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The efficacy of precision agriculture techniques in assessing soil degradation in Punjab: A study based on soil testing data

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Abstract

Punjab, recognized as India's agricultural heartland, is grappling with critical soil degradation stemming from intensive farming practices, characterized by excessive chemical fertilizer application, monoculture cropping systems, and unsustainable groundwater extraction. This study aimed to evaluate the efficacy of precision agriculture techniques, with a specific focus on soil testing, in assessing and potentially mitigating this degradation. Employing a mixed-methods approach, the research utilized primary survey data collected from 95 farmers across six strategically selected villages in the Fatehgarh Sahib and Rupnagar districts of Punjab. The survey instrument was meticulously designed to capture data on farmers' awareness, adoption, and perceived barriers related to soil testing practices. The analysis revealed a significant discrepancy: while a substantial majority (78.3%) of farmers demonstrated awareness of soil testing benefits, only a small fraction (16.7%) had implemented these practices on their farms. This disparity underscores the presence of practical impediments, including economic constraints, logistical challenges related to access to testing services, and a perceived lack of the requisite technical expertise. Notably, an educational video intervention, designed to address knowledge gaps and demonstrate soil testing procedures, resulted in a dramatic increase in farmers' stated intention to adopt soil testing (91.7%). This finding highlights the potent influence of targeted educational interventions in driving behavioral change. The study concludes by emphasizing the imperative for a multi-pronged strategy to combat soil degradation in Punjab. This strategy should encompass the promotion of sustainable agricultural practices, such as crop diversification and organic farming, substantial investments in rural infrastructure to enhance access to resources, and the implementation of comprehensive farmer education programs. By addressing both knowledge deficits and practical barriers, it is possible to foster the widespread adoption of precision agriculture techniques, thereby safeguarding soil health and ensuring the long-term sustainability of Punjab's vital agricultural sector.

Keywords: Soil degradation, precision agriculture, soil testing, farmer adoption, agricultural sustainability

Introduction

Punjab, India's agricultural powerhouse, faces severe environmental and economic challenges due to intensive farming. Groundwater depletion from excessive irrigation, especially for paddy, threatens long-term sustainability (Khalsa Vox, 2024) ^[1]. Experts warn that Punjab's groundwater levels could drop below 1,000 feet by 2039 if current practices continue (Kumar & Singh, 2020) ^[2]. Soil degradation results from chemical fertiliser overuse and continuous wheat-paddy cropping (Singh & Kaur, 2024) ^[3]. The excessive and imbalanced use of fertilisers has led to soil and water quality degradation in Punjab (International Journal of Farming Research, 2024) ^[4]. Rising input costs, climate change, and economic struggles add to farmers' distress (Times of India, 2024) ^[5]. Declining net farm productivity, rising production costs, and inadequate marketing systems have contributed to the deceleration in farm income growth (BISA, 2023) ^[6]. Rural infrastructure gaps in education, healthcare, and agricultural knowledge limit farmers' ability to adapt (Punjab Rural Development Fund, 2024) ^[7]. Limited storage facilities and food processing units for non-cereal crops hinder diversification efforts (Kaur & Sharma, 2021) ^[8]. Poor healthcare reduces labor efficiency, while a lack of

agricultural libraries and digital resources hinders access to modern techniques. The study recommends crop diversification (shifting to pulses, oilseeds, and millets), organic farming, and improved water management (drip irrigation, rainwater harvesting) (BISA, 2023)^[6]. Encouraging the cultivation of less water-intensive crops and adopting efficient water management practices are suggested strategies (Kaur & Sharma, 2021)^[8]. Investing in education, digital literacy, and rural infrastructure can empower farmers with better market access, sustainable practices, and resilience against climate change (Punjab Rural Development Fund, 2024)^[7].

Punjab, the "Granary of India," faces a severe soil degradation crisis due to intensive farming, excessive chemical fertiliser use, monoculture (wheat-paddy cycle), groundwater depletion, and stubble burning (Gill, 2023)^[9].

Overuse of NPK fertilisers and pesticides has depleted essential micronutrients, harmed soil microorganisms, and increased soil toxicity (International Journal of Farming Research, 2024)^[4]. High usage of nitrogenous fertilisers with relative under-utilization of other fertilisers and micronutrients has led to an imbalance in soil nutrients (Gill, 2023)^[9]. Continuous wheat-rice cultivation has exhausted soil nutrients, while paddy farming has worsened waterlogging and salinity (Gill, 2023)^[9]. The continuous cultivation of wheat-rice monoculture over the last four decades has resulted in a serious deficiency of micronutrients in the soil and has adversely affected its fertility (Gill, 2023)^[9]. Groundwater depletion forces farmers to extract deeper, saltier water, damaging soil structure (Kumar & Singh, 2020)^[2].

Punjab, an agriculture-based economy, is pumping the highest volume of groundwater, leading to significant depletion (Kumar & Singh, 2020)^[2]. Stubble burning destroys organic matter and beneficial microbes, further degrading soil while contributing to air pollution (World Biologica, 2024)^[10]. Burning crop residue has significant negative effects, including air pollution and soil quality degradation (World Biologica, 2024)^[10]. Despite government efforts, lack of affordable alternatives keeps the practice widespread (Rediff Money, 2025)^[11]. The Punjab government has allocated funds to promote eco-friendly alternatives to stubble burning, but challenges remain (Rediff Money, 2025)^[11]. The impact includes declining crop yields, rising input costs, increasing farmer debt, and environmental damage, including water contamination and air pollution (Tribune India, 2023)^[12]. Over the past five years, Punjab's wheat production has declined from 178 lakh metric tonnes in 2017-18 to 149 lakh metric tonnes in 2021-22 (Tribune India, 2023)^[12]. Punjab's food security is at risk, with wheat production already dropping despite higher fertiliser use (Tribune India, 2019)^[13]. Fertiliser overuse is eating away Punjab's soil nutrients, leading to decreased crop yields (Tribune India, 2019)^[13].

To reverse degradation, Punjab must adopt sustainable farming

- Crop diversification (pulses, oilseeds, millets) (BISA, 2023)^[6]
- Organic fertilisers & biofertilisers (IndiaSpend, 2024)^[14]
- Efficient water management (drip irrigation, rainwater harvesting) (Irrigation Association, 2012)^[15]
- Alternative crop residue management (Happy Seeders, biodecomposers) (Devdiscourse, 2024)^[16]
- Farmer education & incentives for eco-friendly practices (PANJ, 2024)^[17]

Immediate intervention is essential to restore soil health, ensure long-term agricultural sustainability, and protect national food

security.

During the month of January 2025, students from Chandigarh University went for survey in Fatehgarh Sahib and Rupnagar districts, Punjab. There we collected data from 6 villages (Khan, Kajoli, Manpur, Kotli, Badi rauni, Choti Rauni) wherein we included data from all fields of their agricultural work. There we closely investigated the aspects and operations performed in the soil of Punjab. While performing the survey there, we witnessed many problems that were being faced by the farmers there on a daily basis. Soil degradation is becoming one of the most talked and concerning subject of issue. We have analysed and compiled all such data that we collected regarding this issue. Through our research paper we would like to throw some light on soil degradation.

Materials and Methodology

This study was conducted to understand the soil health and soil quality in the villages of Khan, Manpur, Kajouli, Kotli, Chhoti Rauni, and Badi Rauni in Fatehgarh Sahib, Rupnagar district, Punjab. These villages were selected due to their diverse farming practices and varying levels of awareness regarding soil sampling.

The farmers were selected for the survey using a *random sampling method* to ensure a diverse representation of different farm sizes, cropping patterns, and agricultural experiences. The sample included *small, medium, and large-scale farmers* to assess variations in soil sampling awareness across different farming demographics.

Data Collection

To gather the necessary data, a questionnaire was developed based on primary sources, and interviews were conducted with 120 farmers. A series of structured sessions were held to create the questionnaire, ensuring it addressed the objectives of the study.

The data collection process involved using a systematic questionnaire and conducting in-person, door-to-door interviews. Additionally, personal interviews with senior farmers and residents from nearby villages were also conducted to gather qualitative insights. Questionnaire Structures were; Farmers' awareness and knowledge of soil sampling techniques, Frequency and methods of soil testing, challenges faced in adopting soil testing practices and in addition, the survey worked in 2 phases i.e. Before and after watching video. This Video consist important point like sampling depth necessary equipment, sampling frequency, and typical errors to avoid were covered in the video.

Calculations

1. Total number of farmers
2. Number of farmers

Percentage Formula (%) = (Number of farmers/total numbers of farmers) * 100

Table 1: Number of farmers in respective villages

S.no	Village name	Number of farmers	Farmers in percentages (%)
1	Khan	21	18%
2	Kajouli	23	19%
3	Manpur	25	21%
4	Chhoti Rauni	21	18%
5	Badi Rauni	16	13%
6	Kotli	14	11%
Total		120	100

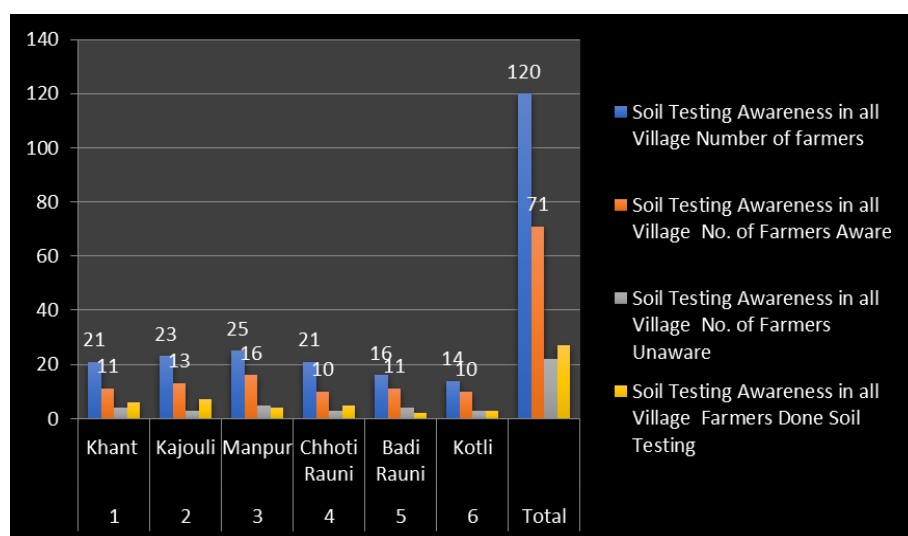


Fig 1: Graphical representation of number of farmers in respective villages

Results and Discussion

A survey of 120 farmers revealed that only 27 had implemented soil sampling on their land. Analysis of village-specific data (Table 1.2) highlighted significant variation in adoption rates, with Kajouli demonstrating the highest prevalence of soil sampling and Choti Rauni the lowest. This study, conducted across multiple villages, underscores a critical divergence between farmers' theoretical understanding of soil testing and its practical application, indicating a low rate of implementation despite acknowledged awareness.

Table 2: Soil Testing Practices Among Farmers

Soil Testing Practice	Percentage of Farmers
No Soil Testing	77.5%
Soil Testing with Mineral Deficiencies	22.5%

Table 3: Number of farmers in respective villages who have done soil sampling

Sr no	Village name	No. of farmers
1	Kajouli	11
2	Khant	4
3	Badi rauni	4
4	Choti rauni	3
5	Manpur	3
6	kotli	2

Implementation of soil testing practices among village farmers

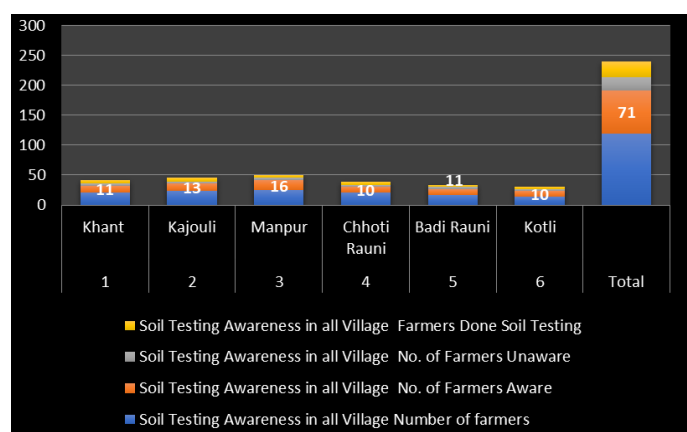


Fig 2: Number of farmers who implemented soil testing

In a research study aimed at evaluating farmers' awareness of soil sampling, it was discovered that 27 farmers had already implemented soil testing on their field, 71 farmers had knowledge of this practice, while 22 farmers were not familiar with it. This suggests that a majority 59.16% of farmers understand the significance of soil sampling even though they had not implemented it, whereas a smaller fraction 18.3% lacks this awareness. Those farmers who are informed about soil sampling recognize its advantages, such as assessing nutrient levels in the soil, enhancing fertilizer application, and boosting crop productivity. Their understanding may stem from agricultural extension services, educational programs, or personal experiences. Conversely, the 22 farmers who lack awareness may not have access to information, resources, or adequate training. To close this knowledge gap, it is essential to bolster extension services, organize training workshops, and offer accessible educational materials on soil sampling methods. Raising awareness among all farmers will lead to improved soil health management, lower production costs, and regenerative Agriculture.

Table 4: Number of farmers with knowledge in respective villages

1	Farmer with knowledge	71
2	Farmers who doesn't have knowledge	22

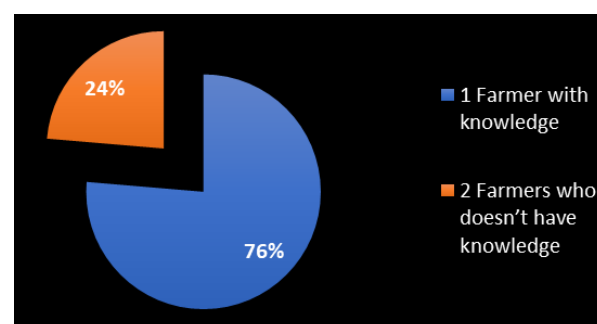


Fig 3: Chart showing farmers with knowledge in respective villages

Farmers who conducted soil sampling

Table 5: Status of farmers and their performance of soil testing

Performed	27
Has knowledge but haven't performed	71
Unaware	22

Despite a seemingly robust level of awareness regarding the benefits of soil sampling, a striking disconnect emerges between theoretical knowledge and practical application. Specifically, a mere 22.5% out of 120 farmers surveyed, reported having actually performed soil sampling on their agricultural land. This starkly contrasts with the broader recognition of the practice's importance, indicating that while a significant number of farmers possess the conceptual understanding of soil sampling, its implementation remains limited. The vast majority, comprising 77.5% farmers, have yet to conduct soil tests, even though a substantial portion of this group, 71 individuals, acknowledge their awareness of the practice. This disparity underscores a critical challenge: the translation of knowledge into tangible action. It suggests that factors beyond mere awareness, such as perceived or real barriers to access, economic constraints, or a lack of practical skills, are significantly hindering the adoption of soil sampling. Therefore, interventions must move beyond simple information dissemination and focus on addressing the practical obstacles that prevent farmers from utilizing this essential agricultural tool.

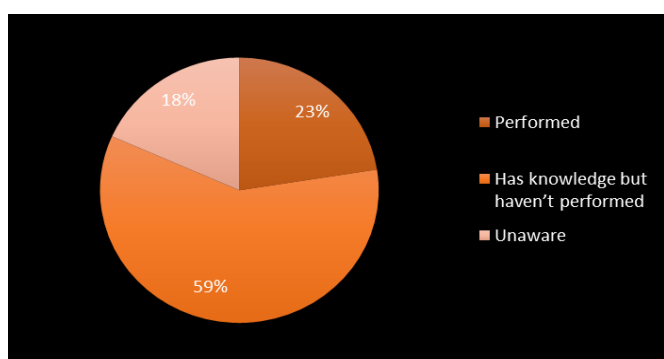


Fig 4: Chart showing Status of farmers and their performance of soil testing

Improvement in farmers' understanding after viewing the educational video on soil sampling

Table 6: Farmers and their status of soil testing

Farmer with no soil testing	77.5%
Farmer with soil testing	22.5%

The data reveals a notable disparity between farmers' theoretical understanding and practical application of soil sampling. While a significant proportion of the surveyed farmers demonstrated awareness of soil sampling as a valuable agricultural practice, a minority remained uninformed, highlighting a persistent knowledge deficit within the community. Furthermore, despite the generally high level of awareness, a stark contrast emerged between knowledge and action: only a small fraction, representing 22.5% of the sample, had implemented soil sampling on their land. Conversely, the overwhelming majority, 77.5%, had not yet undertaken this crucial diagnostic procedure. This discrepancy strongly suggests that the mere recognition of soil sampling's importance does not automatically translate into its adoption. Several potential impediments likely contribute to this gap, including economic constraints related to the cost of soil analysis, logistical challenges concerning the accessibility of sampling services, and a perceived lack of the specialized technical expertise necessary to conduct the process accurately. Consequently, a targeted approach is needed to bridge this gap, addressing not only the dissemination of information but also the provision of practical support and resources to facilitate the

widespread adoption of soil sampling.

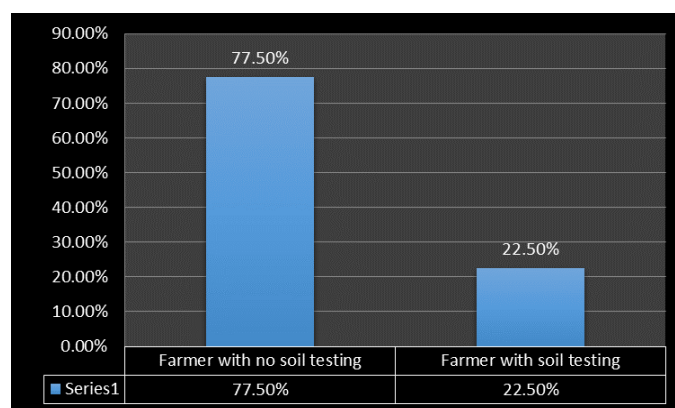


Fig 5: Graph showing Farmers and their status of soil testing

Farmers' inclination towards implementing soil sampling techniques and the driving factors influencing farmers' adoption

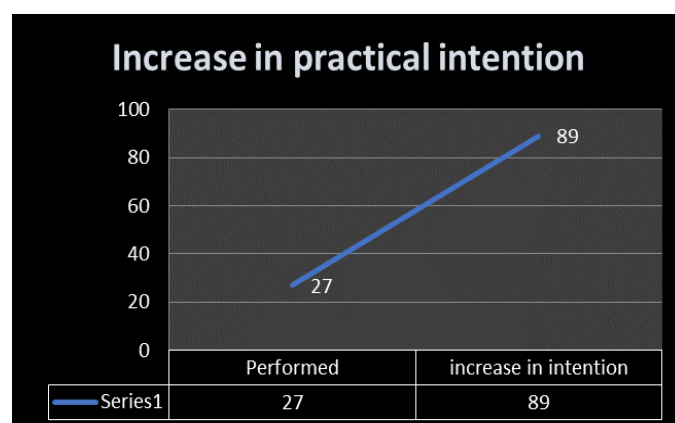


Fig 6: Graph showing increase in practical intention to implement soil testing

Following the presentation of an educational video on soil sampling techniques, a significant increase in farmer interest was observed. Initially, only 22.5% of the group had practical experience with soil sampling. However, after viewing the video, 89 farmers or 74.1% indicated their intention to implement the practice in the future. This notable shift highlights the impact of targeted education on farmer behavior. The substantial change in expressed intent suggests that visual learning tools are effective in conveying the benefits and procedures of soil sampling, thereby encouraging the adoption of improved agricultural practices. This finding underscores the value of accessible educational resources in promoting positive changes within the farming community.

Table 7: Increase in farmer's intention to implement soil testing

Knowledge of farmers	Number
No implementation	93
Increase in intention to implement	89

Factors influencing adoption

1. Simplicity of use as a facilitating factor.
2. Perceived positive outcomes as a motivating factor.
3. Sustainability values as a driver for adoption.
4. Lack of initial understanding as a potential barrier.

Conclusion

Our research reveals a significant problem in Punjab's agriculture: farmers understand the value of soil testing, but they're not doing it. We found a big difference between what they know and what they do. This tells us that just telling farmers about soil testing isn't enough to make them use it. The educational video we showed them did change their minds, with many more farmers saying they plan to do soil testing in the future. This shows that teaching them directly can work. However, we need to do more than just teach. We must also help them overcome the real problems they face, like the cost of testing and getting access to labs. To make farming in Punjab sustainable, we need a combined approach. We have to promote better farming methods, such as crop diversification and organic farming. We also need to improve things in rural areas, like roads and access to information. Most importantly, we need to give farmers the right education and support. This means making sure they have the knowledge and resources to do soil testing and other good farming practices. By focusing on both education and practical help, we can help Punjab's farmers grow food in a way that's good for the soil and good for the future.

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