census data, downloaded from <https://censusindia.gov.in/census.website/data/census-tables>. These steps were followed to construct the sampling frame:

- delete columns in census .xlsx file, except four consecutive columns (Level, Name, TRU and No_HH)
- apply filter in the 'Level' column to delete CD BLOCK, OG and TOWN levels,
- keeping only VILLAGE level
- go to column 'TRU' and ensure only rural categories remain selected
- apply filter in the 'No_HH' column and delete all rows with numbers less than 50 and more than 5000, to ensure that extremely small and very large villages are excluded from the frame

- keep only two columns in the sampling frame ('Name' and 'No_HH') (name of village and number of households in each respective village)
- save this file to apply PPS and to identify 30 villages

(iv) Identifying villages using PPS

When the village selection sampling frame was constructed, the PPS method was applied to obtain the desired number of villages for the survey, using MS Excel and the following steps (a snapshot of five villages is presented below):

→ open sampling frame .xlsx file consisting of two columns:

Name	No. HH
Shahpur	146
Khokhra	188
Nawannagar	245
Gorakhnath	114
Sitoo Majra	54

→ Named three adjacent columns as shown below – Cumulative, Min and Max – that would be derived from 'No_HH' column.

Name	No. HH	Cumulative	Min	Max
Shahpur	146			
Khokhra Na-	188			
wannagar	245			
Gorakhnath	114			
Sitoo Majra	54			

→ Populated these three blank columns using formulae given below up to the last row (Village names should be in column 'A' and the first village name should start from the second cell)

Name	No. HH	Cumulative	Min	Max
Shahpur	146	=B2	1	=C2
Khokhra	188	=C2+B3	=E2+1	=C3
Nawannagar	245	=C3+B4	=E3+1	=C4
Gorakhnath	114	=C4+B5	=E4+1	=C5
Sitoo Majra	54	=C5+B6	=E5+1	=C6

→ The final table looked like the one given here. Cumulative column is the addition of all households chronologically and figure in the last cell of this column denotes the total number of village households in this district. 'Min' and 'Max' are the proxy Ids for each household corresponding to villages. Figure in the last cell of 'Cumulative' column (total number of households) and last cell of 'Max' column (highest Id number allotted) should match.

Village	No. HH	Cumulative	Min	Max
Shahpur	146	146	1	146
Khokhra	188	334	147	334
Nawannagar	245	579	335	579
Gorakhnath	114	693	580	693
Sitoo Majra	54	747	694	747

→generate a random number between 1 and the highest allotted ID number using the formula `RANDBETWEEN(1,X)`; for example, if the highest ID number was 46154, the formula was `RANDBETWEEN (1,46154)`

→ find out in which range of 'Min' and 'Max' row this random number falls and select corresponding village

→repeat this command 30 times and draw villages; if a new random number suggested was in an already-selected village, discard it and do it again until 30 villages are obtained

→ to obtain a reserve pool of 10 villages, follow the same process, starting with generating random numbers.

(v) Household selection from voter's list

The desired number of households (seven) was drawn randomly from village voter lists using an MS Excel spreadsheet, following these steps:

- Open a .xlsx file and save it, after renaming it 'District, Village'
- Name two column headers 'House Number' and 'Family Member Name'
- Referring to village voter list, enter all unique house numbers under 'House Number' column and name of a corresponding family member (preferably the most senior) under 'Family Member Name' column

- d. Double-check voter list to ensure no entry is missed
- e. On 'Data' tab and under the section 'Data Tools', apply 'Remove Duplicates' command to this sheet to ensure only unique house numbers are drawn
- f. Insert two blank columns before 'House Number' column
- g. Assign arbitrary names to both these newly inserted columns(e.g. X and Y)
- h. In second cell of column, immediately before 'House Number' column, type the formula =RAND() and press enter
- i. Obtain a random number between 0 to 1
- j. Drag this cell up to the corresponding last cell of 'House Number' column
- k. Copy this whole column and paste it as 'Values' in the previous blank column
- l. Delete column from which these random numbers were copied
- m. In this random number column, apply either 'sort Smallest to Largest' or 'sort Largest to Smallest' filter by expanding the selection
- n. Select top seven rows to obtain the first list of 7 potential respondents
- o. Keep another set as probable replacement from rows 9 to 15

Note: village voter lists were used to administer the above steps. After using PPS to finalise 30 (plus 10 replacement) villages, the list was shared with participating KVKs who had contributed by obtaining the voter lists.

(vi) Data collection

Students used these steps (which provided village-wise names of pre-identified households) to locate potential farmers for interview. Where a pre-identified farmer was not available (for example, due to migration, being a non-farming household, not growing a crop of survey interest), they contacted a household from the replacement list. Within the household, the interview was conducted with the person (either male or female) who managed the family's

farming affairs. Data were recorded on the student's mobile phone using the Open Data Kit (ODK) Collect app (Hartung et al., 2010). ODK Collect is an open-source Android application used in survey-based data gathering. It supports a wide range of question-and-answer types and is designed to work well without mobile internet or even network connectivity. The raw data were checked by the appropriate university faculty before being transmitted to the ODK data server.

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2. Landscape diagnostic survey (LDS) implementation process through RAWE program

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Overview

The Cereal Systems for South Asia (CSISA) ODK–RAWE program in collaboration with Chaudhary Charan Singh Haryana Agriculture University (CCS HAU) was launched with a vision first to understand the existing production practices of farmers in major cropping systems (rice–wheat, cotton–wheat and pearl millet–mustard) prevalent in the state. The detailed survey with respect to landscape diagnostics for the rice–wheat cropping system (RWCS) was carried out in the three districts of Panipat, Kurukshetra and Yamunanagar. For the cotton–wheat cropping system (CWCS), the target districts were Hisar and Sirsa; for the pearl millet–mustard cropping system (PMCS) Mahendergarh and Rewari were the districts. The second aim of this survey was, firstly, for research scientists, extension agents and policymakers to achieve an in-depth understanding of prevalent practices, and any existing gaps in conducting research, and secondly to build the capacity of agriculture students at the undergraduate level through rigorous field training — the objective here was to strengthen their base and facilitate an understanding of their future clientele, that is, farmers.

Process

I. Strategic Planning

In the first phase of implementation, CSISA research and management teams held meetings with Indian Cultural Agricultural Research Institute (ICAR) and HAU. The plan was then presented to the Vice-Chancellor,

LDS Process Flow – RAWE, HAU

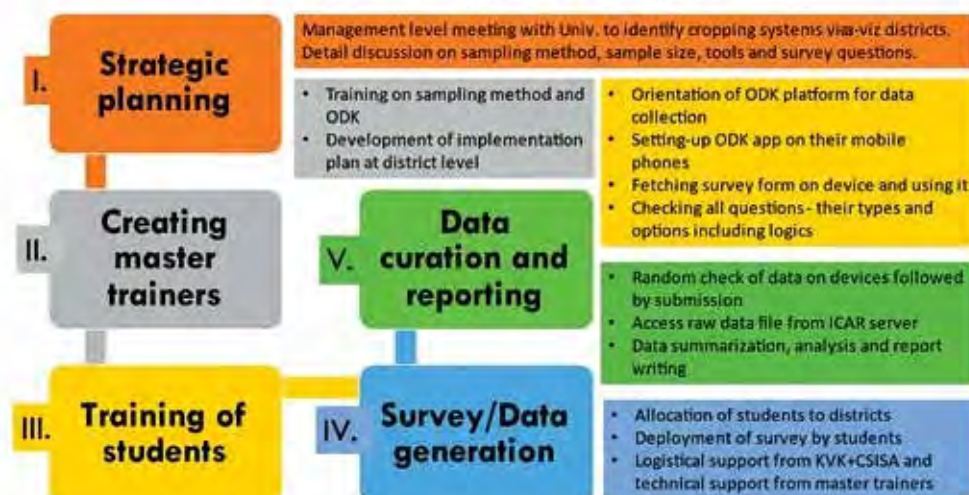


Fig. 1. Process flow of the landscape diagnostic survey conducted for CWCS (Hisar, Sirsa districts), PMCS (Mahendergarh, Rewari districts) and RWCS (Yamunanagar, Panipat and Kurukshetra districts), Haryana.

CCS HAU, Hisar, followed by discussion with the Dean, College of Agriculture. A detailed implementation plan was considered with the teachers allotted the RAWE programme, including the management of such an ambitious pilot vis-à-vis the teachers' experience. During the whole process, teachers were briefed about potential challenges by observing the adoption process of technologies under actual field situations and from the farmer perspective. This new process was part of the capacity building of students, where they were encouraged to focus on evidence-based decision-making, the process of survey design, data collection and data management.

II. Creating Master Trainers

The second phase involved vetting the technique and creation of Master Trainers within HAU. Participants included a team of RAWE teachers, principals from the College of Agriculture (COA) Bawal and Kaul, and all in charge, heads of department of Agronomy, Agricultural Extension, Agricultural Economics, and head of KVK/s, under the leadership of the Dean, COA. It was a two-day program.

Day 1: This smaller group addressed questions in detail, discussing suggestions regarding all the modules including basic information, decision-making, general farm information, plot-level information on variety, irrigation, fertilisers, herbicides, insect pests, yield and cost.



Day 2: Here, the larger group discussed each question with the implementing partners. The relevant choices for each group were discussed, and any suggested addition or deletion incorporated as appropriate. A detailed strategy on program implementation at the field level was also devised. This included placing students in groups, creating group leaders, and deciding in which districts each student would be placed. The voters list from which farmers' names were randomised at the household level was collected by KVK scientists and the randomisation process completed by the university faculty in association with the students.

III. Training of students

This four-day training programme was carried out by the CSISA LDS training and monitoring, evaluation and learning (MEL) teams for the students and an associated team of research scientists and extension scientists, under whose guidance the LDS survey was conducted; 210 students (100 female, 110 male) participated, were distributed according to cropping system and district (Table 1), and placed under the leadership of two HAU faculty members, two KVK extension scientists, and one CSISA research staff member, in each district.

A day of training each was conducted for CWCS and PMCS; there were two days' training for RWCS as the number of students was greater in this group.

Table 1: Break-up of students assigned for various districts.

Cropping system		Male	Female	Total
Rice-Wheat	Yamunanagar	30	-	30
	Kurukshetra *COA Kaul	-	20	20
	Panipat	30	-	30
Cotton-Wheat	Sirsa	30	-	30
	Hisar	-	40	40
Pearlmillet - Mustard	Rewari *COA Bawal	-	30	30
	Mahendergarh	20	10	30
Total		110	100	210



Fig. 1. Process followed to download ODK Collect from Google Play Store on to any android handset. *COA = College of Agriculture.

Students were oriented on how to install and use ODK Collect on their android mobile phones (in case using different handset, students arranged or borrowed android phones for the task).

Step 1: In Google Play Store on any android phone type 'ODK Collect' is as seen in Fig. 1. After the app is installed, open the application, and go to the right-hand corner, where three dots are visible indicating settings. Click on the dots to see the general settings.



Fig. 2. Configuring the general settings in ODK application.

Step 2: Open the general settings to see the server options. Click the server settings to see the option of URL changes needed to be made here on the basis of which is your host server (for this particular project the URL was <http://csd.icar.gov.in:8080/ODKAggregate/>). Next, enter the assigned username and password created by the host partner. Go to the home interface of the application to find Get Blank Form, click on this to get all the forms associated with this URL. Click the form of interest for which the survey is to be done selecting from LDS RAWE HAU Rice Wheat, LDS RAWE HAU Cotton Wheat and LDS RAWE HAU Pearl Millet Mustard.

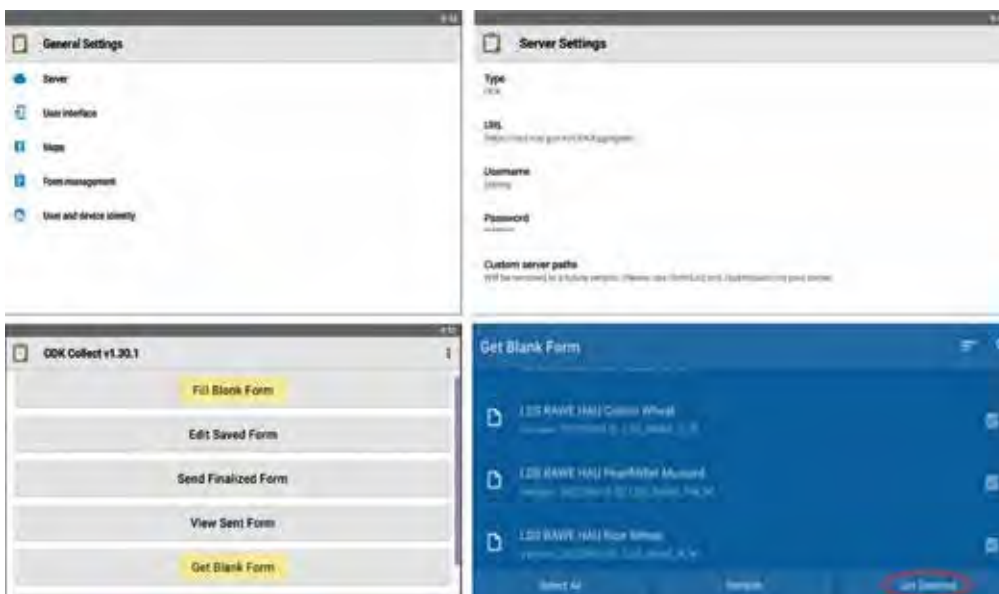


Fig. 3a. Server settings, **3b.** URL, username and password, **3c.** Get Blank Forms Option, **3d.** Get Selected Blank Form.

Step 3: Students dedicated to each cropping system were briefed about the requirements of the survey and made aware of how to probe to get the optimum answers from respondents. Emphasis was given to how best to interact with farmers, that is, on interpersonal communication skills, to convince respondents to devote quality time to the survey. At the same time, providing hints to obtain 'correct' answers was a strict 'No', as these could result in biased answers.



Step 4: Students brought the whole survey into the classroom, where each question was discussed in detail, a process which contributed to improving the questionnaire and making field implementation smoother. On completion of the survey, they were instructed to take the GPS coordinates from the centre of the largest plot for which it had been conducted.

Step 5: The group was taken to field-test the survey, to ensure that students understood the survey questionnaire and were able to communicate accurately with real respondents, that is, farmers.



3. Assessment of adoption process of technologies - a key component for improving academic achievements

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- Keeping the above need to enhance students' skills and equipping them with modern day techniques in mind, the Landscape Diagnostic Survey (LDS) was designed. This survey is designed such that students get to travel to remote locations and survey randomised farmers. The questionnaire is such that it helps them to understand the seed-to-seed concept (sowing till harvest) of the cropping systems along with the cost of cultivation (economics) as well as some basic social structure (attributed to the social science related questionnaire).
- LDS show that the state of Haryana has the net benefit of growing one commercial crop, including rice, mustard, cotton, and wheat. However, prices fluctuate year to year depending upon the situation of crop harvest and on account of agricultural trade. It is now right time to convert opportunities into realities through the digitization of agriculture and machine learning. It is also the time that we constantly monitor adoption with a transparent method.

Assessment of the adoption process of technologies is part of practical knowledge,, enabling students to learn digitization in agriculture and the importance of digitized farm services. The

assessment can be done using an LDS under the existing mandate of the Rural Agricultural Work experience (RAWE) programme and will ensure transparency as part of lessons learned from courses taught to the students.

Throughout the whole process, students will understand serious challenges by observing the adoption process of technologies under actual field conditions, from the farmer's perspective.

Quality of education and career development as part of RAWE

- The Indian Cultural Agricultural Research Institute (ICAR) pursues excellence in the quality of agriculture education, through a network of institutions/state agricultural universities (SAUs). The establishment of the National Accreditation system has now become a fixture of improvement in the quality of education. The RAWE program can help sustain agriculture education with respect to students' present and future employment needs. However, its quality needs to improve, so that students can include it in applications for jobs in the private sector or for admission to higher education.
- Each SAU needs to produce graduates based on market demand, with a profile that illustrates they have genuine practical experience which is evidence-based. Students will need to step out of their comfort zone and become accustomed to real field situations, and this requires improvement on all fronts, including to survey instruments, data collection, data management, data analytics and machine learning.
- The private sector plans to invest in artificial intelligence and machine learning, and this could translate into routine or non-routine jobs for our students. Curriculum improvement in terms of digitization in agriculture and data management can have a high impact on enhancing the skills of graduating students. Great emphasis needs to be attached to learning through case studies, which can be achieved by including land diagnostic surveys during the RAWE program. Proper checks and balances need to be created to improve the employability of students.
- The RAWE programme can be strengthened by investing more in education in this regard. Students should be given practical knowledge equipping them to customise solutions to suit individual farmers. There is a need for trained human resources who understand areas such as commercial agriculture, and opportunities for market research and/or market intelligence.

Course-Curriculums Packages across State Agricultural Universities

In all 71 SAUs, students are introduced to high-yielding varieties or hybrid varieties, agronomic and plant protection measures, high yield-producing livestock, sheep, goat, pig, poultry, marine and fishery development, farm inputs for intensified production systems, post-harvest technologies including processing, preservation, storage, cold chain, packaging, labeling, farm machinery and equipment, and emerging fields of genetic engineering, molecular biology, transgenics, genomic research, and cloning.

Although the land-grant system of agricultural education has kept pace with new trends in developing course curricula, it may have to target a less traditional background and look for evidence-based research and extension systems, where farmers are involved in setting priorities and where yield gaps could be filled by understanding the agri-food systems. There has been a significant development in the field of information and communication technologies, making now the time for digital farm services and big data management. Greater exposure is needed to practical training in all technical courses in the mandated streams mentioned above. For the graduate program, the current recommended ratio is 1:1, which needs reconsidering.

Teacher- student interface

The land-grant system mandates teachers to invest time in teaching, research, extension education and institutional building. In this, teachers also need to understand how the perception of farmers has changed over time. In addition, teachers and students need to understand the random variation in the preferences of individual farmers that could be attributable to the virtues of technology or production practices under reference, and which can vary according to individual farmer needs. The response of the farmer to preference is mostly based on the long-term average performance of any technology. Students need to ensure they are up-to-date with issues such as climate change and digitization in agriculture, which they can achieve through learning-by-doing as part of long-term capacity building. In terms of how technologies are accepted by farmers, students also need to look for clues as to how farmers adopt technologies and which technology best assists farmers to increase their system productivity. A better understanding of this by academia would have the potential to strengthen the interface between teaching, research, and extension. The idea is to transform the system from a top-down to a bottom-up approach, which will involve a more hands-on approach to big data management, from survey design to data analytics, together with a futuristic agenda of machine learning.

Spotlight on feedback loops

RAWE students are adept at handling digital information/data and can adapt quickly to new techniques of data collection like the ODK system. If the LDS process is implemented properly it will provide (1) a much wider scope of teaching, research and extension, by gathering information on the preferences and needs of farmers, and (2) evidence-based feedback for researchers of all streams, contributing to priority setting and to deciding where to invest in extension activities. The RAWE programme will take advantage of and further complement the practical study designed for each course on agronomy, agriculture economics, and agricultural extension. It will also help in expanding digital agriculture, data analytics, and other applications of decision-support tools like machine learning. As part of human resource development, the collaboration with ICAR to set up a new initiative to build a database to improve feedback loops, and advance sustainable solutions and accelerate their adoption through evidence-based analytics, has the potential to add to the value of agricultural education at the undergraduate level. It will also contribute to:

- increasing the capabilities of students, supporting them understand the process of proper feedback on what they have learned and how their learning is operating at the ground level.
- creating trained human resources to meet the need of new challenges in the field of agriculture and allied sciences.
- spotting patterns in technology adoption, understanding yield gaps analysis across districts, and turning datasets into useful information through feedback loops and data analytics
- providing a platform for compiling all factors that help create demand-side synergies for developing better scale and scope for new technologies.
- contributing to creating synergies in the management of food systems across ecologies by understanding logic and profitability from the farmer perspective, using a bottom-up approach.

How to select topics for the landscape diagnostic survey and improve communication

SAUs pre-select the topic(s) for the LDS based on their expertise and long-term commitment toward the state. The criterion for this pre-selection is to assess and further strengthen existing capabilities and knowledge of the universities' research and extension system. RAWE students conduct the survey while staying in KVKs or KVK-based villages. The views of scientists and Directors of Research and Extension will be obtained regarding their needs to improvise their research, development and agrotechnology transfer capabilities.

An in-house evaluation of the data that RAWE students collect will be conducted on the main campus by teachers and concerned KVKs. Students prepare seminar (workshop) materials with the support of teachers. A one-week training and education workshop will be held to (1) train students in the use of innovative and modern methodologies to collect data, (2) discuss outcomes in the convergence platform, such as Agriculture Officers Workshops, and (3) communicate appropriate recommendations to Director, Research and Director, Extension Education with the aim of improving the technical programmes and resource use efficiency.

Lessons learned for a new RAWE programme

- SAUs in India were established based mainly on the land-grant pattern of the United States of America (USA). In India, the idea that the state will provide jobs is being tempered by a more realistic view. In the late 1970s and 1980s agriculture grew faster than other sectors and allowed successive governments to invest substantially in public sector agricultural jobs. The course curriculum for different programmes has been updated at regular intervals to meet the aspirations and contemporary needs of society. Various Dean's Committees have emphasized an impetus on practical learning, including a sound Rural Agricultural Work Experience programme. This new RAWE programme has been developed to expose agriculture students to actual farm-like conditions where they work and interact with farming families, coming to know about their problems and discussing how to overcome them with the help of extension activities. New approaches such as digital farm services which tell farmers how to cultivate crops in different farm situations are emerging.
- Overall, there are four groups actively involved in agricultural development: the government's Department of Agriculture (DOA), academic researchers, extension agencies (in both the public and private sectors), and the farmers themselves. The first step needed for digital change to emerge is the capacity development of all four groups, and to achieve this, focus must be given to enhancing agricultural education. This can be partly achieved by enhancing the skills and problem-solving abilities of agriculture graduates.
- The benefits of enhancing the skills of RAWE students are clear, and will require ground level field knowledge, an understanding of the current cultivation practices of farmers, and hastening the process of providing solutions to farmers' existing problems.
- A broad survey-based design, data management, and data analytics might be one direction towards achieving this process. The education system needs to be re-orientated in such a way that students are equipped with improved skills in handling big data to enable them to compete for decent, high-wage jobs. The important step

taken by ICAR of strengthening the RAWE programme as part of capacity building could contribute to the transition of agriculture education in such a way that it equips students to improve and apply their analytical skills.

- The institutional settings both at ICAR and in SAUs need strong collaboration with the private sector, international institutions, and semi-government agencies, to identify stakeholder needs and obtain evidence-based feedback. This is because in the future, all interventions in research and extension will be guided by market needs, including the needs of farmers. Course curricula and human resources also need development commensurate with the emerging needs of institutions in the public and private sectors, both locally and globally. Course curricula should be made more competitive and needs-based to cater for the human resource demands of digitized agriculture and machine learning.
- The immediate challenge confronting agriculture is to increase the return on investment. The market intelligence mechanism must be redrawn at both the state and national levels. In future, there will be increased competition for water. There will be more land lost to urban and industrial use and ultimately less available for cultivation. The real transformation will arise from a new approach towards education, with increased emphasis on evidence-based learning and priority settings. The aim is to inject and support a sense of purpose by developing the RAWE programme so that it caters to the need for proper MEL. This can be facilitated by the revolution in information technology which has made communication faster and increased the availability of information.
- Information technology can nowadays be used for better and faster linkages among scientists, extension agencies across SAUs, and other institutes involved in agriculture research. Institutes such as Indian Agricultural Statistics Research Institute (IASRI) have created excellent data management facilities which can help in sharing information through Agricultural Technology Application Research Institutes (ATARIs) at the state level and through the division of agricultural education at the national level, which supports institutions/universities to avoid duplication of research. A MEL cell at ICAR has been attempted, to incorporate emerging opportunities in agriculture and higher education. Universities need to be linked through a MEL cell such as this, and each SAU can create a strong human resource around this theme.
- Government funding of universities is decreasing alongside ever-rising committed annual expenses. There is a need to further scale up the land-grant model of a working interface between teaching, research, and extension, in order to strengthen the SAU human resource base. In fact, a huge human resource needs raising, to face the challenges and threats posed by climate change on the one hand and the globalization of the national economy on the other.

- The mission of an agricultural university might be described as “enhancing the productivity and profitability of the agricultural sector on an ecological and economically sustainable basis”, and this can be accomplished by undertaking activities which have a clearly defined direction. The LDS-based RAWÉ programme supports students to identify challenges and opportunities, and to understand the lessons learned to enhance their future practice.
- Data such as these also indicate the need to introduce a mechanism of oversight of what is happening at ground level. Such systematic institutionalization of the RAWÉ programme will assist students to understand practical constraints, as well as data analytics and management: a new area for students both within the domain of agriculture and outside it.
- In summary, the effective planning of development in agricultural education, research and extension requires (1) an awareness of opportunities, (2) setting objectives, (3) identifying alternatives, and (4) comparing alternatives, considering the goals so as to formulate supporting plans.

RAWE programme: practical, diagnostic-based agricultural education

Development of Human Resources through RAWE program • a strong research, teaching, and extension interface, attracts farmer's primary interest, optimises greater technology extension, provides feedback to research, and adds value to each	Organisation and Management structures • availability of infrastructure including faculty and stakeholders, and farmers • KVK programme in each district • public and private sector groups • institutional capacity to support RAWE programme • collaboration with CSISA project
Identifying status of technology adoption and changing trends • identify partners for hybridization network, precision agriculture, micro-irrigation, input suppliers, biotechnology research, abiotic and biotic stress, nutritional security, digitization of agriculture, big data and machine learning • identify partners within and outside the state	Response to an identified need: problem focus • understanding farmers' problems from their perspective • understanding farmers' objectives and their environments (biophysical and socio-economic) • understanding farmer needs and innovative strengths • availability of technical solutions
Inventory • undertake a systematic landscape diagnostic survey, data curation and data management • develop ways of interpreting the database • set priority • create a hypothesis for practical application • identify and document lessons learned	Situational analysis: current status of what works and what does not • identify current scenarios in technology adoption • understand the challenges and opportunities • learn techniques for data collection and data interpretation • prioritize farmer needs/constraints. • identify extension agency intervention points. • feedback to research and extension

Development of Human Resource that work for diversified workplaces	
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|---|--|
| <ul style="list-style-type: none">• improve student knowledge and skills towards digitization of agriculture, machine learning• enable students to realize their potential in organizing seminars• provide workshops, writing reports• ensure documentation of lessons learned, credibility and needs assessment | |
|---|--|

4. Rice-wheat cropping system: long-term challenges and opportunities

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- Haryana farmers are adopting medium-duration rice varieties/hybrids (MDRVs/MDRHs) and short/medium duration hybrids (SDRHs/MDRHs) of rice but avoiding Pusa 44, despite its higher yield. Most rice–wheat production is fuelled by groundwater, resulting in over drafting. The mindset of farmers with less water availability than in Punjab might have had a role in their judicious use of water and growing of MDRV, MDRH and SDRH.
- In rice-based cropping systems, rice controls the time available for a succeeding crop(s) in rotation. Understanding farmers' needs is essential when considering innovative suggestions. In addition, long duration rice varieties take too long to fit well into the 200% or 300% cropping intensity.
- Herbicides such as butachlor and pretilachlor have maintained their efficiency in transplanted rice since the 1980s. In wheat, however, poor efficiency and use of herbicide mixtures, or repeat spraying of herbicides, are indicative of possible multiple resistance in *Phalaris minor*, which could be of the same magnitude as happened in 1993–94, if not attended to properly.
- Data on paddy yields across districts show that farmers take paddy yields seriously when considering adopting non-basmati rice. System profits in the Yamunanagar district, and both market price and yield in Panipat district, are the most important factors when considering the adoption of any variety. Adoption of basmati varieties has happened even when the minimum support price (MSP) is not available. Most basmati is sold via private trade.

- Overall, a high yield-oriented breeding strategy is tied to acceptable quality, with maturity duration of up to 145 days. Integration with mechanization and agronomic management will contribute to the wide adoption of new varieties in the system. The focus currently being attempted to resolve diversification or to contribute to making the system climate resilient is moving toward the management element of the cropping system. The focus on developing medium or short duration rice varieties can continue, but any change must be accompanied by the assumption that varieties with a duration of 140–145 days will continue.
- The adoption of some technologies like basmati rice or hybrids is very wide and uniform; however, the adoption of fertilizer-based recommendations varies widely, even in similar ecologies representing farmers in Punjab and Haryana. How a balanced use of NPK is happening across two states should be studied by a much larger database across three districts.
- Alternate crop establishment methods (such as direct-seeded rice or unpuddled machine-transplanted rice) will shape agronomic management, providing reduced mileage and crop establishment costs, better time management, more intensification, and increased system productivity.
- Three districts with dominant RWCS have system optimization characteristics, with the dominance of basmati rice, non-basmati rice, and hybrids in the rice phase, and timely sown wheat varieties in the wheat phase. Timely transplantation of rice (preferably before 1 July) followed by timely seeding of wheat (before 10 November) has provided the foundation for the optimisation of the whole cropping system. The influence of uncertainties associated with the unpredictable monsoon in the rice phase and high-temperature terminal heat stress in the wheat phase is better resolved by time management. Time management can help when introducing a third crop, especially a pulse or green manure crop, which helps in decreasing the soil fatigue that occurs with cropping system intensification.

1.0 Introduction

Rice and wheat are India's staple foods, and with the country's increasing population, food security has been the principal concern. RWCS, with rice occupying an area of 43.8 million hectares and wheat occupying 29.3 million hectares, has played a major role in securing and sustaining India's food security. In Haryana state, the crop production pattern is dominated by RWCS. Rice cultivation is mostly assured irrigation-based, with monsoon rain in the range of 450–650 mm from June to September. System growth has beaten population growth and generated employment for the rural masses, while assured groundwater-based irrigation has promoted and expanded RWCS in Haryana. However, over-exploitation and poor

management of groundwater has led to a drastic decline in Haryana's water table (Humphreys and Gaydon, 2015). The irrigation water requirements of paddy fields are very high, at 1200–1300 mm; this high level of water consumption is mainly due to high amounts of percolation and evaporation.

After decades of continuous cropping, the system is facing new challenges, not in terms of its productivity growth but because of issues such as the decline in water table levels, urbanisation, pest pressure, nutrient mining, and burning of crop residue. The profit margins of farmers have declined due to an increase in the cost of labour, energy, and inputs, with questions on the sustainability of this cropping system raised over the last few decades and policymakers making substantial investments in its diversification. Between 2015 and 2022, a great deal of investment was made in the in situ management of rice residue. However, farmers have shown no interest in diversifying this cropping system because of the uncertainties associated with alternatives, to the extent that they even ignore subsidies that the government offers for alternate cropping systems. This system has performed better than any other cropping system, including PMCS and CWCS. The expansion of rice into non-traditional areas such as Hisar, Rohtak and Jhajjar districts is evidence of greater farmer confidence in RWCS as opposed to any other cropping system. For the individual farmer, stability in income is more important. This reflects the larger logic of risk-free cash flow and food security in RWCS.

RWCS and CWCS farmers have faced unprecedented challenges in the form of weed resistance in wheat and insect resistance in cotton, but even these have not encouraged them to diversify their cropping system. Pushing recommendations that farmers do not accept is not sustainable; rather, it will make a resolution less likely to be achieved. As nothing has changed, the option is to work on how to sustain RWCS. The LDS results will aid understanding of trends in farmers' technology adoption and preferences, facilitating evidence-based arguments about adoption patterns of production practices and leading to a virtual cycle of priority setting in any given ecology. We envisage a future in which market opinion is sought before and after the evolution of technologies. The survey aims to address the issue of skill s development, and to equip RAWE students (as well as teachers) with the necessary capacities in data collection and data analysis. It is also aimed at understanding the sustainability of RWCS and how to optimise the use of resources without compromising yields.

2.0 Methods

There are two requirements of SAUs under the land-grant pattern. The first is that research, extension and teaching are integrated; the second is that each of these three functions need access to data in a well-organised way. There are mandatory agriculture officers

workshops (AOWs) involving the larger participation of top management. This would resolve two issues: first, the need to generate recommendations, and second, the acceptance of these recommendations by farmers. The second issue is critical as understanding the response of farmers is more important than the recommendations themselves.

The LDS is different from thematic surveys. Thematic surveys conducted for each fragmented technology produce focused outcomes, including the adoption of a specific variety in a specific domain, or specific technology (such as zero tillage) in a specific domain. However, they are rarely useful for obtaining a cohesive picture of all production practice adoption in different districts of every state. With LDS on the other hand, care has been taken to obtain a fair representation of farmers to understand the factors affecting their decision-making. For farmers to adopt new technology, three conditions are important: zero risk, easy market access, and profits. The LDS results will contribute to assisting farmers, policymakers, and researchers to achieve advanced data visualisation. It will facilitate a collaboration between research and extension functions to understand variations between districts and between best and average-performing farmers and to set priorities based on farmer needs.

Villages were randomly selected. The team prepared high-quality photos of most of the weeds prevalent in all ecologies of rice, followed by a poster of 40 weeds with their inflorescence to facilitate easy identification. Farmers were involved by being asked to identify the ten most common weeds in their largest plot. The team recorded the serial number of these identified weeds, then asked farmers again about the most troublesome in order of yield losses they cause. The serial number was again noted, and then other questions on weed management options were asked. If the farmers identified a particular weed which had the maximum effect on yields, it was recorded as the number one troublesome weed in the largest plot.

3.0 Results

3.1 Landholding size and tenure status

The process of leasing-in is increasing in all districts (11.0% of households across the three districts). Panipat has the greatest number of lease-ins (15% HHs) and Yamunanagar district the smallest (Table 1), indicating a greater interest in RWCS among farmers in Panipat district. This may be due to better trade facilities for basmati rice in this district. The lease-in rates across RWCS are very high, ranging from INR40,000 to INR50,000/acre lease for one year. The indication is that farmers are shifting towards RWCS across the three districts and beyond. The intention of farmers to spend more on leasing land indicates that this cropping system still has much higher relevance for sustaining farmers' income. It also reflects the confidence of farmers in the aggregate system performance (Erenstein et al., 2007).

Table 1: Leased-in, shared-in and owner-cultivated land of sample households in Kurukshetra, Panipat and Yamunanagar districts, Haryana (n=829).

Districts	% HHs (Leased- In)	% HHs (Shared- in)	% HHs (Owner cultivated)	Average cultivated land (Acres)	Average rice cultivated area (Acres)	Average wheat cultivated area (Acres)
Kurukshetra	12	04	84	11.4	8.0	9.5
Panipat	15	03	81	10.5	8.8	9.3
Yamunanagar	05	02	93	5.5	4.7	5.0
Average (n-829)	11	03	86	9.1	7.2	7.9

Note: Share of land owned and land tenure status by district category

Land utilisation in each season is more than 80% for rice and wheat, with little scope for an alternate crop. This indicates that introducing a third crop (such as mung bean) of 60–65 days maturity duration immediately after harvesting wheat is the best option for sustaining this cropping system. If this does not work, then rice followed by mustard followed by mung bean could be the best option. In this case, mung bean will be well secured due to its seeding in mid-March. There are potential gains for farmers from cost savings through zero tillage in the wheat phase and direct seeded rice in the rice phase. These trends will have significant and long-term consequences for diversification.

3.2 Size of holding

Evidence is emerging that shows that the operational landholdings of farmers are the same as reported earlier and are not decreasing. The percentage of households who reported leased-in land is relatively high in RWCS districts compared to CWCS or PMCS areas. The number of households representing semi-medium (32.4% HHs), medium (24.7% HHs) and large (9.7% HHs) landholdings is the highest in Kurukshetra, and lowest in Yamunanagar, with semi-medium, medium and large landholdings of 28.7%, 15.1% and 0.7% of households' total landholding, respectively (Fig. 1). The number of households representing small and marginal farmers is 55.5% in Yamunanagar, against 33.2% in Kurukshetra and 42.6% in Panipat districts. Overall, semi-medium, medium, and large landholdings make up 67%, 57% and 44% of households in Kurukshetra, Panipat and Yamunanagar districts, respectively. The adoption of hybrids is highest (42% HHs) in Yamunanagar district where landholdings are relatively small. The high cost of seed and the possibility of more input use is not affecting the preference of farmers to adopt hybrids

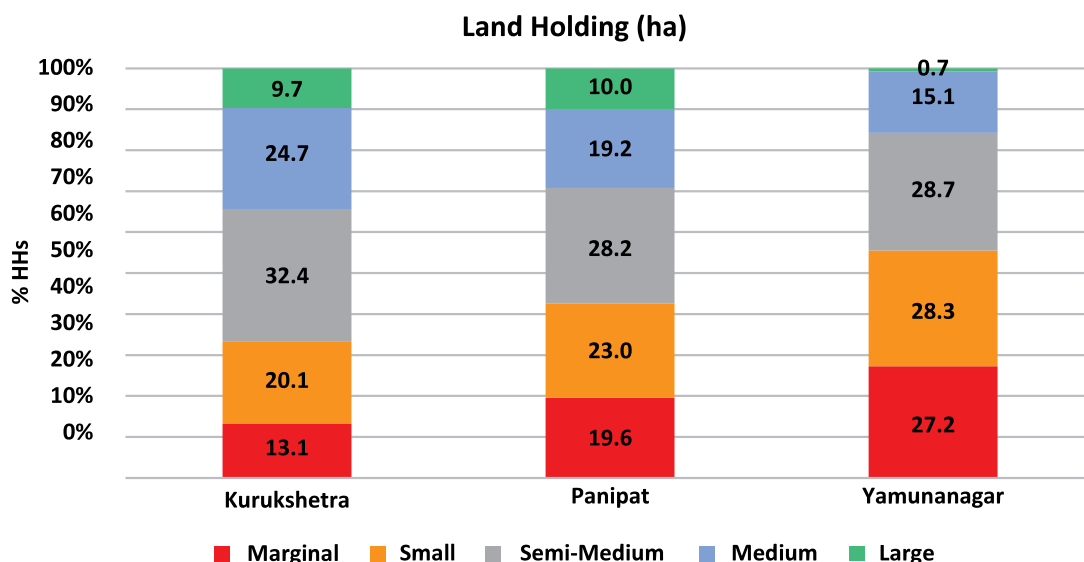


Fig. 1. Landholding size of farmers surveyed in Kurukshetra, Panipat and Yamunanagar districts, Haryana.

in Yamunanagar, possibly because of an increase in reliance on intensification in the district for improving the cashflow of small and marginal farmers. After several years of focus on diversification, the area under this cropping system is increasing due to farmers considering RWCS to be a more mechanised and risk-free system needing fewer visits to monitor the crops. An increase in the size of holding would indicate increased interest in RWCS.

3.3 Education level

The education level of farmers in RWCS based HHs is relatively better than the education level of HHs of CWCS. In this cropping system, about 68% HHs are educated up to 10th standard or higher, with 12% HHs attaining bachelor's degree (Fig. 2). That means these HHs are better placed in making informed decisions regarding their future goals and the current short-term goals of sustaining family income. Most farmers with this level of education can have well informed decisions on the needs of varieties, agronomy, and machines to work in synchrony with the proper coordination of each unit.

3.4 Social Structure

The LDS found diverse caste representation, with 61% of households belonging to the general category and 33% in the so-called 'backward' caste (OBC) category (Fig. 3). Scheduled caste representation was limited; OBC representation was split between several castes. There is better coordination among different categories of farmers because landholding size was uniform, as was the possession of tube wells and tractors.

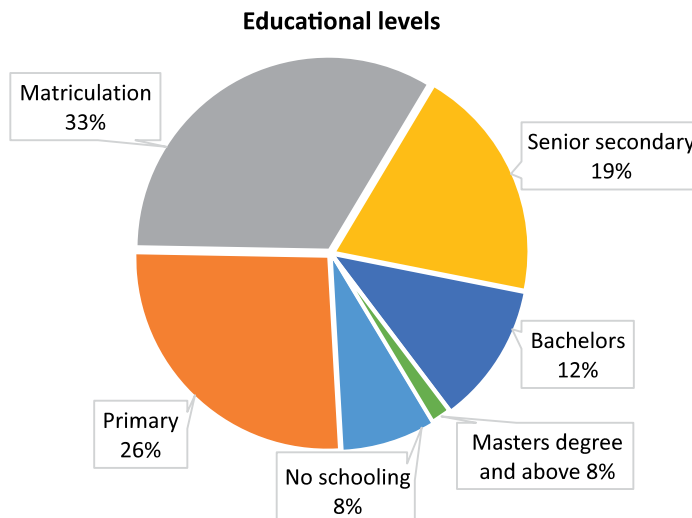


Fig. 2. Education level of surveyed RWCS households in Kurukshetra, Panipat and Yamunanagar districts, Haryana.

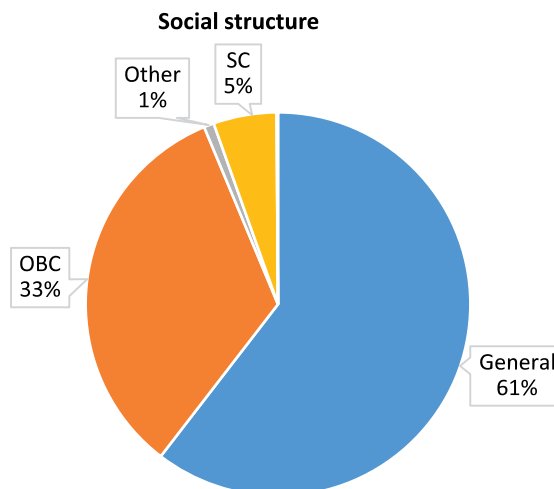


Fig. 3. Caste of sample RWCS households in Kurukshetra, Panipat and Yamunanagar districts, Haryana

OBC - Other backward class, SC - Schedule caste

3.5 Organisation of family and their animal assets

The average household size in the surveyed districts was 6.3 members of whom 1.9 members were involved in agriculture. This is higher than the surveyed households in PMCS or CWCS. The average number of animals owned per household across all three districts was 3.8 (Fig. 4), less than households of other cropping systems covered in this survey.

Bullocks were used for transport from home to field and back; most animals were kept for their milk. Operations from seed to harvest were almost 100% tractor operated. Adoption of technologies could be associated with the need of households for more mechanisation from seed to harvest, and with time allocation, if needed, by individual households to alternative crops in a move towards diversification.

3.6 Agro-advisory services

Farmers surveyed used digital services basically for weather-related field operations (29.4% HHs), however, they were not widely embraced. Of those who received messages, only 29.1% made use of them (Table 2). These trends indicate that such digital services are picking up, and that utilisation will further improve when messages are composed with the large-scale consensus of all the relevant actors, including institutions such as Indian Agricultural Research Institute (IARI), Punjab Agricultural University (PAU), CCS HAU and DOA, and the private sector.

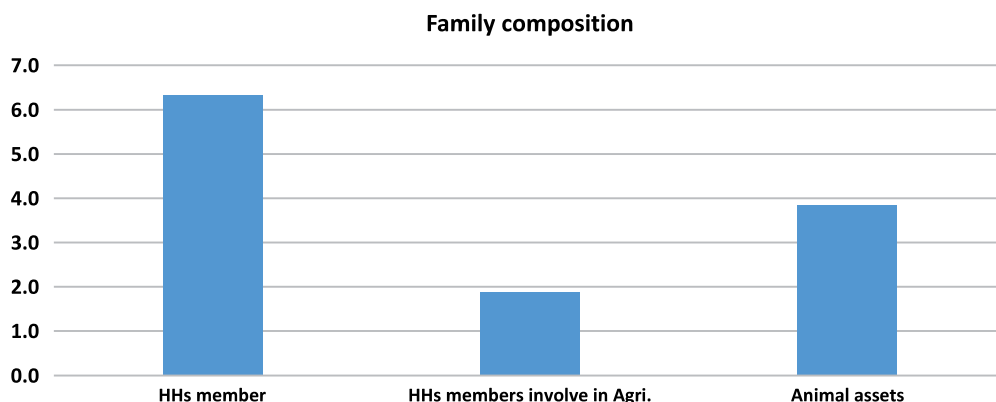


Fig. 4. Composition of households, members involvement in agriculture and ownership of animal assets.

Table 2. Adoption and usefulness of e-Mausam agro-advisories provided to farmers by CCS HAU, Hisar

Survey statement		Advisory Benefits		
Did you receive any agro-advisory from e-Mausam HAU?	Number advisory received	224	% received	29.41
Utilisation of advisory %				
Do you follow the agro-advisory received from e-Mausam of HAU?	Advisory followed (% HHs)	Fully 29.1	Partly 58.6	No 12.3

3.7 Involvement of women farmers

The participation of women in decision-making regarding the adoption of production practices is only 21% (Fig. 5a), of which 51% participated in the LDS survey jointly with their husbands (Fig. 5b). Education level, age, and land size affect women's participation; in RWCS the level of education in girls was better, expected to be higher than matriculation or senior secondary level. The average landholding is nine acres across the surveyed districts; better-educated women with more than two hectares (especially in Kurukshetra and Panipat) tend to participate more in non-farming activities than farming activities.

3.8 Cropping system

Growing a third crop in the same field (increasing the cropping intensity to 300%) is an individual preference, adopted by 23%, 13%, and 3% of households in Kurukshetra, Panipat, and Yamunanagar districts, respectively (Fig. 6). Important crops preferred by farmers are sugarcane, potato, mung bean, sesbania, and sorghum. Scope for a third crop is possible in Yamunanagar because of the dominance of hybrid rice, but in the other two districts, the scope for a third long-duration crop, for example, basmati varieties (Panipat) or non-basmati rice varieties such as PR 114 (Kurukshetra), is limited. The increasing need for green manure or a summer pulse crop, or the need for green fodder to support the ruminant population, has encouraged farmers to grow a third crop. These crops, along with potato or sugarcane in Yamunanagar district, could be targeted to introduce short-duration rice varieties or hybrids, rather than diversifying rice by introducing other crops, which is not happening.

Joint decision making process

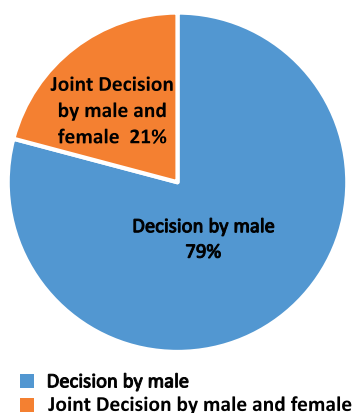


Fig. 5a. Participation of women farmers in decision making of cultivation practices in RWCS in Haryana.

% Participation female jointly in interview

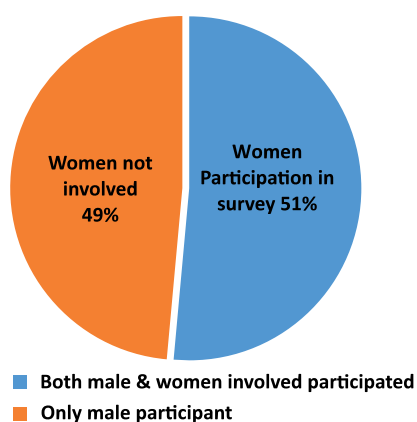


Fig. 5b. Participation of women farmers in the survey.

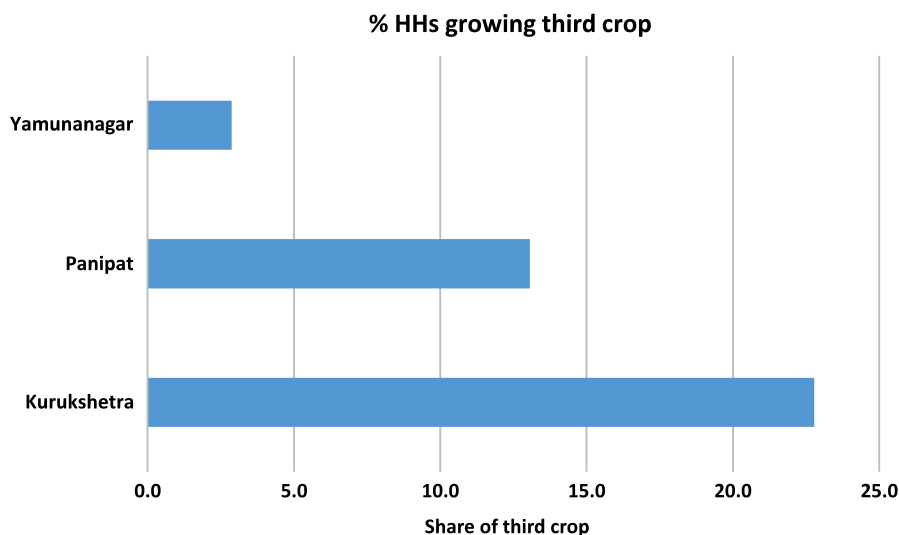


Fig. 6. Percent share of third crops in rice wheat cropping system in Kurukshetra Panipat and Yamunanagar districts of Haryana.

Note: Important crops included Sugarcane, Potato, Mung bean, Seshbania and Sorghum

3.8.1 Adoption of varieties/hybrids in rice

Farmers in RWCS across the three districts have adopted different varieties, with Panipat dominated by the basmati group, Kurukshetra by the PR group, and Yamunanagar by a mix of hybrids and varieties, mostly from the PR group. The success of basmati rice has had a positive impact on farmers' income. The share of basmati rice varieties by household is 91%, 33% and 11% in Panipat, Kurukshetra and Yamunanagar districts, respectively. Respondents (Fig. 7) reported a preference for basmati varieties (91%), non-basmati varieties (77%) and hybrids (42%), respectively. There is a much higher penetration of non-basmati rice varieties: Kurukshetra (76.4% HHs), Yamunanagar (25%) and Panipat (8.9%). The adoption of hybrids is 41.5% in Yamunanagar and 12.3% in Kurukshetra.

3.8.2 Adoption of varieties/hybrids in different districts

The breakdown of all varieties grown by respondents in Panipat district shows that Pusa 1121 and Pusa 1718 are more favoured by farmers, with 49% and 26% of households (Fig. 8a), respectively, growing them in 2021. Panipat district has dominance of basmati varieties, with 91% of households growing Pusa 1121 (49.0% HHs), Pusa 1718 (26.0% HHs), CSR 30 (4.0% HHs), and PB 1 (2.0% HHs). PR 114, a long duration variety, has been adopted by 7.6% of households. This provides plenty of scope for private sector millers around Panipat and Kurukshetra to influence varietal preference (of short duration varieties), if partnerships are

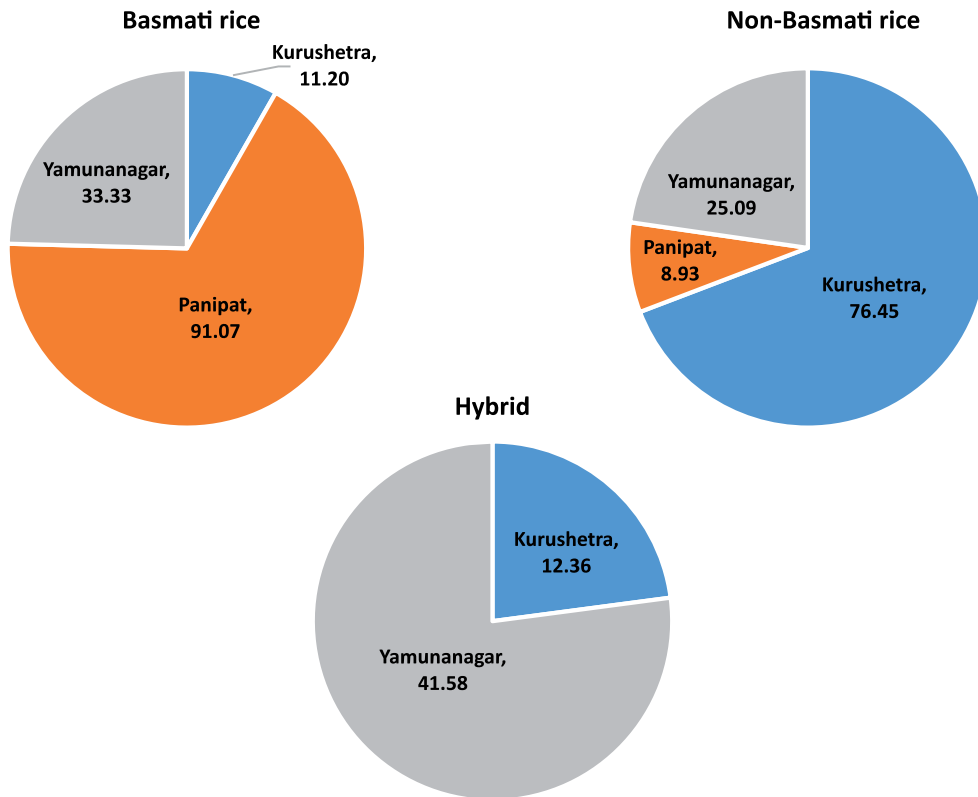


Fig. 7. Adoption of different categories of varieties/ hybrids in three districts of Haryana.

developed between millers and farmers on the one hand and millers and research organisations on the other. These mills can buy more basmati and export a better quality final product. Mills can also contribute to reinforcing good agronomic practices to sustain the export of rice. Incentives to follow good agronomic practices will help maintain a good market price for farmers. If we include a non-basmati variety such as PR 114, the trend indicates that the tendency of Panipat farmers is towards relatively long duration varieties. This indicates a demand for high yields and the existence of private trade. The demand for high yields will lead to a preference for long duration rice within each category.

In Yamunanagar district the top five varieties/hybrids adopted are; PB1 (17%), PR 126 (10%), Arize 6444 (8%), Pusa 1509 (7%) and Arize 6129 (6%). The remaining 50% (referred to as 'other') mainly comprise MDRHs or SDRHs (Fig. 8b). There is a sharp split in preference for hybrids in Yamunanagar district (Fig. 8b) where it has been adopted by

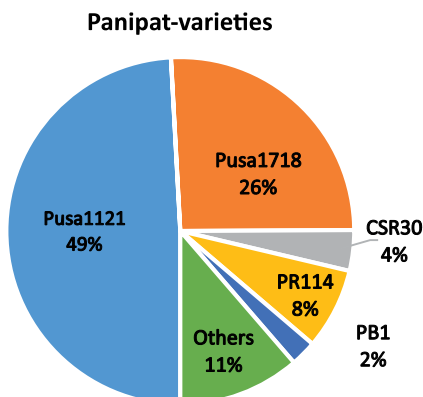


Fig. 8a. Varietal adoption by households (n=291) in Panipat, a district dominated by the basmati group of varieties.

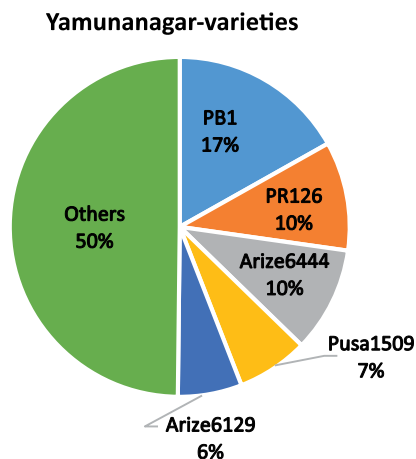


Fig. 8b. Varietal adoption by households (n= 279) in Yamunanagar, a district dominated by hybrids.

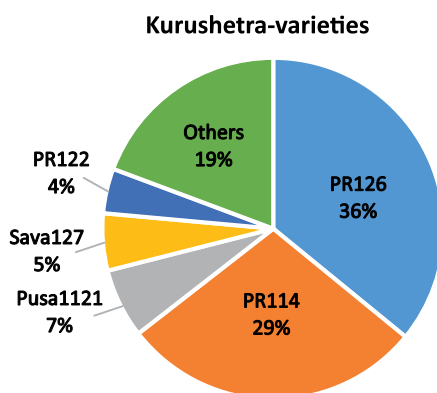


Fig. 8c. Varietal adoption by households (n=259) in Kurukshetra, a district dominated by the non-basmati group of varieties.

almost 42.0% of households compared to about 5% in Kurukshetra. Hybrids/varieties adopted by farmers include Arize 6444 Gold (10.0% HHs), PR 126 (10.4% HHs), Pusa 1509 (9.0% HHs), Arize 6129 (6.6% HHs), Sava 134 (6.0% HHs) and Sava 127 (3.4% HHs); Other hybrids include Arize 6129, Pioneer 28P67 and Pioneer 25P35. A total of 23 hybrids have been adopted by farmers. From the basmati group, the adopted variety is PB1 (16.8% HHs). Rice hybrids in this district have facilitated farmers to intensify their cropping system, with a 200% and 300% cropping intensity and a scope which includes potato, mung bean, and even summer mung bean or black gram.

In Kurukshetra district there is a tendency to grow long-duration varieties such as PR 114 or PR 122; however, this seems to be changing in favour of short-duration varieties like PR 126 (Fig. 8c). The PR group of varieties (especially PR 126) adopted by 35.9% of households (Fig. 8c) in Kurukshetra has supported farmers to avoid the use of long duration varieties (e.g. Pusa44). Farmers also grow PR 114 (28.6% HHs) which takes 145 days to mature and whose quality is better, with less breakage during processing. The grain is thin, long but strong, and is sometimes used for mixing with export-quality rice, but the yield is less than many other non-basmati rice varieties. The number of millers has increased around Kurukshetra with the increase in much-needed market support, especially in the non-basmati group because of its slightly higher price for varieties such as PR 114. Other varieties include PB 1121 (6.6% HHs), Sava 127 (5.4% HHs) and PR 122 (4.2% HHs). The remaining varieties/hybrids are used by just 19% of households. There is a good balance of 145 day-duration varieties. On average, farmers in this district stick to the non-basmati group. An earlier LDS conducted in these ecologies (Singh et al., 2020) showed a similar pattern (90% HHs) of adoption of basmati in Kaithal (the district adjacent to Kurukshetra). Based on such a wide spectrum of varieties/hybrids across the three districts, the breeding program at CCS HAU needs to be better targeted. Adoption of varieties from CCS HAU's HKR group has slowed sharply, with only 3.6% of households in Kurukshetra district adopting HKR 126.

3.8.3 Farm gate prices

The average farm gate price across varieties was INR2066, INR3083 and INR2176/quintal, for Kurukshetra, Panipat and Yamunanagar districts, respectively, and the average farm gate price of non-basmati, basmati and hybrid varieties was in the order of INR2966, INR1988 and INR2078/q, respectively. Surprisingly, the farm gate prices of non-basmati rice varieties and hybrids were INR1988 and INR2028/q, respectively. The varietal spectrum itself has provided an advantage to Panipat farmers, with an average farm gate price of INR 3083/q compared to INR 2176/q for Yamunanagar farmers and INR 2066/q for Kurukshetra farmers. The different adoption patterns of varieties across the three districts may be because of MSP. This trend (Figs.9a & b) opens the door for private hybrids which are medium or short duration. This could be a reason for farmers to change from long duration rice varieties to short duration hybrids/varieties. Private trade, which is much better in these districts due to the infrastructure of a network of millers, will support the promotion of variety diversification.

This reflects both a good market price and the research support for new basmati varieties from IARI. Basmati paddy is a unique product of Haryana, having unmatched quality characteristics and aroma, making it an important export commodity among food grains, with 4.4 million tons exported from India in 2019. According to Basmati Export Development Foundation (BEDF), founded by Agricultural and Processed Food Products Export

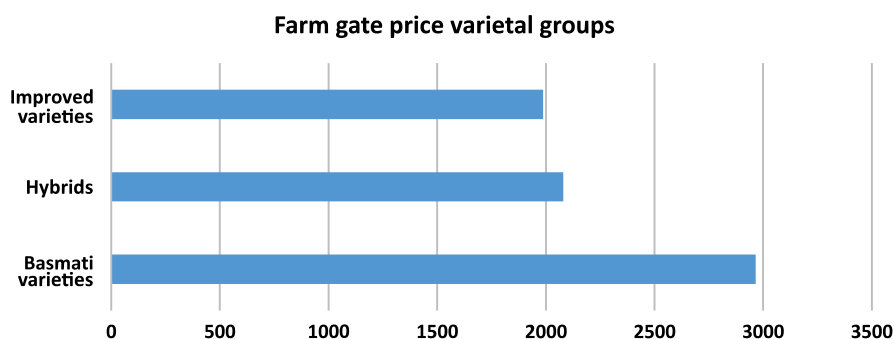


Fig. 9a. Farm gate price of rice reported by respondents in Kurukshetra, Panipat and Yamunanagar districts across varieties. Average price reflects the impact varietal combinations.

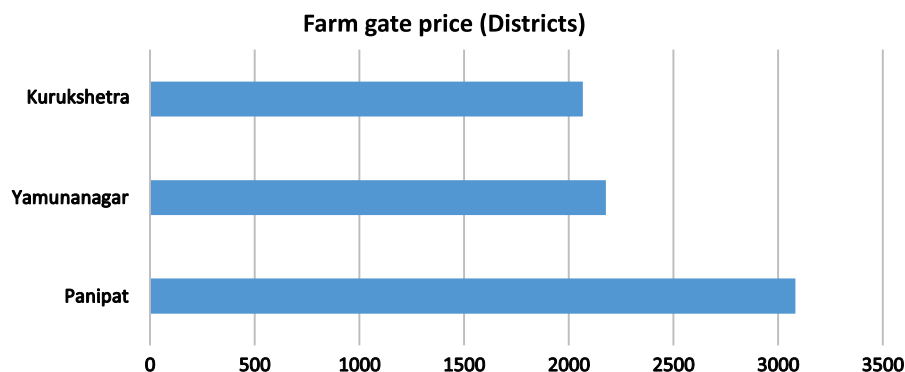


Fig. 9b. Farm gate price of rice reported by respondents in Kurukshetra, Panipat and Yamunanagar districts. The relative contribution from varietal combination is reflected in the average farm gate price in different districts.

Development Authority (APEDA), export of basmati paddy has been in the range of 30%–40% of India's total rice export. The yield potential of the basmati group of varieties is less than the non-basmati group, including hybrids. This group should need fewer external inputs than non-basmati rice, including fewer chemical inputs, increasing its added advantage in the export market. In fact, this was not seen in the pattern of fertiliser use found by this survey. Farmers in the three districts have adapted to market price fluctuations while adopting varieties. Tangible signs are already visible in Panipat where area expansion is happening for basmati varieties. However, they are using the same rate of N or slightly less and are yet to adapt to a proportionate decrease in N use considering their low yield potential. PB 1509 is a short-duration variety, meaning that its use would render rice fields ready for early wheat sowing and that it should be advocated in place of PB 1121 to achieve better system productivity. Herbicide-tolerant genes have also been introduced into this variety, and its use could provide a big boost for DSR in the region. As basmati rice is transplanted late, concerns regarding climate change – especially with respect to uncertainties associated with rainfall – can be

better resolved with its promotion. As the largest exporter of premium rice, Haryana, with its network of millers and traders, is the best state to grow basmati rice, and an increase in investment in the basmati rice program should be part of a long-term strategy as part of a resilient rice–wheat cropping system.

3.8.4 Paddy yield

Paddy yield trends provide a mix of high yields and high farm gate prices as two crucial factors affecting decision-making in the adoption of new varieties. The average yield in the Kurukshetra district (6.5 t/ha) was higher than in Yamunanagar (6.3 t/ha) and Panipat districts (4.8 t/ha) (Fig. 10). The paddy yield of basmati varieties Panipat district ranged from 4.5–5.0 t/ha, compared to 5.6 t/ha with non-basmati PR114. With farm gate prices (Figs. 9a and b) for basmati rice generally staying higher (INR2966/q) than non-basmati rice (INR1988/q), farmers in Panipat district, with an average paddy yield of 4.8 t/ha, earned INR20,000/ha more than Kurukshetra farmers, whose average paddy yield is 6.5 t/ha. However, in the Kurukshetra district, the paddy yield from Sava 127 was reported at 7.6 t/ha. The average yield of non-basmati rice in the Panipat district was 5.6 t/ha (Fig. 11a); in addition to its farm gate price, the ecology of Panipat – especially in light of some blocks being affected by poor water quality – is unique, with the possibility of relatively less yields from non-basmati rice.

The majority of farmers in the Kurukshetra district were found to focus on non-basmati rice (76.4% HHs) with PR 126 dominating. Kurukshetra district has a very high tube well density

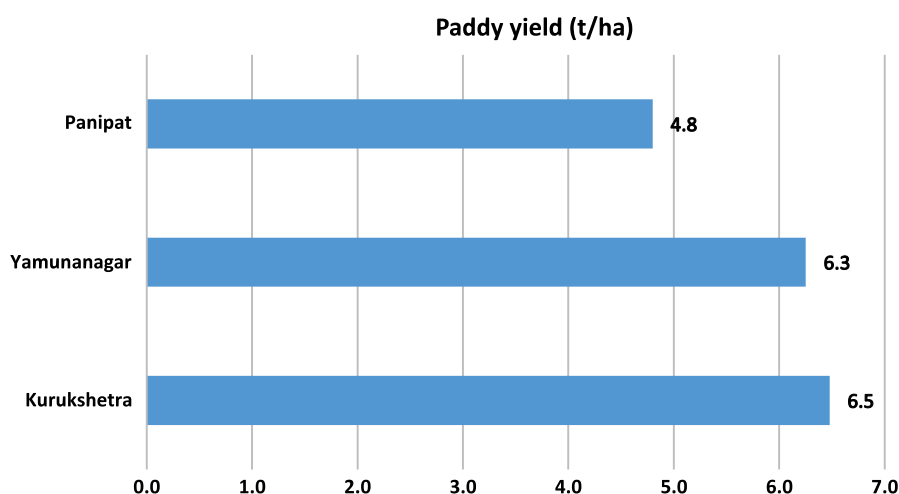


Fig. 10. Paddy yields in Panipat, Yamunanagar and Kurukshetra districts, Haryana. Largest plot paddy yield data is averaged across varieties in each district.

with good quality water. Farmers (28% HHs) in this district also grow PR 114, which is a long-duration variety. Hybrids have expanded more aggressively in Yamunanagar district, with paddy yields of 6.8 t/ha from Arize 6129, a short-duration hybrid (Fig. 11c).

The average groundwater level is variable across Panipat, with poor water quality in some blocks. Water quality and tube well density are good in Yamunanagar district but the cropping system is more intensified and diverse. These three different trends are based on the excellent groundwater situation, with averages in favour of non-basmati rice in Kurukshetra. The market price of basmati varieties and the mix of good and relatively poor quality underground water

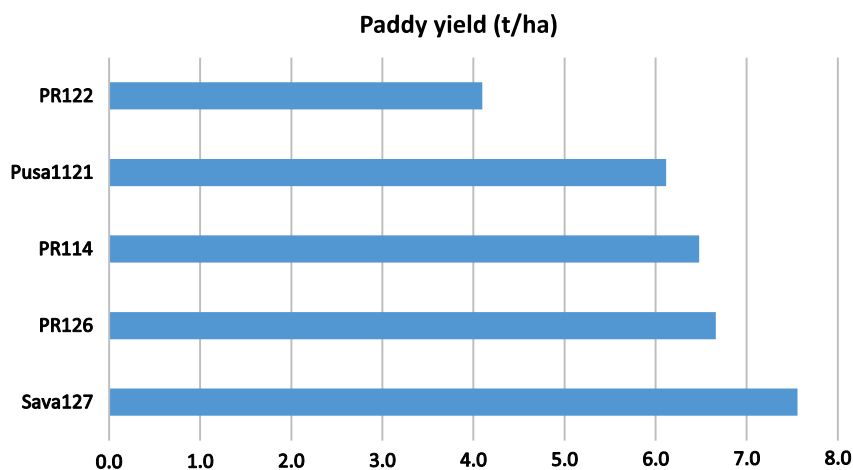


Fig. 11a. Paddy yield of top-ranking varieties adopted by farmers in Kurukshetra district, Haryana.

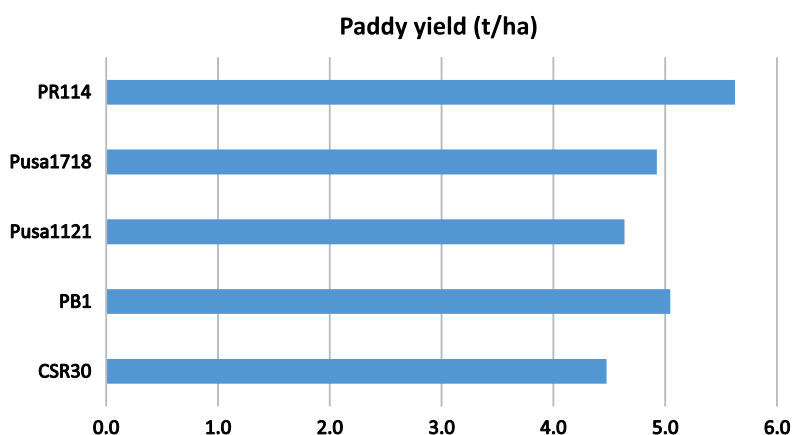


Fig. 11b. Paddy yield of top-ranking varieties adopted by farmers in Panipat district, in Haryana.

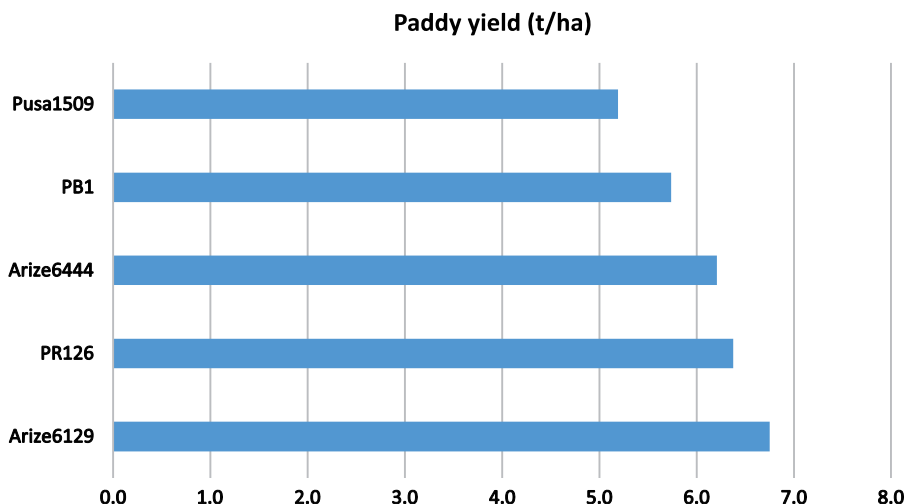


Fig. 11c. Paddy yield of top-ranking varieties adopted by farmers in Yamunanagar district, Haryana.

skewed averages in favour of basmati varieties in Panipat. In Yamunanagar the requirement of a high intensity of intervening crops (e.g., potato before wheat and summer maize, or a pulse crop in the summer season) skewed averages in favour of short or medium duration hybrids.

Farmers have adopted hybrids because they need to increase intensification. Haryana, especially regarding non-basmati rice, needs varieties to be developed which are more stable and have much wider adaptability, to prepare for projected climate change and uncertainties with respect to unpredictable weather. For better adaptability, varieties need much wider diversity with testing sites covering a much greater area as was done in the past, when so many stable varieties existed.

3.8.5 Irrigation in rice

Provision of an irrigation infrastructure based on electricity-powered tube wells has been an incentive for farmers to raise nursery seedlings early and transplant rice early. However, in the case of basmati rice, transplanting was mostly done late by at least 7–10 days, with the late arrival of the monsoon not exerting additional pressure on farmers. This practice provides a scenario where the growth and development of the crop occur during the peak of the monsoon rains, with limited or no use of tube well-based irrigation in most years, except during a few uncertainties in drought years. This part of agronomic management, with the use of hybrid rice in Yamunanagar and basmati varieties in the Panipat district, can help insulate the rice crop from uncertain rains.

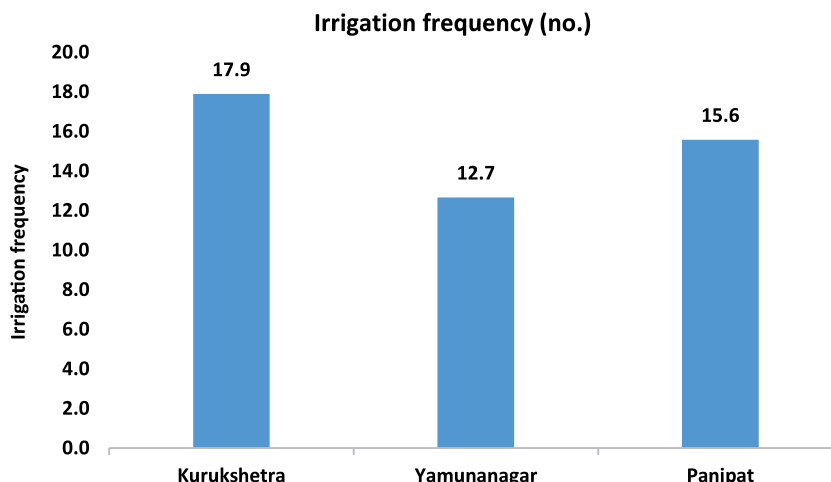


Fig. 12. Irrigation frequency in paddy in Kurukshetra, Panipat and Yamunanagar districts, Haryana.

In terms of time management, mechanisation from seed to harvest has facilitated the intensification of cropping systems in Yamunanagar, especially with almost 40% of households adopting medium or short duration hybrids. Groundwater management will have a major and critical role in the sustainability of the country's agricultural production in future. Such data sets indicate scope for better agronomic management, because farmers in Haryana face the problem of a falling water table. Medium duration hybrids may therefore be headed for a much wider spread, as they are well placed to bridge yield gaps between genotypes of different classes of maturity. Since paddy fields remain flooded, the land should be laser levelled, with a degree of slope facilitating drainage when needed.

3.8.6 Nutrient management in rice

The use of N, P₂O₅ and K₂O in Kurukshetra district across varieties/hybrids was 164.2, 49.1 and 14.1 kg/ha, respectively. The corresponding use of these nutrients in Panipat is 156.1, 47.6 and 9.8 kg/ha, and 146.9, 56.5 and 22.1 kg/ha, respectively, in Yamunanagar. When averaged over districts and varieties, the use of N, P₂O₅ and K₂O in rice is 155.6, 51.1 and 15.5 kg/ha, respectively (Table 3). When averaged over districts, N use in basmati rice varieties is 152.4 kg/ha. An assessment of the previous record (Singh et al., 2010) in these ecologies indicates that the use rate of these nutrients has not increased since 2007.

Basmati rice, a special type of rice grown in South Asia for its better cooking quality parameters, is a geographical indicator. Its varieties obtain premium prices, approximately INR1000 higher than non-basmati rice (Fig. 9a, b). Varieties such as Pusa Basmati 1121 and

Table 3. District-wise use of N,P and K (kg/ha), percentage of household users and paddy yield (t/ha) in Kurukshetra, Panipat and Yamunanagar districts, Haryana.

District	Crop category	Average use of Nitrogen (Kg/ha)	Average use of Phosphorus (Kg/ha)	Average use of Potash (Kg/ha)	Yield (t/ha)
Kurukshetra	Basmati	163.3	38.7	7.7	5.95
	Users %	100	65.5	10.3	
	Non Basmati-Hybrid	161.4	73.7	34.5	7.07
	Users %	100	78.1	6.3	
	Non Basmati-Improved	165.1	46.7	11.7	6.47
	Users %	100	78.8	12.6	
		164.4	49.1	14.1	6.49
Overall Kurukshetra (n-259)		100	77.2	11.6	
Users %					
Panipat	Basmati	156.0	46.9	9.8	4.72
	Users %	100	89.8	17.0	
	Non Basmati-Improved	157.1	55.0	10.1	5.63
	Users %	100	96.2	26.9	
Overall Panipat (n-291)		156.1	47.6	9.8	4.80
Users %		100	90.4	17.9	
Yamunanagar	Basmati	138.3	57.1	23.5	5.69
	Users %	100	98.9	36.0	
	Non Basmati-Hybrid	150.0	57.3	23.8	6.56
	Users %	100	98.3	41.7	
	Non Basmati-Improved	152.4	54.3	17.5	6.44
	Users %	100	92.9	30.0	
Overall Yamuna Nagar (n-279)		146.9	56.5	22.1	6.25
Users %		100	97.1	36.9	
Overall Districts Total (N-829)		155.6	51.1	15.3	5.82
Users %		100	88.5	22.3	

and Pusa Basmati 1509 have good yield potential (averaging 4.8 t/ha), with excellent global acceptability at a farm gate price of INR3341/q.

The use of N in basmati rice varieties is 163.3, 156 and 138.3 kg/ha in Kurukshetra, Panipat and Yamunanagar districts, respectively; the use of P is 38.7, 46.9 and 57.1 kg/ha in

Kurukshetra, Panipat, and Yamunanagar districts, respectively. The corresponding use of K in these districts is 7.7, 9.8, and 23.7 kg/ha (Table 3). Basmati rice was seen as an important part of a cropping system and may help in sustaining soil health, as it needs fewer nutrients than other varieties. In fact, CCS HAU has recommended less use of N for basmati varieties (80 kg N/ha and 30 kg P/ha), and zero N use if the preceding crop has been a green manure crop (*Sesbania*). This is for traditional basmati rice varieties, which are tall with much less yield potential. The survey is left with questions, such as is the recommendation of NPK use in basmati rice less than in non-basmati rice? If yes, then why are farmers using such high doses of N, P₂O₅, and K₂O in basmati rice? There is no straightforward answer to this; to find it may require studying the interaction between nutrients and large-scale field trials in the farmer's field. There could be a case for tall varieties like CSR 30, and traditional basmati, which have been replaced by varieties like Pusa 1121 which is short in stature and responds to N and P application. With these new basmati varieties, a good number of farmers are obtaining paddy yields of 6.0 t/ha. In fact, in the current varietal spectrum of basmati varieties, nutrient management could be the single most important factor for improving growth and yield.

Overall, the use of N in basmati varieties and non-basmati hybrids is the same, at 152.4/ha across all three districts (Table 4). The use of N in non-basmati varieties is 161.4 kg/ha. This contrasts with earlier reports by Erenstein et al. (2007) on the different trends of N use, when results were 180, 159 and 103 kg N/ha in superfine, evolved basmati and traditional basmati, respectively. Farmyard manure (FYM) is used by a limited number of farmers. Past research conducted by International Rice Research Institute (IRRI)

Table 4: District-wise use of N, P and K (kg/ha) and percentage of user households across three districts in Haryana.

Paddy category	Average use of Nitrogen (Kg/ha)	Average use of Phosphorus (kg/ha)	Average use of Potash (kg/ha)	Yield (t/ha)
Basmati	152.4	48.6	12.8	5.0
Use %	100.0	90.1	20.9	
Non Basmati-Hybrid	152.4	60.8	26.1	6.7
Use %	100.0	94.1	34.2	
Non Basmati-Improved	161.4	49.2	12.9	6.4
Use %	100.0	83.7	18.0	
Overall	155.6	51.1	15.3	5.8
Use %	100.0	88.5	22.3	

showed that the submergence and management of rice soils results in biological and chemical processes, leading to uniquely different nutrient cycling, nutrient supply to crops, and decomposition of organic materials than in well-drained, aerobic soils. Organic materials typically have less benefit to the physical, biological, and chemical properties of submerged rice soils than to well-drained, aerobic soils (Buresh and Dobermann, 2010), with a decomposition of organic materials in submerged soils needed for rice cultivation slower than in well-drained soils (Buresh et al., 2008).

The LDS found the use of P to be greater with hybrids, at 60.8 kg/ha. The recommended dose of P is applied to the preceding wheat, with farmers using 48.6 kg/ha for basmati rice and 49.2kg/ha for non-basmati varieties. There are a few pockets where farmers use both diammonium phosphate (DAP) and single superphosphate (SSP) with the same recommended dose; this is somewhat at odds with the situation in the adjacent ecology of Punjab, where farmers do not use P in rice cultivation. K use is close to that in Punjab but is still on the high side. Recommendations for P and K use have come from CCS HAU; P and K use is discouraged in rice by PAU if already applied in wheat. Recommendations for nutrients and other inputs come from many sources, revealing a degree of risk for farmers who rely on the advice of dealers when investing in input use without first ascertaining whether this is accurate. Local institutions such as CCS HAU and PAU should plan jointly to regulate NPK application in these ecologies, as Punjab farmers continue to obtain much higher paddy yields with almost no use of P.

It is argued that N fertilizers might enhance P uptake through positive interaction between N and P, and that K uptake also increases significantly with the application of more N along with organic manures. It is claimed that hybrids need NPK more than varieties (Kumar and Prasad, 2004). In fact, an alternative argument states that hybrids' need for pesticides has increased because N use renders rice hybrids more susceptible to pests and disease (Cheng, 2009). What scientists of CCS HAU and PAU think about soil health and how it might have affected different adoption patterns in the concerned states is a matter of debate. There is broad disagreement about the use of P and K in rice, but not about N. A good sign is that farmers in each state have not reacted against the recommendations of their scientists.

Nutrient management in rice demands a new type of thinking in these states, especially in Haryana. This is because in Punjab (with high yields), nutrient management in rice is dominated by N with almost no use of P or K. This is one recommendation which is quite distinctive in Punjab, with no adverse effect on soil health. In contrast, in Haryana yields are the same but the use of P is much higher than in Punjab. The important point here is to acknowledge the problem, otherwise it cannot be fixed. The framework by which to understand the problem is lost if the focus is diverted to soil testing alone rather than to the factors which help improve efficiency. Integrating FYM and green manures with mineral fertilisers offers a huge potential for improving soil health. However, FYM and green manure use is not widespread and will remain

so, as there is a mismatch between the animal population and the need for FYM. The survey results appear contradictory to those describing the situation in Punjab, where from the start only N management is happening, and yet the soils are in good health (Dillon et al., 2021). These trends are valuable for scientists to be able to converge and revise recommendations based on the evidence generated by such datasets.

3.8.7 Weed management in rice

Table 5 presents the top-ranking weeds of rice, with *Echinochloa crusgalli* and *E. colona* the most troublesome. These weeds are adapted to wet ecologies and under puddled

Table 5: Top five most troublesome weeds in rice, Kurukshetra, Panipat and Yamunanagar districts, Haryana.

Kurukshetra			Panipat			Yamunanagar		
Rank	Weed	%HHs	Rank	Weed	%HHs	Rank	Weed	%HHs
1	<i>Echinochloa crusgalli</i>	47.1	1	<i>Echinochloa crusgalli</i>	56.7	1	<i>Echinochloa crusgalli</i>	54.8
2	<i>Echinochloa colona</i>	10.8	2	<i>Echinochloa colona</i>	19.2	2	<i>Echinochloa colona</i>	22.2
3	<i>Ischaemum rugosum</i>	6.1	3	<i>Ischaemum rugosum</i>	13.7	3	<i>Leptochloa species</i>	10.7
4	<i>Leptochloa species</i>	5	4	<i>Leptochloa species</i>	2.0	4	<i>Eleusine indica</i>	2.8
5	<i>Cyperus difformis</i>	3.8	5	<i>Paspalum distichum</i>	2.0	5	<i>Ischaemum rugosum</i>	1.7

transplanted rice, with *Echinochloa crusgalli* more prevalent in high productivity areas. Weed management in rice across the three surveyed districts was easy, with farmers continuing to use herbicides such as butachlor, pretilachlor and anilophos (Table 6). These herbicides, recommended in the 1980s and 1990s, are still used by almost 80% of households. These trends indicate how some herbicides show resilience for such a long time with a monoculture (such as continuous rice) with high yields and

Table 6: Herbicide use in paddy in Haryana

Herbicides	HHs	%Yield (t/ha)
Pretilachlor	41.9	5.7
Butachlor	30.9	6.0
Bispyribac sodium	8.6	5.6
Pendimethalin	5.3	6.5
Oxadiargyl	1.8	4.9
Anilphos	0.8	5.5
Others	2.3	5.6

Note: 91.55% of households overall herbicide use.

transplanting carried out in the same timetable. Most cases generally see a sharp decline in the response of target weeds to the same herbicide (such as butachlor) used continuously for about 10–12 years (Baltazar, 2017); however, this has not happened here. Worries about the development of herbicide resistance and the need for diversification in herbicides or herbicide rotation do not exist in the surveyed area, with farmers still maintaining paddy yields of 6.0 t/ha following the treatment of butachlor, the first herbicide of choice for chemical weed control in transplanted rice. That herbicides such as butachlor and pretilachlor have maintained their efficiencies in transplanted rice constitutes a significant lesson learned. Due to the resilience of these herbicides, weed management in rice is far cheaper than in wheat, where resistance is a big issue. It seems the maintenance of 2–3 cm of water in rice fields after the application of these herbicides has contributed to sustaining their use for this long. Pendimethalin applied pre-emergence by 5.3% of households shows good promise, with paddy yields of 6.5 t/ha. This fits well with the package of practices used for butachlor and pretilachlor. The full potential of these herbicides may only become clear in the future, but it seems apparent that the integration of water is helping them to sustain, with flooding rice after transplanting limiting the emergence of many weeds. Minimising weed competition in the early stages, as is being done by these herbicides and water maintenance, has been particularly important since the introduction of chemical weed control in the 1980s. Post-emergence treatment (e.g. bispyribac) at 30–45 days after transplanting is underway, with 8.6% of households obtaining paddy yields of 5.6 t/ha; this is a follow-up treatment in some cases. Labour is also used in many cases for roguing out the uncontrolled population, and this is reflected in the cost of weed management. Herbicides such as butachlor or pretilachlor, long used as pre-emergence weed control, are being replaced by bispyribac or used in combination with pyrazosulfuron. This has been introduced basically because of complex weed flora, or weed flora dominated by *Cyperus rotundus*, which cannot be controlled by the acetanilide group of herbicides. With post-emergence treatment, the application of herbicides in standing water could be a problem.

3.8.8 Cost of cultivation of rice

To maintain parity in expenditure on inputs with a different user base, the data were used to calculate the cost of users' inputs. The total number of households surveyed were 259, 291 and 278 from Kurukshetra, Panipat and Yamunanagar districts, respectively. Calculating costs for rice cultivation risks a small increase in the overall cost of a few field operations; however, differences were marginal. The average cost of cultivation involving manual harvesting plus manual or machine threshing was INR54,686/ha against an average of INR46040/ha with combine harvesting (Table 7). Combine harvester use alone accounted for an almost 15.8% decrease in the cost of cultivation.

Table 7: Paddy cultivation costs (INR/ha) in three districts, Haryana.

Field operations in Paddy	Kurukshetra Panipat		Yamunanagar	Average cost
Land Preparation	10725	10982	11347	11025
Transplanting	7216	8273	7868	7807
DAP	3096	3108	3110	3106
Urea	1763	1809	1678	1751
Potash	1873	1411	1481	1525
Zinc Sulphate	1025	1129	990	1037
Irrigation*	1196	497	637	762
Fertilizer application	1014	1008	1099	1041
Farmyard Manure (FYM)**	4185	3266	3982	3758
Weeding	2362	2442	2458	2389
Insecticides	1804	1964	1404	1721
Insecticides Spray	666	638	601	633
Fungicide	2486	2046	1161	1715
Fungicide Spray	486	597	622	595
Harvesting by manual labour	9861	8215	9277	8567
Manual threshing by labour	3438	6434	6275	6066
Machine Threshing	0	4485	7128	5036
Average cost based on Manual harvesting & manual threshing	53197	53822	53989	53498
Average cost based on After manual harvesting-machine threshing	49759	51872	54842	52468
Harvesting by combine harvester	5705	6434	6275	6066
Average cost based on combine harvesting.	45603	45607	44713	44931

Note: In order to maintain parity the cost of cultivation was calculated on the basis of user of that particular operation.

*Cost is labour used in irrigation.

**is used in the interval of five years in same plot.

Combine harvesting was done by 97%, 43%, and 76% of households in the Kurukshetra, Panipat, and Yamunanagar districts, respectively (Table 8). Manual harvesting is routinely done by farmers growing basmati rice, although this seems to be changing, as 57% of households have adopted combined harvesting in Panipat districts dominated (91% HHs) by basmati rice. The high frequency of manual harvesting, despite much better accessibility to combine harvesters in the region, is because basmati rice is used as fodder for animals and is exported to Rajasthan. The advantage that basmati farmers obtain from the sale of paddy straw has not been included in the survey. Due to problems associated with air pollution from straw burning, finding a resolution to the issue of straw management has become urgent, especially during recent years. Whether straw management will end up favouring in situ management after machine harvesting or in the of bailers is not yet clear; the research establishment has not been able to establish the superiority of either of these two options¹. Supporting farmers by ensuring an adequate price for rice straw would help achieve sustainability goals in terms of preventing air pollution and other outcomes based on its adoption. These contradictory ideas may have to be judged on the merits of profit margins, because if rental value is included in the fixed cost of cultivation, only the straw income will assist farmers, which as well as improving their profit margins, will enable farmers to use zero tillage technology wheat, as it is still happening in Haryana where manual harvesting is common.

Table 8: Inputs used by farmers in three districts, Haryana.

Operations and users	Kurukshetra		Panipat		Yamunanagar	
	Users no.	%	Users no.	%	Users no.	%
DAP	200	77.2	263	90.4	271	97.1
Potash	30	11.6	52	17.9	103	36.9
Zinc Sulphate	113	43.6	88	30.2	145	52.0
Manual Weeding	119	45.9	212	72.9	162	58.1
FYM	122	47.1	135	46.4	65	23.3
Weeding	259	100.0	291	100.0	278	99.6
Insecticide	184	71.0	250	85.9	239	85.7
Fungicide	42	16.2	172	59.1	161	57.7
Harvesting Labour	9	3.5	166	57.0	66	23.7
Threshing Labour	8	3.1	155	53.3	47	16.8
Threshing Machine	1	0.4	11	3.8	19	6.8
Combine harvester	250	96.5	125	43.0	212	76.0

[1] CIMMYT advocates retaining significant amounts of straw as mulch, as part of its conservation agriculture approach.

A fairly good idea could be to use zero tillage machines which evolved in the late 1990s, with the aim of increasing the productivity of wheat with no associated risk to cost. The technology should be such that it is easy to adopt by all categories of farmers.

The high cost of land preparation/transplanting is limiting improvements in the profit margins of rice farmers across all three districts (Table 7), with the combined cost of these two operations in the order of INR17,941, INR19,255 and INR19,215/ha for an average household in Kurukshetra, Panipat and Yamunanagar districts, respectively (Table 7). Further cost (39%–42% of the total variable cost in a machine-harvested scenario) is diverted towards land preparation across all districts. This limit is likely to increase with the cost of labour needed to transplant seedlings, and as the cost of fuel for tillage remains the same or increases. As it is, the number of family members involved in agriculture is already low (1.9/HH) in these districts, dependence on hired labour may increase if this remains the case.

During the last 30 years, much work has been done to promote different crop establishment methods but regardless of the good deal of progress made, adoption rates remain extremely low. DSR is recommended but acceptance by farmers is patchy, although it increased during the COVID–19 pandemic. Published work on DSR indicates great promise but there are still many questions awaiting resolution from research groups. Machine transplanting without puddling can solve the immediate problem of labour shortages without any yield penalty, but machines are costly and there are no business models in place, which is one of the weaknesses of this technology. DSR, especially when practiced with soil mulch after pre-sowing irrigation, is making some progress toward the goal of reducing this cost, and either DSR, machine transplanting or both need to be promoted as a priority. DSR can be made attractive by demonstrating its advantages at system level rather than just during the rice phase. Meta-analysis of published data shows that wheat yield was 8%–10% higher when grown after DSR than when grown after puddled transplanted rice (Kumar and Ladha, 2011).

Technologies such as weed and nutrient management have provided rice farmers with definite yield advantages, which is why weed management and N application have been adopted by almost all farmers across all three districts. Applying N is affordable at INR1750/ha, which is why it is used by all farmers, with investment in N more attractive than FYM or even green manuring, where the labour cost is higher. The per-hectare cost of P is 43% higher than the cost of N, and the experience and knowledge of Punjab farmers who do not use P in rice should be compared with the practice of Haryana farmers, especially when the ecologies are the same. This experience can be field tested. This is the biggest difference in the package of production practices in the two ecologies with the same history of RWCS. LDS data from the 2019 and 2020 surveys indicated that the non-use of P has not reduced rice yield or system yield in Punjab (Singhet al., 2020) or soil health in Punjab (Dillon et al., 2021). These gaps are important to understand, and are directly transferable from farmers of Patiala and Sangrur in Punjab to farmers across the three districts. These differences in NPK use rates and their ratios correlate with recommendations in the domain of each university in Ludhiana and Hisar, which means that farmers are accepting what their SAUs recommend.

The need for restraint in the excess use of some nutrients is important, and to prevent which, CCS HAU and PAU should establish a joint team which converges regularly in the broader context of maintaining soil health. This is precisely the reason why there is a need for substantive change in research strategies, with joint monitoring of input use trends through LDS surveys such as this. This type of monitoring, evaluation, and learning will help calibrate the research work of sister organisations.

Direct costs relative to yield were used in the study (Fig. 7), but rental cost – which is very high in RWCS – were not included in the cultivation cost data. Results show that it is even more relevant to increase productivity growth because only enhanced revenues will increase profit margins, as the cost of cultivation is increasing faster than the minimum support price or farm gate price. This is even more relevant in the case of small farmers who rent land from other farmers. The healthy profit margins for basmati rice can largely be credited to how private trade is operating in the state.

4.0 Adoption of wheat varieties

The scale of adoption of new wheat varieties keeps changing because of the replacement of HD 2967 by farmers in 54%, 77% and 65% of households in Kurukshetra, Panipat and Yamunanagar, respectively (Figs. 13a, b, c). Across the three districts, varieties such as DBW 222 (3% HHs), WH 1105 (4.2% HHs) and HD 3086 (6.8% HHs) are replacing HD 2967 (66% HHs) (Fig. 14). There is some variation between districts, with Kurukshetra (7% HHs) and Yamunanagar farmers (5% HHs) adopting WH 1105. The adoption of HD 3086 is increasing in Yamunanagar district (12% HHs). Between 1990–91 and 1998–99, wheat yields increased every year from 3.4 t/ha to 3.9 t/ha, but never reached 4.0 t/ha. It was only after the 2006–07 season that wheat yields in Haryana exceeded 4.0 t/ha. A sudden rise in temperature in March 2022 impacted negatively on the wheat grain yield; nevertheless, yields stayed higher than the 1998–99 benchmark, due to sowings having advanced by 10–15 days since 2005–06. The variety HD 2967 was released in 2011 and most current varieties are of the same maturity duration, except for HD 2985 which has been grown by very few households (1%–2%) in the three districts. The harvest index of HD 2967, a timely sown wheat variety (TSWV), is higher than HD 2985, even under terminal heat (Harvir Singh et al., 2017), which is why farmers prefer TSWVs, even when wheat sowings are delayed. The survey reported an overall reduction in yields, which were greater where sowings were delayed. New varieties should be in the maturity range of PBW 343

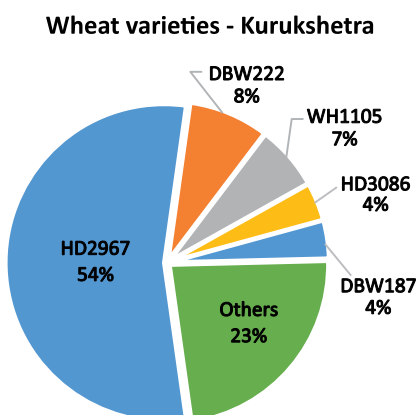


Fig. 13a Wheat varieties in Kurukshetra district, Haryana

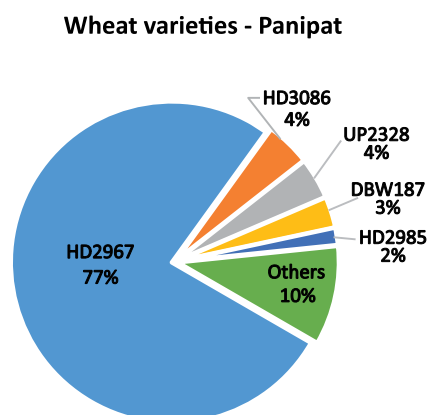


Fig. 13b. Wheat varieties in Panipat district, Haryana

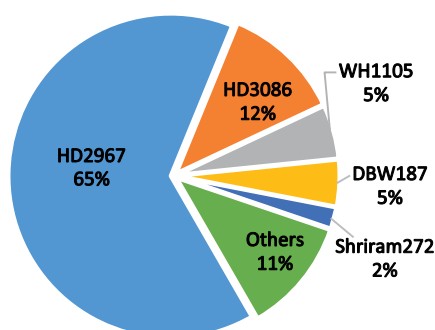


Fig. 13c. Wheat varieties in Yamunanagar district, Haryana

and HD 2967, which are favoured by farmers in Haryana. According to the survey data new variety DBW 187 has emerged as a top performer compared to the most popular variety (HD 2967), with a grain yield of 4.7 t/ha. When viewed specifically for this season, the grain yield in 2022 was affected by the sudden rise in temperature in March, which happens once or twice every ten years. WH 1105 also performed well, with a grain yield of 4.6 t/ha (Fig. 15).

4.1 Zero tillage (ZT) adoption

The first report following the evolution of zero tillage in South Asia (Erenstein et al., 2007) showed that it drastically reduced tractor operations in wheat fields from an average of eight

passes to a single pass, implying a saving of six tractor hours and 36 liters of diesel per hectare. In the areas surveyed, zero tillage contributed to increased yields through a combination of factors: the reduced turnaround time facilitated by earlier sowing, mitigating against the negative effects of the high temperatures during the growing season, which in turn facilitated the maintenance of better regulation of the sink–source relationship in wheat during March’s terminal heat phase.

At 4.4 tons per hectare, zero tillage achieved the highest wheat yields in the survey year, a significant 4.0% yield increase over conventional tillage. The survey also showed grain yields of zero tillage households at an average of 4.8 t/ha compared to 4.3 t/ha with broadcast seeding or line sowing under conventional tillage (Fig. 16), representing a significant 0.5 t/ha (11.0%) increase. The yield advantage in 2022, when yields were significantly reduced (due to the sudden increase in the March temperatures), makes zero tillage technology a win–win scenario for the future. This could explain the driving force behind the continued adoption of zero tillage since 1997-2002.

Its continued adoption by 8.8% of households would be enough to achieve the estimate suggested by Vincent and Quirke (2002) of a gain to the Indian economy of around ASD1800 million in net present value terms over the next thirty years.

4.2 Nutrient management in wheat

The survey found N fertiliser being applied in similar doses across the three districts, at more than 153.3, 155.8 and 148.4 kg/ha in Kurukshetra, Panipat and Yamunanagar districts, respectively (Table 9), a pattern which has remained unchanged since the late 2000s (Singh et al., 2010). The success of N fertiliser applied at more than 150 kg/ha seems to have

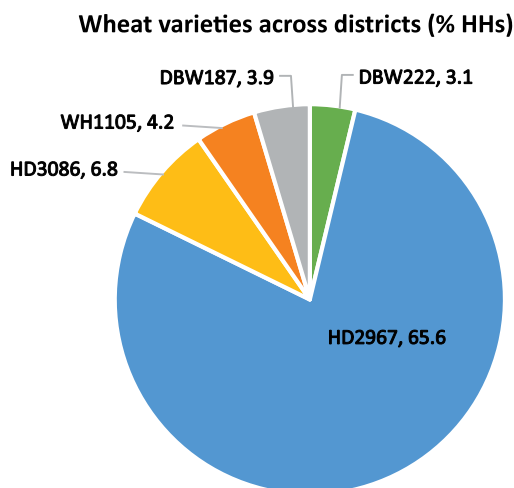


Fig. 14. Adoption of the five top varieties of wheat in three RWCS districts, Haryana.

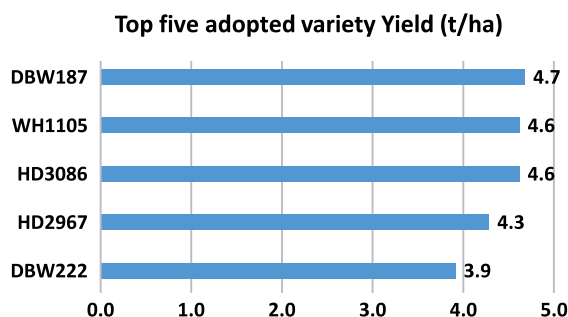


Fig. 15. Grain yield of wheat (t/ha) varieties across three districts in Haryana (n=829, 2021–22)

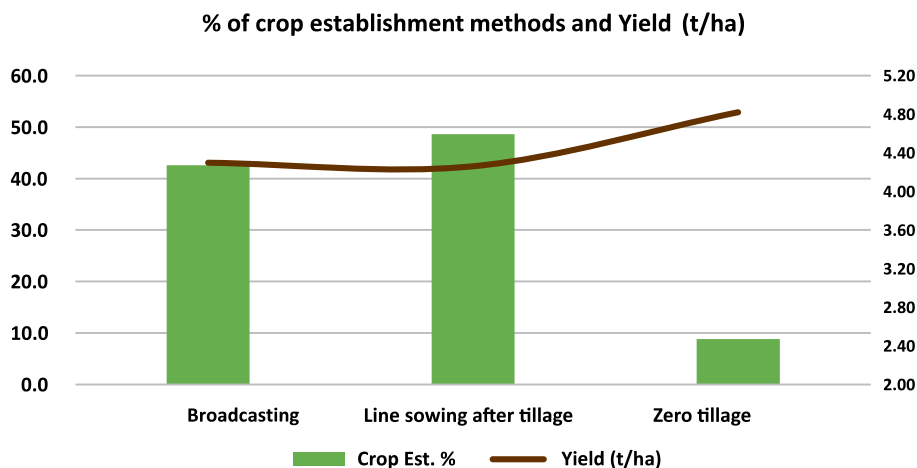


Fig. 16. Adoption of zero tillage technology and its effect on farmers reported grain yield in RWCS (n-829)

Table 9: Pattern of nutrient use in wheat in irrigated RWCS across three districts in Haryana.

Districts	Average use of nitrogen (kg/ha)	Average use of P ₂ O ₅ (kg/ha)	Average use of K ₂ (kg/ha)	Yield (t/ha)
Kurukshetra	153.3	45.3	2.3	4.2
Panipat	155.8	55.9	0.9	4.7
Yamunanagar	148.4	58.1	13.0	4.1
Average use rate	152.5	53.3	5.4	4.3

improved further with the adoption of management practices, which can help yields rise above average. Combining FYM with N was infrequent, with fewer than 4% of households across the three districts. Even basmati varieties grown as a preceding crop in a district such as Panipat makes difference in use of FYM. Similarly, data indicated the use of P₂O₅ to be about 10.0 kg/ha more in Panipat and Yamunanagar than the 45.6 kg/ha used in Kurukshetra district; also, the pattern of NPK use in 2021–22 (the period covered by the current survey) compared to 2006–07 (Singh et al., 2010) runs contrary to the argument that the long-term yield of RWCS is showing symptoms of “fatigue”, with stagnation in yield growth due to the decline in the quality and quantity of soil organic matter. This has also been challenged in work published by PAU (Dillon et al., 2021). Overall, it is important to understand how N use can be reduced by employing better agronomic management, such as zero tillage. The percentage of households using NPK is in the order of 100:100:3.1, 100:100:1.4 and 100:100:21.9 in Kurukshetra, Panipat and Yamunanagar districts,

respectively (Fig. 17). Across these districts a maximum of 8.4% of the households surveyed were using K, amounting to only 73 users out of a total of 829 households, 60 of whom are in Yamunanagar district alone. K users were 7.3%, 1.0%, and 0.5% of households in Yamunanagar, Kurukshetra, and Panipat, respectively. The essentiality of K for the profitable cultivation of RWCS in India has been advocated by several researchers (Tiwari et al., 1992; Singh et al., 2013); however, this survey does not reflect this: K use in high yielding ecologies of Kurukshetra was much less than in Yamunanagar, where diversified cropping systems which incorporate sugarcane and potato may have increased its need.

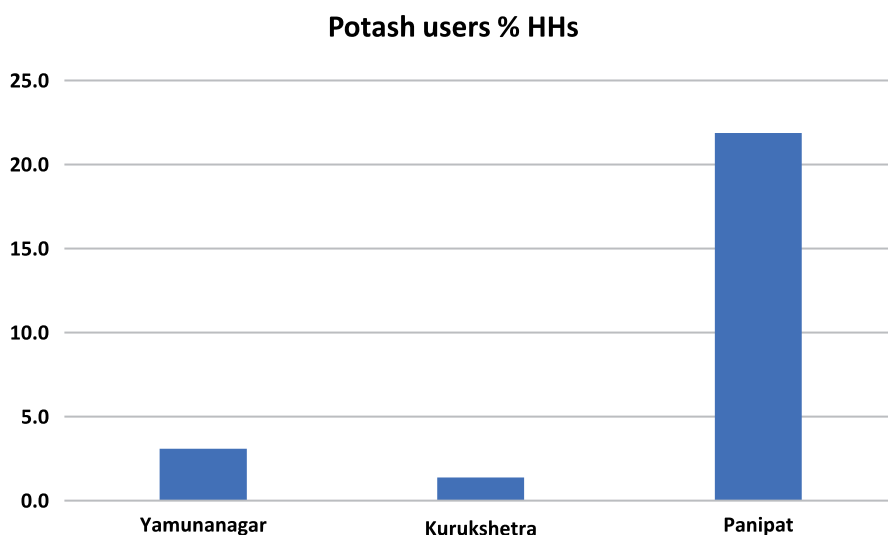


Fig. 17. Potash use pattern (% households) in wheat as part of RWCS in three districts of Haryana. Nitrogen and phosphorus were used by 100% of farmers in the districts surveyed.

4.3 Irrigation

In the three surveyed districts, the number of irrigations varied from 3.4 in Kurukshetra to 4.1 across Panipat. The wheat crop was affected by strong wind and rainfall in the last week of January 2022; average grain yield was 4.7 t/ha in Panipat district where the number of irrigations was more than other districts. Rainfall during January might have affected wheat, with a greater incidence of disease, especially in Yamunanagar district. An increased number of irrigations in Panipat, especially the last irrigation, might have helped wheat to escape the effect of terminal heat (Fig. 18). A fall in the water table is a problem in Kurukshetra but is not so serious in Yamunanagar district.

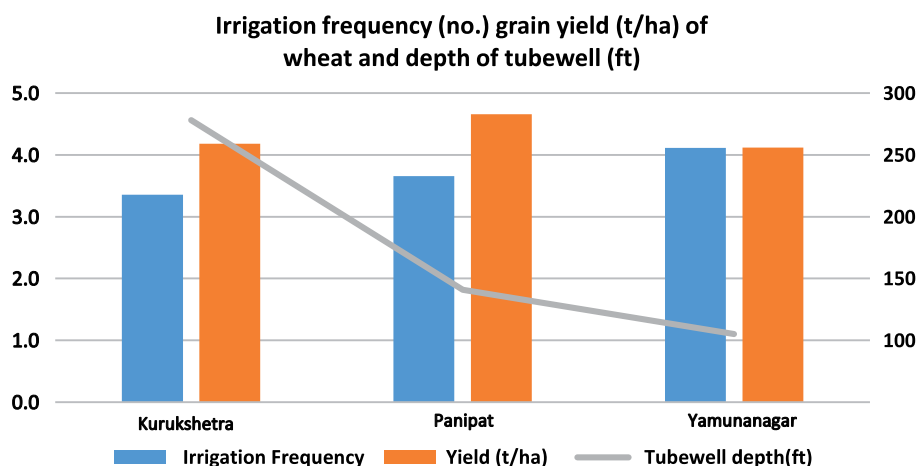


Fig. 18. Irrigation frequency (no.), grain yield of wheat and tube well depth (ft.), in Kurukshetra, Panipat and Yamunanagar districts, Haryana district.

4.4 Weed management in wheat

Weed flora is dominated by *Phalaris minor* across the three districts (Tables 11, 12) and its dominance means there is no diverse herbicide application domain except in some pockets where broadleaf weeds are a minor problem. This type of simplified weed spectrum enables faster development of resistance; this has happened in the past (Malik and Singh, 2010) and has started happening now (Table 13). Quantification and characterisation of herbicide resistance in *Phalaris minor* –the most serious weed for wheat – was conducted by HAU, Hisar in 1992–93. This was the first report of resistance against any weed in India and against *Phalaris minor* in the world. The development of resistance to this herbicide

Table 11: Top five troublesome weeds of wheat crop in three districts of RWCS.

Rank	Kurukshetra	% HHs	Rank	Panipat	% HHs	Rank	Yamunanagar	% HHs
1	<i>Phalaris minor</i>	57.5	1	<i>Phalaris minor</i>	82.1	1	<i>Phalaris minor</i>	94.2
2	<i>Polypogon monspeliensis</i>	12.4	2	<i>Polypogon monspeliensis</i>	7.5	2	<i>Polypogon monspeliensis</i>	3.1
3	<i>Cynodon dactylon</i>	4.6	3	<i>Avena ludoviciana</i>	2.2	3	<i>Rumex dentatus</i>	2.4
4	<i>Poa annua</i>	4.2	4	<i>Chenopodium album</i>	1.8	4	<i>Avena ludoviciana</i>	0.3
5	<i>Chenopodium album</i>	3.5	5	<i>Poa annua</i>	1.1	5	Others	-

led to huge losses in wheat productivity between 1992–93 and 1997–98. New herbicides – sulfosulfuron, clodinafop and fenoxaprop – recommended in 1998 are now showing signs of cross-resistance; nevertheless, clodinafop is still used by 29.4%, 22.0% and 21.1% of households in Kurukshetra, Panipat and Yamunanagar districts, respectively. From 1997 to 2010, these herbicides, dominated by clodinafop, accounted for more than 90% of herbicide use in wheat in Haryana's RWCS. The corresponding use of sulfosulfuron has decreased, with 7.3%, 16.8% and 18.3% of households adopting it, respectively. In the current scenario of cross-resistance, 14.5% of households have started using pyroxasulfone but its potency seems to be less than expected. Nevertheless, this herbicide is better than metribuzin which

is used by 16% of households across the three districts, often with crop injury. A wheat grain yield of 4.2 t/ha was recorded by farmers following the treatment of pyroxasulfone in three districts. This reflects the growing threat of multiple resistance in *Phalaris minor*. Concern about cross-resistance seems to have reshaped *Phalaris minor* control with the use of herbicide like metribuzin, or use of herbicide mixtures or repeat sprays of herbicides which did not happen in

Table 13. Ten most common weeds in wheat in three RWCS districts, Haryana.

Ten most common weeds in wheat	%HHs
<i>Phalaris minor</i>	92.8
<i>Polypogon monspeliensis</i>	64.7
<i>Chenopodium album</i>	49.8
<i>Rumex dentatus</i>	36.3
<i>Avena ludoviciana</i>	31.7
<i>Cynodon dactylon</i>	31.4
<i>Melilotus indica</i>	23.0
<i>Coronopus didymus</i>	22.3
<i>Poa annua</i>	22.3
<i>Anagallis arvensis</i>	15.8

Table 13. Herbicide use in wheat.

Herbicide used	% HHs used			Average Users	Yield (t/ha)
	Kurukshetra	Panipat	Yamunanagar		
Clodinafop	29.3	22.0	21.1	24.0	4.3
Metribuzin	17.4	19.2	11.5	16.0	4.2
Pyroxasulfone	11.2	27.5	3.9	14.5	4.4
Sulfosulfuron	7.3	16.8	18.3	14.4	4.5
Pinoxaden	6.9	2.7	11.1	6.9	4.0
Pendimethalin	1.9	3.8	11.8	5.9	4.5
2, 4-D	3.9	0.7	4.7	3.0	4.1
Metsulfuron	2.3	1.0	3.6	2.3	4.6
Herbicide mixtures	5.4	2.1	6.5	4.6	4.0
Repeat spray (Second spray + more)	10.8	3.8	8.6	7.6	4.2

the past. There is now serious confusion, among farmers, who are using different kinds of mixture or repeat sprayings, as *Phalaris minor* is constituting a major threat to wheat production across the three districts.

4.5 Cost of cultivation of wheat

A study by Erenstein et al. (2007) found the number of tillage operations in Haryana had reduced from an average of eight operations in conventional tillage to only one in zero tillage, which had also reduced diesel consumption to 12.0 l/ha from 48.0 l/ha. According to the current LDS, the cost of land preparation has been reduced to INR3382/acre across the three districts. With a 50% reduction in tillage frequency, the average tillage cost of INR8456/ha is still 20% of the total cost of cultivation (INR40,628/ha). Despite conflicting messages from different research and extension organisations over the last 25 years and so many new types of zero till machines,

Table 14: Cultivation costs of wheat in Kurukshetra, Panipat and Yamunanagar districts, Haryana.

Field operations in Wheat	Kurukshetra	Panipat	Yamunanagar	Average cost
Land Preparation	9390	7985	8079	8456
Crop Establishment	2823	3106	2951	2965
DAP	3198	3229	3205	3212
Urea	1973	1772	1822	1852
Fertilizer Application	954	950	852	918
Irrigation*	3659	1931	2595	2695
Weeding	2580	2843	2215	2553
Diseases management: Fungicide + spray cost	2363	2282	1709	1874
Insect management: Insecticide + Spray cost	2454	2213	1873	2095
Harvesting by manual labour	8273	8305	9333	8931
Threshing machine	5705	5478	4786	5078
Manual harvesting and threshing	43372	40094	39420	40628
Combine harvesting machine	4928	4414	5336	4861
Average cost based on combine harvesting and threshing	34323	30725	30638	31480

Note: In order to maintain parity, the cost of cultivation was calculated on the basis of user of that particular operation. Cost of FYM* (Approx INR 3000/acre has not been included because it was applied by less than 4% in wheat. Moreover, the turn of an acre of field for FYM use comes once in 5–10 years.

*Cost is labour used in irrigation.

**is used in the interval of five years in same plot.

it is nevertheless possible to reach the goal of zero tillage. Even with such conflicting interests, zero till has effectively served its purpose of saving time and energy, and contributed to sustaining RWCS. Zero till as such has added to the resilience of this cropping system. The cost of land preparation for wheat cultivation is 30% less than for rice, which seems to provide a reason for optimism as without the adoption of zero till since 1997, this cost could now have been as high as INR14,000/ha, considering the rental cost of INR700/acre for tillage. In addition, combine harvesting has significantly reduced the cost of harvesting and threshing by almost 46% (from INR8930/ha to INR4163/ha). The LDS indicates that the cost of manual harvesting varied between INR8273/ha in Kurukshetra to INR 9333/ha in Yamunanagar.

In terms of the adoption of different technologies, trends in insect, disease and weed management are influencing farmers' decisions, with almost 25% of households applying insecticides and fungicides. Data also show that fewer than 5% of households used FYM and it therefore was not included in the cost calculation, which comes in at around INR 3000/acre for a small set of users. It is also difficult to gauge the cost of FYM application, as farmers use it just once every five to ten years due to its unavailability at the individual household level. An earlier survey in 2010 showed that on average a (rice) field is treated with organic fertiliser every 15 years and a wheat field every 53 years (Singh et al., 2010). This needs to be seen in a broader context, as most recommendations for RWCS advise the integrated use of FYM with inorganic fertilisers. Figure 19 shows that a minimum support price is important to reassure

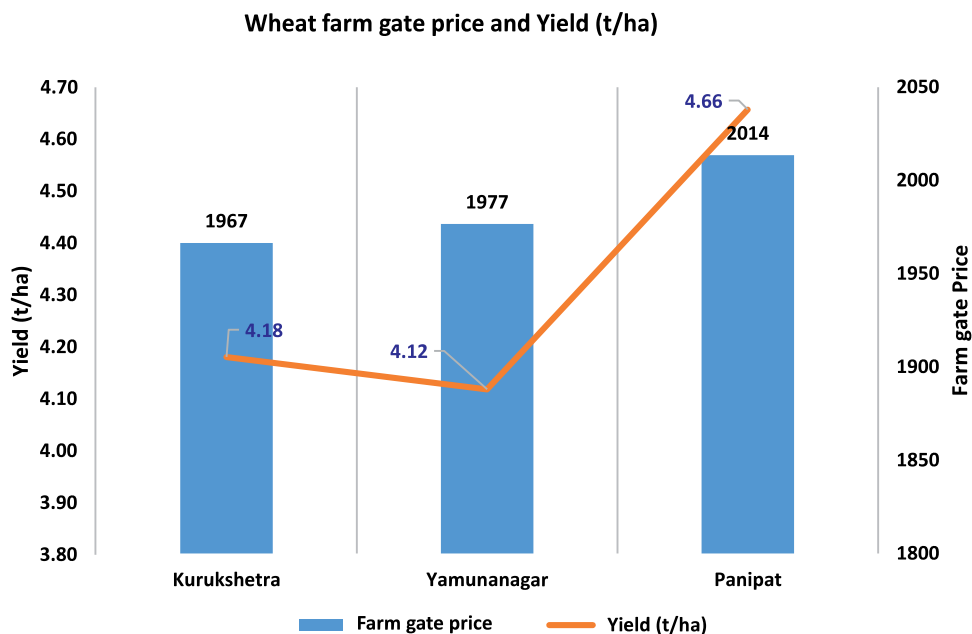


Fig. 19. Wheat grain yield in three districts, Haryana(2021–22, n=829)

farmers, but that residue management is even more important (discrepancies emerged from straw burning and delayed wheat sowings in districts like Kurukshetra, but not in Panipat where straw burning is limited due to the dominance of basmati rice). The wheat grain yield was higher in Panipat (4.7 t/ha) than in Kurukshetra, at 4.3 t/ha.

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5. Adoption of hybrids – a growing niche in pearl millet - mustard rotation

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SUMMARY

- Evidence of the use of hybrids and increasing depth of tube wells, generated by a land diagnostic survey conducted by RAWE students at Chaudhary Charan Singh Haryana Agricultural University, Hisar, warrants detailed discussion by CCS HAU and DOA. This becomes even more relevant when farmers are over-reliant on the pearl millet–mustard cropping system for revenue generation to fulfill their basic needs. Incentives associated with infrastructure change must now be sought, to make practical use of precision agriculture technologies related to micro-irrigation.
- Farmers in two districts are pumping out more water than is being replenished by rainfall or surface flow. There is a need to establish new initiatives to build a database, to improve feedback loops, and advance sustainable solutions for the falling water table in some blocks of Mahendergarh.
- Highly intensive production approaches currently practiced in Haryana do not consider the role of a farming system for diversification, which not only provides an income source but also benefits the environment. A farming system associated with an increase in the number of livestock can make this cropping system more profitable.
- It has been observed that there is a slow increase in yield levels in the pearl millet–mustard–based cropping system, but no decline in the development of hybrids. The study provides evidence that N management is currently becoming more relevant.

- Policy decisions are needed to make canal water accessible (according to its availability) to this area's farmers at critical stages of the crop. In addition, surplus canal water during flood periods can be diverted for this reason through a lift canal system. The surplus water can also be used for recharging the groundwater through river beds in the region.

1.0 Introduction

Pearl millet (*Pennisetum glaucum* (L) R. Br. emend. Stuntz) is grown in rainfed and in arid and semi-arid areas of India, and Haryana ranks fifth in terms of area coverage under this crop, with PMCS practiced in the state's dry regions. It is one of the most important sources of staple food and animal fodder. The evolution of bajra hybrids in 1965 marked a new chapter in India's crop improvement programme, with the first hybrid bajra (HB1) developed by Punjab Agricultural University (PAU) when HAU was a part of it.

Rapeseed mustard crops in India include toria (*Brassica campestris* L. var. toria), brown sarson (*B. campestris* L. var. brown sarson), yellow sarson (*B. campestris* L. var. yellowsarson), Indian mustard (*B. juncea* L. Czernj & Cosson), black mustard (*B. nigra*) and taramira (*Eruca sativa/vesicaria* Mill.) species. Among these, *Brassica juncea* L. Czern & Coss (Indian mustard) is northern India's most important oil seed crop. The centre of origin for *B. juncea* was the Middle East (Hemingway, 1979), where putative parents (*B. nigra* and *B. rapa*) would have crossed with each other. It then disseminated to other parts of the world including Europe, Asia, and Africa.

Mustard is cultivated over a six million-hectare area and contributes approximately 8.3 million tons to the oil pool of India, with an average seed yield of 1.4 t/ha (DOAC, 2018). Farmers and scientists have responded well to sustain this cropping system. There certainly was a problem in the past when both crops were grown under rainfed conditions, leading to the development of an irrigation infrastructure. PAU's Hisar campus and HAU together took a leadership role in the development of pearl millet hybrids in the 1970s and 1980s; the RH group of varieties (starting with RH 30) evolved via CCS HAU and offered a breakthrough in mustard and a success story in PMCS. India's research and extension system has undergone a thorough evaluation of recommendations from seed to harvest, and the private sector has now started prioritising hybrid technology and precision agriculture. Existing research and extension processes rely on a top-down process; however, as most technologies must pass farmers' field tests before being recommended for scaling out, it is important to understand farmers' needs. New strategies for scaling-out agricultural and natural resource innovations are therefore required, as the technologies under reference were not developed with an understanding of the issues that farmers face – and farmers provide the decisive factor in the development and application of technologies.

2.0 Method

The performance and adoption of technologies may vary slightly within districts and between villages due to different soil conditions, improvements in irrigation, and farmer preferences. The LDS was undertaken in randomly selected villages of Rewari and Mahendergarh districts. In Rewari the villages were Jhabua, Pali, Berlikhurd, Nangal Mundi, Garhi, Bolni, Bariawas, Niganiawas, Chandpur, Jholri, Odhi, Chilhar, JaitpurSekhpur, Mundi, Sanjarpur, Baldhan Kalan, Bhagwanpur, Tatarpur Istmurar, Karoli, Patuhera, Dhawana, Surheli, Siha, Motla Khurd, Gudiani, Suthani, Dhakia, Bairampur and Kutubpuri buzurg (totaling 30 villages); in Mahenderhargh the villages were NangalSirohi, Deroli Ahir, Khaspur, Khampur, Tigra, Khor, Bhusan Kalan, Hazipur, Abdula Nagar, Noonni Awal, Dhanaunda, Sehlang, Bawana, Lawana, Chittaroli, Kotia, Kapoori, Dewas, Jatwas, Jhanjhariwas, Rajawas, Dalanwas, Kamania, Mukundpura, Dostpur, Nizampur, Mohmmadpur, Bhudhwal, Saidalipur and Bighopur (total 30 villages). Students undertaking the RAWE programme were given an ODK electronic survey schedule for benchmarking the current cultivation practices in each village where the PMCS is followed. The data collected were analysed thoroughly using different data analytical tools and techniques. The survey also collected GPS points, which can assist in cross-verifying the agronomic management of these crops in future studies.

3.0 Results

3.1 Land holding

Most farmers surveyed (92% of households) in both districts have their own land (Table 1); some (5.17% and 9.22% in Mahendergarh and Rewari districts, respectively) also leased in land for agriculture and a few (0.69% in Mahendergarh and 1.42% in Rewari) farmed on shared land, with the average cultivated area 5.51 acres in both districts. On average, mustard was grown on about three acres in each district. About 10% of households had adopted a cotton-based system in both districts, with about 4% cultivating cluster bean, vegetables, green gram or black gram. The survey schedule did not include pointed questions on third crops. On average, 62% of the area in Mahendergarh and 44% in Rewari was covered by pearl millet.

This means that every farmer grows alternate crops simultaneously, for their daily needs (that is, for household consumption or as animal feed). The composition of crops is based on natural resource base and size of holding. This cropping system is vulnerable to an uncertain monsoon and there is therefore a limited choice for diversification, except for some pulses in the *kharif* season.

Table 1: Distribution of selected sample households for leased-in, shared, and own land in the study locations (n=572).

Districts	% HHs (Leased In)	% HHs (Shared in)	% HHs (Own)	Avg. Area Cultivated (Avg.) (Acre)	Avg. Area Pearl Millet (Avg.) (Acres)	Avg. Area Mustard (Av.) (Acres)
Mahendergarh	5.17	0.69	94.14	5.09	3.25	3.14
Rewari	9.22	1.42	89.36	5.93	2.60	2.97
Average	7.20	1.05	91.75	5.51	2.94	3.06

Note: *HHs -Households

3.2 Education level of respondent farmers

Level of education impacts on the way a farmer judges their requirements in terms of daily field operations and use of technologies and inputs. Figure 1 presents the education level of PMCS households in Mahendergarh and Rewari districts. Most of the farmers surveyed were literate, with about a quarter having studied up to primary, one fifth up to senior secondary level and one-third having matriculated; 9% of total farmers were graduates and 3% post-graduate. The remaining 6% of farmers surveyed were illiterate or had never attended school. This means that almost 70% had been educated up to 10th standard and beyond, with the implication that they have the basic skills needed to understand new technologies. However, this generation of farmers, has not experienced the Green Revolution, which inculcated trust in public sector institutions such as SAUs. Competition is growing between the public and private sectors for new technologies. The favorable changes in farmers' education background have coincided with the need for increased mechanisation and the application of technologies such as micro-irrigation, which lead to precision farming.

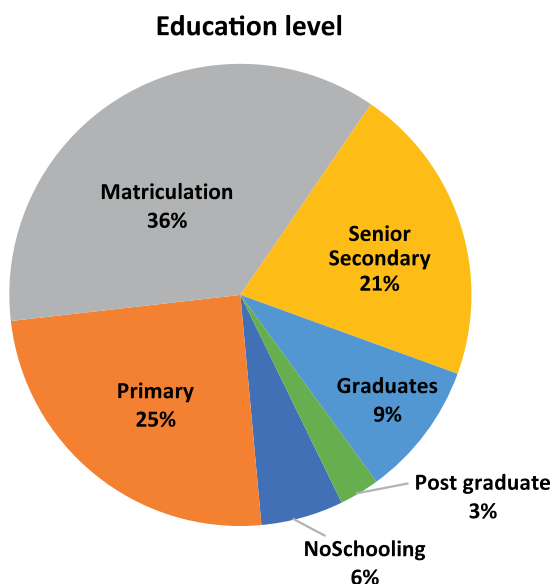


Fig. 1. Education level of PMCS farming households in Mahendergarh and Rewari district, Haryana (n=572).

Better education also reflects the need for outsized earnings from agriculture, which could be an issue with new and emerging problems related to climate change. The application of technologies requiring machinery and precision is not a problem in the surveyed districts.

3.3 Social network

The social network in both districts is dominated by the 'OBC' category, but the social set up is uniform, with most households having an almost similar standard of living, as witnessed by farm size. Figure 2 demonstrates that social stratification of households in terms of PMCS production practices in Mahendergarh and Rewari districts comprised almost three-quarters (71%) of so-called OBC {caste: Ahirs (Yadav)} with about 26% belonging to the general category (mainly Rajput and Jat). Scheduled caste households do not own agricultural land; nonetheless, a few farmers(3%) grow crops, either leasing-in agriculture land (owned by the gram panchayat or individual farmers) or cultivating crops on a shared basis. With a limited option to diversity except towards an animal component, there is likely to be a significant increase in the participation of young farmers in the workforce gravitating towards jobs in the public and private sectors. Young males in the area have traditionally joined the

defence services, and with new development in the area and an increased number of manufacturing units in both districts, the number of those engaged in agriculture is likely to continue to decrease. The former agrarian structure (Hirashima, 2001), with large numbers of non-farm households working as agriculture labour for farming households, appears to be disappearing, with the former obtaining income from a range of sources. This impacts on labour availability.

In addition, avenues of employment from new industries are opening in Bawal, Manesar, Dharuhera and Bhiwadi areas in these clusters. Because a large section of population was involved in agriculture in the past, technological innovations were the only means of absorbing abundant labour: now mechanisation is the only way to compensate for scarce and costly labour.

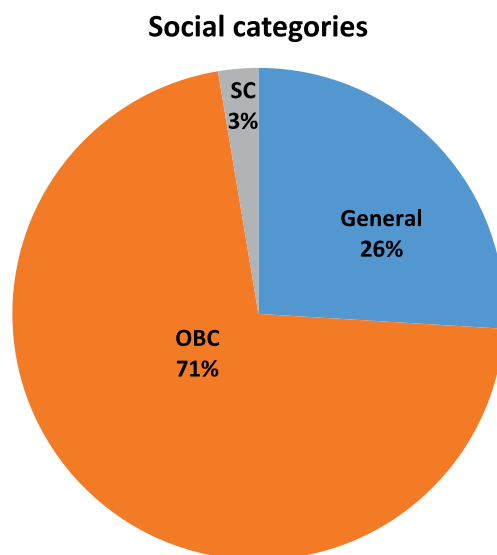


Fig. 2. Social stratification of households according to PMCS production practice in Mahendergarh and Rewari districts, Haryana.

3.4 Family composition

According to the survey data, households in these districts (Mahendergarh and Rewari) comprised nuclear families with an average of six members (Fig. 3.) and an average of 2.6 members per household involved in agriculture work. Most households had animal assets, with an average of 3.2 ruminants each, meeting their domestic demand for milk and butter and acting as a source of supplementary income. The presence of more animals may help farmers to ensure sustained income, especially during years of drought and other biotic or abiotic stresses. Typically, incomes from farming are still low, and farmers now need to develop resilience to second generation problems related to the climate crisis, biotic and abiotic stresses, and environmental issues. Our aim is to create a framework within which new agronomic management strategies, especially mechanisation or micro-irrigation, or precision agriculture, can help improve productivity growth, as well as monitor and manage these second-generation problems. If diversification towards alternate crops is not possible in these arid districts, it would be better to increase the number of milch animals, as the scope for excellent fodder is always there in these ecologies due to higher area under rice-wheat cropping system.

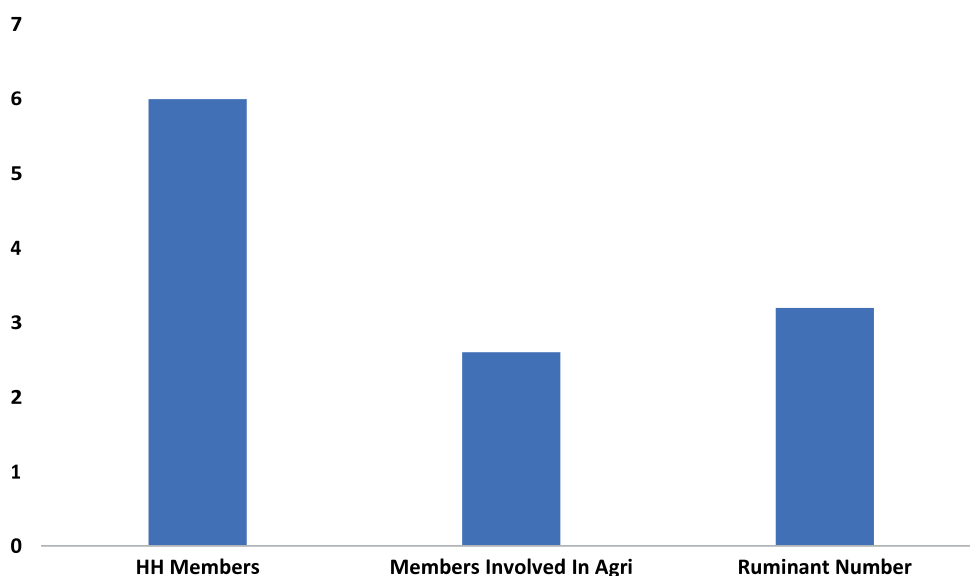


Fig. 3. Household members and their linkage between alternate sources of income from animal assets or other operations.

3.5 Women participation in decision making

Figure 4a illustrates the contribution of women to decision-making in farming households based on the responses of the 12 women respondents who participated in the survey.

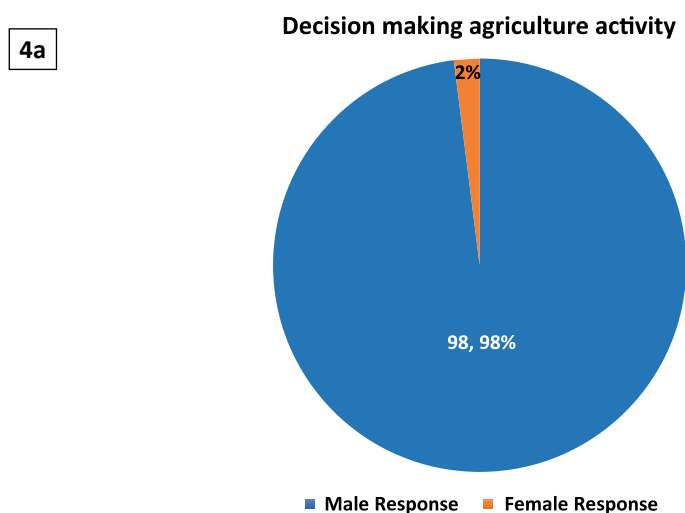


Fig. 4a. Gender-wise bifurcation of all respondents covered during survey with respect to decision making (n = 572).

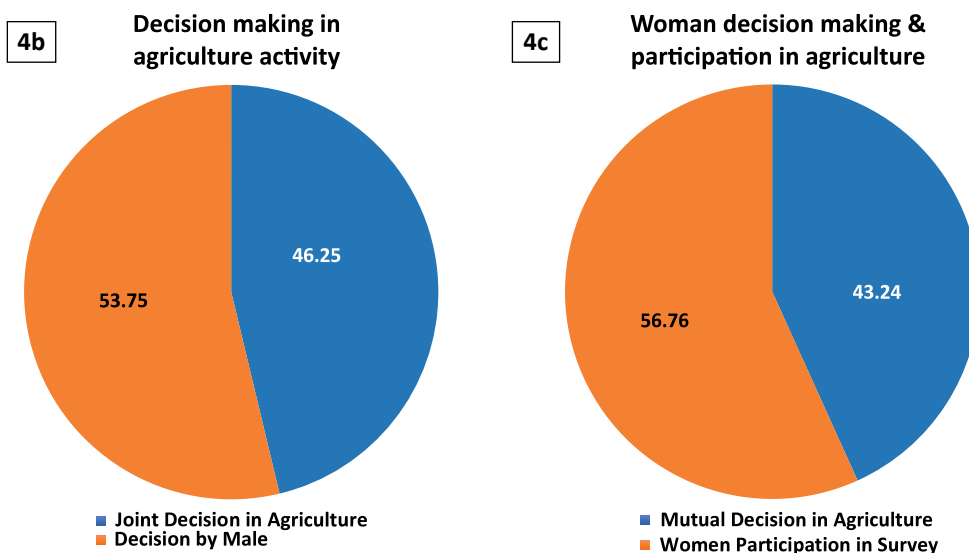


Fig. 4b, 4c. Participation profile of women farmers in decision making of cultivation practices in Pearl millet and Mustard cropping system in Haryana

When asked about the participation of female household members in decision-making regarding PMCS cultivation operations, more than half of male respondents (about 54%) reported not involving their spouse; 46% said they do (Fig. 4b). Figure 4c presents the involvement of women in terms of them responding to questions during the interview, with almost identical results: 57% of total male respondents did not involve their wives during the interview, and 43% replied to questions jointly with their spouse. The indication is that many women in farming are likely to face constraints to their equitable participation in agriculture, including lack of training or access to new technology. It may be added that in the past, the necessary use of heavy agricultural implements precluded women from working in the field, resulting in their role depending on what could be deemed traditional female farming practices: even today, women are much more involved in activities such as animal-rearing, light field operation transplanting, interculture or harvesting, even though mechanisation now has the potential to create more of a level playing field. In the meantime, it has been found that agrarian women often have better understanding of various biotic and abiotic problems or processes and, as this survey shows, are not necessarily excluded from decision-making.

3.6 Farm advisory services

Nowadays, digitised tools are being used to understand weather patterns and data on the adoption and usefulness of e-Mausam Agro-Advisories generated by CCS HAU were studied (Table 2) to determine their usefulness. These digital tools are assisting farmers to gain insights into their field operations, enabling them to address emerging challenges to ensure better yields in the face of uncertain rains. During cropping seasons, 20% of total respondents received 115 advisories from CCS HAU, of which about 15% were not followed. The remaining 85% were found useful but utilised fully by just 18% of households, and partly by 67%, to manage their crops.

Table 2. Adoption and usefulness of e-Mausam Agro-Advisory given to farmers through CCS HAU, Hisar in Mahendergarh and Rewari districts, Haryana.

Survey statement	Advisory Benefits			
Did you receive any agro-advisory mobile phone message from e-Mausam HAU	No. advisory Received	115	% received	20.1
Utilisation of advisory %				
Do you follow the agro-advisory received Mousam of HAU?	Advisory followed	Fully	Partly	No
		18.3	67.0	14.7

3.7 Size of holding

Respondents to the LDS were categorised into marginal, small, semi-medium, medium, and large farmers according to landholding size as per government criteria, with the majority being small and marginal (Figs. 5a & 5b). In Mahendergarh, 72% of farmers (38% small, 34% marginal) and in Rewari, 63% of farmers (33% small, 30% marginal) held less than two hectares of land. Only 1% and 2% of total respondents (n=572) in the two districts, respectively, were classified as large farmers, having more than 10 hectares of land. Given the size of the holding of the majority of farmers, the increase in spending on inputs and labour cannot be compensated if yields do not increase in the same proportion. Farming can become profitable only if farmers adopt new technologies, and these will be accepted only if they are considered risk free and ensure sustained profits. To achieve this, it is essential to understand the needs of farmers.

3.8 Soil type

Soil texture data, on average, revealed little variation between the two districts (Figs. 6a and 6b), where soils are almost entirely light (61% and 56% in Rewari and Mahendergarh, respectively) and medium. Just 2% of soils were reported heavy in Rewari and none in Mahendergarh. There are sand dunes in the southern part of the state surveyed,

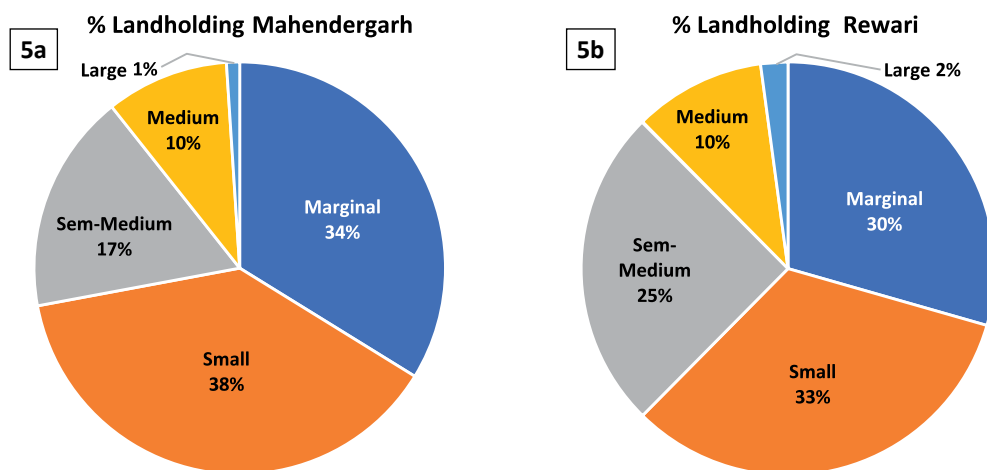


Fig. 5a, 5b. Size of landholding (marginal 0–1, small 1–2, semi-medium 2–4, medium–10, large more than 10 hectares) of farmers in Mahendergarh and Rewari districts, Haryana.

with soils here being of poor fertility. All the soils of both districts are well-drained, with none of the respondents in either district encountering waterlogging. Yields of pearl millet (2.2 t/ha) and mustard (2.3 t/ha) were assessed under different soil textures and found to be almost the same (around less than 2.2 t/ha) in light- and in medium-textured soils (Fig. 6c).

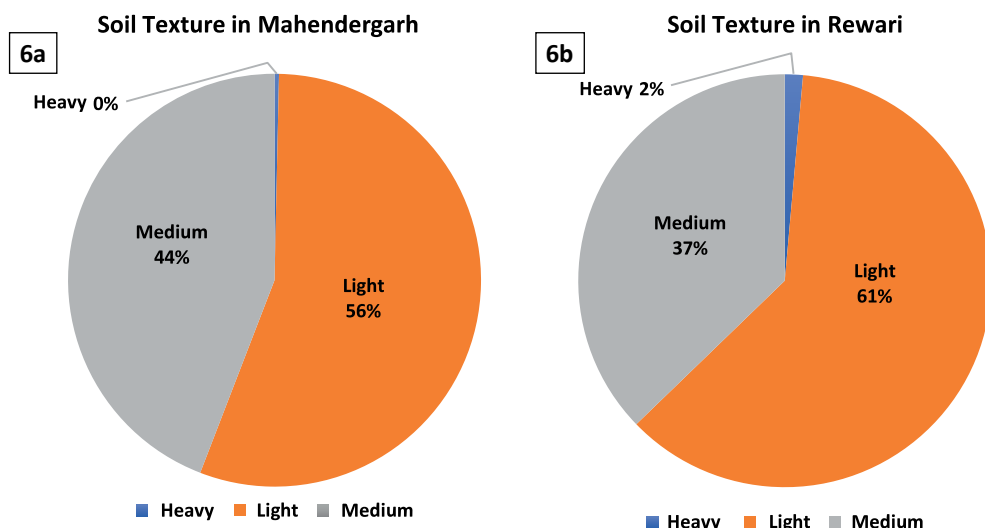


Fig. 6a, 6b. Soil textures in Mahendergarh and Rewari districts, Haryana.

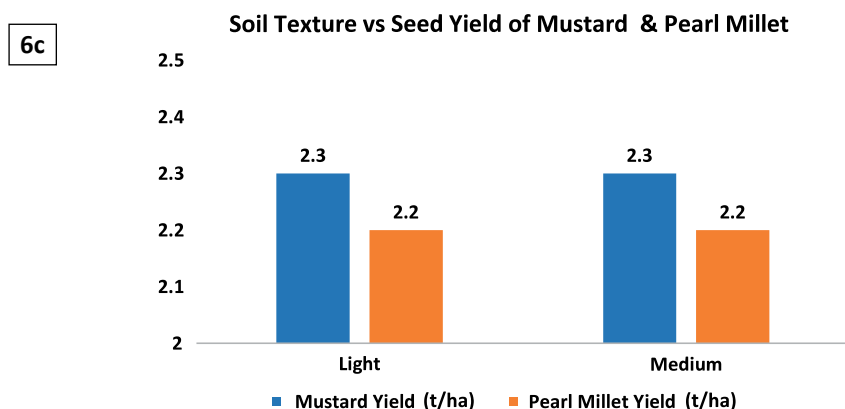


Fig. 6c. Effect of soil texture on the seed yield of pearl millet and mustard.

3.9 Cropping system

Mahendergargh and Rewari districts were totally dependent upon rainfall until electrification in Haryana in the 1970s facilitated tube well irrigation, with some crops such as gram and kharif pulses did not respond well to. In the 1980s and 1990s, wheat took over the area from gram in the rabi season, and during the last 30 years, after the groundwater level started receding, farmers have been shifting to a greater area under mustard. The cropping pattern in south Haryana has thus continuously been undergoing change depending upon the intensity of irrigation, assured prices, and new varieties of crops and their response to tube well water. Besides pearl millet in the kharif and mustard in the rabi seasons (Table 1), respondents grow other crops (Figs. 7a, 7b), with kharif cotton the main crop grown by many farmers, followed by kharif pulses (green gram, black gram and sorghum) for fodder. During the rabi season, other than mustard, wheat was respondents' priority crop, followed by chickpea.

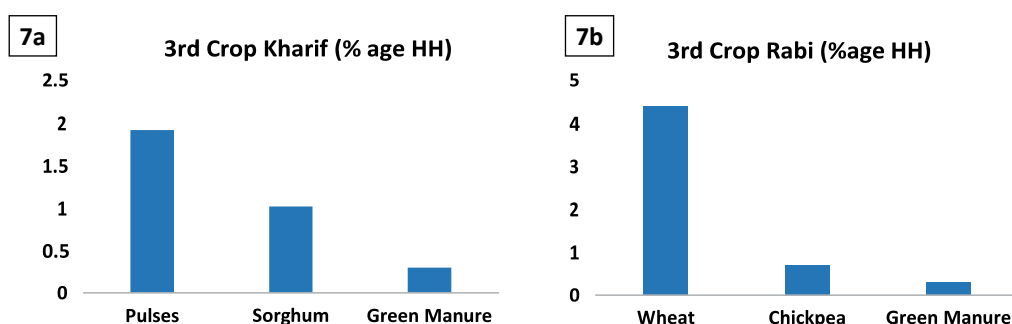


Fig. 7a, 7b. Percentage of PMCS households planting an additional crop in the kharif and rabi seasons (n=572).

3.10 Seed rate

In the two districts surveyed, the seed rate of mustard is around 1.2 kg/acre (3.0 kg/ha) (Fig. 8), although by using different varieties many farmers use up to 2kg/acre (5 kg/ha). Thinning then adds to cultivation costs. Seed quality and farmers' innovation are important factors in seed rate reduction and keeping in mind the maxim 'seed saved is seed produced', nurturing such trends is important, as after being introduced, on balance they are likely to persist. This would involve forging alliances with the private sector, which is important for new technologies in seed as well as micro-irrigation.

3.11 Source of irrigation

These districts are in the arid part of Haryana, where the irrigation infrastructure includes a large network of sprinklers, part of the state's modern agriculture development and efficient water use. Nevertheless, water withdrawal has remained steady since the popularisation of the

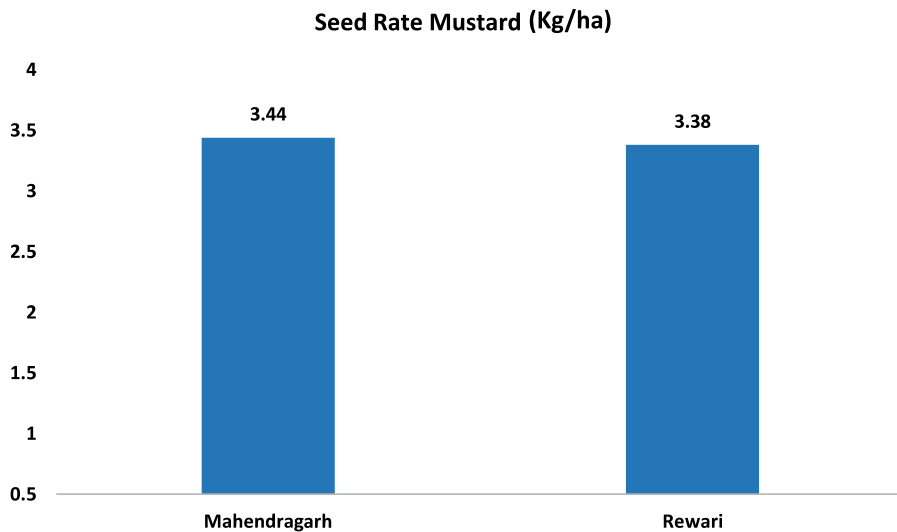


Fig. 8. Seed rate (kg/ha) of Indian mustard by farmers in Mahendergarh and Rewari districts, Haryana

sprinkler irrigation system (Figs.9a and 9b). Groundwater use was stimulated by the intensification of PMCS in the region, and the proliferation of tube wells has brought some economic gains due to the increased intensification of and the improved yield levels in

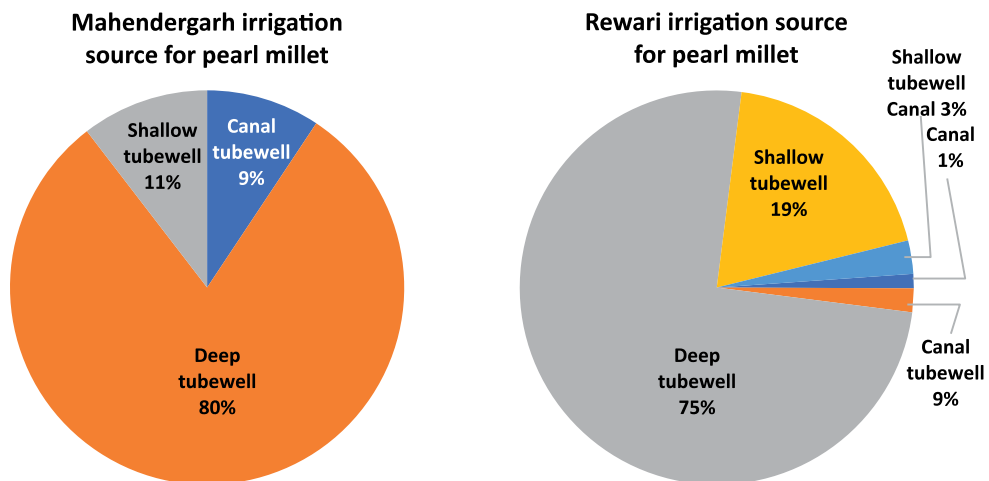


Fig. 9a, 9b. Sources of irrigation as reported by respondent farmers (n=572) in two pearl millet-growing districts (Mahendergarh and Rewari), Haryana.

each crop in rotation. Figures 9a–dc show that in both districts the major irrigation source for pearl millet (9a, 9b) and mustard (9c, 9d) was deep tube wells. In Mahendergarh district, 80% and 84% of respondents have used deep tube wells to irrigate

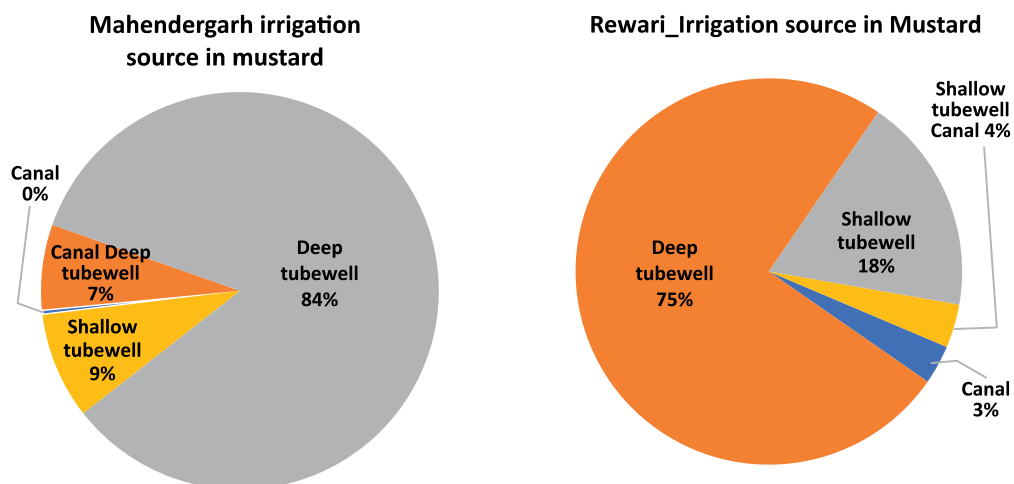


Fig. 9c, 9d. Sources of irrigation reported by farmers (n=572) in two PMCS, Mahendergarh and Rewari districts, Haryana.

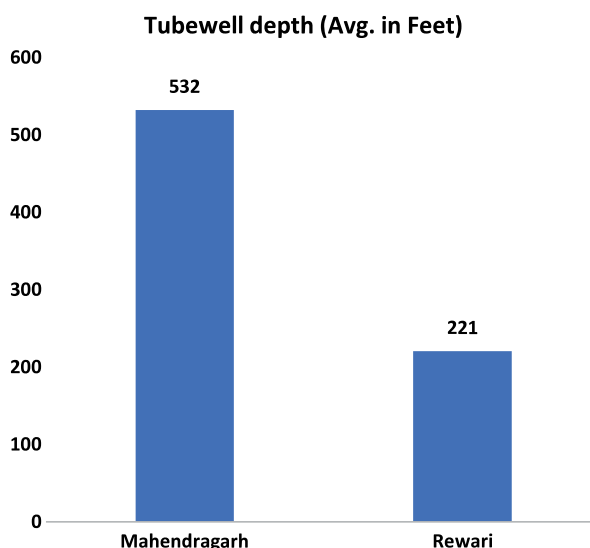


Fig. 9e. Average tube well depth (in ft) in PMCS, Mahendergarh and Rewari districts, Haryana.

pearl millet and mustard, respectively, while in Rewari district 75% of the area under both crops was irrigated by deep tube wells. Some farmers in both districts also use tube wells near canals; however, only 9% and 7% of households in Mahendergarh reported success with pearl millet and mustard, respectively, by so doing. In Rewari district, 3% of households used a canal for irrigating mustard, with tube wells near canals shallower than deep tube wells. The water table in Mahendergarh district is deeper than in Rewari district; in Nangal Chaudhary block, Mahendergarh, the situation is very severe, with water sometimes unavailable for irrigation even up to 1000–1500 ft. Figure 9c indicates that the average tube well depth in Mahendergarh district (532 ft) is more than double that in Rewari district (221 ft) (Fig. 9e), where some areas, particularly Jatusana block near Jawahar Lal Nehru canal, experience waterlogged conditions during the monsoon period (some years).

Intensive withdrawals of groundwater exceeding natural recharge over the years have adversely affected the environment, causing a continuous fluctuation in water table levels. In clusters of villages in Nangal Chaudhary block, tube well depth has increased by more than 1000 ft. The farmers response to this is that with the submersible tube well, the pipe is lowered up to the full depth of the bore. Rainfall is scanty in the region and surface water is restricted due to the limited canal network. The result is that groundwater recharge in Mahendergarh has been much less than its discharge. The groundwater is also of poor quality; nevertheless, due to the inability of canal water to meet farmers' needs, its extraction is increasing. If this is allowed to continue, the issue of depletion may increase many times over, increasing the insecurity and anxiety of farmers.

Tubewell depth in Mahendergarh district highlights the future of the water table in this region and may require imposing a balance between maintaining the high yields of PMCS and minimising the risk posed by the falling water table. Any proposed action needs to be on the basis of likely cropping intensification in the years ahead.

Some of the blocks surveyed overdraw water, resulting in a critical situation. Consequences such as increased fluoride in the water could provide an issue related to human health, which is not new, as this Times of India report shows: (<https://timesofindia.indiatimes.com/city/gurgaon/development-decades-behind-as-struggle-confined-to-water/articleshow/71661081.cms>) 2019); the article also indicates raised levels of nitrates and fluorides in the water. The depletion of the aquifer with the sinking of new submersible tube wells also reduces the water availability of neighbouring farmers with small land holdings.

An awareness-raising programme is needed every two to three years, including proper monitoring, evaluation, and learning, with the results disseminated to all the relevant actors. As with RWCS, in PMCS the maintenance of the water table is also the biggest challenge, with farmers refusing to change a cropping system which they have sustained for so long. Fixing this problem, especially the drought-like situations that

keep creeping into the monsoon season, the adoption of hybrids in the cropping system demonstrates the need for CCS HAU to review its strategy to evolve hybrids and collaborate with the private sector to enable knowledge-sharing. At a policy level, decisions are needed to make canal water available throughout the area at critical stages of crop development. Surplus canal water could also be diverted to this region during times of flood through a lift canal system, and could also be used for recharging groundwater through river beds in the region.

3.12 Effect of tube well depth on the seed yield of crops

To understand the effect of tube well depth on the seed yield of crops, the LDS compiled data on average yields of pearl millet and mustard (Fig. 10), and Fig. 11 presents the range of tube well depth in Mahendergarh district. About 27% of respondents in Mahendergarh use tube wells 500–1000 ft deep to irrigate their crops; about 12% have tube wells that are >1000 ft, results which indicate the extent of water scarcity in this zone. Pearl millet and mustard yields varied only by 0.1 t/ha with variation in tube well depth.

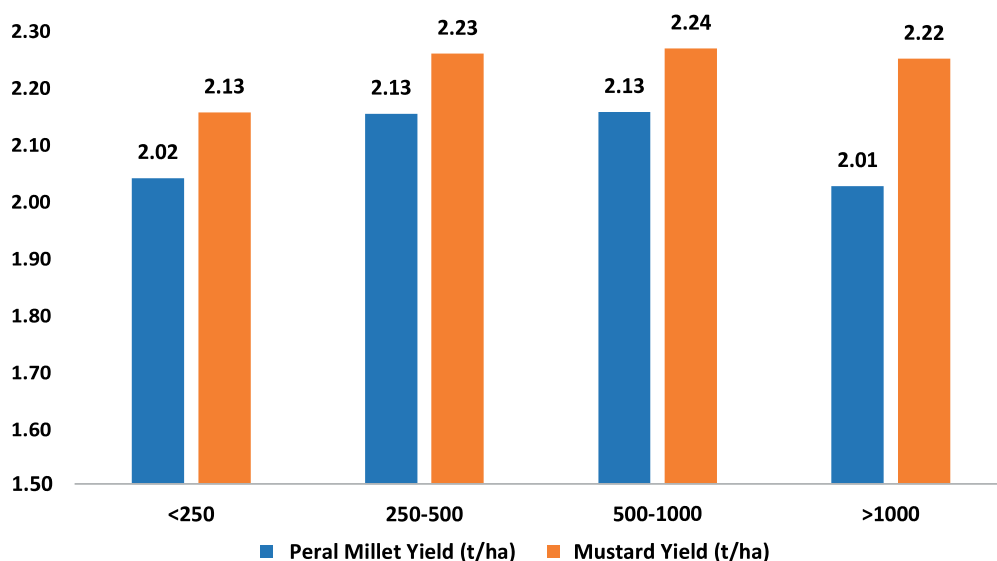


Fig. 10. Seed yield in PMCS and average tube well depth in Mahendergarh district, Haryana.

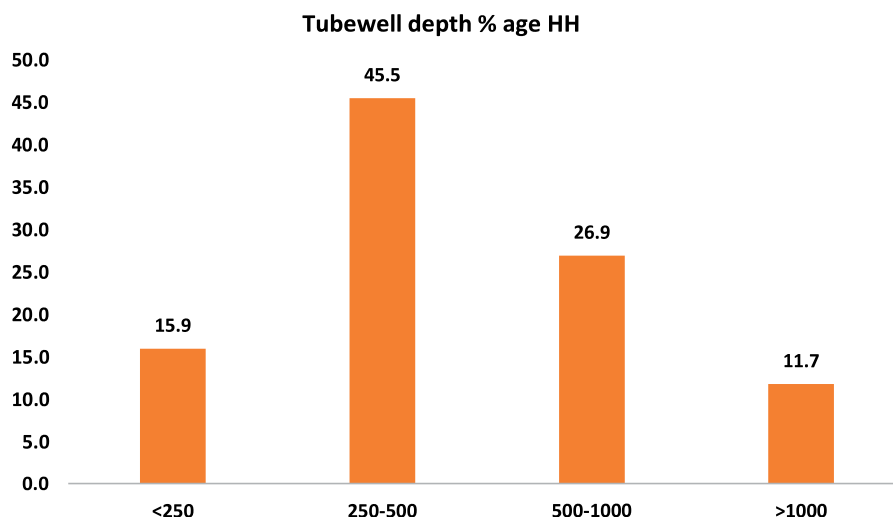


Fig. 11. Tube well depth of households (n=264) in Mahendergarh district, Haryana

Pearl millet yield increased from 2.02 t/ha to 2.13 t/ha as tube well depth increased from <250ft to 250–1000 ft; it then declined to 2.01 t/ha with tube wells of >1000 ft. Similarly, mustard yield increased from 2.13 t/ha with tube well depths of <250 ft, to 2.23 t/ha when tube well depth was from 250–500 ft, and remained constant up to depths of 1000 feet or more. The effect of water depth is not as strong as yield data suggests. As we cannot account for electricity costs (which are almost the same across depths), such effects on yield are expected.

3.13 Adoption of hybrids and open pollinated varieties

The evolution of bajra hybrids in 1965 marked a new chapter in India's crop improvement program. The first of these, HB1, was developed by PAU when HAU was part of it, with HAU's development of HHB 67 was another breakthrough. The focus at the time was on developing a short-duration hybrid of around 65–70 days; the current focus has widened this to 80–85 days duration. These hybrids have the additional advantage of staying green until harvest and thus also serve as fodder for animals.

CCS HAU has displayed standards of excellence in evolving the best mustard varieties. R30 with 130–135 days maturity, released in 1985 for both rainfed and irrigated systems and with an oil content of 39%, was able to break yield barriers in mustard, with wide adoption across the states. In early 2013, RH 749 was developed, maturing in 145 days and with the highest yield potential of 2.4–2.6 t/ha. Currently RH 725, maturing in 143 days, is being promoted as the best performer, with a yield potential of 3.5 t/ha. The yield potentials of most of these varieties are impressive, making it difficult to understand why they are losing steam.

One reason could be the easy availability of ample amounts of seed at the time it is needed. An ICAR-sponsored project (1989) initiated systematic and coordinated efforts to stimulate hybrid development in rapeseed mustard in India, catalysing private investment in hybrid research. In the meantime, farmers are experiencing a fall in water table levels after the continued success of the widespread use of sprinkler irrigation. It is this stress-like situation which seems to be encouraging the emergence of opportunities for mustard hybrids. The entry of the private sector into the seed sector has been a positive development, providing farmers with a choice of the best varieties and hybrids available in the market.

3.13.1 Crop improvement - pearl millet

The spectrum of hybrids and varieties in pearl millet and grain yields has already been mentioned. Reflecting on the history of hybrid development, starting with the first hybrid from PAU to the 100% adoption of hybrids, acts as a reminder that such developments affect not just the immediate situation but also future years, while past groundwork means there are currently about 10 hybrids in the market, with grain yields ranging from 2.1–2.38 t/ha.

The Pioneer brand has been adopted by 68.6% of households in Mahendergarh and 81.5% of households in Rewari districts (Fig. 12a). Of all the hybrids, Pioneer 86M90 has been adopted by 31.6% and 51.6% of households in these two districts, respectively, while Proagro (Proagro9444) hybrids have been adopted by 9.7% and 2.8% of households.

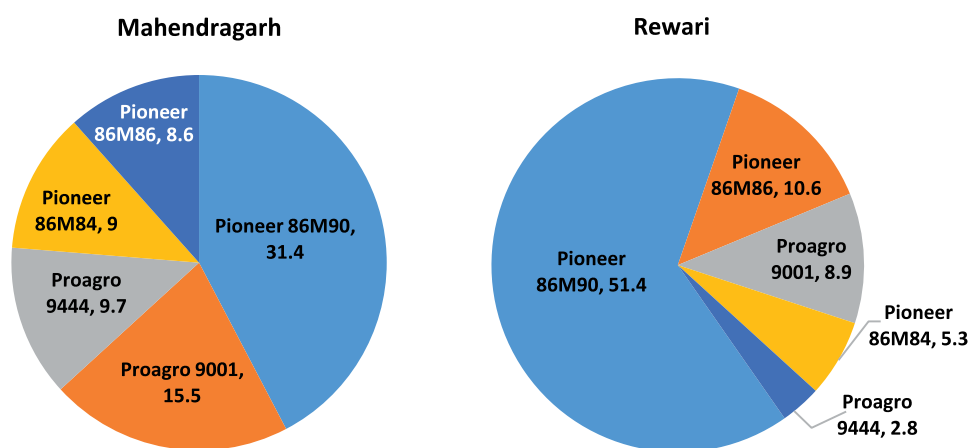


Fig. 12a. Household adoption of pearl millet hybrids in Mahendergarh and Rewari districts, Haryana.

Hybrids listed as 'other' are grown by 16 households. The varieties grown by the 21 farmers surveyed in Mahendergarh, whose average yield is 2.16 t/ha are Dhanya, Dhanya 234, Dhanya MP7366, Dhanya MP7888, HT 4252, Kaveri 6277, Kaveri Super Boss MH1553, Kaveri Super Seeds, Pioneer 86M11, Pioneer 86M88, Proagro 1091, Proagro 5094, Proagro 9450 and Shriram 8842. The average yield of all hybrids ranges from 2.1–2.3 t/ha (Fig. 12b).

The average productivity of pearl millet in Haryana is 2.1 t/ha, close to double the all-India average of 1.24 t/ha (Directorate of Millets Development, Report, 2020). CCS Haryana Agricultural University, Hisar should be proud of its success in developing the best pearl

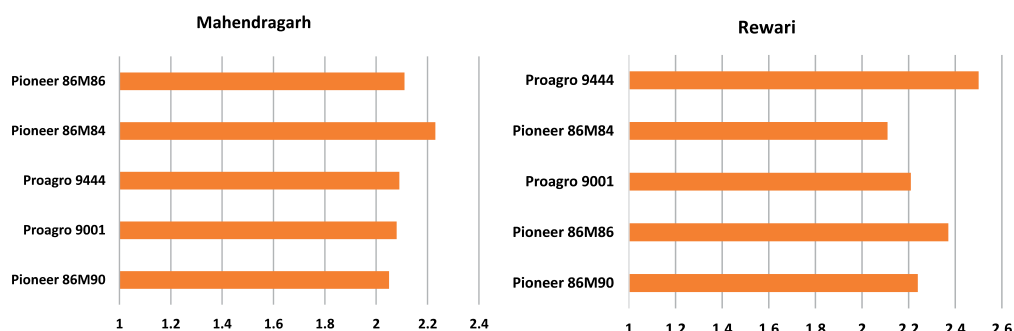


Fig. 12b. Grain yield (t/ha) of pearl millet hybrids in Mahendergarh and Rewari districts, Haryana.

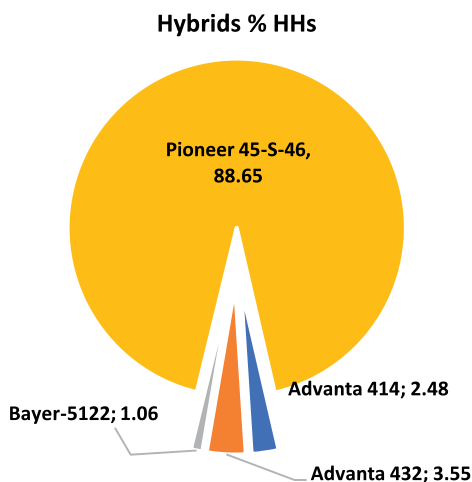


Fig. 12. Adoption of important mustard hybrids/varieties by farmers (n=290) in Rewari district, Haryana.

and the best Indian mustard open-pollinated varieties. Ecologically, Haryana is uniquely capable of improving its research and extension outcomes by developing partnerships with the private sector, and generating the resources needed to sustain PMCS. The almost-100% adoption of hybrids in these two districts provides a vision of an all-India yield growth in pearl millet.

3.13.2 Crop improvement for mustard

The adoption of open-pollinated varieties or hybrid mustard seed is presented in Figure 13a, seed yields for mustard in Mahendergarh and Rewari districts in Figure 13b, and average yields across districts in Figure 13c. Almost 99% of households have adopted mustard hybrids in these two surveyed districts of Haryana, possibly the first state in India to have reached this milestone. Here again, Pioneer has the biggest share, with 88% and 87% of households having adopted Pioneer 45S46, with an average seed yield of 2.1 t/ha in Mahendergarh and 2.3 t/ha in Rewari districts. These hybrids have not given an extra edge to varieties or other hybrids. Other hybrids or open-pollinated varieties adopted by ten farmers in Mahendergarh were Advanta 414, Dhanya, Nandi 300, Proagro 5222, RH 0749 and RH 0781. Similarly, hybrids or varieties (used by 12 households) listed under 'other' include AHBJ-7044, Dhani, other, Proagro 5222, RH 0725, RH 8812, Star 10-15, Tata MJ1 and Tierra S5-630. The average yield of hybrids/varieties listed as other varied from 2.1 to 2.3 t/ha.

The farmers based their selection of Pioneer45-S- 46 on two reasons: its high yield and higher (more than 40%) oil content, which mean the crop fetches a higher price in the

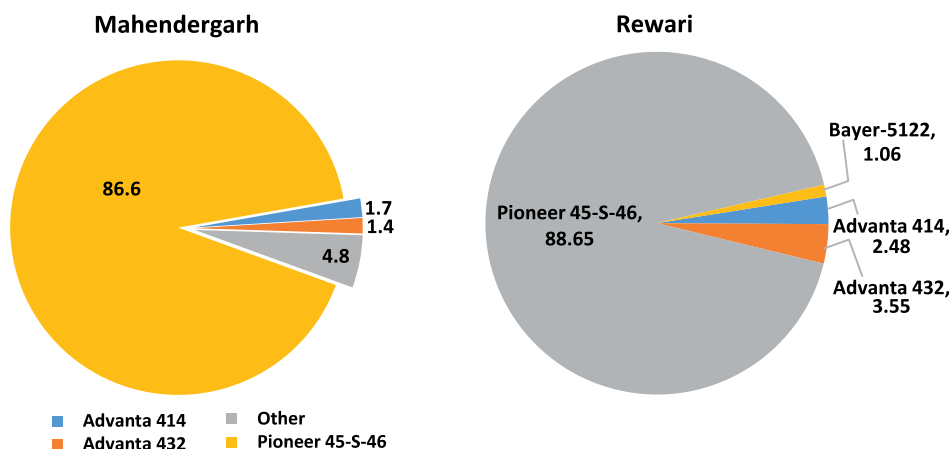


Fig. 13a. Percentage of households (n=554) cultivating mustard hybrids, Mahendergarh and Rewari districts, Haryana.

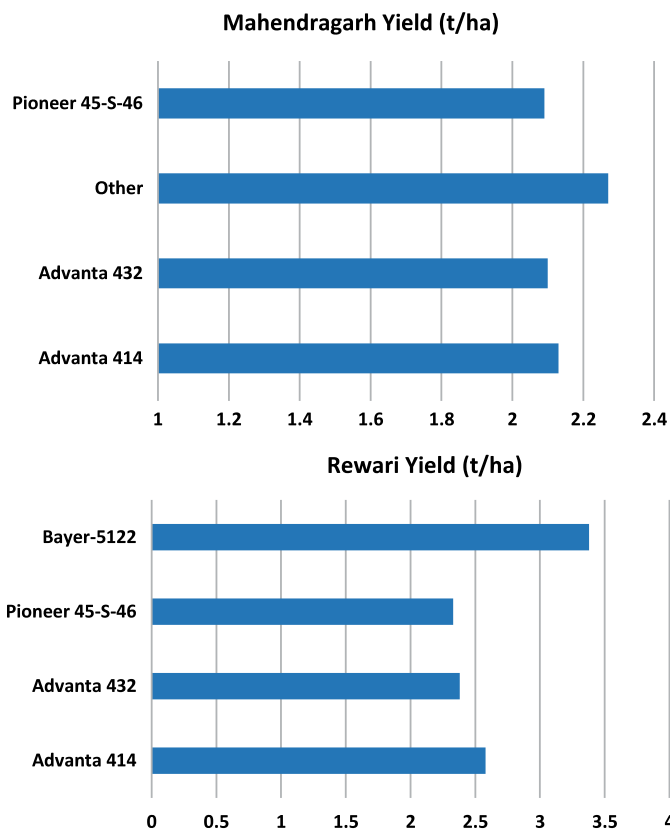


Fig. 13b. Seed yield (t/ha) of mustard hybrids in Mahendergarh and Rewari districts, Haryana.

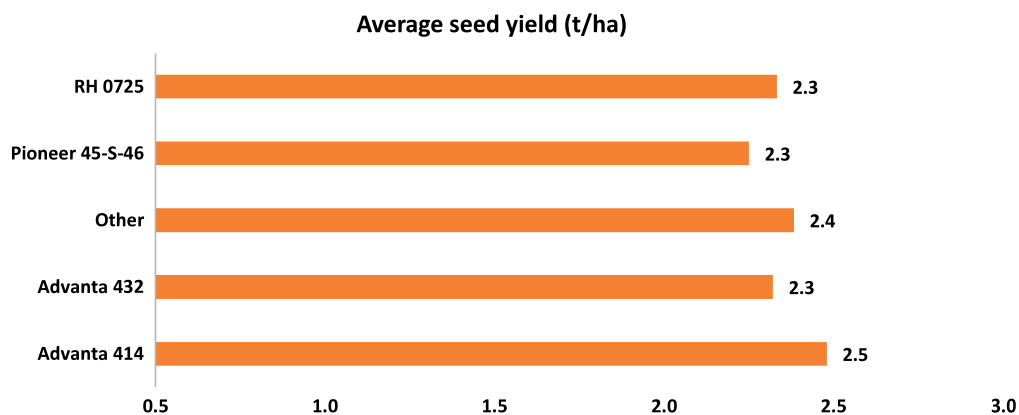


Fig. 13c. Seed yield of mustard hybrids/varieties in PMCS, Haryana (n=572).

market. Average mustard yield in Mahendergarh district was 2.18 t/ha, while Pioneer 45-S-46 yielded 2.17 t/ha (the national average yield which is more than 1.5 t/ha of 2020-21 national average). The farmers' cultivation of hybrids happened to slow the adverse effects of the falling water table in Mahendergarh and Rewari districts. Similarly, early sowing provides a yield advantage with long-duration varieties like RH 30, RH 749 and RH 725; however, early-sown varieties also encounter high-temperature stress, which reduces mustard's early growth and seed yield. Mustard hybrids have had a role, especially when very early sowings have not been possible. Most hybrids (Bayer 5222, Pioneer45S46, and Pioneer45S42) evaluated in the past had a maturity duration of 130 days and a 40%–41% oil content (Mishra et al., 2019). Data from PMCS show an approaching paradigm shift in the crop improvement programme, especially in mustard. Water scarcity may constrain PMCS productivity, leading to an even greater adoption of hybrids. However, explaining this change is not currently possible, as many data are missing on the adoption of varieties such as RH 30 and RH 749, not to mention RH 725. Nevertheless, data on the status of hybrids favoured by more than 98% of households in these two districts has thrown up something unexpected and therefore needs to be tested. Until new data is made available, this may be treated as the factual situation on the ground. This epitomizes this survey's element of surprise. It might also lead to debate about how hybrid use has increased, even when yields stay the same.

The average yield of mustard (2.2 t/ha) in these two districts is as good as those of pearl millet, with a market price in 2021–22 of INR6050/q against a minimum support price of INR5050/q. Mustard can be considered the most profitable rabi crop in the region; indeed, in terms of profit margins, it is highly successful, determining the fortunes of farmers, with profit margins at nearly INR 80,000/ha (on the basis of minimum support price) and INR 100,000/ha (market price). However, despite these good profit margins, and support for pearl millet for human consumption and animal feed, the increasing tube well depths – up to 1000 ft in some blocks – and/or the fall in the water table may mean these crops are not sustainable.

Pearl millet and mustard have equal productivity; however, mustard's profitability is much greater than pearl millet's and must be sustained. Scientists need to be on the ground and work with farmers to ensure they make informed decisions about developing new varieties /hybrids. Resilience is crucial and can be achieved especially through precision farming and improved irrigation efficiency. The survey shows that both pearl millet and mustard collectively have acquired the distinction of complete dominance by hybrids.

The identity of this region as one of pearl millet hybrids was well-known – hybrids were introduced here much earlier in 1970s – however, its identity as one of mustard hybrids is quite recent. The dominance of hybrids in PMCS is supporting the interests of farmers,

who are working to maximise the yield of the cropping system rather than that of component crops. There are several reasons for this:

- The private sector's business model is thriving because farmers have started growing pearl millet hybrids of about 80+ days duration. This has happened because sowings have been advanced after one pre-sowing irrigation. The goal of farmers now is to connect sowing their mustard crop with harvesting pearl millet.
- Unlike pearl millet, mustard farmers have benefited from the high yield of open pollinated varieties, with yield levels being the same or more than hybrids. In this survey alone, the average seed yield of three respondents growing RH 725 was 2.44 t/ha. It seems that farmers have used mustard hybrids to avoid the adverse effect of water stress, to which hybrids are more resilient.
- CCS HAU is well-known for developing the best varieties, including RH 30, RH 749, and now RH 725. The private sector has gradually expanded the network of dealers and distributors which possibly has contributed to persuading farmers to accept hybrids. An excellent network of dealers/sub-dealers can keep stocks of seed and replenish these stocks evenly across the region.
- Adoption of Pioneer 45S46 by more than 89% of households in both districts offers a clue to the motivation and needs of farmers. It costs INR 920/kg, the highest among current hybrids. However, hybrid seed cost is not a constraint if productivity is good, and it fits the requirement of the market.

The current scenario seems to indicate that a small reduction in maturity duration is needed for mustard and a small increase in duration is needed for pearl millet in future varieties/hybrids to be developed by SAU. In addition, an increase in oil content will increase the interest of traders by providing a better market price.

3.14 Use of Farmyard Manure (FYM)

The survey results indicated a preference among farmers for using FYM (Fig. 14) for pearl millet (68.1% HHs) rather than mustard (1.2% HHs) (Table 3). This is associated with favourable temperatures and a longer turnaround time after it is applied, generally in the summer season. Some cattle dung (the source of FYM) is burnt as dung cakes to meet household energy needs, thus limiting its scope for application in the fields. Also, the survey did not address the question of frequency of FYM use by farmers in PMCS. Our earlier experience in rice showed that a field is treated with organic manures just once every

15 years. In general, in PMCS the average quantity of FYM ranged from 2.0–2.2 t/ha. Its application did not change the pattern of fertiliser use in either crop. The significant residual effects of FYM applied to pearl millet on the succeeding mustard crop is also a reason for the limited use of organic manures in mustard. Apart from contributing modest quantities of primary nutrients (0.5%–1.5% N, 1.2%–1.8% P₂O₅ and 1.2%–2% K₂O on a dry weight basis), FYM also offers a good source of the secondary micronutrients necessary for plant growth. Wherever feasible and practical, application of FYM is important to soil C sequestration and improving soil quality.

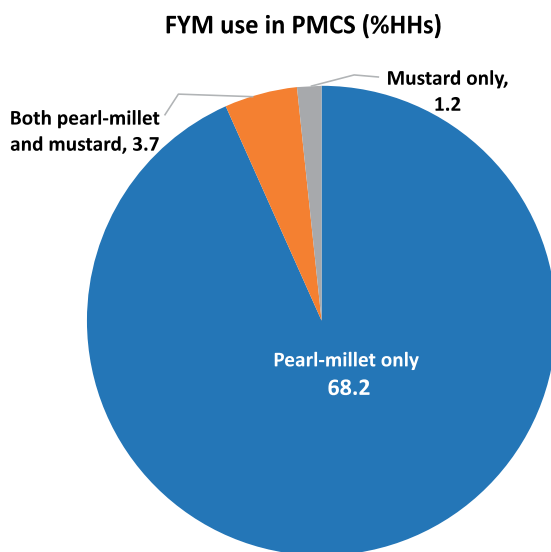


Fig. 14. Pattern of farm yard manure use in PMCS, Haryana.

3.15 Fertilizer use pattern in PMCS

The survey results show that N application in pearl millet (96.7% HHs) and mustard (98.9%) is important and the preferred option of farmers in Mahendergarh, with a similar trend apparent in Rewari district (Table 3). Urea was the major source of N for all farmers, with one top-dressing the most common method of application in both crops, some N coming from a basal application of DAP, and a very small amount (reported by 3%–6% HHs) also coming from a basal application of urea. On average, pearl millet farmers used 58.4 kg N/ha in Mahendergarh and 65.6 kg N/ha in Rewari districts. With mustard, N use in both districts varied from 72–77 kg/ha; the frequency of N application was the same (one top dressing) for pearl millet and mustard. The percentage of respondents using P was 96%–99% across the two districts. The use of K was reported by 9.2% of households in Rewari; no K use was reported by Mahendergarh farmers. Similarly, 5% of households in Rewari and 0.7% of households in Mahendergarh reported applying Zn to mustard. If we take a step back and analyse the current yield trends at less than the recommended N use, PMCS yield has improved. Farmers are currently increasing their yields by using longer duration hybrids and by using N and P but not K. Using less than the recommended dose of N (70.0 kg/ha against the recommendation of 150 kg N/ha) indicates that farmers can increase yields by increasing the dose of N in pearl millet. N is the most crucial plant nutrient, with even the response of P better if N is used appropriately. Legumes as a way of supplying N are not rotated as frequently as in the past. If most yield gains in modern varieties

Table 3: Effects of NPK with and without FYM (t/ha) on pearl millet and mustard yields (t/ha).

Districts	Application pattern of FYM	Pearl millet Yield(t/ha)	Fertilizer use in pearl millet		Mustard yield (t/ha)	Fertilizer use in mustard	
			N (kg/ha)	P ₂ O ₅ (kg/ha)		N (kg/ha)	P ₂ O ₅ (kg/ha)
Mahendergarh	FYM applied in pearl- millet	2.09	58.9	31.8	2.16	77.9	47.4
	FYM applied both in pearl millet and mustard	2.33	53.9	25.8	2.53	66.6	44.0
	No FYM Applied	2.09	58.0	29.0	2.19	71.1	45.0
	Average	2.10	58.4	30.8	2.18	75.5	46.5
Rewari	FYM applied in pearl- millet	2.28	64.8	33.7	2.32	71.7	50.1
	FYM applied both in pearl millet and mustard	2.21	67.5	28.9	2.46	50.2	33.1
	No FYM Applied	2.20	68.3	36.9	2.39	77.3	50.6
	Average	2.25	66.0	34.5	2.35	72.6	49.6

Note* 68.5% farmers HHs used FYM at interval of 4 Years, cost of FYM included labour cost too.

of cereal are due to N fertiliser, PMCS yields can also be increased by increasing its use. This is because an adequate supply of nutrients, especially for hybrids with high yield potential, can increase rainfall productivity, as the number of irrigations does not exceed an average of one: the water supply is almost fixed. Any additional factor (such as N application) which increases yields will increase water use efficiency. The balancing of N use rates, water use efficiency, and yield is the most important strategic point for PMCS in Haryana. N is the most important nutrient, and, being a protein, is involved in several metabolic processes which strongly influence the growth, productivity, and quality of crops. The harvest index is a fundamental factor affecting the capacity to mobilise photosynthates to plant organs, with economic value (Alvarez, 2022). Application of higher-than-existing rates of N/ha may result in the production of a greater number of secondary branches and siliquae plant; the same is the case for pearl millet. As farmers have started using pre-sowing irrigation in pearl millet and the crop-growing season is increasing, more N may be needed to improve system productivity in these districts. N and P use rates according to tube well depth are provided in Figs. 15a and 15b. Use of essential major nutrients (that is, N and P) also fluctuates as per depth of tube well in Mahendergarh district in pearl

millet (Fig. 15a). Doses of both N and P increased with the increased depth of tube wells. Use of N was estimated to be 61% more where tube well depth was >1000 ft, as opposed

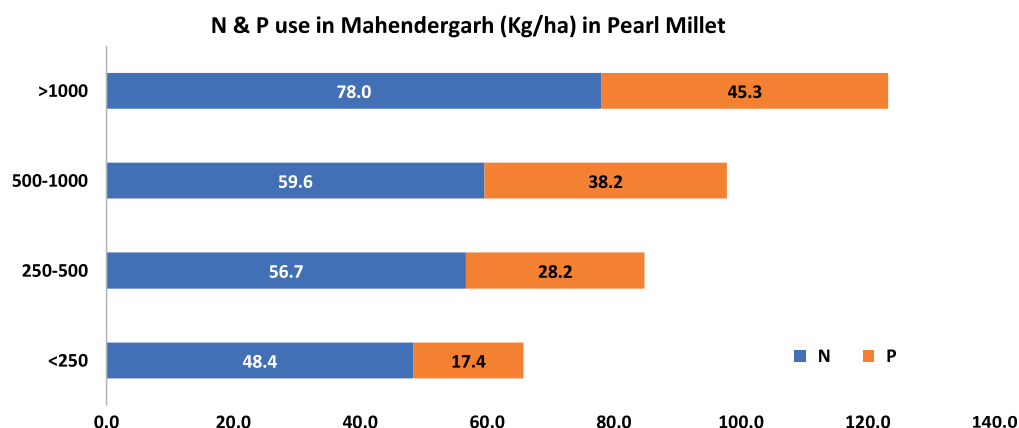


Fig. 15a. Use of nitrogen and phosphorus (kg/ha) in pearl millet according to tube well depth as reported by respondents in Mahendergarh district, Haryana

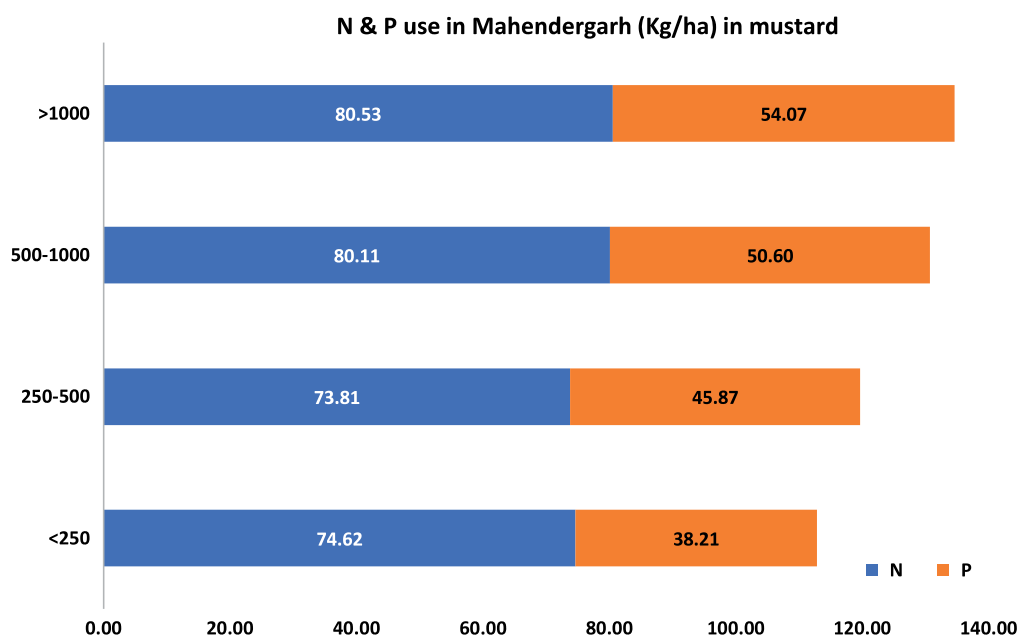


Fig. 15b. Use of nitrogen and phosphorus (kg/ha) in mustard according to tube well depth as reported by respondents in Mahendergarh district, Haryana

to tube well depth of <250 ft. The extent of fluctuation was greater for P: use of P increased by 62%, 121%, and 160% with increases in tube well depth from <250 to 250–500, from <250 to 500–1000, and >1000 ft, respectively. This might be linked to resources available to farmers or their risk-bearing capacity. N use in pearl millet increased up to 80 kg/hain blocks or villages where tube well depths were highest. N response seems to have depended on the characteristics of soil (medium) and on cropping intensity; this warrants further study. N use in pearl millet is determined on the basis of the yield potential of hybrids. However, this is not the case with mustard, where N use is the same across a tube well depth. The trend of N and P use according to tube well depth in mustard was not comparable to that in pearl millet: in mustard, N and P doses were enhanced marginally with an increase in tube well depth from <250 feet to >1000ft (that is, by 8% and 41%, respectively) (Fig. 15b). In both districts, DAP was the only source of P other than SSP. However, the direct effect of SSP in meeting the need of sulfur (S) in mustard needs further study. Almost all farmers surveyed used DAP as a basal dose as per the recommendation of CCS HAU, and in general, used a lower dose of P in pearl millet than in mustard. As with RWCS, the lower the temperatures encountered during mustard growth, the greater the amount of P required in the early growth stages, due to the low rate of P diffusion in the soil.

3.16 Irrigation

Lack of water in the southern districts is not an issue in Haryana, where micro-irrigation techniques such as sprinklers are used to save irrigation water (Fig. 16). Here, the main reasons for improved PMCS yield were better subsidies and a greater need to conserve water, given the districts' undulating topography and sandy soils. Mahendergarh and Rewari districts get the smallest allocation of canal irrigation water; however, these districts have done exceptionally well by adopting micro-irrigation, which besides saving water also offers higher production.

3.17 Cost of cultivation

3.17.1 Cost of cultivation of pearl millet

In the data presented here, the out-of-pocket payments from seed to harvest have been considered. Farmers' spending on the installation of deep tube wells is increasing, with shifts in attention to submersible tube wells incurring increased infrastructure development costs within small farms. This has not been counted as part of the expenses. Costs of tillage have increased to an average of INR 6152/ha. Individual farmers may not be able to purchase new machines, but the creation of private service providers will provide a steady stream of revenue from seed to harvest. The scarcity and cost of labour have increased the cost of manual weeding to INR4721/ha (Mahendergarh) and INR3154/ha (Rewari).

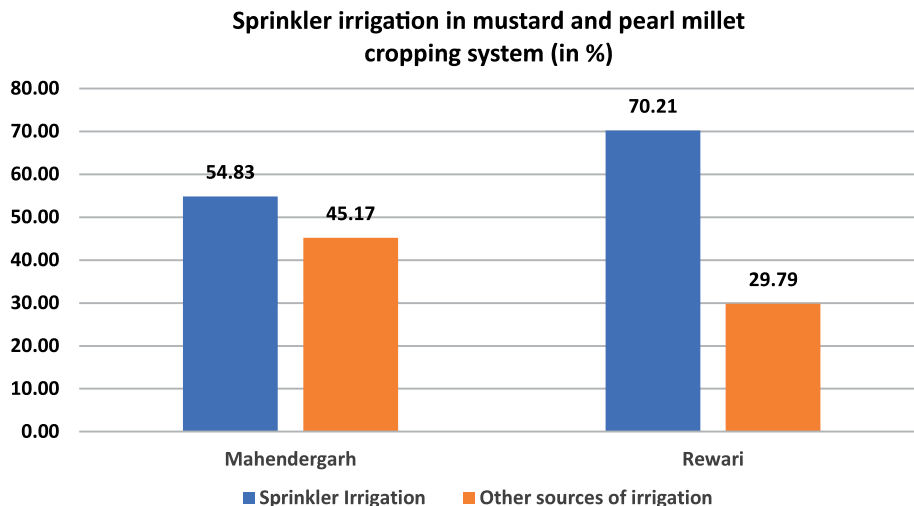


Fig. 16. Use of nitrogen and phosphorus (kg/ha) in mustard according to tube well depth as reported by respondents in Mahendergarh district, Haryana.

Harvesting and threshing costs have also increased, to an average of INR13,233/ ha (Table 4), highlighting the need for mechanisation at every stage of agricultural production. With few (especially post-emergence) herbicides at the farmers' disposal, the cost of weed management is also set to rise, and if the rental value of the land is taken into consideration there is an indication of a serious decline in profits from pearl millet cultivation. It is important therefore to approach every research and extension effort from a system perspective, and to incentivise farmers to achieve efficiencies by increasing their spending on new technologies, such as include precision farming through micro-irrigation systems and automation.

3.17.2 Cost of cultivation of mustard

When it comes to new technologies, the LDS data show that small and marginal farmers have adopted hybrid mustard despite the seed cost of INR2305/ha, which compares unfavourably to the cost of OPV seed. Using hybrid seed is the only way farmers can see to enhance their income and blaming high costs for the non-adoption of any technology is therefore not a credible argument. Harvesting and threshing costs (INR8243/ha and INR4662/ha, respectively) were ascribed to the use of manual labour, which is becoming increasingly scarce and costly. For all categories of farmers, obtaining a high income from mustard cultivation (Table 4) is an important way to realise gains, with cultivation costs that are comparatively low (INR 38,377/ha) compared to every other crop except pearl millet. Even the combined cumulative costs (INR71,153/ ha) will make this system profitable, with higher profit margins than those obtained with pearl millet.

Table 4: Cost of pearl millet cultivation based on primary data of 290 respondents (Mahendergarh) and 282 respondents (Rewari) districts, Haryana.

Production cost variables	Mahendergarh	Rewari	Average
Seed	1731	1934	1831
Land preparation	5562	6758	6152
Irrigation	1266	1018	1144
Herbicide	242	438	339
Herbicide	365	650	506
Weeding	4722	3153	3948
Harvesting	12927	13549	13233
FYM	2753	2178	2469
DAP	1823	1910	1866
Urea	643	718	680
Fertilizer application cost	338	483	410
Overall direct cost	32371	32789	32577

Note* Direct cost (out of pocket exp.) details does not include the cost of dry fodder of pearl millet. MSP of Rs 2250/qr for the year 2021-22. The FYM cost is based on average of four years for respondent who used FYM. Harvesting cost also include threshing cost.

The more interesting aspect of agriculture in Haryana is that there is one commercial crop in each of the state's four zones. Mustard farmers saw increased profits in 2021 due to good market price of mustard seed, and improved yields resulting from the large-scale adoption of hybrids. As labour, energy, and input costs are rising (see cost of tillage, weeding and harvesting, and threshing), mustard may continue to be more profitable, as it requires less use of inputs and labour than cotton, rice and wheat. However, energy costs could still be a drag on profit margins and tillage costs could be reduced. Labour intensive crops like cotton may see a decline in profits, but the profit margins of mustard and basmati rice could increase. In isolation, each crop may help farmers to improve profit margins and spend on the crops they grow in rotation with these crops. Owing to its high profit margins, mustard can be designated the commercial crop of this region, as low productivity in one crop will not challenge food security and farmers' disposable income as a result. These data provide grounds for optimism and indicate that the strength of the cropping system matters more than the yield of individual crops within it. Nevertheless, with input costs rising and yields stagnating, dependence on limited water resources will be a challenge. If yields do not increase, farmers will become demotivated. If we look at diversification, there is a need to understand this interaction (between food security and profit margins) through the lens of the success of PMCS. Farmers are adopting PMCS with

hybrids in both crops for the perceived benefits of the system rather than for any benefits provided by pearl millet or mustard individually. As for an alternative, introducing a pulse crop such as mung bean as part of a management strategy could be an option, replacing pearl millet and having a low cultivation cost.

3.18 Weed management.

Diagnostic monitoring of farmers' fields is important, as this can provide hypotheses by which to test the effects on weed flora of shifts in cropping patterns, crop management techniques and herbicides. Prior to this LDS, *Physallis micrantha* had not been identified as a

Table 5: Cost of cultivation and net returns of mustard of respondents from Mahendergarh (n=290) and Rewari (n=282) districts, Haryana.

Production cost variables	Mahendergarh	Rewari	Avg. cost of production
Land preparation	8580	12540	10532
Seed	2249	2363	2305
Fertilizer	4864	5912	5381
Irrigation	4913	3203	4070
Weeding	4641	1684	3183
Harvesting	7973	8522	8243
Threshing	4823	4496	4662
Farm gate price	5944	6197	6069
Overall direct cost	38043	38720	38377

Note* Direct cost (out of pocket exp.) details does not include the cost of dry fodder of pearl millet.

Table 6. Top five most troublesome weeds in mustard and pearl millet in Mahendergarh and Rewari districts, Haryana.

Rank	Mustard		Rank	Pearl millet	
	Most troublesome weeds	% HHs		Most troublesome weeds	% HHs
1	<i>Chenopodium album</i>	40.38	1	<i>Physallis micrantha</i>	31.47
2	<i>Orobanche aegyptiaca</i>	12.41	2	<i>Amaranthus viridis</i>	12.41
3	<i>Avena ludoviciana</i>	9.44	3	<i>Dactyloctenium aegyptium</i>	9.62
4	<i>Cynodon dactylon</i>	8.22	4	<i>Rottboellia cochinchinensis</i>	8.39
5	<i>Asphodelus tenuifolius</i>	6.99	5	<i>Catharanthus pusillus</i>	6.47

problem for pearl millet, but this survey has identified it as an important weed in PMCS. It used to be considered a widespread species and now is also referred as *P. angulate* and locally also called *Rasbhari*. Farmers were already aware of the other weeds presented in Table 5. Diagnostic monitoring of farmers' fields and the prevalence of *Orobancha aegyptica* in mustard has provided the hypotheses for testing the effects of cropping patterns, crop management techniques, and herbicides on weed flora shift.

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6. Lack of proper pest monitoring, evaluation, and learning: impact on the success of Bt. cotton in the cotton-wheat cropping system

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SUMMARY

- The first round of technological success came in 1978, through breeding the short duration cotton variety H777, using mass selection from a farmers' variety called *Bikaneri Narma*. The second round of success came after the approval of Bt. Cotton (*Bacillus thuringiensis*), which had a vital role in halting the adverse effect of resistance in *Helicoverpa armigera* (American bollworm). The first initiative intensified CWCS, whereas the second initiative helped in scaling up production and provided resilience to support pest management and decreased pesticide use.
- Further success may come from a strategic focus on post-bollworm resistance management using Bt. technology. This is because the foundation technologies and their acceptance have gradually started showing the emergence of new problems. How much shift has happened and how it will change the trend needs more focused attention and evidence through a change in strategy in favour of survey and surveillance of cotton. Watchfulness and the monitoring of changes in pest spectrum, through light traps, pheromone traps or in situ assessments, is essential. This should be highly granular: risk assessment can be done best in farmers' fields and not on experimental farms where operations are mostly under controlled conditions.

- The problem of pink bollworm (PBW) and whitefly is eroding the advantage of new varieties and agronomic practices. Alternative solutions can include the use of different non-chemical methods and public awareness-raising. Similarly, trends regarding shifts in the weed spectrum in wheat are veering towards resistance development and its management.
- The frequency of pesticide use is a changing cycle, with trends moving gradually in the direction of a very small increase in the frequency of pesticide sprays, a complex of PBW, cotton leaf curl virus disease (CLCuD) and wilt, or a combination of all three. The possibility of a reduction in the frequency of pesticide use from the current average of three applications is slim. Integrated pest management, which focuses on the prevention of pests and the damage they cause, should be promoted where Bt. cotton remains promising.
- Heavy rains during September and their damaging effects which lead to serious yield reduction have pushed farmers in Hisar into RWCS from CWCS. Increase in the water table in the areas bordering the CWCS belt may result in a decrease of the area under cotton and an increase in the area under rice. Hisar district used to have a leading position in cotton production but is now struggling to resolve yield barriers. The current situation dictates the urgency of canal lining in the areas where a rise in the water table may reduce the area under cotton.
- The end of the era of cheap labour has made the harvesting and threshing of cotton costly, and the scarcity of labour may even delay the picking process, spreading it over a few months. This may encourage farmers to adopt mechanical picking of cotton, which should be promoted. The labour shortage may become a trigger for the mechanisation of CWCS, from seed to harvest.

1.0 Introduction

Cotton is the collective name given to four species of plants in the *Gossypium* genus: *Gossypium hirsutum*, *G. barbadense*, *G. arboreum* and *G. herbaceum*, which are perennial shrubs in the family *Malvaceae*. Only *G. hirsutum* (American cotton) and *G. arboreum* (desi cotton) are grown in these ecologies, with American cotton dominating. CWCS is long-established in north-western parts of Haryana and is a grain-plus-cash cropping system, with cotton being the fabric of the area's economy and wheat a component of food security. The economy of districts in Haryana including Sirsa and Hisar is consistently influenced by the production and processing of cotton. There is lot of agri-trading, agro-industry and agricultural export through public and private sector investment in agricultural marketing infrastructure and facilities.

Cotton cultivation is more successful in the western and south-western districts than the north and north-eastern parts of Haryana, where the area and production under desi cotton have decreased (Pooja Rani, 2019). There was a serious decline in the yield of cotton in the late 1990s and early 2000s due to insect resistance, as well as a serious information vacuum that led to speculation that pesticide quality was the culprit.

Wheat yields are relatively low because of its delayed sowing, which in turn is due to the late vacation of the cotton fields. The main requirement for improving system productivity was the introduction of early maturing cotton. This was strikingly new in the intensification of CWCS, with early maturing varieties of American cotton making it possible to increase wheat yields in this system.

The creation of a good marketing infrastructure has encouraged farmers to grow commercial crops, such as cotton in Sirsa, Hisar, and Bhiwani districts, rice in north-east Haryana and the bordering districts, mustard in Rewari and Mahendergarh districts, and sugarcane in central parts of the state, including Rohtak and Sonapat districts. The need for a regular cash flow encouraged a line of thinking among farmers where crops and livestock assume greater relevance, providing another sign of farmers' financial stability. These are part of broader trends: the monoculture of CWCS and unlimited use of pesticides during the late 1990s and early 2000s resulted in slow cotton yield growth, with serious problems of crop failure due to pest resistance in cotton. This crisis led to a notable shift towards the use of

Bt. cotton. Bt. cotton, which provides resistance to several bollworm species, was commercialised in India in 2002. The Maharashtra Hybrid Seed Company (Mahyco) and Monsanto were the first to evolve Bt. cotton, followed by Rasi Seeds in 2004. This cropping system is encountering new challenges brought about by the rising water table; nevertheless, CWCS has increased gradually in new ecologies, with a great deal of research and extension efforts having stabilised the system. The scope of change to the status quo through diversification is limited, as cotton is a cash crop which protects the interest of farmers. The systematic institutionalisation of a monitoring, evaluation, and learning programme would help to understand practical issues, with the introduction of a mechanism of oversight needed to ascertain what is happening at the ground level.

2.0. Study area and survey methodology

2.1 Adoption survey of production practices in cotton-wheat cropping system

The production has become more commercial but risky with the development of insect resistance and delayed wheat sowing. The research and extension planning process needs to contain far more evidence-based decision-making and up-to-date information on the adoption patterns of different technologies in CWCS. This will contribute to the understanding of how technologies have been adopted and what could be important feedback for researchers and policymakers. It is also important to find out more about farmer preference, and how varietal spectrum, pest spectrum, and investments have changed, as well as how the university should prioritise its research and extension, and how much investment DOA needs to make in extension activities, including incentives to farmers. There is a need to retreat from a top-down in favour of a bottom-up approach. Detailed farm survey data collected from two districts were expected to demonstrate regional differences; the yield variability across districts has been sufficiently accounted, and technology adoption has changed since 2000 when insect resistance impacted on the scenario with a focus on IPM.

2.2. Study area

The LDS is a representative sample survey conducted in two districts – Sirsa and Hisar – which have been the core areas of CWCS in Haryana. Sirsa is situated in the south-west of the state (latitude 29.250 N, longitude 75.40 E) at an altitude of 202 m above main sea level. Its climate is extreme: arid, very hot in summer and very cold in winter. The maximum temperature recorded in May and June is 47°C and the minimum touches 1.5°C in December and January. Dust storms, which adversely affect cotton in sandy areas of the district, are common in summer. The rainy season starts in July and lasts up to September, with 75% of rain falling in July and August; however, rainfall is uneven and scanty, averaging around 300 mm and varying considerably from year to year. In addition to CWCS, other rotations are paddy–wheat, cotton–raya, guar–wheat, and guar–raya[2]. Citrus and *ber* orchards also exist in Sirsa. There is scope for planting horticultural plants, citrus, *ber*, guava and aonla. There are fewer than 30 rainy days per annum.

Hisar district (28° 59' to 29° 49' N latitude, 75° 11' to 76° 18' E longitude) has two subdivisions (Hisar and Hansi) and nine development blocks. Annual rainfall is erratic, ranging from 300–450 mm; humidity ranges from 25%–90%. There are an average of 27

[2] *Raya* is rapeseed; *guar* is an important legume crop; *ber* is a fruit.

rainy days each year (78% SW monsoon, 3% post-monsoon, 7% winter rainfall, and 12% pre-monsoon rainfall). The topography of the district is slightly undulating to the Aeolian plain with moderately-to-severely eroded sand dunes. Soils are Aridisols, ranging from clay-loam to sandy, with a pH range of 7.5–9.0. The amount of nitrogen (organic carbon basis – N), iron, sulphur, manganese (Mn), and zinc (Zn) present in the soil are low; phosphorus (P) ranges from low to medium; there is a medium amount of potassium (K). In Hisar, 69%, 21% and 10% of water is poor, marginal, and good quality, respectively.

Hisar district follows cotton–wheat, paddy–wheat, guar–wheat, and bajra–wheat crop rotations. On average, 68% of soils are sandy loam, 23% are sandy and 9% are clay. Wheat acreage in the district has increased at the expense of gram (a pulse crop) in the late 1970s and 1980s, and the percentage of acreage under the jowar fodder crop has increased slightly.

2.3. Data collection using Open Data Kit

The LDS was conducted by RAWE students from CCS Haryana Agricultural University, Hisar, in October and November 2022. The students were supported by a multidisciplinary team from the departments of Agronomy, Agricultural Economics, and Agricultural Extensions, as well as the KVK teams and the CSISA project. Training was provided in survey design and methodology, as well as hands-on training in data collection. Two districts were pre-selected along with a predetermined number of villages, after which farmers were selected from the villages; ‘village’ here refers to one cluster. Data were recorded on students’ mobile phones using the ODK Collect app (explained by Anurag Ajay et. al., in chapter one of this publication). ODK Collect is an open-source Android application used for survey-based data gathering. It supports a wide range of question-and-answer types and is designed to work well without mobile internet or even network connectivity. Raw data were checked by the relevant faculty of the university before being transmitted to the ODK data server.

3.0 Results

3.1 Factors affecting adoption of technologies

3.1.1 Land holding (acres) and tenure status

Of the total 552 farmers interviewed, approximately 89% had their own land, 8%–10% cultivated leased-in land, and <1% of farmers in Sirsa and 2% of farmers in Hisar shared land (Table 1). The total cultivated area under cotton in Hisar is 2.8 acres and 5.6 acres in Sirsa, with 4.2 acres as the overall average for both districts. Similarly, the average wheat

Table 1: Distribution of selected sample households among leased-in, shared and own land, and average acreage land distribution of cotton, wheat, and under CWCS in the study locations (n=552).

Districts	% HHs (own)	% HHs (leased in)	% HHs (shared)	Averages area under cotton (acre)	Averages area under wheat (acre)	Averages area of CWCS (acre)
Hisar	89.26	8.52	2.22	2.8	3.2	9.4
Sirsa	89.01	10.28	0.71	5.6	6.6	12.9
Overall	89.13	9.42	1.45	4.2	4.9	11.1

cultivated area in Hisar is 3.2 acres and 6.6 acres in Sirsa district, with 4.9 acres the overall average. The area under CWCS is 9.4 acres in Hisar and 12.9 acres in Sirsa, with 11.1 acres the overall average of both districts (Table 1).

In land sharing, owners and tenants share equally in the output and cost of inputs such as fertiliser and seed. With leased-in land, the landowner receives rent in cash, ranging from INR30,000–INR35,000/ acre depending on land quality. There is a shortage of labour, which is generally hired to pick cotton; machines are not used.

3.1.2 Educational status

The study highlights the educational level of all the interviewed farmers (n=552), with 13% never having attended school, 29% having completed primary school and 27% having matriculated; 17% have completed senior secondary, 10% have a Bachelor's degree and 4% have a Master's degree (Fig. 1).

3.1.3 Caste category of sample farmers

The study suggests that 70% of farmers interviewed were from the general category of caste, 18% from the so-called OBC and 8% from other categories. Only 4% were from a scheduled caste (Fig. 2).

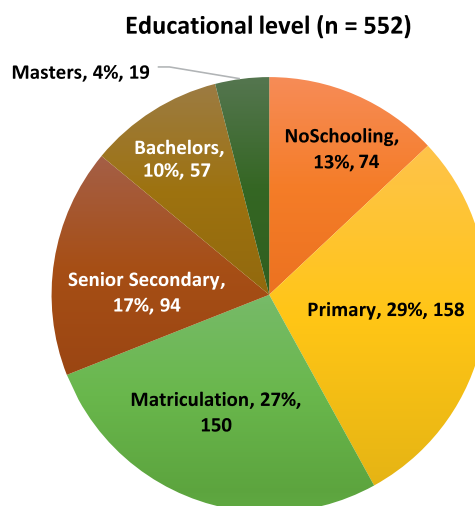


Fig. 1. Education level of households following CWCS, in Hisar and Sirsa districts, Haryana

3.1.4 Household members and possession of ruminants

Households participating in the study averaged six members, with an average of two involved in agriculture and an average of four ruminant animals in each household (Fig. 3). With the relative strength of one ruminant/ha, there is little concern about feed and fodder for ruminants. These households are well-embedded in the farming system, which is probably one reason for their ability to sustain the risks associated with pests and the damage caused by untimely rains once or twice every 10 years.

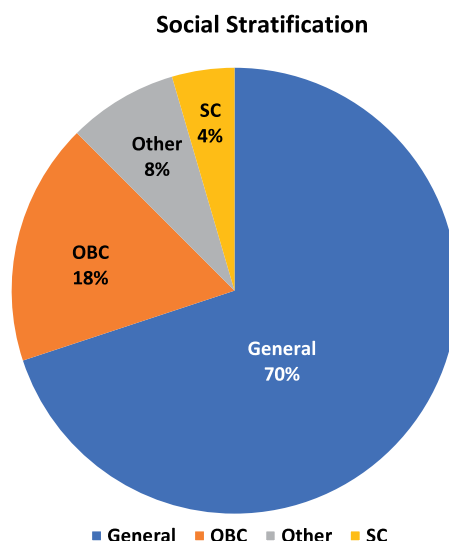


Fig. 2. Social stratification of households in terms of production practice in CWCS, in Hisar and Sirsa districts, Haryana.

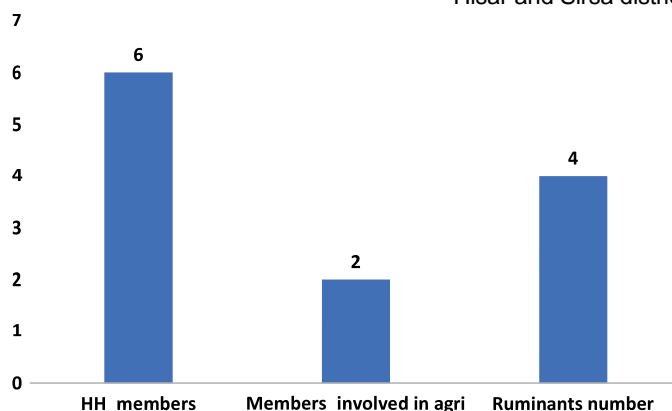


Fig. 3. Break-up of HHs members and their contribution towards agriculture and number of ruminants linked as alternate sources of income.

3.1.5 Women participation

In terms of women's participation in decision-making in agricultural activity, 58% of decisions were made by male household members, 41% were made jointly, and just 1% of decisions were made independently by women (Fig. 4). However, during the interview to assess women's decision-making and participation it was observed that 84% of women farmers participated in joint decision-making along with their male spouse in all agriculture activity, but just 16% participated jointly in the interview (Fig. 5).

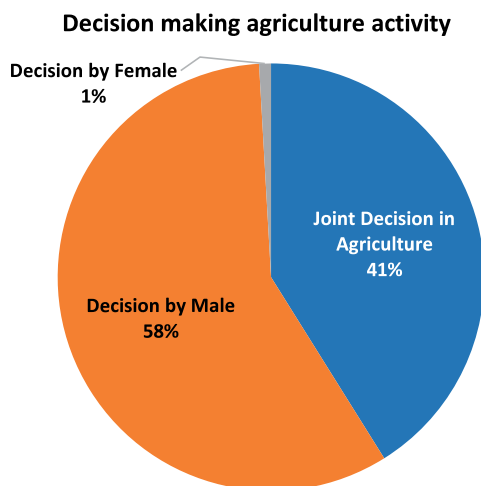


Fig. 4. Role of men and women in decision-making in CWCS, in Sirsa and Hisar districts, Haryana.

Women decision making and participation

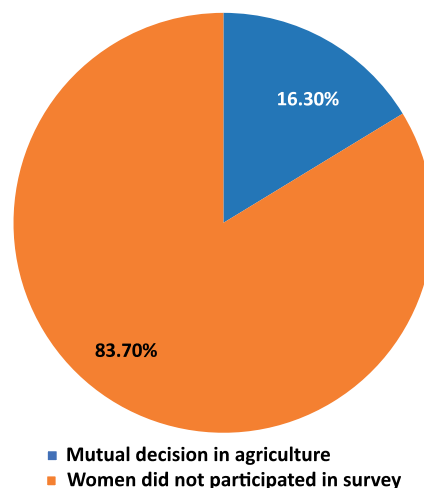


Fig. 5. Participation of women farmers in making decisions about cultivation practices in CWCS, in Sirsa and Hisar districts, Haryana.

3.1.6 Digital farm services

The survey data show that 159 farmers out of 552 (29%) received agro-advisories in the form of mobile phone messages from e-Mausam, HAU. Of these, 14% of farmers followed them wholly, 76% followed them partly and 10% did not follow them at all (Table 2). This suggests that the content of the advisories needs improving to encourage more farmers to follow them: the more farmers follow them, the better. In particular, the agro-advisories should target pest management. This is where a large amount of monitoring and a database is essential to avoid risks associated with misinformation.

Table 2. Adoption and usefulness of e-Mausam agro-advisory provided to farmers through CCS HAU, Hisar.

Survey statement		Advisory Benefits		
Did you receive any agro-advisory mobile phone message from e-Mausam HAU?	No.of advisories received	159	% received	28.8
	Utilisation of advisory %			
Do you follow the agro-advisory received from e-Mausam of HAU?	Advisory followed	Fully	Partly	No
		13.8	76.1	10.1

3.1.7 Land holding characteristics

There is negligible scope for expansion of cultivable land, but still the average

There is negligible scope for the expansion of cultivable land. The average landholding size (<https://pib.gov.in/newsite/PrintRelease.aspx?relid=188051>) in CWCS-based districts is more than in others (8% of landholdings in Hisar, 10% in Sirsa). The proportion of marginal holdings is 10% in Hisar and 7% in Sirsa. Land distribution is highly skewed, with the large majority of farmers in the category of semi-medium landholders and above. A large proportion of households are in the medium and semi-medium categories (26% and 37% of households in Hisar, 36% and 31% in Sirsa, respectively). Almost 80% of households are in the medium and above categories of landholder (Figs. 6a and 6b). With the dry climate (especially in Sirsa district) there is some scope for diversification in favour of fruit crops, especially citrus fruits like *kinnow* and grapes. There is also better scope for precision agriculture, involving tightly controlled operations which can help avoid emerging problems associated with climate change. Problems associated with resistance development can be resolved by diversifying the cropping system. As most farmers belong to the semi-medium and above category, emerging problems could be addressed through better communication between them, for example about good agronomic practices and new pest management recommendations.

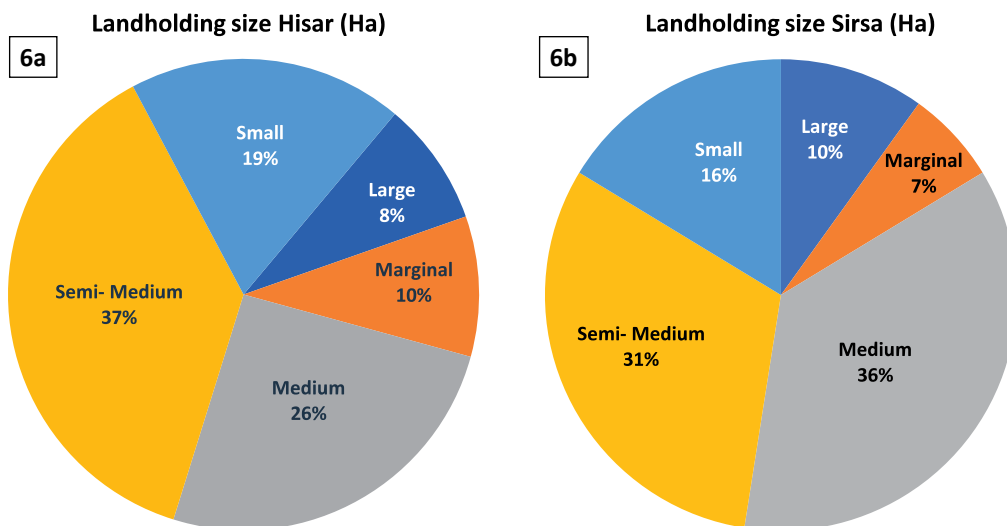


Fig. 6a, 6b. Landholding size (in ha) according to household (%) in Hisar and Sirsa districts, Haryana.

3.2 Adoption of varieties

Bikaneri Narma (an unspecified strain popular with mid-1970s farmers in mid 1970s) which matured a little earlier than all other varieties made the cotton-wheat system more attractive to farmers. H777 was developed by a mass selection of plants from this variety in 1978. Earliness is a desirable character which had two advantages: it leads to the intensification of CWCS and supports the crop to escape late-season pests such as bollworm. The background to subsequent new varieties including HS45 and HS6 was the same.

In India, the hybrid cotton era started after 1970, and four hybrids were released in recognition of their importance. In the 1990s, intensive use of insecticides, especially synthetic pyrethroids created resistance in pests including cotton bollworm (*Helicoverpa armigera* Hübner). The transfer of a gene from *Bacillus thuringiensis* (Bt.) into cotton represents one of the most advanced applications of biotechnology. In 2002, the development and commercial cultivation of the Bt. cotton hybrid, the country's first transgenic product, provided a revolutionary landmark in Indian agriculture second only to the Green Revolution of the 1960s. Bt. cotton proved very useful for farmers, resolving the issue of pest resistance which had caused them a great deal of anxiety in 2001, and saving cotton (and the farmers) from the worst crisis of the time. The Genetic Engineering Approval Committee (GEAC), an apex regulatory government organisation in India, allowed the commercialisation of Bt. cotton in 2002 in India's central and south zones but not in CWCS in the north-western plains. In 2005, GEAC approved 16 cotton hybrids, including six for the north zone, covering CWCS and thus making the technology available to the entire country. This proved a strategic fit for the private sector, resulting in the current almost 100% adoption of Bt. cotton. It was transformational for farmers, improving their profit margins and supporting those trapped in debt because of pest resistance. Bt. cotton brought additional environmental advantages, such as the reduction in the frequency of pesticide spraying; however, recent trends indicate shifts in the pest spectrum in favour of PBW. Unique panel data collected between 2002 and 2008 indicate that Bt. cotton yields increased by 24% in India, alongside the benefit of a reduction in pesticide use (Kathage and Qaim, 2012). Most new developments in cotton have been themed around Bt. cotton (Fig. 6), with a successful two decades having seen many developments, from bollgard 1 (BG I) to bollgard II (BG II) technologies. Most farmers surveyed expressed a preference for American cotton, with only 3% of households reporting growing desi cotton, suggesting a decrease in its demand. Bt. cotton has become an integral part of cotton cultivation (Fig. 6) in these districts, with BG II being the farmers' first preference. Bt. cotton hybrids are no longer dominated by multinationals, with most new hybrids coming from Indian companies such as Rasi Seeds.

Bt. cotton plus BG II technology has shaken up the adoption pattern in cotton in Sirsa and Hisar districts. Rasi Seeds operates on a much bigger scale than when it first appeared in the state, with most Bt. cotton hybrids (90%), including RCH 773, 650 and 926, dominating in two

districts. Among all three, RCH 773 has been adopted by 79% of households in Sirsa, with just one hybrid, Solar 76, having been adopted by 7% of households in the district. RCH 773 has been reported to perform better where there is a whitefly; it also tolerates attacks by sucking pests (Fig. 7), and hybrids which mature early have a better chance of escaping PBW.

Early sowing completed in the first half of May facilitates plants to exploit the favourable period for better growth and at the same time to avoid the late season insect problem (late seeding also leads to more problems associated with CLCuD and fruit shedding). Last irrigation should be cut off a little early to stop the production of the green bolls that feed PBW: this should be done regardless of when the crop is terminated. Mistakes may have occurred in the management of Bt. cotton leading to new pest problems. Farmers in the Hisar district have struggled to harvest good yields, with many encountering heavy losses. To represent the actual yield potential of varieties, seed cotton yield data from the Sirsa district, where farmers remained unaffected from damage caused by rains, have also been included (Fig. 7). Within the RCH group, the best seed cotton yield level (1.6t/ha) was recorded in RCH 773 (Fig. 8). Overall, Solar 76 was the most successful, with average yield levels of 1.8t/ha, and if these yield levels sustain, its adoption may increase in future.

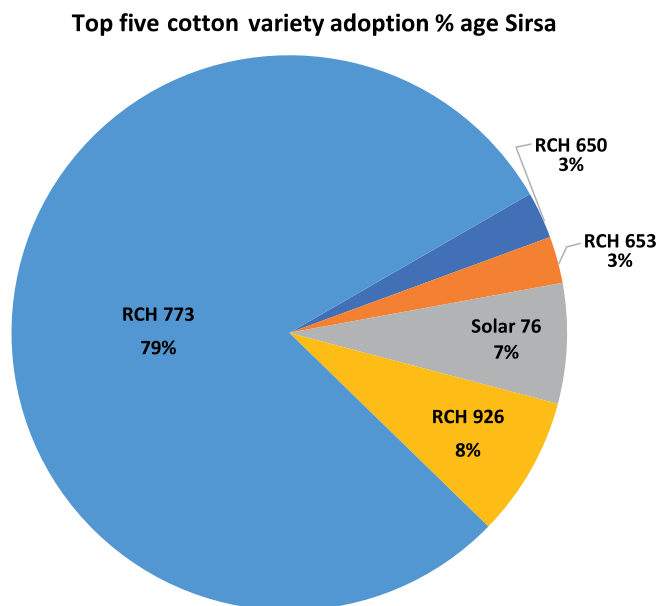


Fig. 7. Percentage of households cultivating Bt. cotton hybrids (2021) in Sirsa district, Haryana.

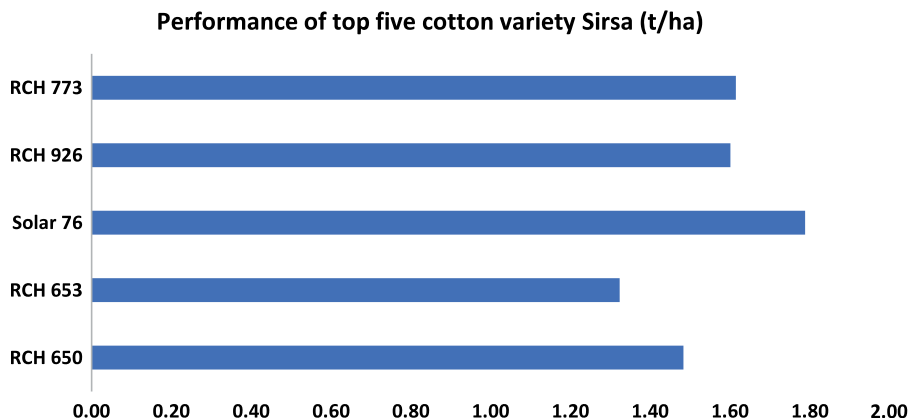


Fig. 8. Seed cotton yield (t/ha) most prevalent Bt. cotton hybrids in Sirsa district of Haryana.

With the introduction of Bt. Cotton, resistance against pests was controlled, saving farmers input costs and improving yield. Earlier reports (Mayee et al., 2008) also showed that after five years of worst-case scenarios, cotton productivity increased significantly, from 300 kg lint cotton/ha to 558 kg lint cotton /ha.

3.3. Seed rate

Highly branched monopodial cotton varieties/hybrid seed require wider spacing than non-sympodial types, with farmers adopting closer (75 x 15 cm or 67.5 x 15 cm) to a wider spacing (75 x 30 cm), depending on the compactness of varieties. For Bt. cotton, farmers adopt a wider spacing of 90 x 90 cm, resulting in a reduction in seed rate from 4–6 kg/ha to 1.4–1.5 kg/ha.

3.4. Irrigation

Cotton is cultivated under irrigated conditions, requiring 800–1000mm of water during the crop period. This includes rainwater during the monsoon season which helps obtain optimum yields.

Respondents reported about 4.5 irrigations in Sirsa and 3.5 in Hisar (Fig. 9), of which pre-sowing irrigation is the most important. Water stress should be avoided during flowering and fruiting which is why irrigation is applied at the end of August and September, with the final irrigation

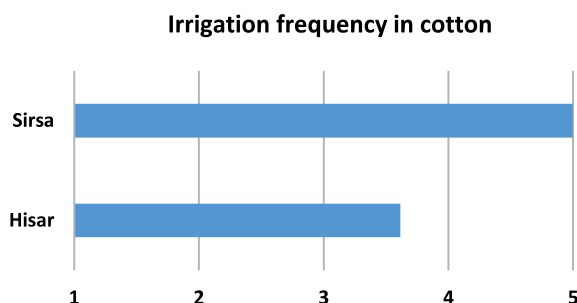


Fig. 9. Irrigation frequency in cotton and wheat

before the bolls start to open. In 2021 and 2022, the rain after this stage adversely affected the crop, resulting in extremely low seed cotton yields in some villages. This has been reported separately by farmers as well.

In Sirsa district, the main irrigation is via the Bhakra canal system. Canal irrigation is the main source of irrigation, with a small percentage of households adopting tube well irrigation. Water conservation techniques (including laser levelling, judicious use of problematic water, and construction of *pucca* water courses) need to be popularised.

3.5 Nutrient management

The use of NPK is close to recommended doses, with the ratio appearing better than in PMCS or RWCS. Farmers have made reasonable use of nutrients, with NPK use in cotton at 103, 54, and 30 kg/ha in Hisar, and 116, 56, and 60 kg/ha in the Sirsa district (Fig. 10). The use of K is greater than in other cropping systems, especially in RWCS. N use is less than recommended for Bt. cotton in CCS HAU's package of practices; P and K use is very close to recommendations. The relative increase in the pest problem might have pushed up P and K (but not N) use. Farmers in Sirsa seem to have a better-informed view of NPK recommendations to increase their yield; farmers in Hisar seem to have an informed view on avoiding risk resulting from the rising water table. In Sirsa, farmers' increased use of K may be to hedge against certain diseases.

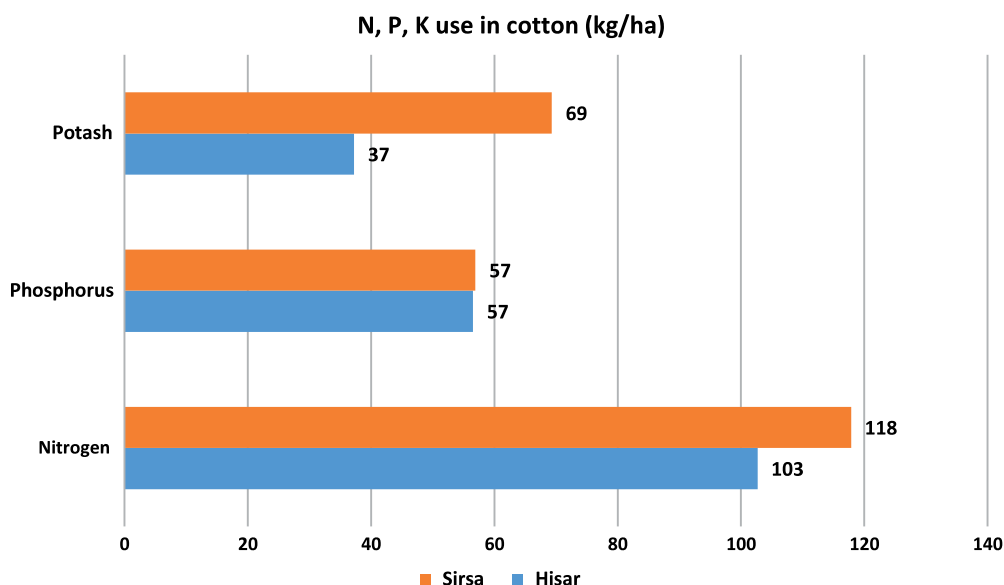


Fig. 10. Use rates of N, P and K in cotton in Hisar and Sirsa districts, Haryana.

Gebaly (2012) reported that cotton accumulates more K from the soil, with developing bolls a strong sink for K. In dry areas like Sirsa, lack of moisture might mean that the cotton plant cannot remove it from the soil, even if K is present. Similarly, P appears more important in the reproductive phase of cotton (Yang et al., 2012), an argument supported by recommendations from HAU. If for any reason P fertiliser is not applied at the time of sowing, it should be applied after the first irrigation (45–50 days) by means of DAP fertiliser using the *pota* method. N use in CWCS in the districts is fairly stable.

In wheat, total NPK use was in the ratio of 141:66:57 in Hisar; in Sirsa, this was 133:72:57 (Fig. 11).

3.6 Disease management

Disease management needs better integration, and LDS data was analysed in an attempt to understand the prevalence of the spectrum of diseases in cotton. The ecosystem has compounded with more than one disease in cotton (Table 3). Although more cases of different pathological diseases affecting cotton have arisen in the last two decades, 51% of households in Hisar and 32% in Sirsa report no incidence of disease (Table 3). The survey indicated that

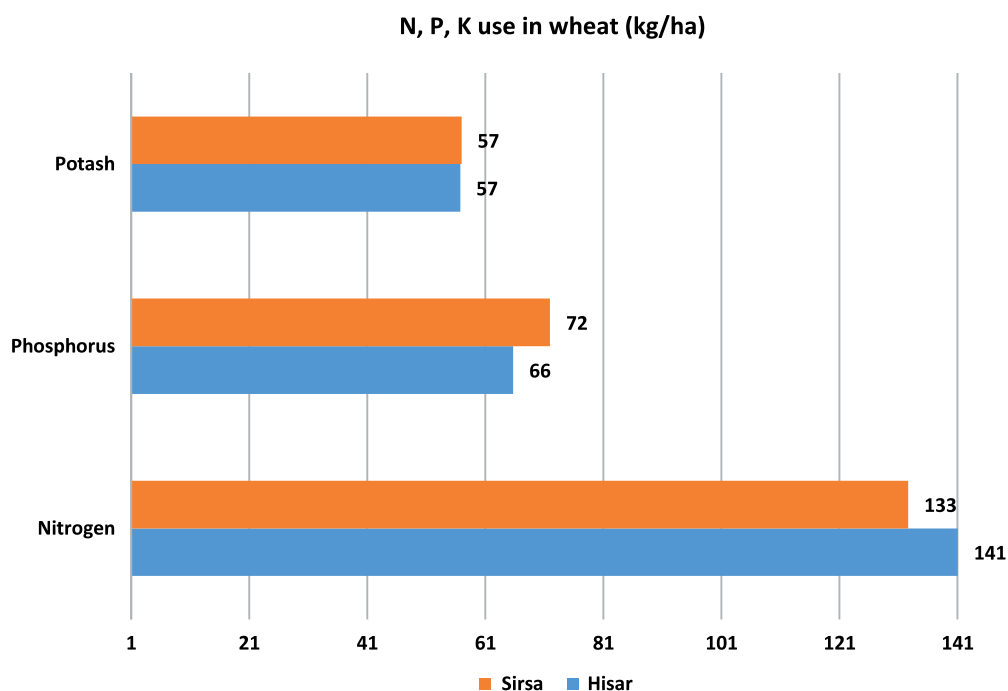


Fig. 11. NPK use in wheat in Hisar and Sirsa districts, Haryana.

Table 3: Plot-level cotton diseases in 2021 by survey respondents in Hisar (n=270) and Sirsa (n=282) districts, Haryana.

District	Disease incidence	No. of HHs (n)	% HHs reported incidence
Hisar	CLCuD	54	20.0
	Wilt	39	14.4
	Both CLCuD and Wilt	39	14.4
	Other disease	1	0.4
	No disease incidence	137	50.7
Total (n)		270	100
Sirsa	CLCuD	24	8.5
	Wilt	51	18.1
	Both CLCuD and Wilt	108	38.3
	Other disease	9	3.2
	No disease incidence	90	31.9
Total (n)		282	100

CLCuD was the most frequently occurring disease, followed by the problem of wilt. Incidence of CLCuD alone was reported by 20% of households in Hisar and 8.5% in Sirsa districts, but its incidence along with wilt was more frequent in Sirsa (38% HHs) than Hisar (14% HHs). The incidence of wilt alone was similar (14%–18%) in both districts; bacterial leaf blight had limited frequency (Table 3). CLCuD decreases with rainfall, which explains its greater frequency in combination with wilt in Sirsa, which is relatively drier than Hisar district. Data indicate that in both districts, a random pattern of diseases has been recorded, with some indication of higher incidence in Sirsa district. This means that these diseases can occur anywhere in CWCS in the state. A host of insects, especially whitefly (*Bemisia tabaci*), are responsible for the occurrence of CLCuD, the prevention of which requires the timely management of whitefly. Farmers use a spectrum of fungicides, insecticides or even growth regulators; however, the focus should be on preventing infestation, making it more important to monitor diseases and any required treatments. The research system should be in a state of readiness to find solutions; when trends are identified, this will facilitate the creation of awareness among farmers, enabling them to take risk-mitigating action in good time. Managing a mix of diseases may compound the schedule of pesticide use, either as mixtures or the sequential treatment of pesticides reported by respondents.

Obtaining primary data such as this from actual agricultural situations in farmers' fields should happen regularly, in order to understand shifts in the pest spectrum and to guide their management options. However, the cumulative incidence has not surpassed expectations arising from past scenarios. The consequence of this change is reflected in the fungicide use pattern in two districts. Even with increased frequency of some of these diseases, only 24.4% of households use fungicide in Hisar, where its use is still very low compared to that of 56.4% of households in Sirsa district (Fig. 12a). The frequency of

one and two sprayings of fungicide is 17.8% and 6.7% of households in Hisar and 54.3% and 2.1% of households in Sirsa districts, respectively (Fig. 12b).

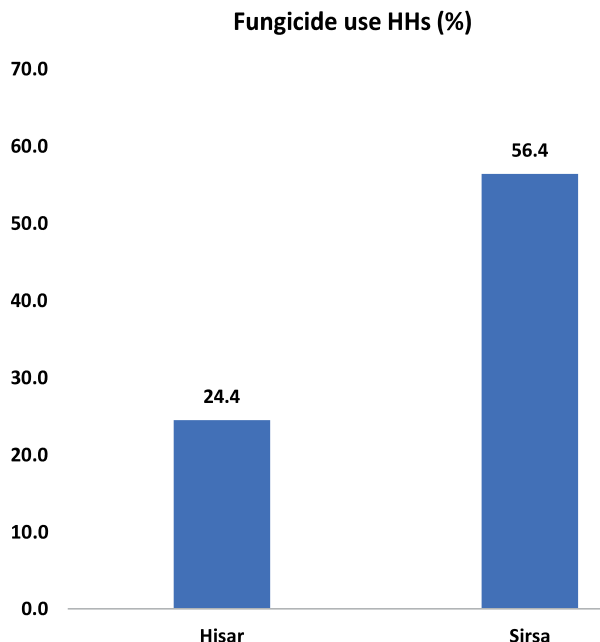


Fig. 12a. Percentage of respondent households applying fungicides to cotton (Sirsa n=282, Hisar n=270).

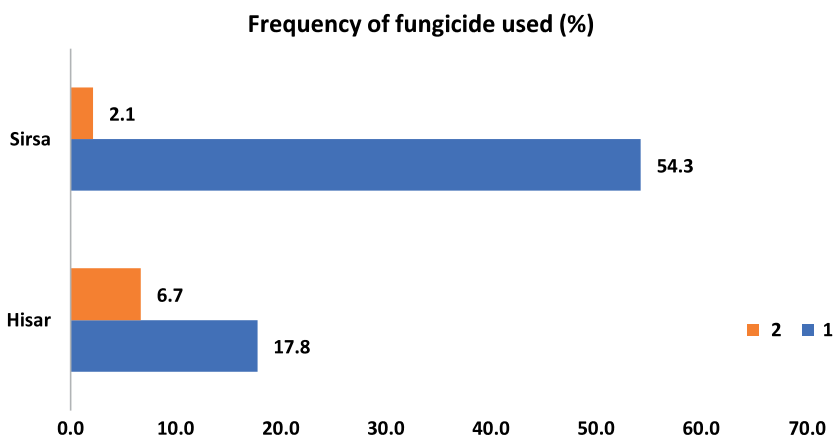


Fig. 12b. Percentage of respondents who applied one or two sprayings of fungicides to cotton (n = 552) in Hisar and Sirsa districts, Haryana

This is because each of these pesticides (as well as a few cases of growth regulators) each have different targets, which is why some pesticides used by farmers also include insecticides, which help to manage whitefly. After the occurrence of these diseases, pesticide use has little effect; nevertheless, some pesticides help to avoid serious losses. Spot treatment with Mancozeb or Carbendazim is more common, used by 35% (22.7%+13.48%) of households in Sirsa and 12.5% (8.15%+4.44%) of households in Hisar districts (Table 4). The economic rationale for using Bt. cotton is that the number of insecticide shots has not increased, as is being argued in many quarters. The most basic consideration is monitoring. If regular surveys and surveillance had been a standard feature in the past, farmers could have avoided heavy losses. Conversely, the private sector was able to evolve Bt. cotton because surveys and surveillance were regular procedures. After all, cotton pests have evolved to survive in an ecosystem that depends heavily on pesticides. The perception that pesticide use has started to increase may not be correct at the time of writing (Table 5) but it may gain weight if a proper monitoring mechanism is not put in place.

Farmers have also reported the occurrence of wilt (also called *parawilt* or *tirak* disease and considered a physiological disorder). Its symptoms include the yellowing and reddening of leaves followed by early shedding/early opening of bolls. Bacterial blight also affects cotton in rainfed and dryland conditions.

3.7 Insect Resistance

During the mid-1990s, poor insect control reflected the pressure farmers were under because of losses to revenue and the high cost of insect management. It was unclear why insects were not being controlled, even after 20 shots of pesticide. This affected farmers but not dealers or distributors, who increased their sales of pesticides, with farmers' revenues much lower than their cultivation costs.

Table 4: Five most frequently used pesticides* against common diseases in cotton. (n=552).

Rank	Hisar (n-270, users- 66)	% HHs	Rank	Sirsa (n-282, users -159)	% HHs
1	Mancozeb	8.15	1	Carbendazim	22.70
2	Carbendazim	4.44	2	Mancozeb	13.48
3	Azoxystrobin + tebuconazole	1.48	3	Azoxystrobin + tebuconazole	04.26
4	Copper oxychloride	1.48	4	Mancozeb + carbendazim	03.55
5	Mefenoxam	1.48	5	Copper oxychloride	02.84

*Note: total number of 24 products used by respondents. The second spray was done by 10.65% users of first spray from both districts.

In the 1990s, intensive use of insecticides, especially synthetic pyrethroids, created resistance in pests such as cotton bollworm, or *H. armigera*. This was a metabolic resistance and is not yet fully understood. Economic Survey (2003–04) by the Directorate of Economics and Statistics, Ministry of Agriculture, highlighted three drought years in the 1970s (1972–73, 1974–75, and 1979–80) and 1980s (1982–83, 1986–87 and 1987–88) which led below-trend growth, while ecological problems such as insecticide resistance frequently led to crop failure and serious loss to farmers income. Risks arising from natural calamities such as drought can be compensated, but those associated with region-specific ecological problems lead to a drop in income per head over a period of four to five years. Most farmers in the late 1990s were heavily in debt and bought most inputs on credit.

Cotton farmers incurred heavy losses from 1996 to 2001 due to the failure to control *H. armigera*, a crisis which led to new opportunities in the form of the evolution and spread of Bt. cotton. In effect, rates of return improved significantly by introducing new management strategies, including Bt. cotton + insecticides.

3.7.1 Prioritising insect resistance in the 1990s and now

Farmers generally operate in a complex and dynamic environment. The cotton bollworm complex includes the false American bollworm (*H. armigera*), pink bollworm (*Pectinophora gossypiella*), spotted bollworm (*Earias vittella*) and spiny bollworm (*Earias insulana*). Among these, *H. armigera* is the most dominant and difficult to control, chiefly due to its having developed resistance to most insecticides. *Helicoverpa* resistance in the late 1990s led to a deep crisis, with the very high frequency of insecticide use (sometimes 20 sprays or more) producing no result, and the lack to alternatives resulting in an inability to manage the *Helicoverpa* issue, eroding any advantage provided by new varieties and agronomic practices. The need to safeguard farmer interests provided the justification for the evolution of cotton able to resist the menace of bollworm, and Bt. cotton, arriving on the scene as a result of genetically modified organism (GMO)-based technology, came to the farmers' rescue (see varietal development). To achieve this, the Bt. gene was isolated and transferred from a bacterium (*Bacillus thuringiensis*) to American cotton. Bt. cotton thus contains a foreign gene which protects plants from bollworm. Bt. must be eaten by insects to cause mortality; Bt. toxins dissolve in the high pH insect gut and become active, attacking the gut cells and punching holes in the gut lining. The Bt. spores spill out of the gut and germinate in the insect, causing death within a couple of days. Even though the toxin does not kill the insect immediately, treated plant parts will not be damaged because the insect stops feeding within hours. Bt. spores do not spread to other insects or cause disease outbreaks on their own. Work on Bt. cotton started in 1995, with GEAC expressing satisfaction with the results in 1999 and granting final approval in 2002. New BGII-based Bt. cotton stacked with diverse genes was released in 2010 to increase the spectrum of insects.

3.7.2 Increased frequency of pesticide use still not obvious but needs regular monitoring

It has been argued that Bt. cotton has reduced pesticide use, needing only two–three sprayings compared to a very high frequency of pesticide use in other existing non Bt cotton (Mayee et al., 2008). This is being contested in some quarters. There are some stories of resurgence of sucking pests, to which farmers have reacted with caution. To understand the real farm situation, Tables 5, 6, and 7 provide detailed statistics of insecticides used by farmers during first, second, and third sprayings and indicate the absolute number of insecticides they use is more than 125. A total of 552 households were asked about their pesticide use pattern in cotton. In Sirsa district, in the first spraying farmers used thiamethoxam (14.6% HHs), pyriproxifen+thiamethoxam (13.4% HHs), flonicamid (12.4% HHs), and spinosad (7.5% HHs). Most other insecticides among the top 10 are used to fight aphids, whitefly, jassid and a few other sucking insects. In Hisar district, the additional component of bollworm treatment was given the highest priority, with the four most important insecticides sprayed being monocrotophos (35.7% HHs), thiamethoxam (9.9% HHs), imidacloprid (8.3% HHs) and flonicamid (7.9% HHs). Table 6 shows the main insecticides used by farmers in Sirsa district are flonicamid, thiamethoxam, pyriproxifen+thiamethoxam, imidacloprid; these are quite common and used by 17.1%, 12.8%, 6.4%, and 5.9 % HHs. In Hisar district, the order of insecticide used by farmers in the second spraying is monocrotophos (17.0% HHs), thiamethoxam (11.5% HHs), flonicamid (9.5% HHs), and chlorantraniliprole (8.5% HHs). In the third spraying (Table 7) the insecticides were flonicamid (11.8% HHs), thiamethoxam (11.8% HHs) pyriproxifen+thiamethoxam (10.6% HHs) and dimethoate (8.2% HHs). In Hisar district, monocrotophos was the most frequently used insecticide (17.9% HHs) followed by chlorantraniliprole (13.5% HHs). The results suggest that farmers stayed with the same group of pesticides, except for monocrotophos which is the top choice of farmers in all three sprayings. Insecticides such as thiamethoxam applied alone or in combination (pyriproxifen+thiamethoxam) were quite common in both districts. The pyriproxifen+thiamethoxam combination seems a unique choice of farmers in the first, second and third sprayings: pyriproxifen as such is not effective against many cotton insects but increases the efficacy of thiamethoxam against important pest like whitefly. A few other combinations are used as tank mixtures, as farmers are struggling to control secondary pests such as aphids and whitefly. Insecticides are recommended by research institutions, but farmers rely on dealers and distributors to decide which treatment to use against new pests. Most recommendations are still based on the scientific evidence of their effectiveness, but tank mixtures are tending to increase, which is not a good sign, as the recommended treatments may not be as effective as expected. Farmers also use a tank mixture of insecticides; however, this may not remain popular if ready-made mixtures are developed as a premix with a label claim, approved by regulators, and made available in the market. These developments warrant

Table 5: Top ten insecticides adopted in cotton, first spraying (n=552).

Rank	Adoption of insecticides Hisar	1st spray	% HHs	Rank	Adoption of insecticides Sirsa	1st spray	% HHs
1	<i>Monocrotophos</i>	Boll worms	35.7	1	<i>Thiamethoxam</i>	Aphids, Whitefly, Jassid	14.6
2	<i>Thiamethoxam</i>	Aphids, Whitefly, Jassid	9.9	2	<i>Pyriproxifen + Thiamethoxam</i>	Aphids, Whitefly, Jassid, Flees, Centripeds	13.4
3	<i>Imidacloprid</i>	Aphids, Whitefly, Jassid	8.3	3	<i>Flonicamid</i>	Whitefly	12.6
4	<i>Flonicamid</i>	Whitefly	7.9	4	<i>Spinosad</i>	Pink boll worm, Thrips, Ants Fruits Fly	7.5
5	<i>Dinotefuran</i>	Aphids, Whitefly, Leaf hopper	3.6	5	<i>Dimethoate</i>	Aphids, Thrips	5.1
6	<i>Cypermethrin</i>	Ants and Bugs	3.2	6	<i>Imidacloprid</i>	Aphids, Whitefly, Jassid	4.7
7	<i>Pyriproxifen + Thiamethoxam</i>	Aphids, Whitefly, Jassid, Flees, Centripeds	3.2	7	<i>Monocrotophos</i>	Boll worms	4.7
8	<i>Chlorantraniliprole</i>	Moths, Beetles, Termites	2.8	8	<i>Profenofos</i>	Bollwarms, Whitefly, Aphids	3.1
9	<i>Spinetoram</i>	Worms, Caterpillar, Thrips, fleas	2.8	9	<i>Dimethoate + Emamectin Benzoate</i>	Aphids, Thrips, Bollworms	2.8
10	<i>Dimethoate</i>	Aphids, Thrips	2.4	10	<i>Emamectin Benzoate</i>	Bollworms	2.8

Table 6: Top ten insecticides adopted in cotton, second spraying(n=552).

Rank	Adoption of insecticides	Hisar 2nd spray	% HHs	Rank	Adoption of insecticides	Sirsa 2nd spray	% HHs
1	<i>Monocrotophos</i>	Boll worms	17.0	1	<i>Flonicamid</i>	Whitefly	17.1
2	<i>Thiamethoxam</i>	Aphids, Whitefly, Jassid	11.5	2	<i>Thiamethoxam</i>	Aphids, Whitefly, Jassid	12.8
3	<i>Flonicamid</i>	Whitefly	9.5	3	<i>Emamectin Benzoate</i>	Bollworms	7.5
4	<i>Chlorantraniliprole</i>	Moths, Beetles, Termites Flies	8.5	4	<i>Pyriproxifen + Thiamethoxam</i>	Aphids, Whitefly, Jassid, Flees, Centripeds	6.4
5	<i>Cypermethrin</i>	Ants and Bugs	6.0	5	<i>Imidacloprid</i>	Aphids, Whitefly, Jassid	5.9
6	<i>Pyriproxifen + Thiamethoxam</i>	Aphids, Whitefly, Jassid, Flees, Centripeds	6.0	6	<i>Diafenthiuron</i>	Aphids, Whitefly	5.3
7	<i>Imidacloprid</i>	Aphids, Whitefly, Jassid	3.5	7	<i>Dimethoate</i>	Aphids, Thrips	3.7
8	<i>Dimethoate</i>	Aphids, Thrips	3.0	8	<i>Diafenthiuron + Pyriproxifen</i>	Aphids, Whitefly, Jassid, Flees	3.2
9	<i>Acephate</i>	Aphids, Army worms Bollworms, Bettels, Bores	2.5	9	<i>Monocrotophos</i>	Bollworms	2.7
10	<i>Dinotefuran</i>	Aphids, Whitefly, Leaf hopper	2.0	10	<i>Profenofos</i>	Bollworms, Whitefly, Aphids	2.7

Table 7: Top ten insecticides adopted in cotton, third spraying(n=552).

Rank	Adoption of insecticides Hisar 3rd spray	% HHs	Rank Adoption of insecticides Sirsa 3rd spray	% HHs
1	<i>Monocrotophos</i> Bollworms	17.9	1 <i>Flonicamid</i> Whitefly	11.8
2	<i>Chlorantranilipro</i> Moths, Beetles, Termites, Flies	13.2	2 <i>Thiamethoxam</i> Aphids, Whitefly, Jassid	11.8
3	<i>le Flonicamid</i> Whitefly	7.5	3 <i>Pyriproxifen + Thiamethoxam</i> Aphids, Whitefly, Jassid, Flees, Centripeds	10.6
4	<i>Thiametoxan</i> Aphids, Whitefly, Jassid	4.7	4 <i>Dimethoate</i> Aphids, Thrips	8.2
5	<i>Cypermethri</i> Ants and Bugs	3.8	5 <i>Emamectin Benzoate</i> Bollworms	7.1
6	<i>Diafenthuiuron</i> Aphids, Whitefly, Leaf hopper	3.8	6 <i>Spinosad</i> Thrips, Ants Fruits Fly	7.1
7	<i>Imidacloprid</i> Aphids, Whitefly, Jassid	3.8	7 <i>Imidacloprid</i> Aphids, Whitefly, Jassid	4.7
8	<i>Pyriproxifen</i> Aphids, Whitefly, Jassid, Flees, Centripeds	3.8	8 <i>Chlorantraniliprole</i> Moths, Beetles, Termites Flies	3.5
9	<i>Pyriproxifen + Thiamethoxam</i> Aphids, Whitefly, Jassid Flees, Centripeds	3.8	9 <i>Cyhalothrin</i> Ants and Bugs	3.5
10	<i>Thiamethoxam</i> Aphids, Whitefly, Jassid	3.8	10 <i>Monocrotophos</i> Bollworms	3.5

detailed research into the use of mixtures and their ratios. In almost all three sprayings the pattern of insecticide use differed somewhat in the two districts, with more frequent use of monocrotophos in Hisar than in Sirsa district. Farmers are more concerned about sucking pests and also against whitefly that causes CLCuD. PBW is present in both districts; however, the trend of pesticide use indicates that Hisar farmers are more concerned about PBW and Sirsa farmers more concerned about CLCuD. More than 90% of households reported using insecticides in the first spraying, falling to 66%–74% in the second spraying and to 34%–39% in the third spraying (Fig. 12).

3.7.1 Pink bollworm: not a major change but an emerging challenge

The adoption of Bt. cotton has assisted farmers to escape the crisis of pest resistance. Data in Tables 5, 6, and 7 indicate that the issue of insect resistance has not been resolved. Trends, however, do not reflect an overall increase in insecticide spray (Fig. 13).

There are some differences in patterns of insecticide use in the two surveyed districts. Farmers in Sirsa focus more on the use of monocrotophos in the first, second, and third spraying, while in Hisar, the focus is more on sucking pests and bollworms (Tables 5, 6, and 7). Newspapers (<https://www.thehindubusinessline.com/economy/agri-business/pink-bollworm-surfaces-in-cotton-early-this-year-in-haryana-punjab/article65546007.ece>) have reported farmers experiencing heavy losses due to PBW, including some in 2016. This trend has stabilised; however, changes to the pest spectrum continue to occur. Survey respondents reported that one, two, and three insecticide sprayings were carried out by 19.5%, 32.5%, and 48.0% of households in Hisar, and 26.4%, 37.8% and 35.8% of households in Sirsa, respectively (Fig.15). This is possibly due to an increase in preventive sprays for CLCuD. Such reports indicate serious insect pressure and even a few indications of uncertainties from the spectrum of insecticides used in three sprayings. The change in the bollworm spectrum is slower than assumed. The pattern of insecticide use against sucking pests indicates that the frequency of bollworm-based insecticides is increasing in Hisar (Tables 5, 6, and 7), with data indicating up to three sprays. There could also be changes in the natural succession within the group of bollworms due to resistance. The increase in incidence of PBW has weighed heavily on the minds of farmers.

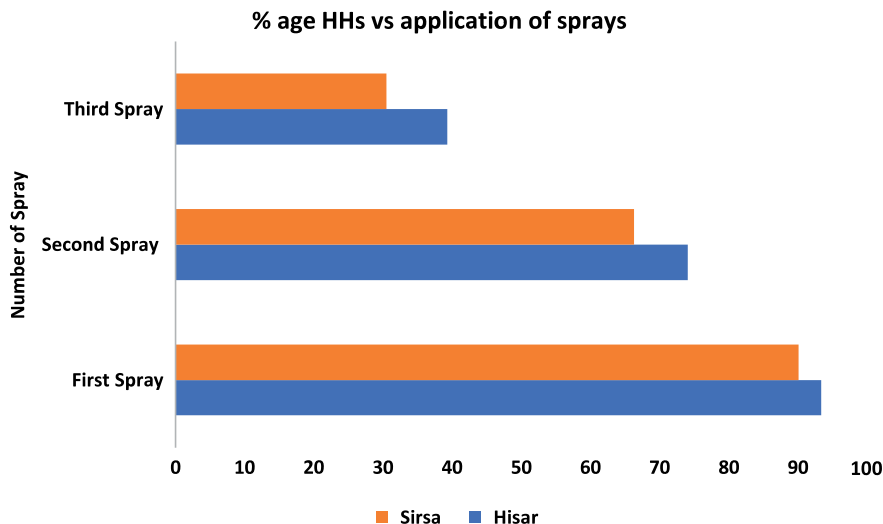


Fig. 13. Percentage of households applying insecticides during first, second and third sprayings in cotton, in CWCS, in Hisar and Sirsa district, in Haryana.

To understand this change, respondents were asked whether they had increased the number of sprays from two to three or sometimes even more (Fig. 14).

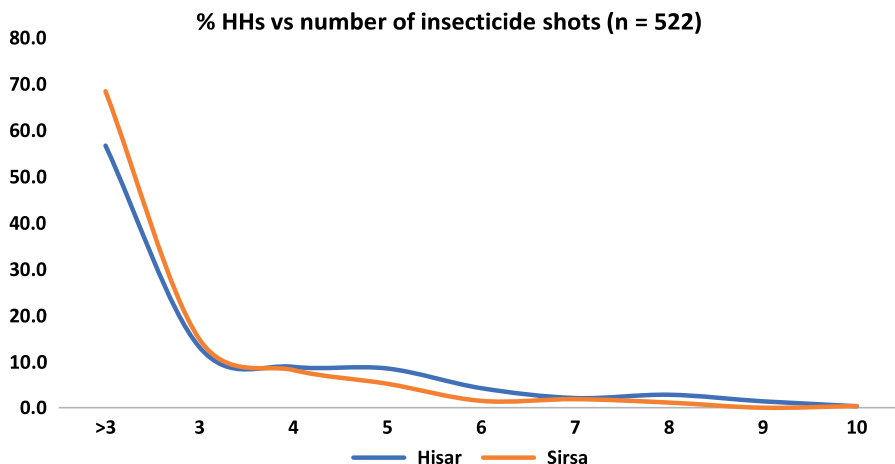


Fig. 14. Respondents using three or more total pesticides in Hisar and Sirsa districts in the 2021 season. This trend is against a background of 10–20 shots of insecticide spray on cotton crops in the late 1990s to 2002 to control pests, especially bollworm.

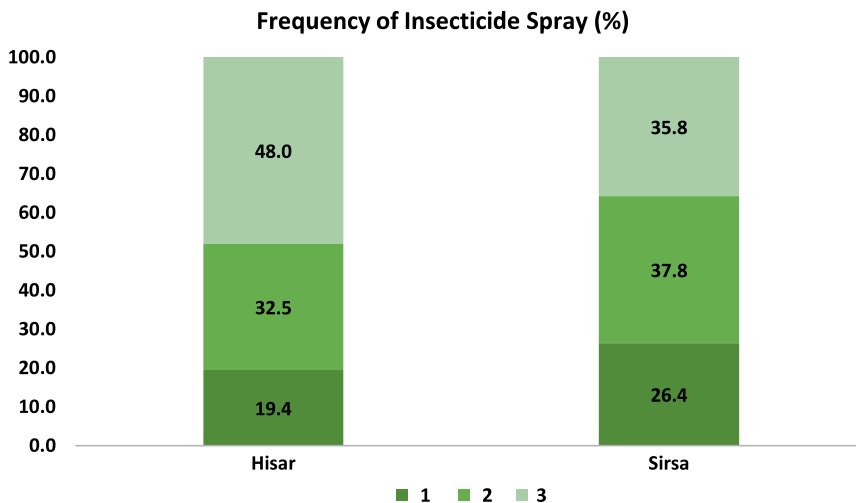


Fig. 15. Insecticide spraying frequency among farmers in Sirsa and Hisar district, Haryana, to manage pests in cotton.

This could be another indicator as to whether overall pesticide use (for insects and diseases) is increasing or not. Data from the LDS conducted in October–November 2022 in Hisar and Sirsa do not indicate a major change; however, the trend of pesticide use is increasing (Fig. 13). The share of respondents who said that number of sprays exceeded three is still very limited (13% and 14.8% of households in Hisar and Sirsa, respectively). Farmers exceeding four, five and six sprayings are 8.9%, 8.5% and 4.3% of households in Hisar, respectively, and 8.1%, 5.2% and 1.5% of households in Sirsa, respectively. There is, however, a net plus in favour of three sprayings or fewer (56.7% of households in Hisar and 68.4% of households in Sirsa) (Fig. 14) which is still good; however, this might change for the worse if a strategy ensuring proper monitoring does not come into effect immediately. The trend is still skewed towards three sprayings or fewer, suggesting that three sprayings are quite common. There are however cases of increased frequency of pesticide, up from two to three, and from three to four sprayings. This is much better when we compare the experience of very high expenditure on pest management with insecticide spraying that exceeded all previous limits during the late 1990s, up to 2002 when pest resistance was at its peak. This means the unprecedented reduction in pesticide use is still intact; however, the trend is upwards. Scientists and extension agencies tasked with pest management need consistently to review pesticide spray schedules to prevent undue increases in pesticide use. Pesticide use analysed in the data presented for pest and diseases addresses the criticism but warrants future studies, as stated below.

A thorough investigation is required to determine what has happened with PBW, employing epidemiological studies and the role of biology, rather than arguing for or against quality of seed or quality of pesticide as happened during the late 1990s when resistance evolution was a fact. The survey results should be documented and applied by the KVK system at different stages of crop development, rather than waiting until an issue arises.

3.7.4 Monitoring, evaluation and learning to avoid risks

The unprecedented adoption rate Farmers seem of Bt. cotton by Haryana farmers has almost reached 100%, and its continued adoption answers some of the questions, especially with respect to long-term environment impacts. Although the sustainability of the system was questioned at the time and Bt. cotton technology contested by those expressing concerns about the genetic modification of crops, its introduction supported by farmers however averted a crisis, extricating farmers from the debt trap of the preceding five years. A strong survey and surveillance program as part of IPM in cotton pest management was a need then and so it is even now. When Bt. cotton was released, PBW incidence was negligible. Farmers seem to have neglected the method of utilising non-Bt. cotton seeds to grow as refuse or a trap crop, which might be also a reason for PBW becoming an important pest in cotton. This could be an ecological side effect, like the outbreak of secondary pests in some states (Mohan et al., 2016). The trends given in pesticide use patterns, both for insects and diseases (Fig.13), should address the unhealthy confusion between environmentalists and scientists working on genetically modified crops. With PBW becoming a serious pest, the pest management programme is not focusing on this. In most cases, PBW is detected at the end of the crop cycle. The recently developed transgenic cotton, BG II, offers suppression of the cotton bollworm, including PBW, but a reduction is needed in the overwintering population in cotton sticks, which threatens the following season. Shedding of floral buds and bolls is quite common in cotton, and carries insect infestation, including PBW. Insect pests need to be monitored regularly every week during the vegetative phase and twice a week during the reproductive phase.

The greatest lesson from these developments is that without proper monitoring, evaluation, and learning, the cause and effects of any new crisis will be difficult to discover. In retrospect, Bt. technology proved extremely useful in terms of resistance in *Helicoverpa* – prospectively, PBW can also adapt to Bt. cotton and provide as serious a problem as that which occurred with *Helicoverpa*. Farmers who reported yield decline indicated that seed quality was an issue and perceived that PBW could be a severe problem with poor quality seed. The purpose of MEL should be to attend to the interests of the average cotton farmer in ecologies best suited to cotton. For protection against bollworm, Bt. cotton should not be taken for granted as insecticide resistance may develop in this case as well.

The limited increase in the frequency of farmers spraying suggests that PBW may be a low frequency risk, although its impact could be greater if a proper monitoring mechanism is not in place. The factors affecting the increased incidence of PBW are not new, and indeed, the shift might have happened over a long period of time. Between 2014–2017, PBW larval incidence in Bt. cotton was found to be less in India's northern cotton cultivating zone than in central and southern India, where PBW larval recovery from BGI cotton bolls was high, in the range of 28.85%–72.49% (Mohan et al., 2016; Naik et al., 2018). PBW infestation causes locule damage of 37.5% and 13.58% in non-Bt. and Bt. cotton, respectively, about 160 days after planting (Naik et al., 2014). The distributional consequences of PBW are an issue. PBW infestation level might have changed the perception of farmers in favour of new seed or increased frequency of pesticide use; however, the latest shifts favouring PBW threaten to allow a crisis-like situation to reemerge, if not handled properly. Diversification could be more resilient, specifically for PBW; however, this will be the farmers' last resort, as there are no better alternatives, except for a few such as the cultivation of *kinnow* (Orange).

3.7.5 Integrated Pest Management

In CWCS, productivity is increasing at a much slower rate than in other cropping systems. More pesticides are used to produce increased output, and the integrated pest management programme is not producing the desired results (although its total collapse has been postponed to some extent by the training of extension agencies and farmers). A successful kharif campaign in cotton will depend more than anything else on IPM, which will require epidemiological data, a monitoring programme, regulations to govern a recommended schedule of insecticides (including strict quality control), and ensuring that the indiscriminate use of synthetic pyrethroids ceases. Such interventions should be implemented in conjunction with resistant varieties and sound agronomic practices.

The time has come to initiate “pest management farm services” in CWCS, through the ICAR/SAUs KVK system. The incidence of pests such as PBW must be tracked, allowing researchers to understand how its resistance or resurgence happens in a field situation; pesticide resistance management committees should be constituted by DOA and include representatives from CCS HAU and the private sector: greater emphasis is needed on the dissemination of knowledge about IPM in cotton, and each district should conduct a training workshop, with participants including agriculture field officers and SAU scientists.

3.8 Weed management in cotton

The most common weeds in cotton reported by respondents are (in Haryana district) *Echinochloa colona* (70.7% HHs), *Physallis micrandha* (52.2% HHs), *Dactyloctenium aegyptium* (48.5% HHs), *Echinochloa crusgalli* (15.2% HHs) and *Amaranthus viridis* (30% HHs), and (in Sirsa district) *Dactyloctenium aegyptium* (91.1% HHs), *Echinochloa crusgalli* (47.8% HHs) and *Echinochloa colona* (48.5% HHs) (Table 9). The underlying impact of this type of simplification of weed flora in favour of annual grasses is the use of post-emergence herbicides, including glyphosate and paraquat (non-selective herbicides), pendimethalin, (both pre-emergence and post-emergence), propaquizafop, pyriproxyfen sodium, fenoxaprop, trifluralin, and pinoxaden+propaquizafop. Farmers' adoption of different weed management practices did not affect the seed cotton yield. Interculture using mechanical methods is a usual practice for controlling weeds in cotton, and farmers have largely accepted mechanised weeding using a tractor-mounted cultivator when the crop reaches one foot high. Nevertheless, there are signs that weed management in cotton is undergoing changes.

Table 8: Weed management practices adopted by respondents in cotton for Sirsa and Haryana districts of Haryana (n = 552).

Weed management cotton	HHs No.	HHs %	Seed cotton yield (t/ha)*
Herbicides	25	04.5	1.4
Herbicides + One manual / mechanical weeding	55	10.0	1.4
Herbicides + Two manual / mechanical weeding	138	25.0	1.5
Herbicides + Two or three manual / mechanical weeding	34	06.2	1.7
One Manual/mechanical weeding	24	04.4	1.5
Two Manual/mechanical weeding	207	37.5	1.5
Three Manual/mechanical weeding	60	10.9	1.6

*Note: 1. Herbicides include, Glyphosate, Paraquat (directed spray), Propaquizafop, Pyriproxyfen sodium, Pendimethalin, Fenoxaprop, Trifluralin, Pinoxaden + Propaquizafop

2. Treatment of herbicide alone there is more representation of Sirsa district

*Seed cotton yields are rain affected village (41% HHs, mostly in Haryana district) has not been included

Among the farmers surveyed, in 2021–22, average seed cotton yields ranged from 1.38–1.69 t/ha (Table 8). Late rains in September damaged cotton in 23 villages (41% HHs), in Haryana district. Wider row spacing of cotton has facilitated farmers' use of mechanical weeding, with 37.5% and 10.8% of households carrying out two to three weedings, respectively.

Table 9: Ten most common weeds in cotton, Hisar and Sirsa districts, Haryana (n=552).

Rank	Hisar	% HHs	Rank	Sirsa	% HHs
1	<i>Echinochloa colona</i>	70.7	1	<i>Dactyloctenium aegyptium</i>	91.1
2	<i>Physallis micrantha</i>	52.2	2	<i>Echinochloa colona</i>	48.5
3	<i>Dactyloctenium aegyptium</i>	48.5	3	<i>Echinochloa crusgalli</i>	47.8
4	<i>Digitaria sanguinalis</i>	31.5	4	<i>Rottboellia cochinchinensis</i>	44.8
5	<i>Amaranthus viridis</i>	30.0	5	<i>Digitaria sanguinalis</i>	43.0
6	<i>Rottboellia cochinchinensis</i>	23.3	6	<i>Eragrostis tenella</i>	41.1
7	<i>Echinochloa crusgalli</i>	15.2	7	<i>Eleusine indica</i>	30.7
8	<i>Leptochloa species</i>	13.7	8	<i>Cynadon dactylon Euphorbia</i>	29.3
9	<i>Eragrostis tenella</i>	11.1	9	<i>Euphorbia hirta</i>	27.0
10	<i>Digitaria ciliaris</i>	10.4	10	<i>Bracharia mutica</i>	20.0

Farmers thus gain the significant advantage of being able to manage most weeds successfully, including the complex weed flora which exists in CWCS. Hot and desiccating winds have rendered the herbicide performance relatively poor; however, 4.1% of households continue to use a range of herbicides, with yield performance being same as mechanical or manual weeding (1.38–1.69 t/ha). It would be wise to focus on mechanical weeding and balance it with an increased use of pesticides (insects are diseases). Scientists should follow this lead of mechanised weed management in cotton and explore options around optimum mechanical weeding times or new tools facilitating timely weeding, as the likelihood will probably persist of more complex weed flora dominated by perennial, beyond the range of herbicidal control.

3.9 Seed cotton yield

The lower-than-expected cotton yield indicated by the current survey was attributable to untimely rains (which could be a one-time event) and pink bollworm infestation (the emergence will remain of new pest problems alongside existing diseases). The LDS attempted to isolate the effect of late rains on cotton yields by looking at yield performance in areas affected by rains and itemising such data sets in a separate column. Data show that a yield loss of more than 65.5% in Hisar and 58.4% in Sirsa, was due to untimely rains in September. The comparison may be little misleading; however, this was the only way to segregate the effects of agronomic management and pest management on seed cotton yield: presenting aggregate data from rain-damaged and undamaged crops would have been misleading.

A cotton harvest which produces 75% less seed cotton yield is unprofitable for farmers in villages affected by late rains. The current trend of late rains in 2021 and 2022 indicates the need for understanding these unusual trends in the monsoon rain.

Table 10: Average seed cotton yield (t/ha) reported by respondents, Hisar and Sirsa districts, Haryana. Yield data is segregated into seed cotton yield affected by/not affected by rains.

District	Seed cotton yield (Avg.)	Seed cotton yield HHs not affected by late rains	Seed cotton yield of HHs rain affected	loss (%)
Hisar (n-270)	1.05	1.49	0.51	65.5
Farm gate price (INR)	6842	7158	6450	-
Sirsa (n-282)	1.61	1.64	0.68	58.4
Farm gate price (INR)	8106	8129	7325	-

Seed cotton yield (kg/ha) of respondent households in Hisar and Sirsa districts, Haryana (n=552), the seed cotton yields from villages affected by late rains have been given separately (Hisar-120 and Sirsa-8 HHs)

The LDS survey showed that farmers in Sirsa district outperformed farmers in Hisar, with much higher yields. Very poor yields in Hisar were not due to bad management or biotic stress, but to excessive rains at or near first picking (Table 10). Untimely rains at the end of September 2021, especially in Hisar district (which had a slightly greater number of rainy days than Sirsa) reduced yields to 65.5% and 58.4% in Hisar and Sirsa, respectively.

3.9.1. Shift in area under cotton due to hydrological reasons

Weather conditions like these and the rising water table in Hisar district will accelerate farmers' shift towards rice. Sirsa district experienced less impact of untimely rains, as a result, an average seed cotton yield of 1.6 t/ha was still observed.

Within Hisar district and a few villages in Sirsa, seed cotton yield was very low, contributed to by the untimely rains at the end of September 2021. The current season has also been bad for cotton, especially in the Hisar district. It is unclear whether rainfall trends were monitored carefully enough. This needs improvement, with better predictive models on monsoon behaviour. The rising water table and such weather events, even for one or two years every 10 years, will discourage farmers from growing cotton. Water-logging is one of cotton's most

serious stresses, as reduced oxygen impairs further growth and development (Zhang et al., 2021). The significant damage to cotton yields because of rains or a rise in the water table again points up diversification, with a reduction in the area under cotton in Hisar district. The asset base of water resources and the future problems associated with a rising water table have been adequately covered in earlier reports (Kumar et al., 1996; Kumar et al., 1999) by HAU.

A rising water table in cotton-growing districts including Jind and parts of Rohtak and Hisar has rendered some farmers unable to grow cotton and reduced the areas under cotton cultivation. At the same time, however, new technology created new areas, with the result that the area under cotton has remained the same or increased since 2002–2003. In the process, the area has expanded in Bhiwani district, which is also a drier part of the state. Farmer confidence has remained intact, as those in the cotton-growing belt are relatively large and cannot compromise on cash returns generated by cotton. As such, cotton is regarded as a cash crop, and the cash nature of any crop has an influence on farmers, which in this case is reflected in the area's expansion in Bhiwani district.

Before the introduction of Bt. cotton, productivity had reduced significantly, and its adoption and spread enhanced cotton yields proportionately across India (Mayee et al., 2008). Seed cotton yields in Hisar district would also have sustained had they not been seriously affected by untimely rains (Table 10). This suggests the need for technology development or investment in risk reduction. Protecting farmers, who may be the main breadwinner of the household, mitigates increased risks faced by the future generation. The loss of a cash crop creates economic uncertainty, and farmers with water-logging stress are replacing cotton with cash crops such as rice. This is unavoidable. In the case of insect resistance, which can cause 100% crop loss, the technology of Bt. cotton seems to be the only practical solution.

3.10 Cost of cotton cultivation

The high cost of pest management (INR6500/ha for Hisar, INR3272/ha for Sirsa) has compromised farmers' profits. The best way to protect their interests is to guard against new challenges brought about by shifts in the pest spectrum by effective resistance management. There is still no evidence of resistance in PBW development in Bt. cotton, but constant monitoring for resistance is required. Another consideration is how to counter the rising cost of labour. The cost of picking cotton ranges from INR15,181/ha in Sirsa to INR 12,698/ha in Hisar (Table 11). As labour continues to be used for harvesting, when the fluffy cotton fibre bursts and opens the bolls, the only way to protect farmers' interests is to ensure these costs are cut by adopting mechanisation.

Farmers employ conventional tillage and prepare a fine seed bed after heavy pre-sowing irrigation to facilitate good emergence and avoid moisture loss due to the hot, desiccating wind, common from the end of April to the end of May. Average tillage costs (INR7695/ha) are also rising faster than the cost of inputs like fertilisers and pesticides. The cumulative impact of the costs of these three components – labour, tillages and inputs – will depend on how much farmers sustainably increase their yield. There is a definite economic rationale for constantly reviewing these components. In order to reduce cultivation costs a reorganising is required with respect to operations that need more labour and more energy. This also illustrates the need for changes in technologies.

The costs of energy, labour and inputs depend on how mechanisation and shifts in the pest spectrum play out in future. Mechanisation is the only way to harness the ecological advantage of these districts. As yields are not increasing at the same pace as cultivation costs, savings in these three cost variables should assist farmers to improve their profit margins. Cultivators are used for the added advantage of uprooting weeds competing with crops for natural resources, with the cost of this operation (plus some costs of manual weeding) higher in Sirsa (INR5282/ha) than in Haryana district (INR3285/ha). The cost of FYM including its loading, unloading and distribution in the field, is also increasing; however, this study assumes that each acre uses FYM just once in five years or even longer. One ruminant/ha should sustain the availability of FYM in this region. These trends are visible because only 20% of surveyed households are using FYM.

Table 11. Direct costs (INR/ha) of the cotton crop averaged over two cotton-growing districts, Haryana.

Variable cost of cultivation (INR/ha)	Hisar	Sirsa	Total
Land preparation	7499	7882	7695
Crop establishment	3818	4663	4250
Farmyard manure - FYM	8903	7523	8311
Irrigation	3921	3119	3511
Fertilizer cost	4602	4320	4458
Weeding	5282	3385	4313
Insecticide	4758	2482	3595
Insecticide spray	1745	790	1257
Picking	12698	15181	13966
Total cost	53226	49344	51356

To understand the yield-enhancing factors, the research and extension system must study the performance of the top 10% of households that could obtain a seed cotton yield of 2.49 t/ha in Sirsa district, if the right balance of seed cotton yield and cultivation costs is achieved. There is a large yield gap of almost 2.0 t/ha between the top and bottom 10% of performers, which is unusual (Fig.16). There were heavy rains in the third week of September 2021 which affected the yields drastically. The yield losses experienced by farmers due to rainfall during the harvest season also fetched them a lower farm gate price (Table 10). Untimely rains are not a usual phenomenon in this month, but the following year (2022) heavy rains again affected crops. Therefore, strategies to address such challenges need to be in place if it were to happen again. Data suggest that we need to reduce expenditure in the above three field operations, but at least incrementally increase the seed cotton yield needed to maintain profit margins. There is evidence (Table 10) that Hisar district is already experiencing losses due to damage caused by untimely late rains.

In the recent past, higher cultivation costs have started affecting the profit margins of farmers in CWCS. There is also the high cost of credit obtained from artiyas (local moneylenders), even though bank credit is available. This increase in cultivation cost also leads to decrease in area of cotton and increase in the area under rice. We may have to review the plan to expand the area under cotton in southern Haryana and in Bhiwani

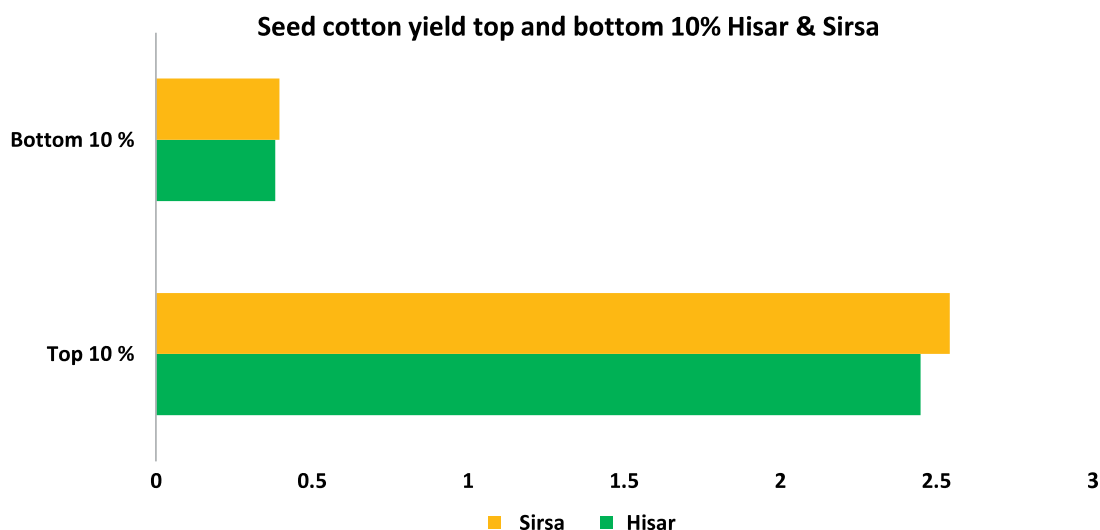


Fig. 16. Seed cotton yield (kg/ha) of the top and bottom 10% of performers in CWCS, Hisar and Sirsa districts, Haryana

districts to replace pearl millet, which generally faces problems with procurement. [FH1] New and emerging problems related to pest management have allowed the private sector to dominate in all sectors, including new varieties and inputs, especially pesticides. In response, strong collaboration with the private sector is needed, not only in developing new technologies but also to monitor changes in the pest spectrum at regular intervals, with a strong focus on a joint survey and surveillance programme. A kind of “convergence platform” should be developed to prepare joint strategies at the beginning of the cotton season.

4.0 Wheat

Cotton is a long duration crop, providing less space for a wheat crop and thus limiting the potential that can be harnessed by CWCS. The LDS shows that the wheat crop has done well in Haryana even under the elevated terminal heat scenario of 2022. The yield reported here is for the crop harvested in April 2022; this was a difficult year, but farmers were still able to seed their crop more or less on time, an advancement brought about by mechanisation.

4.1 Adoption of wheat varieties

Two timely sown wheat varieties (HD 2967 and HD 3086) have been adopted by 50%–51% of households in Hisar and Sirsa districts; their duration is a little longer than other varieties (Figs. 17a and 17b). WH 711, HD 2851 and WH 1105 are each grown by 8%–10% of Hisar households. HD 2851 is more popular in Sirsa than in Hisar district. Cotton is a long duration crop, and in CWCS wheat sowing is delayed and expected to be a late-sown crop; however, none of the popular varieties in this survey are in the late sown variety group. All the varieties used have produced yields in the same range, except WH 711 which was the highest yielder in Sirsa district, at

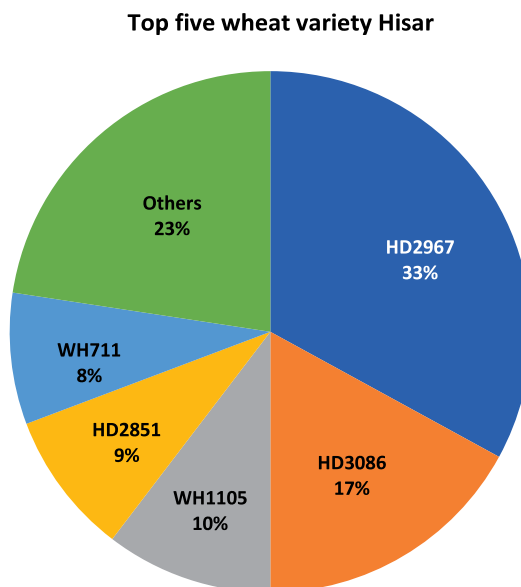


Fig. 17a. Wheat varieties cultivated as part of CWCS in Hisar district, Haryana.

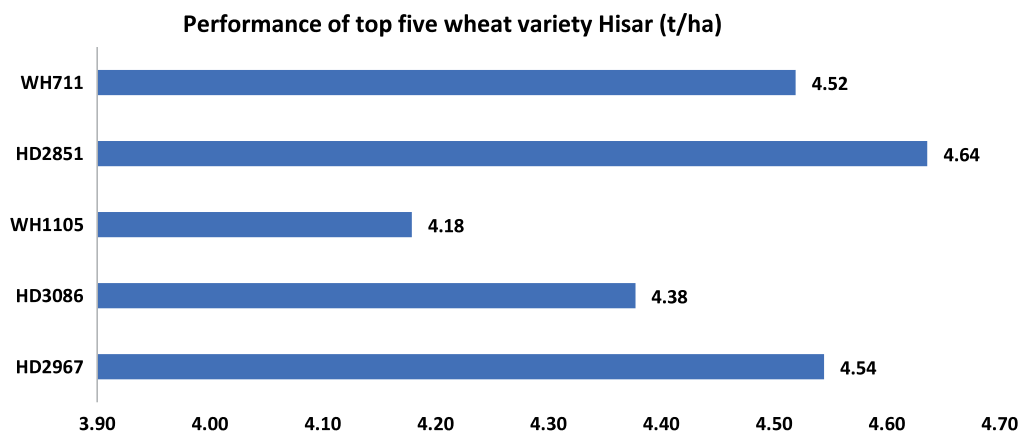


Fig. 17b. Grain yield of different wheat varieties in Hisar district.

4.6 t/ha (Fig. 17d). The grain yield of WH 1105 was 4.15 t/ ha, against a yield of 4.5 t/ha in WH 711 in the Hisar district(Fig. 17b). In the Sirsa district, the grain yields of wheat varieties like DBW 187 and HD 2851 were low, at around 3.8 t/ha.

4.2 Nutrient management

Nitrogen is fundamental to sustaining CWCS and appears to be a precondition for the better utilisation of other inputs, including irrigation water. Farmers in Sirsa and Hisar districts applied N at a rate of 141 and 132.6 kg/ha, respectively. In Hisar, P and K use was as recommended, at 65.7 and 57.0 kg/ha, respectively; in Sirsa, these were 72 and 57.0 kg/ha, respectively (Fig. 18).

For a crop like wheat, nitrogen is as important as food is to humans. The longest running long-term experiment at Rothamsted Research station, UK (Source: <https://www.rothamsted.ac.uk/long-term-experiments>), shows that the performance of wheat depends on how it has been fertilised, with those treatments having received the optimum amount of N doing best.

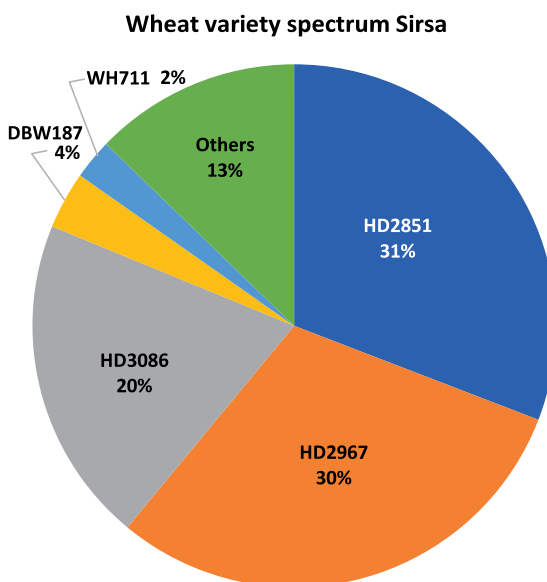


Fig. 17c. Wheat varieties cultivated under CWCS in Sirsa district, Haryana.

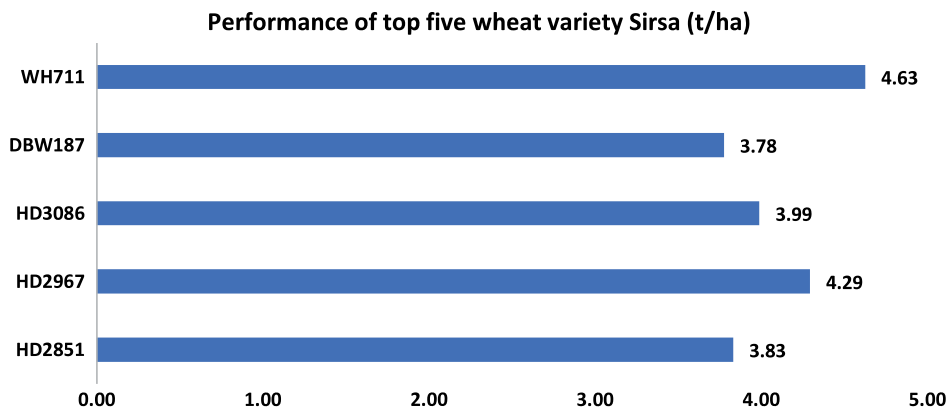


Fig. 17d. Grain yield of different wheat varieties in Sirsa district, Haryana.

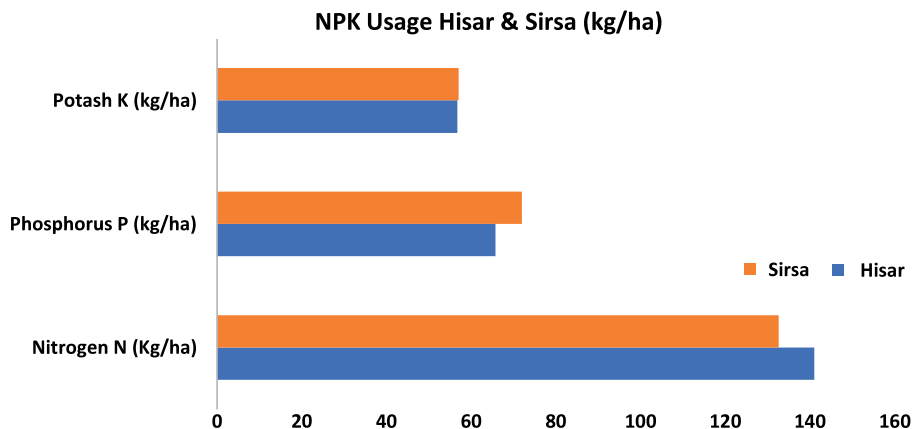


Fig. 18. Nutrient applications (kg/ha) in wheat as part of CWCS in Hisar and Sirsa districts, Haryana.

Author in The Economist, 20 December, 2022, indicated that experiments like these show that P applied without N is not enough, and that “there is an absolute necessity of supplying nitrogen to enable soil to produce more wheat”. Although including legumes in crop rotations is one way of restoring N, this is not common in CWCS or in areas where better irrigation has favoured other cropping systems. FYM use by farmers is too low, unable to meet demand, even for a high feed and fibre yield-producing system like CWCS; 80% of the excellent yield performance of new varieties is due to N fertiliser (The Economist, 20 December, 2022).

4.3. Irrigation in wheat.

In the two districts surveyed, irrigation in CWCS is mainly achieved through a canal-based system alongside tube well-based irrigation. Soils are mostly light, with sandy loam and sandy soils dominating. The number of irrigations reported was 5.0 in Sirsa and 4.5 in Hisar districts (Fig. 19).

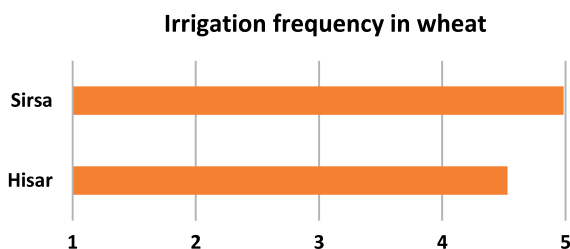


Fig. 19. Average frequency of irrigation in wheat, Hisar and Sirsa districts, Haryana.

4.4. Weed management in wheat

Reduction in wheat productivity depends upon the type of weed flora and weed density (Table 12). Herbicidal weed control seems unavoidable and has proved efficient. The monoculture of RWCS with relatively high soil moisture is congenial for weeds such as *Phalaris minors* (which seems to have developed cross-resistance (Table 12). In CWCS, also among grasses *Phalaris minor* dominated (reported by 91.1% of households in Hisar and 88.3% in Sirsa) because of light soils in the districts and relatively little moisture. Dependence on Isoproturon for very long periods resulted in resistance to this herbicide (Malik and Singh 1995).

Table 12. Ten most common weeds in wheat in CWCS, Hisar and Sirsa districts, Haryana (n=552).

Rank	Hisar	% HHs	Rank	Sirsa	% HHs
1	<i>Phalaris minor</i>	91.1	1	<i>Phalaris minor</i>	88.3
2	<i>Chenopodium album</i>	73.7	2	<i>Chenopodium album</i>	72.7
3	<i>Avena ludoviciana</i>	25.2	3	<i>Polypogon monspeliensis</i>	56.4
4	<i>Polypogon monspeliensis</i>	23.7	4	<i>Avena ludoviciana</i>	52.8
5	<i>Cynadon dactylon</i>	22.2	5	<i>Cynadon dactylon</i>	34.8
6	<i>Rumex dentatus</i>	17.4	6	<i>Poa annua</i>	31.6
7	<i>Amaranthus spinosus</i>	15.9	7	<i>Rumex dentatus</i>	28.7
8	<i>Gnaphalium purpurium</i>	14.8	8	<i>Anagalis arvensis</i>	24.1
9	<i>Poa annua</i>	13.7	9	<i>Melilotus indica</i>	19.5
10	<i>Anagalis arvensis</i>	10.0	10	<i>Coronopus didymus</i>	17.7

Polypogon monspeliensis is becoming troublesome, which seems to be a recent change. There is no practical way for these farmers to switch to alternative crops – a solution has to be found within the existing cropping system, in the absence of which farmers are attempting management options such herbicide mixtures extension interventions and repeat sprayings. Resistance management of bollworm (in the cotton phase) and *Phalaris minor* needs to be a top priority for research and extension interventions in these cropping systems.

Weed management in wheat is becoming more complicated, with the use of unrecommended herbicide mixtures and/or multiple shots of herbicides that are unheard of and have not been recommended by researchers. Unable to control weeds in one shot, households in Hisar (15.6%) and Sirsa (23.0%) are using two shots of herbicides; 15.6% and 18.4% of households, respectively, are using tank mixtures of herbicides, often with no yield advantage. Wheat grain yields ranged from 3.8 t/ha in Sirsa to 4.3 t/ha in Hisar following treatment with herbicide mixtures, compared to grain yields of 4.1 t/ha in Sirsa and 4.5 t/ha in Hisar districts (Table 13) following the application of herbicides alone or in two shots. Wild canary grass (*Phalaris minor*) is a great concern, even in CWCS: it has been observed that in certain locations where wheat productivity is high, the intensity of this weed is high even here. Herbicides are purchased at the recommendations of shopkeepers in rural areas, who are untrained and unequipped with up-to-date information. Scientists, therefore, need to be on guard against herbicide resistance and work to recommend new herbicides or new combinations. More research

Table 13. Weed management practices adopted by respondents (n=552) in wheat.

Districts	Weed Managements practices in wheat	Number of HHs across districts	Current user HHs of weed management options (% HHs)	Grain wheat yield (t/ha)
Hisar	Sole herbicide (One molecule)	166	61.5	4.5
	Herbicide used as mixtures	42	15.6	4.3
	Herbicide used in two shots	42	15.6	4.5
Hisar overall		250	92.6	4.4
Sirsa	Sole herbicide (One molecule)	142	50.4	4.1
	Herbicide used as mixtures	52	18.4	3.8
	Herbicide used in two shots	65	23.0	4.1
Sirsa overall		259	91.8	4.0

is needed into new tank mixture ratios, in order to reduce the cost of treatments and so as to be able to recommend only those which act in synergy with each other, rather than using a herbicide which is antagonistic to the main herbicide. This is happening in these districts, with a few farmers using 2,4-D as a tank mixture with clodinafop, reducing the latter's efficiency. This could result in the development of resistance in *Phalaris minor*, even in CWCS. The principal reason for the dominance of this weed is that, like cereals, it is better at utilising nitrogen (which is applied more frequently in wheat). Over the years, even under CWCS, competition favoured this weed over others, at least in some pockets where herbicide mixtures or more than one shot of herbicide is used. When a resistant *Phalaris minor* develops it will out-compete other weeds, thus leading to the creation of simple weed flora. *Phalaris minor* is a major threat to wheat production, particularly in high-productivity CWCS regions. Data from the CSISA/KVK surveys show that using tank mixtures of two or three herbicides and repeat spraying of herbicides has become common in Punjab and Haryana, implying a growing threat of multiple resistance in *Phalaris minor*.

4.5. Wheat yield

The average wheat grain yield of the top 10% of households across both surveyed districts was 5.85 t/ha; that of the bottom 10% was just 2.44 t/ha (Fig. 20). Average wheat grain yields in Hisar were 4.46 t/ha and 4.06 t/ha for Sirsa farmers. Wheat productivity was lower than in RWCS and PMCS, mainly because of delayed sowing in wheat

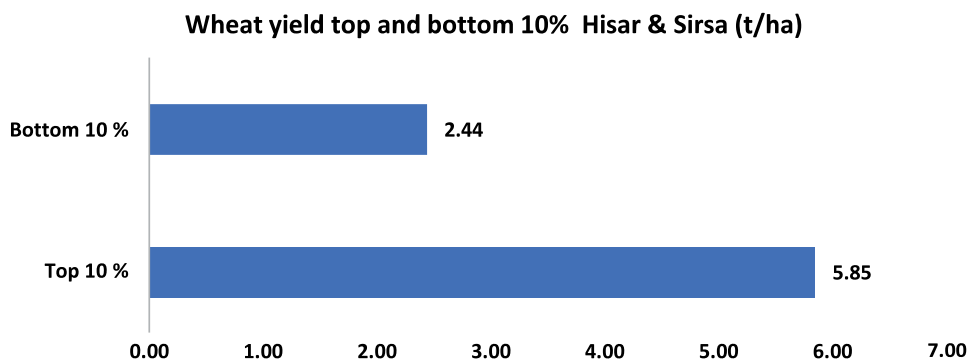


Fig. 20. Average wheat grain yield in CWCS, Hisar and Sirsa districts, Haryana.

Scaling-up early sowings by means of stubble management in cotton and then sowing by zero tillage can save 7–10 days. Mechanised harvesting of cotton is another intervention which can help improve both cotton and wheat productivity by avoiding losses wheat varieties in cotton and advancing the sowing of wheat (such losses have occurred even after the increased use of timely sown wheat varieties) (TSWVs). Late sown wheat varieties are not used in this cropping system, even under late sowings. While farmers grow TSWVs as part of CWCS, the area under newly released varieties is not increasing. There is thus considerable scope to increase productivity in CWCS by promoting TSWVs rather than LSWVs. This requires a broader strategy, designed to sequentially increase the focus on evolving use of TSWVs rather than LSWVs, even under this cropping system. The average sowing dates in Sirsa and Hisar districts are 13 and 15 November, respectively. The benefits of early wheat sowing can be self-amplifying to provide other improved management options which beat the terminal heat.

4.6. Cost of wheat cultivation

As far as income is concerned, a typical farmer focuses on the monetary gains of production, and rarely the time costs or rental value of their land, thus overstating the value of their production in the process. With the rental value of the land at INR15,000/acre in Hisar and INR16,000/acre in Sirsa, INR38,500/ha needs to be included in the cost of cultivation. Adding interest to working capital (at a 7% interest rate), the additional INR2674/ha produces a total fixed cost of INR41,174/ha, which exceeds the variable cost of wheat cultivation. Arguably, this is not included in the cultivation costs, with only the variable cost having been given (Table 14). Weed management in wheat seems to be under strain, with the cost of herbicide-based treatments rising, at INR2163 and INR1827 in the Hisar and Sirsa districts, respectively. This may be due to the farmer responding to possible cross-resistance with repeat spraying or employing a herbicide mixture, especially in the Hisar district. The cost of crop establishment is even higher, at INR 3543 and INR 3020/ha in Hisar and Sirsa districts, respectively. Sowing of wheat happens after pre-sowing irrigation and under *vattar*[1] conditions. Labour costs are a major part of spending on irrigation, with some farmers irrigating when cotton is still in the field. After the final picking, the removal of cotton sticks and residues from the field come at a high labour cost. Taken altogether, these high cultivation costs often render wheat cultivation uneconomic when it is planted late after cotton.

Promoting zero tillage in wheat, among other advantages, has resulted in a significant drop in cultivation costs. Zero tillage also facilitates early wheat seeding and significant yield advantage and should be promoted and integrated with other technologies which contribute to the

[1] Moist soil.

Table 14: Variable cost details of wheat cultivation in CWCS, Hisar and Sirsa districts, Haryana.

Variable cost of wheat (per hectare)	Hisar	Sirsa	Grand total
Land preparation	7028	7110	7070
Crop establishment	3543	3020	3276
Weeding	2163	1827	1992
FYM + labour	1041	1151	1096
Irrigation	4824	3166	3977
DAP	3208	3174	3191
Urea	1684	1477	1578
MoP	1135	1366	1233
SSP	1793	806	995
ZnSO ₄	1233	1194	1214
Harvesting and threshing			
Manual harvesting (Hisar n-91, Sirsa n-33)	8312	5712	7012
Threshing after manual harvesting (Hisar n-91, Sirsa n-33)	6350	4803	5577
Cost of cultivation (Manual harvesting & threshing)	42313	34806	38210
Harvester combine (Hisar n-178, Sirsa n-249)	4331	3771	4051
Cost of cultivation* (Machine harvesting)	31982	28062	29672

*Total cost of cultivation is based on the manual harvesting and threshing (Hisar n-91, Sirsa n-33) cost of cultivation

Manual harvesting and threshing 11.6% in Sirsa and 32% in Hisar

intensification of CWCS. In the two districts surveyed, total spending on harvesting and threshing using manual labour was INR 8312/ha (Hisar) and INR 5712/ha (Sirsa); with machine use, these costs are reduced to an average of INR4051 across districts. The total cost of cultivation (manual harvesting and threshing) was INR 38,210/ha, compared with INR 29,672/ha when based on combined harvester use. This represents about 25% and 21% of total spending by farmers in Hisar and Sirsa districts, respectively, and indicates the need for mechanisation in CWCS.

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