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Farmers' Attitudes and Awareness Towards Fertilizer and Pesticide Use: Health and Environmental Implications

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Agrochemicals;
Farmer awareness;
Fertilizer;
Pesticides;
Occupational health;
Sustainable agriculture

Abstract

The Green Revolution increased agricultural productivity in India but also intensified dependence on chemical fertilizers and pesticides, raising environmental and health concerns. This study assessed farmers' knowledge regarding agrochemical use in Kaithal, Kurukshetra, and Karnal districts of Haryana. A structured questionnaire survey was conducted among 180 farmers from nine villages, and data were analyzed using descriptive statistics and chi-square tests. Findings revealed significant gaps in awareness and adoption of recommended agrochemical dosages. Only 38% of farmers followed recommended fertilizer application practices, while knowledge of fertilizer types, application rates, and balanced nutrient management was limited. Information was mainly obtained from fellow farmers (50%) and mass media (35%), whereas only 5% consulted government extension services. Pesticide use was largely based on visible pest infestation (50%) and personal experience (40%). Inadequate protection, unsafe handling, and health symptoms indicated occupational risks. Strengthening extension services, farmer training, and sustainable farming practices is essential.

1. Introduction

India's agricultural sector has undergone profound structural and technological transformations since the advent of the Green Revolution in the 1960s, a milestone that fundamentally reshaped the nation's food production system (Mishra et al., 2021). The Green Revolution, driven by scientific advancements pioneered by Dr. M. S. Swaminathan, promoted the large-scale adoption of high-yielding crop varieties alongside increased use of chemical fertilizers, pesticides, and irrigation infrastructure to mitigate food scarcity and enhance national food security (Parayil, 1992; Sebby, 2010; Harwood, 2020; Gollin et al., 2021). These interventions resulted in a substantial increase in food grain production, enabling India to meet the demands of a rapidly growing population. Agriculture continues to be a critical pillar of the Indian economy, supporting the livelihoods of a large segment of the population and contributing significantly to national income (Yadav and Dutta, 2019). However, the long-term dependence on chemical-intensive farming practices has raised serious concerns regarding environmental sustainability, ecosystem health, and human well-being (Jote, 2023; Grover et al., 2024).

India faces an inherent challenge of sustaining agricultural productivity under severe resource constraints, as it supports nearly 17.84% of the global population with only 2.4% of the world's land area and about 4% of freshwater resources (Indian Agrochemical Industry Report, 2016). This imbalance has driven a sharp escalation in the use of agrochemicals, particularly synthetic fertilizers and pesticides, to maximize crop yields and stabilize food supply (Mishra et al., 2022; Penuelas et al., 2023). Fertilizer consumption in India has increased more than thirteen-fold since the 1970s, positioning the country as the second-largest consumer globally after China (IFA, 2017; FAI, 2020). The consumption of nitrogen, phosphorus, and potassium (NPK) fertilizers has expanded from 65.6 thousand tonnes in 1951 to over 30.6 million tonnes in 2023–2024, with further growth projected for 2024–2025 (Fertilizer Association of India, 2023). Similarly, pesticide production has risen substantially, from approximately 102,240 tonnes in 1998 to over 258,000 tonnes in 2023 (Aktar et al., 2009; Government of India, 2023). While these inputs have played a pivotal role in enhancing agricultural productivity, their excessive and often indiscriminate application has intensified environmental degradation and public health risks, particularly in high-input agricultural states such as Punjab, Haryana, and West Bengal (Malik and Choudhary, 2024).

The environmental consequences of conventional farming practices, where intensive fertilizer and pesticide use, tillage, and residue burning are evident practices across Indian agro-ecosystems, have led to profound disturbances in soil–water–atmosphere interactions, undermining ecosystem resilience and long-term agricultural sustainability (Grover et al., 2025). Excess nitrogen application has significantly altered biogeochemical cycles, contributing to elevated emissions of reactive nitrogen compounds and a marked decline in nitrogen use efficiency (Viancelli and Michelon, 2024). Phosphatic fertilizers exhibit low plant uptake efficiency, with nearly 85% remaining in the soil or lost through runoff and leaching, leading to phosphorus accumulation and eutrophication of freshwater bodies (Kumar et al., 2023). In addition, the long-term application of chemical fertilizers and pesticides has resulted in the accumulation of heavy metals such as cadmium, lead, and arsenic in agricultural soils, as well as persistent pesticide residues in air, water, and food chains (Atafar et al., 2010; Mishra et al., 2021). The growing dominance of fluorinated pesticides accounting for more than half of newly approved agrochemicals due to their chemical stability and bioavailability has further amplified concerns regarding environmental persistence and ecological toxicity (Jagani et al., 2025).

Beyond environmental impacts, the health implications of prolonged exposure to agrochemicals pose a significant challenge for farming communities. Numerous studies have linked fertilizer and pesticide exposure to acute symptoms such as skin irritation, headaches, dizziness, and nausea, as well as chronic conditions including respiratory disorders, endocrine disruption, reproductive abnormalities, and various forms of cancer (Dhankhar and Kumar, 2023). Evidence from agricultural regions in South and Southeast Asia demonstrates elevated risks of chronic respiratory diseases, diabetes, and cardiovascular disorders among populations exposed to pesticides and fine particulate matter (Wongta, 2025). In India, unsafe handling practices—such as inadequate use of personal protective equipment, improper storage, and premature harvesting following pesticide application—further increase exposure risks (Nitu et al., 2016). The World Health Organization estimates that nearly 20,000 deaths occur annually due to unintentional pesticide poisoning, with South Asia bearing a disproportionate burden of these fatalities (Boedeker et al., 2020).

Despite the magnitude of these environmental and health challenges, farmers' awareness and understanding of the safe use, handling, and disposal of fertilizers and pesticides remain uneven and often inadequate. Socio-economic determinants such as education level, farm size, income, access to extension services, and institutional support strongly influence farmers' perceptions, attitudes, and agrochemical use practices (Parveen, 2010; Costa et al., 2021). While some farmers acknowledge the potential health and environmental risks associated with chemical inputs, limited technical knowledge and constrained access to alternatives hinder the adoption of safer practices, including integrated pest management (IPM), biofertilizers, and other sustainable nutrient management strategies (Nitu et al., 2023; Yoganandham and Usha, 2023). In intensive rice–wheat systems prevalent in Haryana, excessive reliance on chemical inputs has contributed to soil organic carbon depletion, micronutrient imbalances, and increasing soil toxicity, posing a serious threat to long-term agricultural resilience (Debangshi and Ghosh, 2022).

Against this backdrop, the present study aims to assess farmers' attitudes and awareness regarding the use of fertilisers and pesticides, with a specific focus on their perceived health and environmental implications. Emphasis is placed on high-input agricultural regions such as Haryana, where agrochemical dependence is particularly pronounced. By synthesizing empirical evidence and existing literature, this research seeks to identify knowledge gaps, behavioral drivers, and regional patterns influencing agrochemical use. The study further aims to evaluate farmers' awareness of safe handling and disposal practices, examine their attitudes toward chemical inputs, and assess perceived risks to human health and the environment. The findings are expected to provide evidence-based insights to support policy interventions, targeted training programs, and extension strategies that promote sustainable agricultural practices while balancing productivity with ecological integrity and public health protection.

2. Material and Methods

2.1 Study Area: The study was conducted in state of Haryana, India, focusing on three major rice–wheat producing districts, Kaithal, Kurukshetra, and Karnal. These districts represent high input agricultural systems characterized by intensive use of chemical fertilizers and pesticides under the dominant rice–wheat cropping pattern. The region is therefore suitable for assessing farmers' attitudes, awareness, and perceptions related to agrochemical use and its health and environmental implications. Within each district, three villages were purposively selected based on the predominance of agricultural activity and accessibility for field surveys. A total of nine villages were included in the study: Sangri, Guliyana, and Kithana from Kaithal district; Kamoda, Pindarsi, and Barna from Kurukshetra district; and Pundrak, Rukanpur, and Uchana from Karnal district, as shown in Table 1. The spatial distribution of the selected villages is illustrated in Fig. 1.

2.2 Selection of Sample: From each selected village, 20 farmers were randomly chosen, resulting in a total sample size of 180 respondents (9 villages × 20 farmers). Eligibility criteria included: (i) farmers aged 18 years or older, (ii) individuals whose primary livelihood depended on agriculture, and (iii) active involvement in crop production during the study period. Prior to participation, respondents were informed about the objectives of the study, and verbal consent was obtained. Farmers were assured that the data collected would be used solely for academic and research purposes.

Table 1: Study sites and the corresponding sample size across districts and villages.

District	Tehsil	Village	Sample size
Kaithal	Kaithal Kaithal Kaithal	Kithana Guliyana Songri	20 20 20
Kurukshetra	Pehowa Thanesar Thanesar	Kamoda Pindarsi Barna	20 20 20
Karnal	Karnal Karnal Karnal	Pundrak Rukanpur Uchana	20 20 20

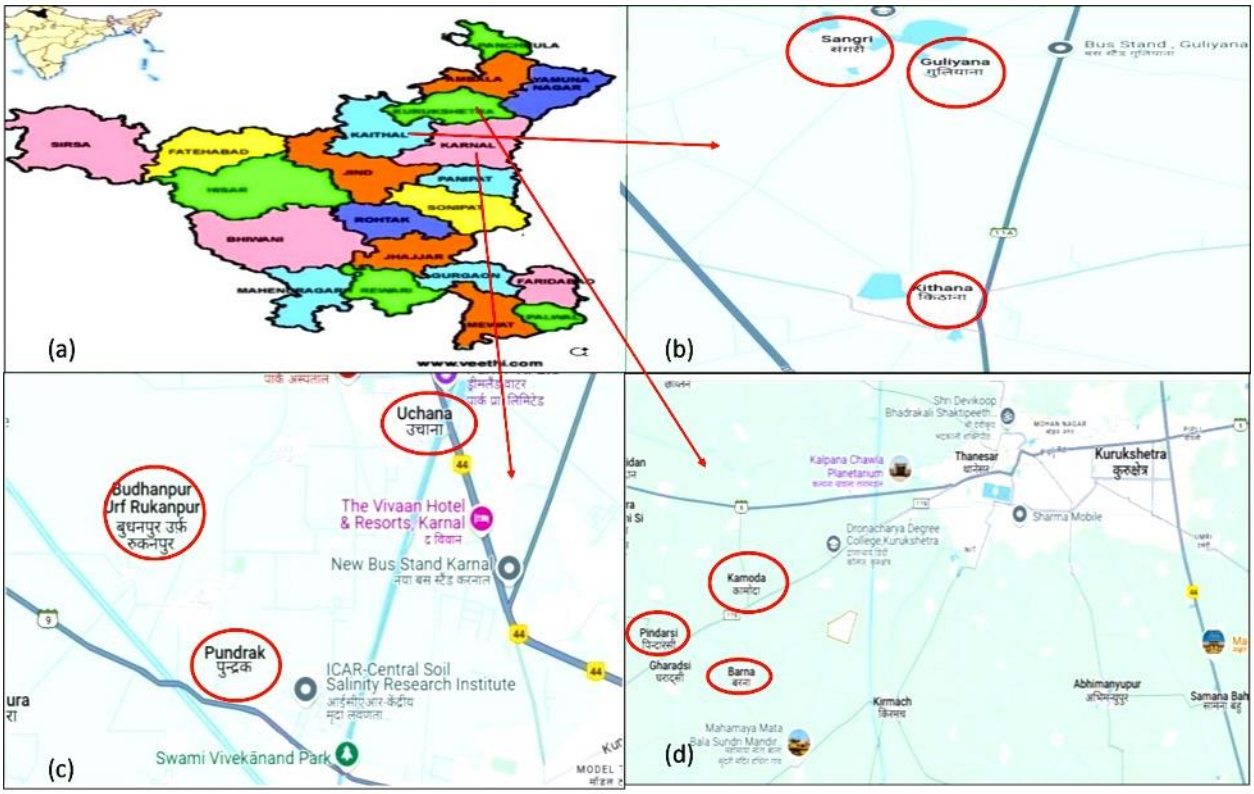


Fig. 1. Location of the sampling sites in (a) Haryana and the study sites in districts of (b) Kaithal, (c) Karnal, and (d) Kurukshetra, India

2.3 Data Collection: Data were collected using a structured questionnaire, developed following an extensive review of existing literature, preliminary field visits, informal discussions with farmers, and consultations with agricultural extension personnel and subject experts. The questionnaire was designed to comprehensively capture farmers' knowledge, attitudes, practices, and perceptions related to fertilizer and pesticide use. Primary data collection was carried out through face-to-face interviews, enabling clarification of questions and improving the reliability of responses. Interviews were conducted individually to minimize peer influence and response bias. The questionnaire comprised both closed- and open-ended questions and was organized into six thematic sections, as summarized in Table 2. The questionnaire covered socio-demographic characteristics, knowledge of fertilizer and pesticide use, attitudes toward chemical inputs,

perceived health and environmental impacts, factors influencing decision-making, and awareness of safe handling practices and personal protective equipment (PPE). This comprehensive structure ensured a holistic assessment of agrochemical use and its implications at the farm level.

Table 2: Key Insights from the Questionnaire Questions.

Section No.	Questionnaire Section	Purpose	Type of Information Collected
1	General Information	To assess basic socio-demographic and personal details of farmers	Age, gender, educational background, type of land ownership, main occupation, farm size, types of crops, farming practice, and farming experience
2	The farmer's knowledge of fertilizers and pesticides	To collect the farmers' knowledge and understanding regarding the use of fertilizers and pesticides	Types of fertilizers and pesticides used, knowledge of dosage guidelines, selection and mixing criteria, application frequency, challenges during application, and impact on soil health
3	Farmer attitudes towards chemical inputs	To gather information on farmers' attitudes, beliefs, and perceptions toward the use of chemical fertilizers and pesticides	Opinions on the necessity and effectiveness of chemical inputs, perceived benefits, and willingness to adopt alternative practices
4	Perceived Health and Environmental Impacts	To identify farmers' perceptions regarding health and environmental consequences of chemical inputs	Pesticide exposure through different body parts, self-reported common health issues, long-term effects on soil health, and environmental pollution
5	Factors Influencing Farmers' Decision-Making	To understand the socio-economic factors influencing farmers' input choice	Reasons for using chemicals, peer influence, access to training, and previous experiences affect decision-making
6	Awareness regarding pesticide handling and personal protective equipment (PPE)	To examine the level of awareness and safety practices followed by farmers while handling pesticides	Knowledge and use of PPE, pesticide storage and disposal methods, awareness of safety guidelines, and emergency measures

2.4 Data Analysis: Following field data collection, survey responses were systematically coded and entered into Microsoft Access, where they were cross-verified to ensure data consistency and accuracy. The validated dataset was then exported to Microsoft Excel (version 21) and SPSS (version 21) for statistical analysis. Descriptive statistics, including frequencies, percentages, and mean values, were used to summarize farmers' responses across different variables. To assess differences between observed and expected frequency distributions, a Chi-square (χ^2) goodness-of-fit test was employed. The null hypothesis (H_0) assumed a uniform distribution of responses across categories (Norman and Streiner, 2008; Lithourgidis et al., 2016). Statistical significance was determined at $p < 0.05$.

3. Results and Discussion

The results of the questionnaire survey are presented under six thematic sections: socio-demographic characteristics of the respondents; farmers' knowledge and practices regarding fertilizers and pesticides; attitudes towards chemical inputs and sustainable alternatives; perceived health and environmental impacts; factors influencing decision-making; and pesticide handling

and personal protective practices. The analysis is based on responses obtained from 180 farmers representing nine villages across Kaithal, Karnal, and Kurukshetra districts of Haryana.

3.1 Socio-demographic characteristics of the surveyed farmers: The socio-demographic characteristics of the respondents are presented in Table 3. The age distribution showed that the largest proportion of farmers belonged to the 31–40 years age group (32.22%), followed by the 41–50 years (20.55%) and 51–60 years (18.33%) age groups. Farmers aged 18–30 years constituted 15.55% of the sample, whereas 13.33% were between 61 and 70 years of age. Thus, the study predominantly represented economically active and middle-aged farmers involved in agricultural decision-making. The respondents were predominantly male (95.55%), while female farmers accounted for only 4.44% of the sample. This distribution may reflect the predominance of male respondents involved in farm management and agricultural decision-making within the surveyed households. The respondents represented varying educational backgrounds, ranging from no formal education to higher education. Rice–wheat was the dominant cropping system across all three districts. Conventional farming was practiced by 87.22% of the respondents, whereas organic and natural farming were reported by 10.00% and 2.77% of farmers, respectively. These findings demonstrate the continued predominance of conventional, chemical-intensive agriculture in the surveyed region. The low proportion of farmers practicing organic and natural farming also suggests that the transition towards alternative production systems remains limited.

Table 3: Descriptive socio-demographic profile of the surveyed farmers.

Variable	Category	Kaithal	Karnal	Kurukshetra	Total (%)
Age distribution	18–30 years	12	8	8	15.55
	31–40 years	13	22	23	32.22
	41–50 years	12	13	12	20.55
	51–60 years	13	10	10	18.33
	61–70 years	10	7	7	13.33
Gender	Male	56	58	58	95.55
	Female	4	2	2	4.44
Type of farming practice	Conventional	54	50	53	87.22
	Organic	6	7	5	10.00
	Natural	0	3	2	2.77

Note: n = 180.

The predominance of conventional farming observed in the present study is consistent with the continued influence of intensive rice–wheat production systems and input-dependent agriculture in the Indo-Gangetic Plains. The findings are also in line with observations that farmers' management decisions are strongly shaped by production requirements, technological familiarity, and perceived economic security (Pingali, 2012; Gupta et al., 2025).

3.2 Farmers' knowledge and practices regarding fertilizer and pesticide use

3.2.1 Compliance with recommended fertilizer management practices: The results mentioned in Table 4 indicated considerable variation in farmers knowledge and compliance with recommended fertilizer management practices. The overall compliance with recommended fertilization practices was reported as 37.57%, indicating substantial scope for improving technical knowledge and adherence to recommended nutrient management practices. The findings suggest

that although farmers routinely used chemical fertilizers, their knowledge of recommended dosage, balanced nutrient application, and safe handling was limited. Only 38% of farmers followed recommended fertilizer application practices, as also highlighted in the manuscript abstract. Knowledge of fertilizer types, appropriate application rates, and balanced nutrient management was therefore not uniformly distributed among the surveyed farmers.

Table 4: Compliance with recommended fertilizer management practices among surveyed farmers

Practice	Response/Compliance	Percentage (%)
Awareness regarding appropriate use of chemical fertilizers	Yes	51.70
Knowledge of recommended dosage/application guidelines	Yes	38.30
Reading safety labels before chemical use	Yes	30.00
Mixing different chemicals during application	Yes	35.00
Use of chemical and organic fertilizers in combination	Yes	20.00
Maintenance of fertilizer application records	Yes	48
Interest in training or guidance programmes	Yes	40.00

Note: Percentages are based on n = 180

Note: Overall compliance =37.57%

The relatively low proportion of farmers following recommended application guidelines indicates that routine use of fertilizers does not necessarily correspond to scientifically informed nutrient management. Similar gaps between fertilizer use and adherence to recommended practices have been reported in previous studies, where limited technical knowledge and inadequate access to extension services influenced farmers' fertilizer management decisions (Rahman et al., 2020).

3.2.2 Sources of information and fertilizer-use patterns: Farmers relied primarily on informal sources of information regarding fertilizer use. Fellow farmers constituted the most important source of information (50%), followed by mass media, including television, newspapers, and social media (35%). Private companies were reported as the main information source by 10% of respondents, whereas government extension agencies accounted for only 5% (Table 5).

Table 5: Primary sources of information regarding fertilizer use among farmers

Source of information	Frequency (n)	Percentage (%)
Government extension agencies	9	5
Fellow farmers	90	50
Mass media	63	35
Private companies	18	10

Note: n = 180. $\chi 2$ (fertilizers) = 97.2, df = 3, $p < 0.001$

The chi-square test indicated a highly significant difference in the utilization of information sources ($\chi^2 = 97.2$, df = 3, $p < 0.001$), confirming that farmers do not rely equally on different channels for fertilizer-related information. The strong dependence on fellow farmers demonstrates the importance of peer networks in influencing agricultural decision-making. The limited role of government extension agencies indicates a potential gap between formal agricultural advisory systems and farmers' day-to-day management decisions. The dominance of informal information channels is consistent with observations reported by Ngowi et al. (2007), who found that farmer-to-farmer communication played an important role in pesticide-related decision-making.

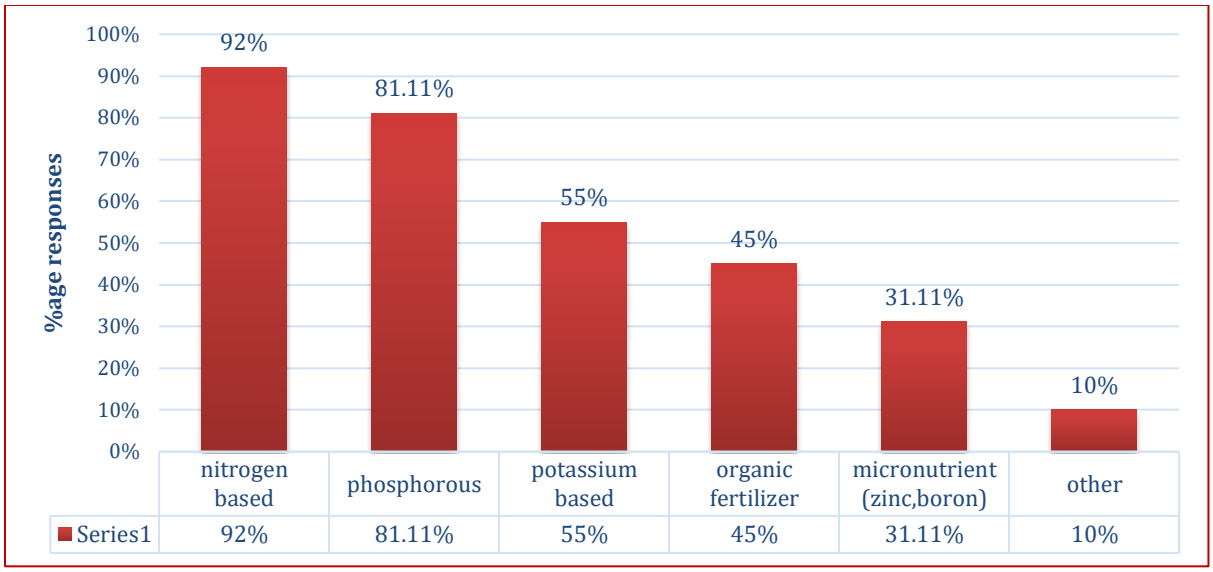


Fig. 2: Fertilizer use patterns among the surveyed farmers.

The use of fertilizers was dominated by nitrogen-based inputs, followed by phosphorus- and potassium-based fertilizers (Fig 2). Organic fertilizers and micronutrients were comparatively less frequently reported. The observed pattern reflects the continuing importance of conventional nutrient inputs in intensive rice–wheat production systems. The predominance of nitrogen-based fertilizers is consistent with fertilizer-use patterns reported for cereal-based agricultural systems and reinforces concerns regarding nutrient imbalance and inefficient fertilizer management (Ladha et al., 2016; Penuelas et al., 2023).

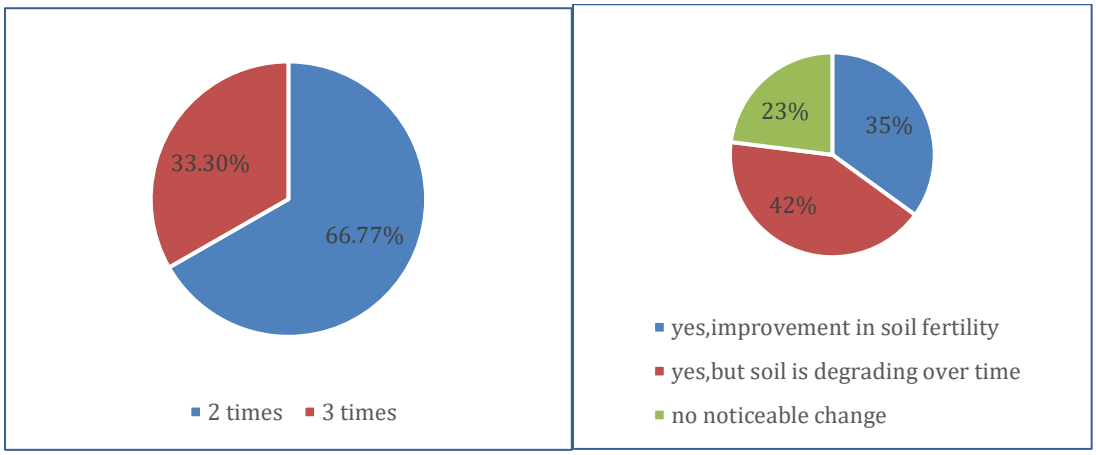


Fig. 3 (a) and (b) Fertilizer application frequency and its perceived impact on soil quality.

In terms of application frequency in Fig 3(a), 66.77% of farmers applied fertilizers twice during each cropping season, while 33.30% applied fertilizers three times. This trend suggests a preference for more frequent fertilizer applications, likely aimed at maximizing short-term yields instead of optimizing nutrient-use efficiency. However, when considered alongside the low compliance with recommended dosages (as indicated in earlier findings), this frequency may be more indicative of repeated corrective applications rather than a well-planned nutrient

management strategy. This could increase the risk of nutrient losses and soil degradation. Farmers' perceptions of soil quality as shown in Fig. 3(b) indicate a significant discrepancy between the intensity of inputs used and the outcomes observed. While 35% of respondents reported improvements in soil fertility, a larger proportion (42%) acknowledged that soil quality was deteriorating over time, and 23% noted no noticeable change. This perception of soil degradation, despite the high use of fertilizers, suggests a declining response to chemical inputs. This decline may be attributed to nutrient imbalances, reduced organic matter, and the long-term overuse of synthetic fertilizers.

3.2.3 Challenges and decision-making regarding chemical use: The major challenges and factors influencing pesticide-use decisions are presented in Table 6. High cost was identified as the most important challenge, reported by 61% of respondents. Concerns regarding the availability of quality fertilizers were reported by 44%, while 36% identified inadequate knowledge of proper application methods as a major challenge. Environmental concerns were comparatively less frequently identified, accounting for 28% of responses. Pesticide-use decisions were mainly based on visible pest infestation (50%) and personal experience (40%). Only 5% of respondents relied primarily on expert recommendations, while another 5% based their decisions on availability and cost. The results demonstrate that economic considerations and experiential knowledge play a central role in farmers' agrochemical-use decisions. The limited dependence on expert recommendations suggests a need to strengthen locally accessible agricultural advisory and extension systems. The importance of economic constraints is consistent with Sheahan and Barrett (2017), who also identified financial and input-related constraints as important factors affecting agricultural input use.

Table 6: Challenges faced by farmers and factors influencing pesticide-use decisions

Variable	Response/indicator	Frequency (n)	Percentage (%)
Challenges in chemical application	High cost	110	61
	Availability of quality fertilizers	79	44
	Lack of knowledge regarding proper application	65	36
	Environmental concerns	50	28
Decision-making regarding pesticide use	Based on pest infestation	90	50
	Based on expert recommendation	9	5
	Personal experience	72	40
	Availability and cost	9	5

Note: n = 180.

3.2.4 Compliance with recommended pesticide-use practices

Compliance with selected pesticide-use practices was uneven (Table 7). A relatively high proportion of farmers checked weather conditions before pesticide application, with 60% reporting full compliance and 30% partial compliance. However, compliance was substantially lower for pesticide rotation and adherence to recommended dosage and safety guidelines. Only 40% of respondents reported rotating pesticides to prevent resistance, whereas 50% were non-compliant. Similarly, approximately 39.4% followed recommended dosage and safety guidelines, while

26.1% were partially compliant and 34.4% were non-compliant. Reading safety labels was also limited, with only 30% of respondents reporting compliance. Furthermore, 60% indicated that they had not received guidance regarding pesticide use.

Table 7: Compliance with recommended pesticide-use practices

Practice	Compliant, n	Partially compliant, n	Non-compliant, n
Rotate pesticides to prevent resistance	72	18	90
Check weather conditions before pesticide application	108	54	18
Follow recommended dosage and safety guidelines	71	47	62
Read safety labels before using pesticides	54	–	126
Received guidance regarding pesticide use	72	–	108

Compliant = Yes; Partially compliant = Sometimes; Non-compliant = No. n = 180.

These findings indicate a distinction between practices associated with immediate and visible risks, such as checking weather conditions, and practices requiring more technical knowledge, such as pesticide rotation and dosage management. The low level of label reading and formal guidance highlights the importance of strengthening farmers' knowledge regarding pesticide resistance, recommended dosages, and safe handling.

3.3 Farmers' attitudes towards chemical inputs and sustainable alternatives

Farmers' perceptions, decision drivers, adaptive practices, and barriers to reducing chemical dependence are summarized in Table 8. A strong belief in the necessity of chemical fertilizers for maintaining crop yield was evident, with 70% of respondents strongly agreeing and 20% agreeing with this statement. Only 4% disagreed. The willingness to adopt biopesticides and organic fertilizers was more variable. Forty percent of respondents expressed willingness to adopt such alternatives, whereas 31% were unwilling and 29% were uncertain. The principal motivation influencing farmers' decisions regarding chemical reduction was the need to maintain high crop yields (40%). A perceived lack of alternatives was reported by 30%, whereas cost saving, preference for organic products, and environmental concerns accounted for smaller proportions.

The results demonstrate a clear gap between farmers' willingness to consider alternative practices and their actual adoption. Although 40% expressed willingness to use biopesticides and organic fertilizers, only a limited proportion reported practices such as biological pest control and composting. The perceived risk of reduced crop yield was the most important barrier to reducing chemical inputs, reported by 60% of respondents. This finding suggests that farmers' dependence on chemical inputs is strongly associated with production security and risk avoidance. Similar findings have been reported by Chèze et al. (2020), who demonstrated that farmers' reluctance to reduce pesticide use is closely associated with concerns regarding productivity and economic risk. Government subsidies were identified as the most important measure that could facilitate the adoption of organic alternatives, followed by improved availability of biofertilizers and biopesticides and training programmes. These findings are consistent with Piñeiro et al. (2020), who emphasized the importance of financial support, institutional assistance, and capacity building in promoting the adoption of sustainable agricultural practices. Mechanical pesticide application was dominant, with 80% of farmers reporting the use of machine spraying, compared with 20%

using manual spraying. Pest infestation level was identified as the most important factor affecting pesticide application, followed by weather conditions, crop growth stage, and expert recommendations.

Table 8: Farmers' perceptions, decision drivers, and practices related to fertilizer and pesticide use

Variable	Indicator	Frequency (n)	Percentage (%)
Belief regarding the necessity of fertilizers for crop yield	Strongly agree	126	70
	Agree	36	20
	Neutral	10.8	6
	Disagree	7.2	4
Willingness to use biopesticides and organic fertilizers	Yes	72	40
	No	55.8	31
	Maybe	52.2	29
Motivation and decision drivers	Maintaining high yield	72	40
	No alternatives	54	30
	Cost saving	18	10
	Organic product	9	5
	Environmental concern	9	5
Alternative and adaptive practices	Natural fertilizer	54	30
	Biological pest control	18	10
	Crop rotation	54	30
	Composting	18	10
	Reduced/no-till farming	36	20
Constraints to reducing chemical use	Limited knowledge about alternatives	36	20
	High cost of organic/biological products	36	20
	Risk of lower yields	108	60
Support and enabling measures	Government subsidies for organic alternatives	79.2	44
	Better availability of biofertilizers and biopesticides	52.2	29
	Training and awareness programmes	28.8	16
	Other	19.8	11
Factors affecting pesticide application	Pest infestation level	84.6	47
	Weather conditions	41.4	23
	Crop growth stage	36	20
	Expert recommendations	18	10
Application technology	Manual spraying	36	20
	Tractor/machine spraying	144	80
Safety and storage practices	Separate storage area	108	60
	Same area as food/animal feed	36	20
	Outdoor without cover	18	10
	Other	18	10
Disposal of pesticide containers	Dispose in an open area	90	50
	Burn	32.4	18
	Bury	21.6	12
	Reuse	36	20

Storage and disposal practices also revealed important areas of concern. Although 60% of respondents reported maintaining a separate storage area for agrochemicals, 20% stored them in the same area as food or animal feed. In addition, disposal in open areas was reported by 50% of respondents, while 20% reused empty pesticide containers. These findings indicate a continuing need for improved awareness and infrastructure for safe agrochemical storage and disposal. Similar concerns regarding pesticide handling and disposal have been reported in other agricultural communities (Udayanga et al., 2024; Hu, 2020).

3.4 Perceived health and environmental impacts of chemical inputs: Farmers' perceptions regarding routes of pesticide exposure, health symptoms, and environmental consequences are presented in Fig. 4 and Table 9. The major perceived routes of pesticide exposure were oral and dermal exposure, each reported by approximately 76% of respondents. Eye exposure, skin exposure, and inhalation were also commonly recognized, reported by 61%, 76%, and 60% of respondents, respectively. The recognition of multiple exposure pathways indicates that farmers possess some awareness of direct occupational exposure to pesticides. Skin contact, inhalation, ingestion, and eye exposure are recognized routes through which pesticide exposure may occur (Mnif et al., 2011; Mostafalou and Abdollahi, 2017). The most commonly reported health symptoms associated with pesticide exposure were skin irritation, breathing difficulty, and dizziness. These findings should be interpreted as self-reported health experiences or perceptions and not as clinically diagnosed health outcomes. The occurrence of self-reported symptoms following pesticide exposure is consistent with previous studies highlighting potential short- and long-term health consequences associated with unsafe pesticide handling (Damalas and Eleftherohorinos, 2011; Shekhar et al., 2024). Farmers' perceptions of the environmental consequences of chemical inputs were mixed and often uncertain. Only 10% of respondents agreed that fertilizers and pesticides could affect water bodies, whereas 60% disagreed and 30% were uncertain. In comparison, 40% recognized a decline in beneficial insects and 40% perceived a possible long-term decline in soil fertility. Similarly, 40% believed that chemical inputs could affect wildlife and biodiversity. Only 20% of respondents considered biofertilizers and biopesticides to be viable alternatives to conventional chemical inputs, while 40% disagreed and 40% remained uncertain.

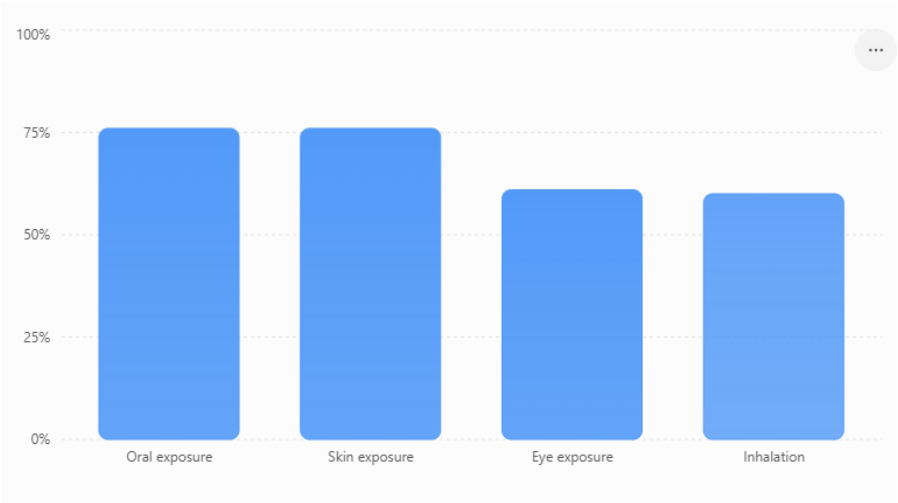


Fig. 4: Farmers' perceived routes of pesticide exposure through different parts of the body.

Table 9: Farmers' perceptions of environmental and ecological impacts of chemical inputs (n = 180)

Opinion	Yes, n (%)	No, n (%)	Not sure, n (%)
Chemicals affect water bodies	18 (10%)	108 (60%)	54 (30%)
Decline in beneficial insects	72 (40%)	45 (25%)	63 (35%)
Long-term decline in soil fertility	72 (40%)	63 (35%)	45 (25%)
Biofertilizers and biopesticides as alternatives to chemical inputs	36 (20%)	72 (40%)	72 (40%)
Pesticides and fertilizers affect local wildlife and biodiversity	72 (40%)	54 (30%)	54 (30%)

Note: n = 180.

The findings indicate fragmented environmental awareness among farmers. While a substantial proportion recognized potential impacts on beneficial insects, soil fertility, and biodiversity, awareness regarding possible effects on water bodies was particularly limited. The large proportion of respondents expressing uncertainty about several environmental consequences further indicates a need for targeted environmental education and extension programmes. These findings support the broader argument that farmers' environmental perceptions and production decisions are influenced not only by scientific information but also by practical experience, economic priorities, and the availability of alternatives. Improving awareness of nutrient losses, pesticide transport, biodiversity impacts, and long-term soil health may therefore be important for promoting more sustainable input management.

3.5 Factors influencing farmers' decision-making regarding chemical use: The predominance of productivity enhancement and crop-loss prevention as reasons for agrochemical use indicates that farmers' decisions are primarily influenced by production security and the perceived need to maintain stable crop yields. In the present study, 51% of respondents identified increasing crop productivity as the main reason for using chemical fertilizers and pesticides, while 32% reported prevention of crop losses as the primary reason (Fig. 5). These findings suggest that chemical inputs are valued mainly for their perceived immediate contribution who reported that farmers' pesticide-use decisions are strongly influenced by the need to reduce the risk of crop losses. At the same time, the finding that 50% of respondents expressed willingness to adopt alternative or organic practices (Fig. 6) does not necessarily contradict their reliance on chemical inputs for production security. Importantly, this 50% represents willingness to consider alternative or organic practices rather than actual adoption of organic farming. The two responses therefore reflect different aspects of farmers' decision-making: the preference for chemical inputs reflects concerns about immediate productivity and crop-loss risk, whereas willingness to consider alternatives indicates an openness to changing practices when suitable conditions and safeguards are available. This interpretation is further supported by the finding that 60% of respondents identified the risk of reduced crop yield as a major barrier to reducing chemical inputs.

Economic considerations may also influence this willingness to consider alternative practices. Farmers are likely to evaluate alternative farming systems not only in terms of productivity but also in relation to input costs, expected returns, market opportunities, and the availability of institutional support. In the present study, 20% of respondents identified the high cost of organic or biological inputs as a constraint, while 44% identified government subsidies for organic alternatives as an important measure for facilitating adoption. Thus, the willingness to adopt alternatives appears to be conditional upon both production security and economic

feasibility. Although potential benefits such as premium prices for certified organic produce and reduced dependence on external inputs over the longer term may improve the economic attractiveness of organic farming, these factors were not directly measured in the present study and therefore cannot be considered demonstrated drivers of farmers' decisions.

Accordingly, the coexistence of a strong preference for chemical inputs and willingness to consider alternative practices should not be interpreted as an inconsistency. Rather, it suggests that farmers recognize the perceived short-term production benefits of agrochemicals while remaining open to alternative systems if concerns regarding yield risk, input costs, market returns, and institutional support are adequately addressed. This interpretation is consistent with Chèze et al. (2020), who reported that farmers are more likely to reduce pesticide use when they are confident that crop productivity will not decline. Similarly, Möhring et al. (2024) emphasized the importance of economic considerations and production outcomes in farmers' decisions to adopt organic agriculture. Therefore, facilitating a transition towards alternative farming practices would require not only technical and extension support but also measures that reduce perceived economic and production risks, including access to affordable alternatives, appropriate incentives, reliable markets, and mechanisms that support farmers during the transition.

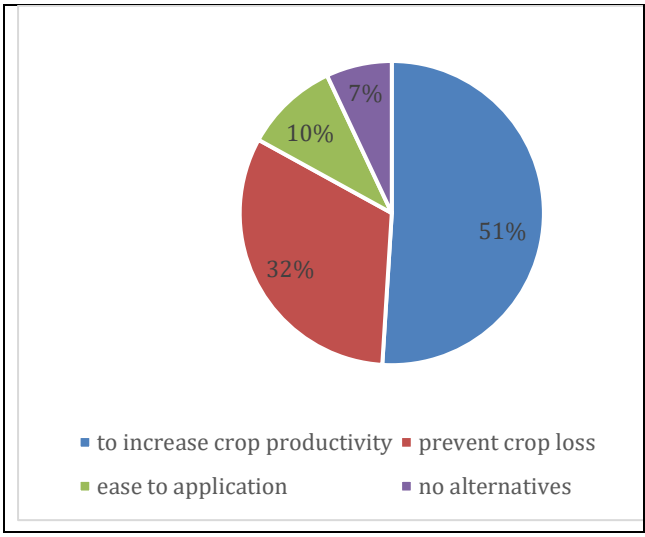


Fig. 5: Farmers' reasons for using chemical fertilizers and pesticides.

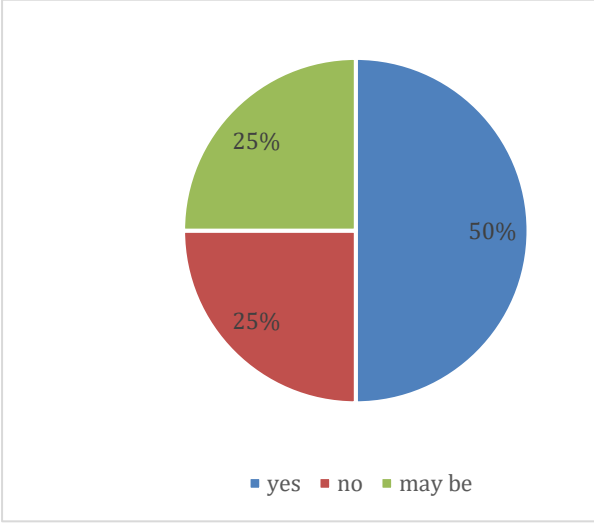


Fig. 6: Willingness of farmers to adopt organic and alternative farming practices.

The results suggest that a substantial proportion of farmers may be receptive to alternative practices, provided that concerns regarding economic security and crop productivity are adequately addressed.

3.6 Awareness regarding pesticide handling and personal protective practices: The findings related to pesticide handling and hygiene practices are presented in Table 10. Overall, the results indicate a mixed pattern of safe and unsafe practices. Seventy-five percent of respondents reported that they did not eat, drink, or smoke while spraying pesticides. A high proportion reported taking a bath after spraying (90%), and all respondents reported changing their clothes following pesticide application. In addition, 95% reported checking wind direction before spraying.

Table 10: Safety and hygiene practices followed by farmers during and after pesticide use

Practice	Yes (%)	No (%)
Eat, drink, or smoke while spraying pesticides	25	75
Take a bath after spraying	90	10
Change clothes after spraying	100	–
Store food items in a pesticide bottle after use	10	90
Determine wind direction before spraying	95	5
Wash sprayer/bottle in ponds/canals/rivers	84	16

The high proportion of respondents reporting post-application hygiene practices and attention to wind direction indicates awareness of certain immediate risks associated with pesticide application. Similar relationships between risk perception and safer pesticide-use practices have been discussed by Jallow et al. (2017) and Tsakiris et al. (2025). However, important unsafe practices remain. Ten percent of respondents reported storing food items in pesticide containers after use, representing a potentially hazardous practice. Similar concerns regarding pesticide-container misuse have been reported in farming communities in Nigeria and Iran (Yami et al., 2025; Nasrabadi et al., 2025).

3.7 Overall synthesis of the findings: The present study demonstrates a clear gap between the routine use of agrochemicals and farmers' technical knowledge, environmental awareness, and compliance with recommended management practices. Conventional farming dominated the surveyed population, while organic and natural farming practices were adopted by only a small proportion of respondents. Farmers primarily depended on fellow farmers, personal experience, and visible pest infestation when making fertilizer and pesticide management decisions. Formal extension services and expert recommendations played a comparatively limited role. The results also revealed low compliance with several recommended practices, particularly reading safety labels, pesticide rotation, adherence to recommended dosage, and receipt of formal guidance. At the same time, the findings indicate that farmers are not necessarily unwilling to consider sustainable alternatives. A substantial proportion expressed willingness to adopt organic or alternative farming practices. However, the perceived risk of lower yields, high costs, limited knowledge, and inadequate availability of alternatives remained major barriers. The results therefore suggest that efforts to reduce excessive dependence on chemical inputs should not rely solely on awareness campaigns. Effective interventions should combine farmer training, strengthened extension services, demonstration of economically viable alternatives, improved availability of biofertilizers and biopesticides, safe storage and disposal infrastructure, and policy incentives. Such integrated interventions may help address the observed gap between awareness, willingness, and actual adoption of improved agrochemical management practices.

4. Conclusions

The study conducted in the rice–wheat intensive districts of Kaithal, Karnal, and Kurukshetra highlights the continued dominance of chemical-intensive agriculture and its associated health and environmental implications. Although the Green Revolution significantly improved food security, it also entrenched heavy dependence on fertilizers and pesticides, which now poses serious sustainability challenges. Findings reveal moderate awareness but limited technical understanding among farmers regarding correct dosages, application methods, and safety

precautions. A majority do not read safety labels, and only a small proportion consistently follow recommended guidelines. Fertilizer use is heavily skewed toward nitrogen-based inputs, with limited adoption of organic alternatives. Pesticide decisions are largely based on personal experience or peer advice rather than expert consultation. While some farmers recognize environmental and health risks, overall awareness of long-term impacts on soil fertility, water quality, and biodiversity remains low. Health symptoms related to pesticide exposure, such as skin irritation and respiratory problems, are common, yet protective measures and safe storage/disposal practices remain inconsistent. Awareness and adoption of sustainable alternatives such as Integrated Pest Management (IPM), biofertilizers, and biopesticides are minimal. Farmers' strong belief that chemical inputs are essential for yield security reflects risk-averse behavior shaped by economic pressures, high input costs, and limited institutional support. The study underscores a clear gap between awareness and sustainable practice. Farmers are not inherently resistant to change; rather, their decisions are guided by economic rationality and structural constraints. Therefore, reducing chemical dependency requires integrated interventions, including strengthened extension services, practical training, improved access to bio-inputs, financial incentives, and effective policy support. Aligning environmental sustainability with farmers' economic security is essential for enabling a realistic and lasting transition toward safer and more sustainable agricultural systems.

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