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Agronomic practices adopted by farmers to maintain sustainable crop production and increase profitability in Punjab

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Abstract

Punjab is often referred to as “the cereal bowl of India” due to its significant contribution to India's central grain food pool, particularly in rice and wheat. It played a crucial role during the Green Revolution by ensuring food security. However, some concerns have been raised in recent years due to the overuse of fertilizers, heavy pesticides, herbicides, and other chemicals, as well as the excessive use of water for irrigation, which has led to continuous monocropping and soil fertility issues, resulting in low Production. Our study examines the agronomic practices adopted by farmers in Punjab to maintain sustainable crop production and increase profitability, with a focus on how these practices influence crop yield and income. During the survey, sixty farmers were questioned in the north Indian state (Punjab) and the district of SAS NAGAR from six different villages (Barauli, Choti Ghandua, Fatehpur Jattan, Thablan, Doom Chheri, and Dholan Majra), where we learn that the most crops grown are rice and sugarcane. The collected form includes the seed rate, fertilizer dosage, seed treatment, number of irrigations provided, organic manure used, major weeds infesting the fields, herbicides used, major pests attacking crops, pesticides used, major diseases infesting the fields, disease chemicals used, and the yield range of crops. The study revealed the practices employed by farmers to achieve maximum yields and profits.

Keywords: Novel agronomic practices. Sustainable crop production. Farmer profitability. resource management

Introduction

Agriculture is the cornerstone of India's economy, sustaining nearly 65% of its population, with Punjab being a major contributor to the national food security and self-sufficiency. Known as the "Granary of India," Punjab's intensive farming has historically driven high yields of wheat and rice^[1]. However, farmers face significant challenges, including water scarcity due to erratic rainfall, rising costs of inputs like fertilizers and seeds, and the impacts of climate change, such as soil degradation and increased pest pressures^[2]. The goal of sustainable crop production is to maximize yields while ensuring economic profitability and environmental health^[3]. Critical agronomic practices such as seed treatment to improve germination, nutrient management for soil fertility, efficient irrigation to conserve water, and integrated weed and pest management are vital to achieving this balance. Punjab's agriculture is grappling with groundwater depletion as the state relies heavily on tube wells for irrigation, leading to a drop in water tables by approximately 0.5 meters annually in some regions^[4]. Soil health has deteriorated due to imbalanced fertilizer use, with excessive nitrogen application contributing to nitrate leaching and environmental pollution^[5]. Climate change exacerbates these issues, with projections indicating a potential 10-20% reduction in wheat yields by 2050 due to rising temperatures. To counter this, farmers are increasingly exploring diversification into crops like pulses and oilseeds, which require less water and improve soil nitrogen levels through natural fixation.

Extension services play a crucial role in disseminating knowledge on precision farming technologies, such as drip irrigation and variable rate fertilizer application, which can reduce input costs by 15-20% while maintaining yields. This study aims to achieve the following objectives: (1) to investigate the agronomic practices adopted by farmers for crop production in Punjab, (2) to evaluate their role in maintaining sustainability and profitability, and (3) to provide recommendations for bridging gaps between traditional and recommended practices. By analyzing the adoption levels of these practices among farmers and evaluating their effects on crop yields and farm profitability, this paper identifies barriers to adoption, such as limited access to resources or knowledge, and proposes strategies to promote sustainable agriculture for long-term productivity and resilience.

Literature review

Punjab's agriculture has been documented by, who found that farmers in Punjab often apply fertilizers and seed rates above recommendations, and the dominant crops are wheat-rice^[6]. With increased yield for short duration and risk of soil health issues in the long run. The Food and Agriculture Organization (FAO,2023) highlights good agricultural practices (GAP) as central to achieving environmental, economic, and social sustainability^[7]. Conservation agriculture, integrated nutrient management, and organic amendments are increasingly being recognized as solutions to Punjab's current challenges. For instance, conservation

agriculture practices, such as zero tillage, have been shown to reduce water use by up to 20% while maintaining yields, offering a viable path to sustainability^[8]. Similarly, organic amendments like farmyard manure improve soil organic matter, countering the degradation caused by intensive monocropping^[9]

Further studies emphasize the need for crop diversification to mitigate the risks associated with the rice-wheat monoculture. Introducing legumes into the rotation can enhance soil fertility and reduce dependency on synthetic fertilizers, with studies reporting up to 30% improvement in soil nitrogen levels^[10]. Research on precision agriculture in Punjab shows that GPS-guided machinery and soil sensors can optimize resource use, potentially increasing profitability by 10-15%^[11]. Challenges in adoption include high initial costs and lack of technical training, as noted in surveys of smallholder farmers. Climate-resilient varieties, such as drought-tolerant wheat cultivars, have been developed and tested, demonstrating yield improvements under stress conditions. Integrated pest management (IPM) strategies, combining biological controls with judicious chemical use, have reduced pesticide applications by 30% in pilot programs without compromising yields. These findings underscore the importance of policy support, including subsidies for eco-friendly inputs and strengthened extension networks, to accelerate the transition to sustainable agronomy in Punjab.

Materials and Methodology

The study was conducted in the Sahibzada Ajit Singh Nagar (SAS Nagar) district of Punjab, India, a key agricultural region known for its intensive rice-wheat cropping system and contributions to national food security. The selected villages (Barauli, Choti Ghandua, Fatehpur Jattan, Tabhala, Doom chheri) are located in the Kharar and Bassi Pathana tehsils, representing a mix of smallholder farming communities with average landholdings of 3-5 hectares, focusing on cereal and cash crops like rice, wheat, sugarcane, maize, and berseem. A total of 60 farmers were selected on a random basis from these villages, with 10 farmers per village, to balance representation. A detailed interaction was conducted with the farmers regarding their social status, family details, agronomic practices, crops grown, yield, marketing, incomes, and problems faced. Interviews were semi-structured, lasting 30-45 minutes each, and conducted in the local Punjabi language to ensure comprehension and rapport. The farmers were interviewed at their homes and in their fields during the kharif season to capture recent harvest data and off-season reflections. To fully document the agronomic practices implemented by farmers, a comprehensive questionnaire was prepared, structured into sections covering seed selection, treatment, fertilizer and manure application, irrigation schedule, pest and weed management, harvesting techniques, and postharvest losses. This was done to ensure every aspect was fully covered and every possible data collected with a proper sequential analysis for each farmer parameter.

After data collection from farmers, responses were transcribed and classified using a Microsoft Excel spreadsheet for quantitative variables and qualitative insight. Graphical representations, such as bar charts for crop distribution and pie charts for problem prevalence, were

generated to visualize trends.

Results and Observation

Social profile and land holdings

As per data collected, out of 60 farmers surveyed, 39 farmers (65%) belong to a joint family system with an average of six members in the family. The average land holding recorded was 3.2 hectares (8 acres), and only 12 farmers (20%) reported leasing additional land. This indicates that most farmers operate on relatively small, owned landholdings, which influences their resource allocation and adoption of modern practices.

Table 1: Social Profiles and Land Holdings of Farmers in Punjab

Category	Number of farmers	percentages
Joint family	39	65%
Nuclear family	21	35%
Average family size	6members	-
Average land holding	3.2ha	-
Farmers with lease-in land	12	20%

Major crops grown by farmers in the kharif season

The agricultural system in the studied areas is dominated by a rice-wheat cropping pattern. And out of 60 farmers, 51 farmers (85%) grow wheat, 15 farmers (25%) grow maize, 10 farmers (17%) grow sugarcane, and 8 farmers (13%) grow berseem. While the Green Revolution's legacy is reflected in the reliance on rice and wheat, some farmers' use of maize, sugarcane, and berseem indicates diversification efforts that could enhance soil resilience and health.

Table 2: Major Crops Grown by Farmers in the Kharif Season

Crop	Number of Farmers	Percentage
Rice	51	85%
Wheat	39	65%
Maize	15	25%
Sugarcane	10	17%
Berseem	8	13%

Seed rate followed by farmers

Rice: According to data collected from 60 farmers, 51 grow rice, with an average area of 1.2 hectares per farmer. Dominant varieties include PR126 (23 farmers, 45%), PR124 (9 farmers, 17%), PUSA44 (8 farmers, 15%), and others, such as PR121 and PR122 (11 farmers, 23%). The average seed rate is 10 kg/ha; 25 farmers use certified seeds (5 kg/ha), while 26 farmers use saved seeds/private agencies (15 kg/ha). Seed cost averages 1200 Rs/ha. Sowing occurs from mid-May to June with a spacing of 20x15 cm (transplanting dominant, used by 46 farmers or 90%). Only 5 farmers (10%) treat seeds, and only 6 farmers (12%) conduct soil testing, indicating a highly inorganic approach with limited adoption of recommended practices. The reliance on saved seeds (26 farmers for rice) and minimal seed treatment (10% for rice) contributes to lower yields due to variability in seed quality. The low adoption of soil testing (12% for rice) leads to suboptimal fertilizer application, risking nutrient imbalances and soil fatigue.

Wheat: Out of 60 farmers, 39 grow wheat with an average area of 1.1 ha per farmer. Varieties include PBW826 (25 farmers) and PBW550 (14 farmers). The average seed rate

is 101 kg/ha, with seeds costing 4100 Rs/ha. Sowing occurs in November with variable spacing, and broadcasting is used by 35 farmers (90%). Only 4 farmers (10%) treat seeds, reflecting minimal adoption of seed treatment. Limited seed treatment (10%) and reliance on broadcasting (90%) may reduce yield consistency due to uneven seed distribution and poor germination rates.

Maize: Out of 60 farmers, 15 grow maize with an average area of 0.75 ha per farmer. The variety grown is PMH-1/2 (all 15 farmers). The average seed rate is 17 kg/ha, with private seeds at 22 kg/ha (7 farmers) and SAU seeds at 12 kg/ha (8 farmers). Seed cost averages 950 Rs/ha. Sowing occurs in Jan-Feb/Oct-Nov with 68 cm spacing by direct sowing (all 15 farmers), with no seed treatment (0 farmers). The absence of seed treatment (0%) and reliance on private seeds with higher rates (7 farmers) increase costs without guaranteed yield benefits, limiting sustainability.

Sugarcane: of 60 farmers, 10 grow sugarcane with an average area of 1 ha per farmer. Varieties include Co238 (5 farmers) and CoPB95 (5 farmers). The average seed rate is 33 kg/ha, with bud costs at 1850 Rs/ha. Sowing occurs in Feb-Mar with 90x40 cm spacing, and 2 farmers (20%) treat seeds.

Limited seed treatment (20%) may expose sugarcane to disease risks, though the use of recommended spacing supports better crop establishment.

Berseem: Out of 60 farmers, 8 grow berseem with an average area of 0.6 ha per farmer. The variety is JB1/Berseem (all 8 farmers). The average seed rate is 25 kg/ha, costing 1500 Rs/ha. Sowing occurs in Mar-Apr with 23 cm spacing in line sowing (all 8 farmers). Consistent use of line sowing and appropriate seed rates supports berseem's role as a fodder crop, though limited adoption (8 farmers) restricts its impact on diversification.

Table 3: Represent the overall of crops grown, average cost, and seed rate

Crop	Average seed rate(kg/ha)	Number of farmers	sources of seed (per farmers)	seed cost (INR/ha)
Rice	11	51	Saved/private seed (25), KVK/SAU (26)	1200
Wheat	100	39	SAU/Retailer (20), saved seed (19)	4200
Maize	18	15	Private (7), SAU (8)	1000
Sugarcane	33	10	Private/Retailer (6) SAU (4)	1850
Berseem	25	8	Private/KVK (5) SAU (3)	1500

Fertilizer doses applied by farmers

As per the following table, rice and wheat are the primary crops, with maize, sugarcane, and berseem mostly for fodder. In these areas, and the nutrient management concerning all those crops was displayed. The table shows the overall types of fertilizers used, along with their dosages and the common methods of application. Out of 60 farmers, 55 (92%) use inorganic fertilizers, with urea and DAP being dominant. Application methods include basal, broadcasting, and foliar.

(125:30:30) and for wheat is NPK (120:60:40), for sugarcane NPK (270:60:40), for maize is NPK (120:150:60), and for Berseem NPK (80-100:40-60:20-40). According to our data, Urea and DAP were mostly used in rice and wheat, but can change according to the crop sources and methods used for application were basal/broadcasting and foliar application. Under-dosing of fertilizers (urea at 100 kg/ha for rice vs. the recommended 137 kg/ha) and minimal soil testing (10 farmers or 17%) contribute to yield gaps. The lack of potassium application risks long-term soil health.

Inorganic fertilizer

As we know, the recommended dose for rice crop of NPK is

Table 4: Fertilizer Doses Applied by Farmers (inorganic)

Crop	Number of farmers	Urea(kg/ha)	DAP (kg/ha)	MOP (kg/ha)	Application method	Application timing
Rice	55	100	50	5	Foliar, basal, broadcasting	Pre-sowing 25 DAS
Wheat	54	110	60	10	Broadcasting	Pre-sowing 35 DAS
Maize	48	90	40	5	Direct application	Pre-sowing at tasseling
Sugarcane	51	190	50	15	basal	At planting 50 DAS
Berseem	45	50	30	5	Line application	Pre-sowing

Organic Fertilizer

Farmyard manure (FYM) is used by 42 farmers (70%), who integrate it with inorganic fertilizers. The integration of

FYM by 70% of farmers is a positive step toward sustainability, but inconsistent application across crops limits its impact on soil health.

Table 5: Fertilizer Doses Applied by Farmers (Organic)

Crops	Number of farmers (FYM)	FYM rate(t/ha)	Number of farmers (Vermicompost)	Vermicompost rate (t/ha)	Integration with inorganic
Rice	42	8	13	2	Yes, with urea/DAP
Wheat	39	6	11	1	Yes, with urea
maize	31	4	9	1	Yes, with DAP
Berseem	30	4	8	1	Yes, with SSP
Sugarcane	36	10	12	3	Yes, with DAP/urea

Major weeds observed by farmers and their management

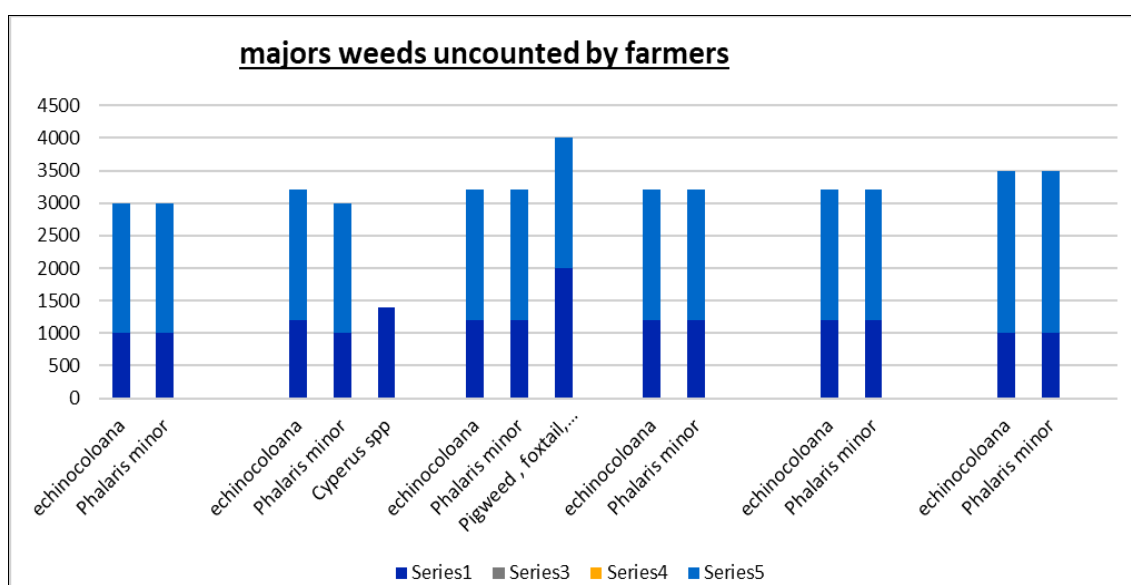
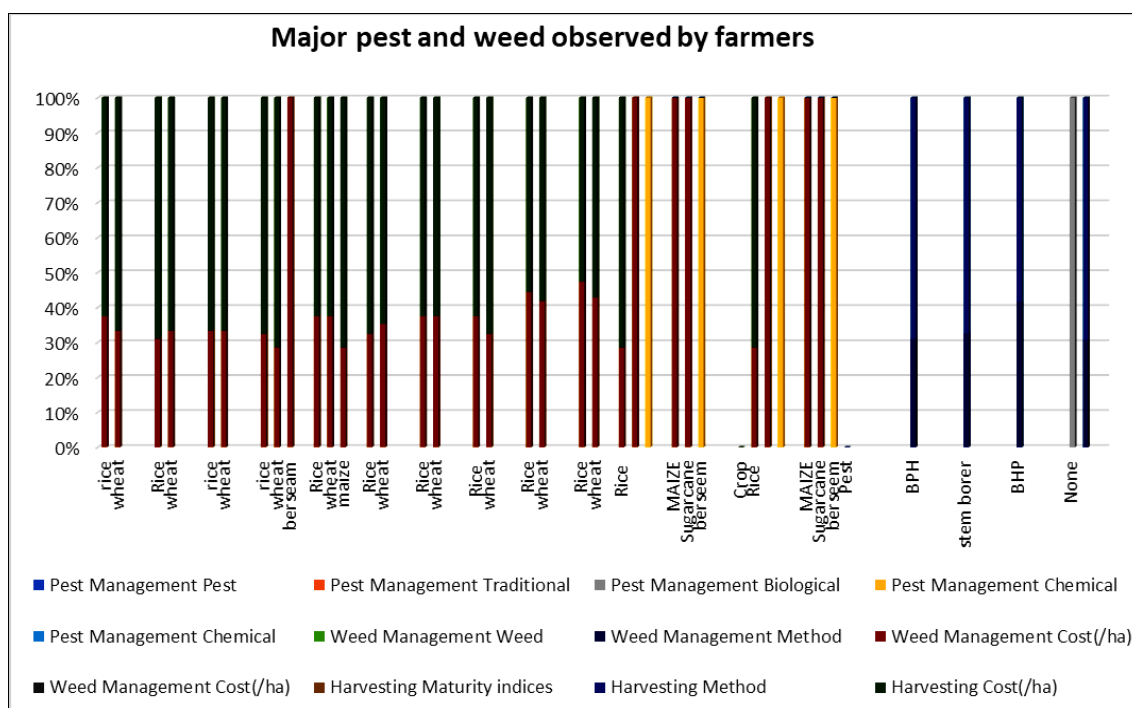
As per the table and the data collected, dominant weeds were *Echinochloa* spp grass in rice, *Phalaris minor* (canary

grass) was primary in wheat, *Cyperus* spp in Berseem, and for maize/sugarcane, weeds like *Echinochloa* and *Cyperus* [2].

Table 6: Major Weeds Observed by Farmers and Their Management Practices

Crop	Major weeds	Management methods	Number of farmers (%)	Management cost (INR/ha)
Rice	<i>Echinochloa</i> spp, <i>Cyperus</i> spp.	Hand +pre-emergence, chemical	54 (90%)	1200
wheat	<i>Phalaris minor</i> , <i>Chenopodium</i> spp	Post-emergence, Hand, Combined	51(85%)	1000
Berseem	<i>Cyperus</i> spp,	Hand +herbicides	45 (74%)	950
Maize	<i>Echinochloa</i> , <i>Cyperus</i> spp	Pre-emergence	48 (80%)	1800
Sugarcane	<i>Cyperus</i>	Pre-emergence	51(85%)	-

The following graphs represent the major pests and weeds



Harvesting methods

Harvesting methods were mostly mechanized, with a combine harvester used by 90% of farmers, reflecting the

adoption of machinery in Punjab's rice-wheat systems. Manual harvesting was rare and limited to smaller holdings. Average cost 1900/ha, varying by crops and methods, and

the maturity index was reported as “grain turns hard” with optimum harvest timing. Rice was harvested by combines with manual methods in small plots, average cost of

2000/ha. Wheat farmers use a combine harvester, and for Berseem, manual harvesting

Table 7: Harvesting Methods Employed by Farmers

Crop	Maturity Indices	Harvesting Method Farmers%	Cost (INR/ha)
Rice	Hard grain	Combine (95%), Manual (5%)	1800
Wheat	Hard grain	Combine (90%), Manual (10%)	2000
Berseem	Fodder stage	Manual + Plougher (100%)	2100
Maize	Hard grain	Combine (67%), Manual (33%)	2000
Sugarcane	Maturity	Manual (100%)	—

Yield record

As per the table, the average yield of rice crop is around 37.4q/ha, for wheat 33.9 q/ha, berseem 280q/ha, maize 38q/ha, and sugarcane 70 q/ha. Those yields are below PAU potentials due to suboptimal practices: rice (37.4 q/ha vs. 60-80 q/ha), wheat (33.9 q/ha vs. 50-60 q/ha), maize (38 q/ha vs. 50-60 q/ha), sugarcane (70 q/ha vs. 80-100 q/ha),

and berseem (280 q/ha vs. 300-350 q/ha). Yield gaps of 20-40% are attributed to under-dosing fertilizers, low seed treatment, and inadequate soil testing. Bar charts show rice yields are highest in Barauli (40 q/ha) due to better irrigation, while wheat yields are lowest in Dhumaheri (30 q/ha) due to poor soil management.

Table 8: yield records

Crop	Variety	Average yield (kg/ha)	Average area(ha)	Number of applications
Rice	PR126	37	2.1	19
Wheat	PBW-826	33	1.8	15
Berseem	JB-1	280	5	1.0
Maize	PMH-1	38	1-2	0.8
Sugarcane	NCO-334	70	-	1.0

Problems faced by farmers

Several significant issues were found based on survey data gathered. Table 9 illustrates the prevalence of these issues, which were measured using a binary response system (1 for confronting the problem, 0 otherwise). Marketing limitations, climate uncertainty, pest management challenges, irrigation restrictions, electricity shortages, machinery access, seed availability, network problems, fluctuating market prices, labor shortages, gaps in financial support, and fertilizer availability delays are the main problems. Cultivation expenses are linked to input costs and profitability, although they were not noted as a major issue on their own.

1. Marketing Constraints

About 50-60% of farmers reported trouble selling their produce, mostly because they relied on a small market. They also had to deal with problems like delayed payments, expensive transportation (INR 1,000-2,000/ha), and restricted access to other markets (like private buyers). Due to their lack of negotiating leverage, smallholders with dispersed landholdings (average 3.2 ha) are disproportionately impacted.

2. Climatic Uncertainties (Raining Time)

Unpredictable rainfall was mentioned by about 20-30% of farmers as a significant problem that shows water constraint and interferes with planting and harvesting dates. This is connected to the wider effects of climate change in Punjab, where unpredictable monsoons cause crop losses (e.g., crop yield reductions of 10-15% in villages like Fatehpur Jattan during kharif seasons).

3. Machinery Access

Around 20-25% of respondents reported limited access to

machinery (proper equipment, such as seeders, harvesters, and tractors), relying on rentals with high costs. And some farmers may face availability issues, leading to yield loss.

4. Labor Shortages

Approximately 10-15% of farmers faced labor challenges due to high wages (300-500 INR per day).

5. Financial Support

About 20-25% of respondents mentioned insufficient funding, which included low scheme uptake (for example, only 20-30% use KCC or are part of KVK)

6. Pest Management Challenges

Between 40 and 50 percent of respondents reported having insect problems; frequent pests were yellow stem borers, leaf folders, brown plant hoppers (BPH), and general pests in wheat. Without efficient biological or integrated pest management (IPM) alternatives, an over-reliance on chemical controls (85-90% adoption) has resulted in resistance and increased costs (INR 1,200-2,000/ha).

7. Timely Availability of Fertilizers

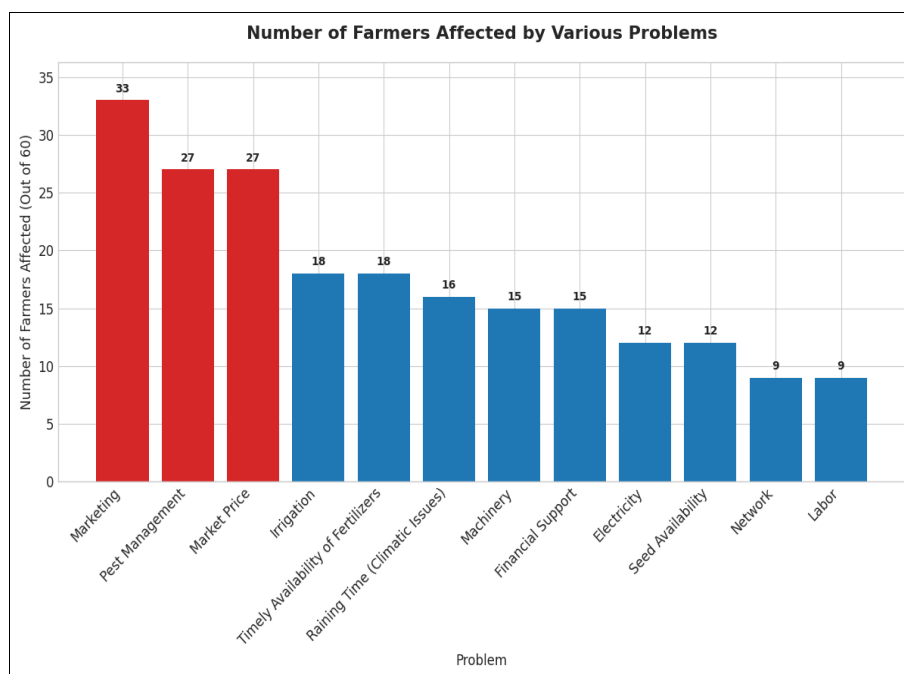
25-30% of farmers experienced delays in purchasing fertilizer, frequently as a result of supply chain problems during busy times. This results in less-than-ideal dosage (urea at 90-110 kg/ha as opposed to the suggested 125-150 kg/ha), which affects yields.

8. Network and Extension Services

Poor network connectivity and limited extension contact affected 10-15% of farmers, hindering access to real-time advisories on weather, markets, or schemes. This gap reduces the adoption of sustainable practices like soil testing (only 10-20% reported).

Table 9: Prevalence of Problems Faced by Farmers Across the Six Villages

Problem	Number of Farmers Affected (out of 60)	Percentage (%)
Marketing	33	55%
Raining Time (Climatic Issues)	16	26%
Pest Management	27	45%
Irrigation	18	30%
Electricity	12	20%
Machinery	15	25%
Seed Availability	12	20%
Network	9	15%
Market Price	27	45%
Labor	9	15%
Financial Support	15	25%
Timely Availability of Fertilizers	18	30%
Cost of Cultivation	3	5%



Discussion

The results highlight the continuation of high-input rice-wheat systems in Punjab as a Green Revolution inheritance, guaranteed food security, but at an environmental and economic price for minor farmers^[12]. Yields (rice 37.4 q/ha, wheat 33.9 q/ha) are consistent with recent state means (rice ~6,878 kg/ha or 68.78 q/ha in 2024, our research is a reflection of smallholder reality), but suboptimal for PAU potentials (rice 60-80 q/ha, wheat 50-60 q/ha) because of under-dosing of fertilizers (e.g., N 41-46 kg/ha compared to 148-222 kg/ha recommended). The optimality is compounded further by inadequate soil testing and K neglect, and a risk of nutrient imbalances and soil fatigue^[13]. application rates (rice 12.5-20 kg/ha) also tended to differ from PAU's (20-25 kg/ha nursery equivalent), salvaged seeds, causing variability and low yield. Chemical dominance of weed and pest control (85-90%) manages the immediate hazard but causes resistance (e.g., for Phalaris minor on wheat), escalating costs (INR 1,400-1,800/ha) without long-term IWM integration^[14]. Mechanized harvesting for high quantities (90%) saves labor but causes a loss (2-5%) if not well-timed. Other broader issues for smallholders are fragmented farms, low adoption of

schemes, and climatic exposure (e.g., unpredictable rains, 20-30% reported)^[15]. Residue burning also continues (10%), despite measures such as no-burn practices, and soil and air degradation ensue. Farmer perspectives indicate that socio-technical barriers, such as a lack of affordable alternatives and awareness, contribute to the persistence of residue burning in Punjab. Diversification (e.g., berseem/maize in 15-25%) improves resilience, but monetary constraints (poor risk-bearing capacity) delay its adoption^[16].

Sustainable transitions also involve supporting diversification of crops (e.g., rice-wheat-pulse) and natural farming practices (eg, mulching), and saving 30-50% of water and enhancing soil health. Effective management of cereal crop residues, such as through mulching and incorporation, has been shown to improve soil fertility and sustainability in the rice-wheat systems of the Indo-Gangetic Plains. Policies should also improve extension services, credit delivery, and market access to organic crops for strengthening the smallholders^[17]. The adoption of climate-smart agriculture practices can further mitigate climatic risks and enhance crop income. The future studies may look at smart apps (Farmonaut for precision farming) to bridge

such gaps. Recent studies using remote sensing data highlight the growing adoption of precision farming techniques in Punjab, which can optimize resource use and improve sustainability^[18].

Conclusion

Based on the data collected, it is concluded that rice and wheat are the main crops grown in these areas, supplemented by sugarcane, maize, and berseem. The data reveal the reliance on inorganic-intensive approaches, with seed rate and fertilizer applications consistently below PAU recommendations^[19]. This underdosing is followed by minimal soil testing and low potassium use. Weed control is mostly done by chemical and increases the risk of herbicide resistance due to low adoption of integrated weed management^[20]. The harvesting is almost fully mechanized with a combine harvester. Key findings reveal that the average seed rates range from (11.8kg/ha⁻¹4.7kg/ha) for rice and (100kg/ha⁻¹08kg/ha) for wheat, and the fertilizer application (Urea averaging 90 kg/ha⁻¹10 kg/ha) compared to the PAU recommendation is little deficient, usually due to saved seed and no testing of soil. Adoption of strategies to reduce the negative effects of chemicals in Punjab's agriculture, such as crop rotation and optimizing fertilizer application, could further enhance sustainability and environmental protection. These measures, combined with farmer education on residue management to curb burning practices, would mitigate socio-technical barriers and promote resilient systems. Additionally, integrating regenerative techniques like direct seeding rice can conserve water and boost yields while lowering emissions, fostering a pathway to eco-friendly profitability for smallholders. Strengthening extension services and improving access to credit and markets will facilitate the adoption of these practices, particularly for smallholder farmers with limited resources, ensuring long-term sustainability and food security in Punjab's agriculture.

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