International Journal of Agriculture, Environment and Biotechnology
Citation: *IJAEB*: **18**(04): 363-372, December 2025
DOI: 10.30954/0974-1712.04.2025.11

RESEARCH PAPER

Evaluating the Socio-economic Trade-offs of Pesticide Use in Indian Agriculture: A Case Study of Rohtas District, Bihar

Shalini Singh, Prakhar Deep, Ipsita Sen, Bharath Kumar Mannepalli, Ankit Yadav, Rajan Kumar, Kalyan Ghadei and Virendra Kamalvanshi*

Department of Agricultural Economics, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

*Corresponding author: vkvanshi@bhu.ac.in (**ORCID ID:** 0000-0003-1484-3802)

Paper No. 1232 **Received:** 21-09-2025 **Revised:** 24-11-2025 **Accepted:** 01-12-2025

ABSTRACT

Pesticides have become a crucial part of modern agriculture, mainly because they are seen as essential for protecting crops and boosting productivity. However, there are growing concerns about their effects on human health, farm finances, and the environment. This study examines the social and economic trade-offs of using pesticides in Indian agriculture, focusing on farming families in the Rohtas district of Bihar. Using information from field surveys and other sources, the research analyzes how pesticides are used, their health effects, their economic impact, and farmers' views on their social and environmental consequences. The results show a strong reliance on chemical pesticides, mainly because farmers want stable crop yields and financial security. Conversely, the application of pesticides is strongly linked to negative health consequences within agricultural communities, a situation exacerbated by improper handling techniques and insufficient implementation of suggested protective protocols. These health impacts subsequently result in indirect economic strains, manifested through increased medical costs and diminished labour productivity. Despite the acknowledged health and environmental hazards, persistent pesticide use is indicative of systemic limitations, insufficient availability of alternative solutions, and escalating pest pressures. The research results expose a core contradiction, wherein productivity improvements are coupled with health, economic, and environmental hazards, thereby highlighting the critical need for safer operational methods, more robust institutional frameworks, and sustainable pest management strategies within agricultural systems.

HIGHLIGHTS

- Pesticide application demonstrably boosts both agricultural output and farm profitability; however, sustained dependence on these chemicals incurs considerable concealed health expenses and medical costs for farming families over time.
- Despite a high level of farmer awareness regarding the hazards associated with pesticides, inadequate utilization of personal protective equipment and direct exposure during application contribute to a prevalence of health issues.
- Farmers acknowledge the environmental degradation and the development of pest resistance stemming from pesticide use, thereby highlighting the critical necessity for sustainable alternatives, such as integrated pest management strategies and safer application methodologies.

Keywords: Pesticides, Health effects, Economic costs, Bihar, Sustainability

Agriculture, the environment, and human well-being are inextricably linked, given that agriculture sustains the livelihoods of approximately half the world's populace and constitutes a major employment sector globally. The anticipated increase in the global population, from 6 billion

How to cite this article: Singh, S., Deep, P., Sen, I., Mannepalli, B.K., Yadav, A., Kumar, R., Ghadei, K. and Kamalvanshi, V. (2025). Evaluating the Socio-economic Trade-offs of Pesticide Use in Indian Agriculture: A Case Study of Rohtas District, Bihar. *Int. J. Ag. Env. Biotech.*, **18**(04): 363-372.

Source of Support: None; **Conflict of Interest:** None

to nearly 9 billion, coupled with the dietary requirements of a more affluent population, is projected to result in a doubling of global food consumption by 2050 (FAO, 2009). Consequently, agricultural production has experienced rapid expansion in recent decades, primarily fueled by technological progress. Nevertheless, this intensification has concurrently exerted considerable strain on the environment, thereby necessitating sustainable agricultural practices to reconcile food security with ecological preservation.

Plant protection is of paramount importance in contemporary agriculture. Inputs like fertilizers, irrigation, and improved seeds boost productivity, but they also create conditions that help pests spread quickly. Without effective plant protection, the benefits of these inputs can be completely lost, leading to significant crop losses. As a result, pesticides have become a crucial part of agricultural production, especially in developed countries, because they reduce production risks and stabilize yields in uncertain weather and biological conditions (EC, 2006). Their use has been linked to several benefits, including better crop yield and quality, longer shelf life for crops, less labor for weeding, lower fuel use for weeding, and effective management of invasive species (Cooper and Dobson, 2007).

Despite these advantages, using pesticides also has significant negative effects. Since Rachel Carson's *Silent Spring* was published in 1962, a large amount of scientific research has shown the harmful effects of pesticides on both human health and the environment (Pimentel *et al.* 1992; Pimentel and Greiner, 1997). People can be exposed to pesticides directly, such as those who apply them, or indirectly, through food, water, and the environment. The widespread and uncontrolled use of pesticides has led to significant ecological damage, including the decline of beneficial species, pollution of surface and groundwater, decreased fish populations, and the development of pesticide-resistant pests and weeds (Powles *et al.* 1997; Jutsum *et al.* 1998). In addition, Pimentel *et al.* (1992) highlight other negative effects, such as animal poisoning, food contamination with residues, reduced pollination, and a loss of biodiversity.

Globally, the application of approximately 3 million metric tons of pesticides annually results in over 26 million non-fatal poisoning cases, with nearly 220,000 deaths and 750,000 chronic illnesses reported each year (Richter, 2002; Hart and Pimentel, 2020). Although pesticides are designed to minimize risks, studies continue to report adverse health effects among farmers and non-occupationally exposed populations, including neurological, respiratory, and dermatological symptoms (Damalas and Eleftherohorinos, 2011; Eleftherohorinos, 2008). In India, despite relatively low per-hectare pesticide consumption, indiscriminate use-particularly of organophosphates-has heightened health risks among agricultural workers, who often lack adequate protective equipment (Shetty *et al.* 2011; Choudhary *et al.* 2014; Dey, 2013).

At the same time, pesticides contribute significantly to food security by reducing crop losses, which are estimated to exceed 40 percent globally due to pests, diseases, and weeds (Mahmood *et al.* 2016; Aktar *et al.* 2009). Furthermore, these practices contribute to the management of disease vectors that are responsible for significant human health problems (Mahmood *et al.* 2016). Acknowledging this dual function, international policymakers, especially within the European Union, have implemented more stringent regulations and economic measures designed to curtail pesticide application while simultaneously protecting public health and the environment.

In light of this context, the current research investigates the health consequences of pesticide usage, examines its economic ramifications, and evaluates its wider social effects. Concentrating on farmers in Bihar, the study seeks to enhance the understanding of the social costs and benefits associated with pesticide use, thereby informing the implementation of safer, more sustainable pest management strategies, including integrated pest management and biopesticides.

Existing research underscores the inherent trade-offs between the economic advantages derived from pesticide application and its detrimental health and societal repercussions. Harper and Zilberman (1992) highlighted the regulatory challenges posed by the uncertainty surrounding health effects, advocating for a "safe minimum standard" strategy that prioritizes health considerations over economic benefits. Wilson and Tisdell (2001) elucidated the continued prevalence of pesticide use, notwithstanding escalating costs and negative externalities, attributing this persistence to technological and institutional "lock-in" phenomena encountered by agricultural producers. Furthermore, micro-level evidence demonstrates the considerable health risks linked to unsafe pesticide application practices. Mekonnen and Agonafir's (2002) research revealed a lack of personal protective equipment usage, even though the risks were acknowledged. Conversely, Chitra *et al.* (2006) established significant correlations between pesticide exposure and acute health issues in South Indian farmers. Economically, Yogeshwari (2002) showed that over-application of pesticides significantly inflated cultivation expenses, thereby diminishing farm efficiency.

In summary, existing research suggests that while pesticides boost productivity, their unregulated application incurs substantial health, economic, and social burdens, thereby highlighting the necessity for safer and more sustainable pest management strategies.

METHODOLOGY

Sampling design

The investigation employed a descriptive research design and was undertaken across four villages-Matuli, Lakshmanpur, Ghosia Khurd, and Sanjhauli-situated within Rohtas district, Bihar, an area characterized by its agricultural focus. Rohtas district was chosen because of its significant agricultural practices and diverse agro-climatic environments. To facilitate an unbiased selection of participants, a random sampling method was implemented. The sample comprised 80 farmers, with 20 respondents chosen from each village. This sampling strategy ensured a representative cross-section of farming households, thereby enabling a comprehensive evaluation of pesticide usage patterns and their associated health, economic, and social consequences within the designated study area.

Data Collection

Primary data was collected through personal interviews with the sample of farmers. A structured schedule was employed to evaluate the health, economic, and social consequences associated with pesticide application. Data interpretation was further informed by informal discussions and field observations. Secondary data, encompassing state-wise pesticide consumption figures from 2018 to 2023, were sourced from the Directorate of Plant Protection, Quarantine and Storage.

TERMS AND CONCEPTS

Frequency

Frequency is the number of times a variable is repeated. This measure was used to know the distribution pattern of respondent's variable wise and to categorize the respondents based on their opinion on each activity.

Percentage

Percentage is the number, amount and rate etc., expressed as it is part of a total which is 100. This measure was used for a simple understanding of numeric with different groups. For calculating percentage, the frequency of particular set was divided by the total number of observations multiplied by 100.

Arithmetic Mean ($\overline{X}$)

Mean is defined as the ratio of sum of all the observations to the total number of observations. This measure was used to categorize the dependent and independent variables into low, medium and high categories. Mean was used as a measure to classify the respondents into various categories.

$$\overline{X} = \frac{\Sigma X}{n}$$

Where,

$\overline{X}$ = Mean of the observations

$\sum X$ = Sum of all the observations

n = Total number of observations

Standard Deviation

It defines as the square root of the mean of the square of the deviations of the set of observations from their mean. This measure was used to categorize the dependent and independent variable into low, medium and high categories.

$$SD = \sqrt{\frac{\Sigma\left(X - \bar{X}\right)^2}{n}}$$

Where,

$\bar{X}$ = Mean

n = Number of observations

Categorization of group data

Singh (1975) gave a method to categorize group data into various categories known as 'Singh's cube root method' and gave a formula:

$$S1 = L1 + \frac{\frac{iN}{3} + Ci - 1}{f1} \times h$$

i = indicate category number (i = 1, 2, 3......n)

$S1$= segment (e.g. I, II, III)

$L1$ = Lower limit of the quartile class

$C1$-1 = Cumulative frequency of the class preceding to the quartile class

f = frequency

h = width of the quartile class

N = Total cumulative cube root of frequencies

Karl Pearson coefficient of correlation

In order to find out the relationship between dimensions of utilization of communication sources and personal antecedents of the respondents, Karl Pearson correlation coefficient was calculated. It was calculated using the formula as:

$$r = \frac{\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\left[\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right] - \left[\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right]}}$$

Where,

r = Karl Pearson correlation coefficient

ΣX = Sum of observations of first sample

ΣY = Sum of observations of second sample

ΣXY = Sum of products of observations of both the samples

ΣX^2 = Sum of square of observations of first sample

ΣY^2 = Sum of square of observations of second sample

$(\Sigma X)^2$ = Square of sum of observations offirst sample

$(\Sigma Y)^2$ = Square of sum of observations of second sample

n = Number of observations

Likert scaling technique

Likert scaling, which is a psychometric scale is the most widely used approach to scaling responses in surveys. This technique was used to assess the perception of farmers on the effects of pesticide use in cotton. The response to each perception aspect was recorded as strongly agree (5), agree (4), neutral (3), disagree (2) and strongly disagree (1). To get an overall perception, total scores of all five responses was summed up into three major levels high (45-60), medium (29-44) and low (12-28) perceptions. The relationship between the levels of perception and independent variables was tested.

RESULTS AND DISCUSSION

Pesticide Use Practices and Health Effects

Paddy and wheat were the primary crops cultivated in all four villages studied, with vegetables also being significant, which accounts for the considerable pesticide application observed in these crops. The sustained reliance on chemical pest control is apparent from Table 1; 71.25% of farmers have utilized pesticides for a period of 11-20 years, and an additional 16.25% have done so for over twenty years. This suggests that pesticide use is a well-established practice, rather than a recent development.

Table 1: Application pattern of pesticide by the selected farmers (n = 80)

Years of using pesticide	Farmers (n = 80)
1 to 10 years	10(12.5%)
11 to 20 years	57(71.25%)
21 to 30 years	13(16.25%)
Time of using pesticide	
Before sowing	4(5%)
After sowing	43(53.75%)
Both before and after sowing	33(41.25)
Quantity of pesticide application	
Upto 1 litre	21(26.25%)
1 to 3 litre	46(57.5%)
More than 3 litre	13(16.25%)

Method of pesticide application	
Hand pump	74(92.5)
Drip irrigation	0(0%)
Through tractor	6(7.5%)

Concerning the timing of application, the majority of farmers (53.75%) apply pesticides post-sowing, while 41.25% apply them both before and after sowing, thereby employing both preventative and curative pest-control methods. Only 5% of farmers depend solely on pre-sowing applications. The majority of farmers (57.5%) apply between 1 and 3 litres of pesticide per season, whereas 16.25% apply more than 3 litres, which may indicate either greater pest pressure or larger operational landholdings. Hand-operated sprayers dominate pesticide application methods, with 92.5% of farmers relying on hand pumps, while tractor-mounted sprayers are used by only 7.5%, and none reported drip-based application (Table 1).

Farmers' perception of protective equipment use is presented in Fig. 1., which shows that 90% of respondents reported using protective gear "often", though none reported "always" using it. This partial compliance is further clarified in Table 2, which highlights that while 100% of farmers use long sleeves, long pants, and *gamchha*, only 22.5% use gloves, 3.75% use masks, and none use goggles or boots. This pattern suggests reliance on traditional clothing rather than scientifically recommended personal protective equipment (PPE), increasing exposure risk.

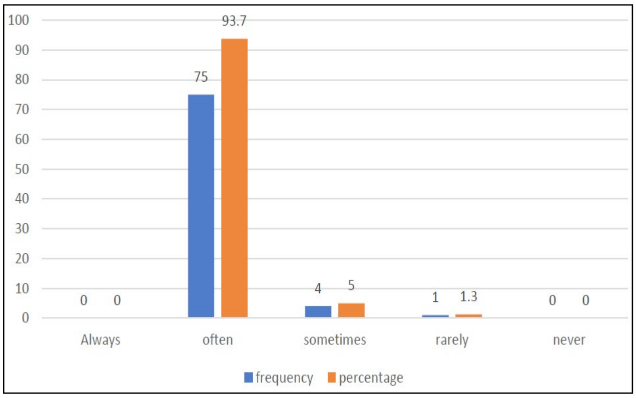

Fig. 1: Perception of farmers to use protective equipment

Direct contact with pesticides during spraying remains widespread. Fig. 2 indicates that the majority of farmers experience direct contact with pesticides during application, confirming inadequate protection and unsafe handling practices. Consequently, the health impacts are nearly ubiquitous among the surveyed individuals. Fig. 3 illustrates that 48.75% of the farmers occasionally and 46.25% frequently encounter health problems subsequent to pesticide application; conversely, no respondents indicated complete immunity.

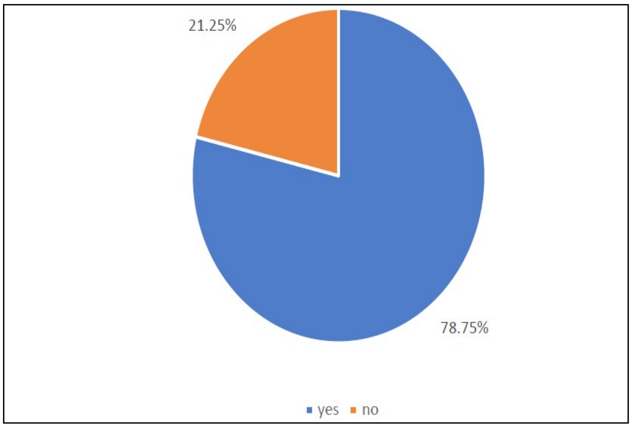

Fig. 2: Contact of pesticides while application of pesticides

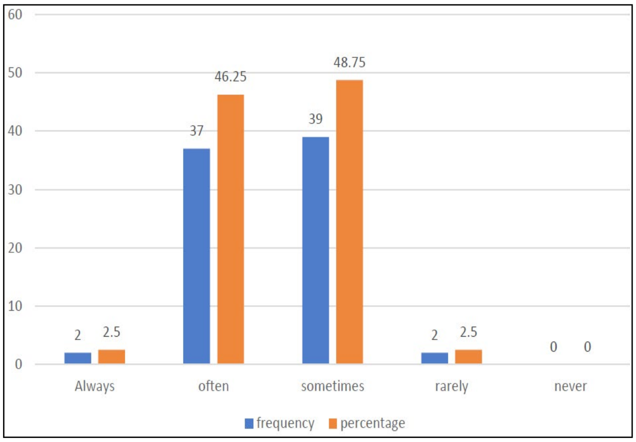

Fig. 3: Perception of farmers experienced health issues after using pesticide

The specific health manifestations are enumerated in Table 2. Allergic reactions were the most commonly reported (96.25%), succeeded by headaches (82.5%), skin irritation (70%), nausea (61.25%), burning eyes (56.25%), and dizziness (45%). Although less common, severe symptoms such as vomiting (3.75%) and diarrhea (8.75%) were nonetheless documented. The duration of these symptoms exhibited considerable variability, with manifestations such as headaches and vomiting persisting for only a few hours, while skin irritation could last for several weeks, thereby suggesting both immediate and extended health consequences.

Table 2: Effect of pesticide application on health of farmers

Symptoms	No of farmers (n = 80)
Headache	66 (82.5%)
Skin irritation	56 (70%)
Burning eyes	45(56.25%)
Nausea	49(61.25%)
Vomiting	3(3.75%)
Diarrhea	7(8.75%)
Dizziness	36(45%)
Allergy	77(96.25%)
Others	8(10%)

Table 3: Duration of pesticide effect on human

Symptoms	Number of days
Headache	2-3 hours
Skin irritation	2-4 weeks
Burning eyes	1-7 days
Nausea	7-8 hours-1day
Vomiting	3-4 hours
Diarrhea	1-2 days
Dizziness	2-3hours-1-2 days
Allergy	1-3 days

Farmers demonstrate a notably high level of awareness regarding the health risks associated with pesticide exposure. As illustrated in Fig. 4, all respondents either concurred or strongly concurred with the assertion that pesticides are causative agents of health problems. As a result, medical consultation is frequently sought; specifically, 72.5% of farmers consistently or frequently seek medical care for health issues stemming from pesticide use (Fig. 5). This underscores a significant, yet often unrecognized, health expenditure linked to the application of pesticides.

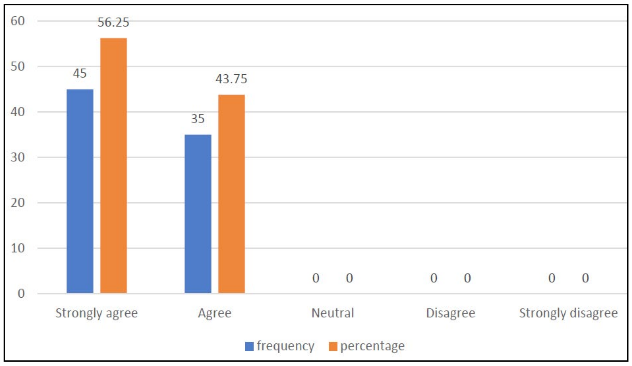

Fig. 4: Perception of farmers that pesticide is responsible for health issues

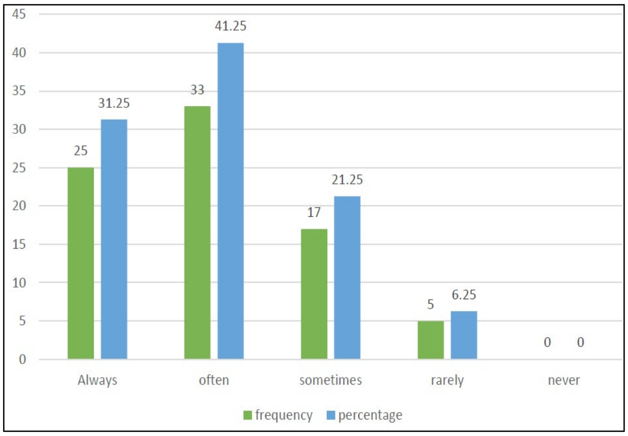

Fig. 5: Farmers take medical attention for health effects due to pesticides

Economic Implications of Pesticide Use

The data on pesticide application reveals a significant dependence on insecticides, which constitute 70% of total usage, succeeded by herbicides (18%), fungicides (10%), and rodenticides (2%) (Fig. 6.).

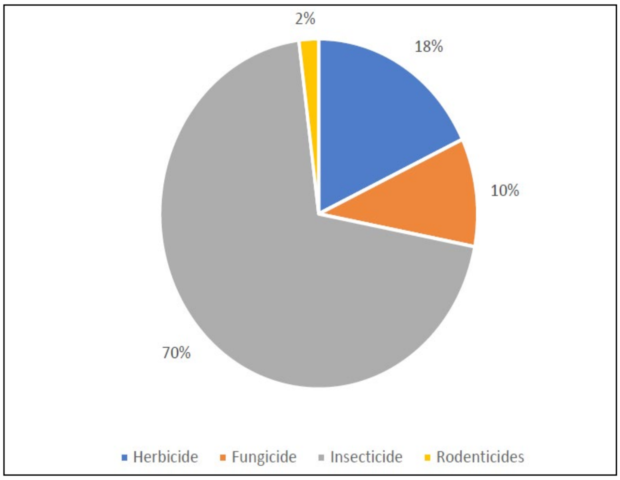

Fig. 6: Types of pesticides used by farmers

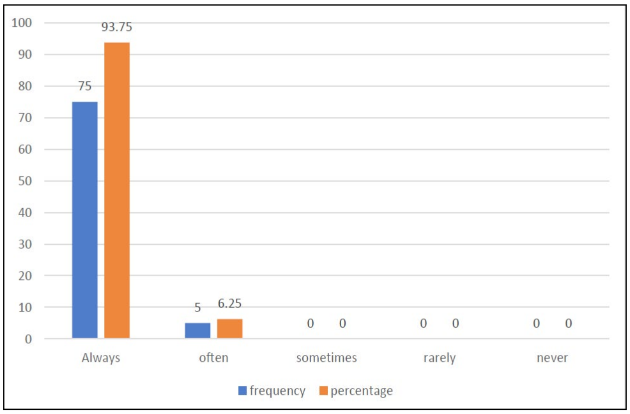

Fig. 7: Pesticide Application Pattern

This distribution underscores the prevalence of insect-induced crop damage within the study region. Furthermore, a substantial majority of farmers (93.75%) indicated consistent pesticide application (Fig. 7), thereby emphasizing the essential role of chemical pest control in local agricultural methodologies.

Analysis of seasonal expenditure patterns (Table 4) demonstrates that pesticide costs peak during the *Kharif* season (45.85%), succeeded by the *Rabi* season (42.32%), while the Zaid season exhibits comparatively lower expenditure (11.82%), which aligns with the seasonal variations in pest pressure. The cumulative annual pesticide expenditure across the surveyed villages totaled ₹ 7,44,050.

Table 4: Total annual expenditure on pesticide

Pesticide	Expenditure (in % ₹ and total cost/ year)
Rabi	3,14,904 (42.32%)
Kharif	3,41,146 (45.85%)
Zaid	88,000 (11.82%)
Total	7,44,050(100.0%)

A detailed cost analysis (Table 5) indicates that the overall pesticide operation cost reached ₹ 8,92,970 annually, with product costs representing the most significant component.

Table 5: Pesticide Application Cost

		Cost (₹ / year)
Pesticide application	Product	7,44,050
	Transport	16,000
	Labour	15,600
	Equipment	1,17,320
	Storage	—
	Abatement cost	4200
	Medical cost	3,00,476
	Operation cost	8,92,970

Medical expenses, in particular, represented a significant economic strain, totaling ₹ 3,00,476, which stemmed from health consequences linked to pesticide exposure. Despite farmers allocating ₹ 1,17,320 for protective gear (as shown in Table 6), the expenditure primarily encompassed clothing rather than standard personal protective equipment.

Table 6: Cost of protective equipment

Equipment	Cost (in ₹ / year)
Gloves	720
Mask	600
Goggles	0
Long sleeves	40,000
Long pants	64,000
Boots	0
Gamchha	12,000
Total	**1,17,320**

Furthermore, health-related treatment expenses (detailed in Table 7) underscore the economic ramifications, with annual health expenditures approximated at ₹ 5,00,476, largely attributable to serious illnesses like cancer. Consequently, these observations suggest that although pesticides enhance productivity, their associated health costs substantially diminish economic benefits.

Table 7: Potential Health Effects and Associated Cost

Health issues	Cost (in ₹/ year)
Headache	1320
Skin irritation	5600
Burning eyes	2520
Nausea	3381
Vomiting	135
Diarrhea	1200
Dizziness	1700
Allergy	4620
Others (Cancer)	4,80,000
Total	**5,00,476**

Social and Environmental Impacts of Pesticide Use

Farmers, notwithstanding the health and economic drawbacks, strongly believe that pesticides are beneficial for their productivity. As shown in Fig. 8, a significant 93.75% of farmers believe that using pesticides increases crop yields. Table 8 shows that, without pesticides, paddy yields decrease by 20-50%. In contrast, using pesticides leads to yield increases of 20-40%. Similarly, wheat yields drop by 10-40% without pesticides, but increase by 20-35% with pesticide use.

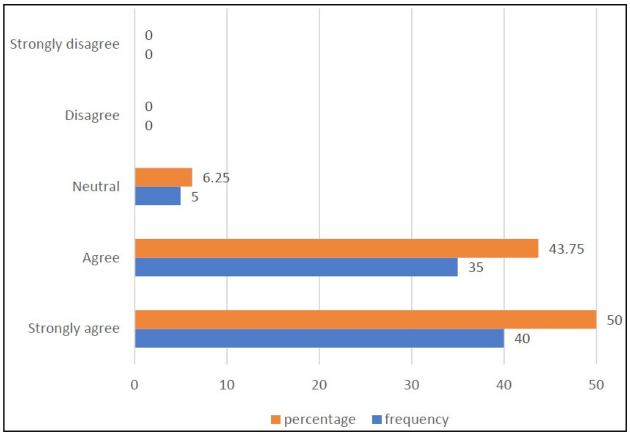

Fig. 8: Relationship between pesticide use andcrop yields or productivity

Table 8: Yield increased due to pesticide use per hectare

Crop	Yield loss without use of pesticide (%)	Yield increases after using pesticide (%)
1. Paddy	20-50%	20-40%
2. Wheat	10-40%	20-35%

Income perception follows a similar pattern. As illustrated in Fig. 10, a significant majority of farmers, specifically 77.5%, concur or strongly concur that pesticides contribute positively to their financial well-being; however, 12.5% express disagreement, which may be indicative of escalating expenses and health-related costs.

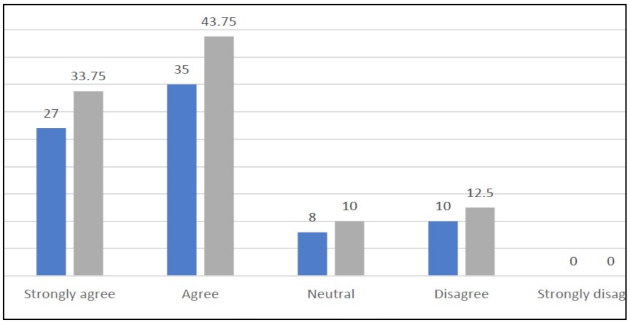

Fig. 10: Pesticides have impact on farmers income

Furthermore, farmers demonstrate considerable environmental awareness. Fig. 11 reveals that 78.75% of farmers recognize the adverse environmental consequences associated with pesticide application, evidenced by a mean Likert score of 4.11, thereby implying a high level of concern. Pest resistance constitutes another developing challenge, as depicted in Fig. 12, where 81.25% of farmers frequently or occasionally encounter pest resistance, thereby signaling a reduction in pesticide efficacy over time.

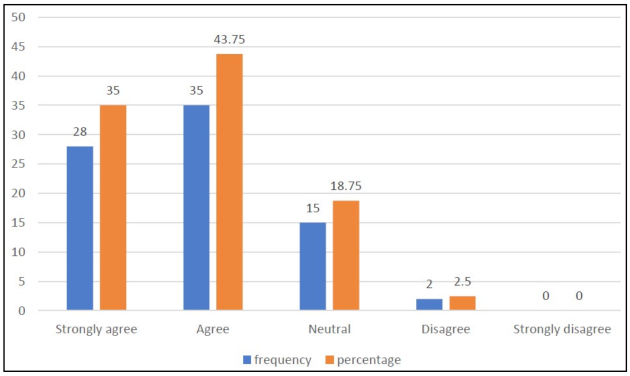

Fig. 11: Pesticide have impact on environment

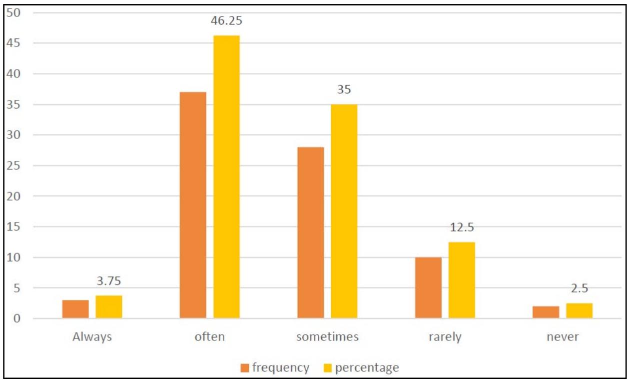

Fig. 12: Perception of farmers that pest develop resistance to pesticide

CONCLUSION

The research presents extensive findings concerning the socio-economic consequences of pesticide application among farmers in Rohtas district, Bihar, highlighting the intricate interplay between agricultural output and the concomitant health, economic, and environmental burdens. Pesticide usage has become a standard practice, especially in the cultivation of paddy and wheat, with the majority of farmers depending on chemical pest control for more than ten years. Insecticides are the most commonly used pesticides, which underscores the extent of insect-induced crop damage and solidifies farmers' reliance on chemical interventions.

Economically, pesticides are generally viewed as inputs that enhance yields and bolster income. A significant proportion of farmers indicated considerable yield reductions in the absence of pesticides, alongside corresponding increases following their application. This understanding accounts for the near-universal and consistent use of pesticides throughout the agricultural seasons, particularly during the *Kharif* and *Rabi* cycles. Conversely, the economic advantages are partially counterbalanced by substantial concealed expenses. Health-related outlays, encompassing treatment for ailments stemming from pesticide exposure, represent a considerable portion of overall pesticide-related expenditures, thus diminishing net farm income.

The health consequences identified in the research are both widespread and concerning. Nearly all farmers indicated experiencing one or more health symptoms, spanning from allergies and headaches to gastrointestinal and neurological disorders. The persistence of these symptoms ranges from a few hours to several weeks, suggesting both acute and chronic exposure effects. Despite farmers' awareness of these hazards and their frequent recourse to medical care, the continued application of pesticides reflects restricted access to safer alternatives and insufficient utilization of scientifically advised personal protective equipment.

Socially and environmentally, the research suggests an increasing recognition among farmers of the detrimental consequences associated with pesticide application. The majority of participants reported environmental harm and noted escalating pest resistance, thereby indicating a reduction in the long-term efficacy of chemical control measures. Notwithstanding this awareness, changes in behavior are constrained by economic pressures and institutional limitations.

In summary, the study posits that although pesticides are crucial for maintaining crop yields and ensuring food security, their unregulated application generates significant health, economic, and environmental costs. Consequently, policymakers should prioritize farmer education, implement and enforce safe-use regulations, and advocate for sustainable pest management approaches, including integrated pest management and biopesticides. These actions are critical to diminishing reliance on chemical pesticides and fostering a more sustainable and health-oriented agricultural paradigm.

REFERENCES

Aktar, Md. W., Sengupta, D. and Chowdhury, A. 2009. Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology*, **2**(1): 1-12.

Chitra, G. A., Murugan, S.S. and Krishnamoorthy, R.V. 2006. Pesticide exposure and health effects among farmers in Thanjavur district, South India. *Journal of Environmental Health Research*, **6**(3): 172-179.

Choudhary, N., Sharma, R. and Verma, R. 2014. Long-term pesticide exposure and its impact on respiratory health of farm sprayers. *Journal of Occupational Health*, **56**(3): 210-215.

Commission of the European Communities. 2006. A thematic strategy on the sustainable use of pesticides. Communication for the Commission to the Council, the European Parliament, the European Economic and Social Committee, and the Committee of the Regions. Brussels, Belgium.

Cooper, J. and Dobson, H. 2007. The benefits of pesticides to mankind and the environment. *Crop Protection*, **26**(9): 1337-1348.

Damalas, C.A. and Eleftherohorinos, I.G. 2011. Pesticide exposure, safety issues and risk assessment indicators. *International Journal of Environmental Research and Public Health*, **8**(5): 1402-1419.

Dey, K.R., Choudhury, P. and Dutta, B.K. 2013. Impact of pesticide use on the health of farmers: A study in Barak valley, Assam (India). *Journal of Environmental Chemistry and Ecotoxicology*, **5**(10): 269-277.

Eleftherohorinos, I.G. 2008. Weed science: Weeds, herbicides, environment, and methods for weed management. AgroTypos. Athens, Greece.

Food and Agriculture Organization of the United Nations. 2009. *How to feed the world in 2050*. FAO. https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Harper, C. and Zilberman, D. 1992. Challenges in pesticide regulation: Uncertainty about health consequences and economic trade-offs. *American Journal of Agricultural Economics*, **74**(5): 1219-1223.

Hart, K. and Pimentel, D. 2002. Public health and pesticide use in developing countries. *In* D. Pimentel (Ed.), Encyclopedia of pest management (pp. 637-648).

Jutsum, A.R., Heaney, S.P., Perrin, B.M. and Wege, P.J. 1998. Pesticide resistance: Assessment of risk and the development and implementation of effective management strategies. *Pesticide Science*, **54**(4): 435-446.

Mahmood, K., Shah, Z., Khan, M.A. and Hussain, M. 2016. Impact of pesticides on environmental and human health. *Journal of Pharmacology and Toxicology*, **11**(4): 123-135.

Mekonnen, Y. and Agonafir, T. 2002. Pesticide sprayers' knowledge, attitude and practice of pesticide use on farms in Ethiopia. *Occupational Medicine*, **52**(6): 311 315.

Pimentel, D. and Greiner, A. 1997. Environmental and socio-economic costs of pesticide use. In D. Pimentel (Ed.), Techniques for reducing pesticide use: Economic and environmental benefits (pp. 51-78).

John Wiley & Sons. Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A. and D'Amore, M. 1992. Environmental and economic costs of pesticide use. *BioScience*, **42**(10): 750-760. https://www.jstor.org/ stable/1311994

Powles, S.B., Preston, C., Bryan, I.B. and Jutsum, A.R. 1997. Herbicide resistance: Impact and management. *Advances in Agronomy*, **58**: 57-93.

Rajendran, R. 2003. Pesticide use and its consequences in India: A critical review. *Environmental Research and Public Health Journal*, **7**(4): 1742-1761.

Richter, E.D. 2002. Acute human pesticide poisonings. *Encyclopedia of Pest Management*, **3**: 757-759.

Sefa, A.M., Alhassan, S.I. and Adu-Gyamfi, A. 2015. Utilization of knapsack sprayers and protective clothing during pesticide application among farmers. *Journal of Agricultural and Environmental Sciences*, **4**(2): 117-128.

Shetty, P.K., Hiremath, M.B., Murugan, M. and Nerli, R.B. 2011. Farmers' health externalities in pesticide use predominant regions in India. *World Journal of Science and Technology*, **1**(4): 01-11.

Wilson, C. and Tisdell, C. 2001. The use of chemical inputs in agriculture: Enhancing productivity and creating negative externalities. *Journal of Agricultural Economics*, **52**(3): 353-366.

Yogeshwari. 2002. Economics and environmental implications of pesticide use in paddy in Shimoga district. *Journal of Agricultural Economics*, **53**(2): 112-125.