Environmental Implications of Integrated Pest Management: A case study of Paddy and Vegetables in Irrigated Eco-system

Alka Singh, Ranjit Kumar, P.K. Jain and A.K. Mangal[*]

Pesticides coupled with other modern inputs undoubtedly have enabled the Indian farmers to achieve unparalleled increase in agricultural productivity over the last five decades. Evidences indicate that pests cause 25 per cent of the losses in paddy, 50 per cent in cotton, 30 per cent in pulses and 20 per cent in sugarcane (Dhaliwal and Arora, 1996). Until recently, chemical pesticides were increasingly relied upon to limit the production losses, but now there is a growing concern of the health hazards associated with pesticide usage. Environmental contamination from the use of pesticide ranges from water, air and soil pollution to alteration of the ecosystem resulting in detrimental effects to non-target organisms. Evidence of pesticide threats to human health and trade-off between health and economic effects have been documented in several studies in the past (Rola and Pingali, 1993; Antle and Pingali, 1994). Although, the pesticide consumption in India is low (0.57 kg/ha) as compared to countries like Japan (12 kg/ha), Taiwan (17 kg/ha) and West Germany (3 kg/ha), the pesticide residues in food especially vegetables in India are the highest in the world. This is mainly due to unregulated use of pesticides. India accounts for one-third of the total pesticide poisoning cases in the world (Puri, 1998).

Experience have shown that such methods of plant protection have proven to be increasingly unsustainable and cost-ineffective due to development of pest resistance, rising pesticide costs, pesticide-induced outbreaks of pests and the negative effects of pesticide use on human health and the environment. The synthetic organic insecticides widely used in agriculture are general biocides having innate ability to cause injury to all living organisms as well as to the quality of environment. The presence of residues of these pesticides in food commodities and other components of the environment has proved toxic to human beings, domestic animals, birds, fish and other non-targeted fauna of the agro-ecosystem.

Despite the fact that the consequences of injudicious use of pesticides in Asia are well documented, crop protection continues to be dominated by dependence on chemicals. The practice of calendar spraying is common among Asian farmers and pesticide subsidies main a major aspect of plant protection policies in many countries (Gopalan, 1998). Though negative externalities cannot be eliminated altogether, their intensity can be minimized through development, dissemination and promotion of environment friendly technologies such as bio-pesticides and bio-agents as well as better agro-economic practices commonly known as Integrated Pest Management (IPM) rather than solely relying on chemical pesticides.

Therefore, a major challenge to plant protection specialists worldwide is the ability to integrate effectively different pest control measures, which must be selected on the basis of their cost effectiveness, sustainability and eco-friendly nature. In India, the paradigm shift in the pest management policy in favor of IPM during the nineties has helped a lot in reducing pesticide consumption in the country. A number of direct and indirect regulatory and policy measures were taken, including import restriction on hazardous chemicals used in agriculture, reduction of subsidies for chemical pesticides, promotion of bio-pesticides, development of IPM packages, training of extension workers and farmers in IPM by establishing Farmers' Field Schools (FFS) and through IPM demonstrations. Even though, it is strongly felt that newer incentives are urgently needed to encourage farmers to reduce pesticide use to assure safe food supply.

[*] Division of Agricultural Economics, Indian Agricultural Research Institute, New Delhi.

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Despite these concerns, little empirical work has been done that attempts to estimate the aggregate environmental benefits of IPM, even in developed countries. Such estimation is difficult because assessing the physical or biological effects of pesticide use on different components of environment is cumbersome and sometimes uncertain. To explore these issues further, the aim of this paper is to quantify the effects of IPM on the risks posed by pesticides to different categories of environment including human beings, and to assess the farmers' willingness to pay for safer options.

Database and Methodology

Sampling Framework

The State Department of Agriculture, Directorate of Plant Protection, Quarantine and Storage, Ministry of Agriculture, Government of India, State Agricultural Universities and other agencies like Uttar Pradesh Diversified Agricultural Project (UPDASP)) have been successfully conducting Farmer's Field Schools (FFS) to sensitize and train the farmers on IPM in several crops. The present study was conducted in Karnal and Kaithal districts of Haryana for paddy IPM and Ghaziabad district of Western Uttar Pradesh for vegetable IPM. The study area represents one of the most progressive regions in terms of productivity and input usage and also characterized by highly commercialized agriculture. Paddy-wheat rotation is most common, and cropping intensity has recently increased further with the introduction of summer paddy in some parts of the Karnal and Kaithal districts. The mono-cropping and high cropping intensity have accentuated the pest problems, depleted ground water resources and worsened soil quality. Tomato and Cabbage are commercially grown in Ghaziabad district and consumes high quantity of insecticides and fungicides. Farmers' prefer to cultivate vegetables commercially in the study area because of its vicinity to Delhi and good supporting infrastructure which makes quick and easy transportation to Delhi and nearby markets, and hence enable them to generate high profits.

For selection of sample farmers, two top ranking blocks in terms of area under Paddy (Karnal and Kaithal districts) and vegetables (Ghaziabad) were chosen, and from each selected block, two villages were selected, one where Farmers' Field School on IPM had already been conducted and the other where no such programme was ever organized. Finally, ten farmers were chosen from each village to make the total sample size of 160. Hence, the study is based on primary data, collected for the year 2003-04 from a sample of 40 IPM trained farmers (received formal training regarding IPM in FFS) and 40 NIPM trained farmers (not attended IPM training in FFS) growing paddy in Haryana and 40 IPM and 40 NIPM farmers growing vegetables (tomato and cabbage only) from western Uttar Pradesh . The primary data on socio-economic characteristics of sample farmers, cultivation practices with particular emphasis on plant protection, adoption of IPM practices and farmers' willingness to pay for safer pesticides in crop production was collected through personal interview method. Besides, secondary data related to toxicity level to different environmental categories (human beings, animals, beneficial insects, birds, and aquatic species) were also collected from published sources for each pesticide used by sample farmers in paddy and vegetables cultivation.

Analytical Approach

Pesticide risk to the environment is often related to the amount of active ingredient applied or expenditure incurred on pesticides. However, both these measures are not the best indicators of risk because pesticides differ with respect to their toxicity, mobility and persistence and thus pose different levels of risk to different components of the environment. Analysis of the environmental benefits of reduced pesticide use must examine the toxicity, mobility and persistence characteristics of the pesticides being used. When farmers reduced the total quantity of pesticidal active ingredient applied but simultaneously substitute highly toxic, mobile and persistent chemicals for relatively lower quantities, it is difficult to argue that environment has gained (Mullen, 1997).

Most of the studies have focused on valuing the human health effects of pesticide (Rola and Pingali, 1993) and little attention has been given to other environmental categories. A few studies have suggested possible approaches for measuring the aggregate environmental costs of pesticides and benefits of IPM (Kovach et al. 1992, Highly and Wintersteen, 1992, Owens et al.1997, Mullen et al.1997, Cuyno et al. 2003. These studies considered the effects of pesticides on different components of environment namely surface water, ground water, aquatic organisms, birds, mammals, beneficial insects and humans (acute and chronic toxicity).

The present study identifies five environmental categories which include human health (acute and chronic effects), animals, birds, aquatic species, and beneficial insects. Active ingredient of each pesticide was assigned three levels of risk i.e. high, moderate and low for each of the five environmental categories. These risk levels were rated on a scale from one to five with one having a minimal impact on environment or low toxicity and five considered to be highly toxic or having a major negative effect on the environment. Information regarding hazard rating as well as toxicity database for each pesticide was obtained from data bases such as EXTOXNET, Pesticide Manual and previous studies. Both toxicity and exposure potential criteria were considered in arriving at the assigned risk for each pesticide used in paddy and vegetable production in the study area. A brief summary of these criteria was presented in Appendix I. These criteria make use of the current state of knowledge with respect to data that indicate pesticide risk to individual environment category. Recognizing the limitations of available data and information, the criteria and hazard categories (as given in Appendix I) make the *ceteris paribus* assumption that highly toxic and persistent chemicals pose a greater risk to different environment categories than pesticides that are less toxic and deteriorate quickly. The detailed description of different criteria and hazard ratings are as follows:

Active and chronic human health criteria

The assignment of acute human health risk level is based on the WHO criteria or EPA criteria. As these criteria require all pesticides to be labeled with “Danger”, “Warning”, or “Caution” based on toxicity. Hence, every pesticide has a corresponding signal word which can correlate with a high, moderate or low rating. Chronic toxicity of a specific pesticide is calculated as the average of the ratings from various long term laboratory tests conducted on small mammals. These tests are designed to determine potential reproductive effects, teratogenic effects, mutagenic effects, and oncogenic effects. Criteria for assigning chronic health risk levels are based on the results of above mentioned tests.

Aquatic Species Criteria

A given pesticide does not affect all aquatic species to the same degree. In this study, the highest level of risk a pesticide poses to any aquatic species is the risk level assigned to that pesticide.

Birds

Assignment of risk to pesticide with respect to the avians is based on the highest level of risk the pesticide poses to any species with in the category, high if LD_{50} is <100 ppm, moderate if LD_{50} is between 50-500ppm, and low if LD_{50} is >500 ppm. There are some pesticides for which toxicological tests have not been conducted. A pesticide is assumed to pose a moderate level of risk to any category where data gaps exist.

Animals

Pesticide Toxicity to mammalian farm animals were assumed to be same as that to human beings.

Beneficial Insects

The assignment of beneficial insect risk to an active ingredient is based on Insect toxicity ratings and is characterized as high, medium or low. However, in case of some of the pesticides, toxicity of pesticidal compounds to beneficial insects has not been formally assessed. Hence, in such cases a low level of risk was assigned to that pesticide.

After the data on individuals risk level associated with each environment category was collected, pesticides were grouped by classes (insecticide, fungicide and herbicide) and score assigned to each pesticide active ingredient were combined with usage data to arrive at an overall eco-rating for each pesticide. An overall eco-rating score was then calculated separately for IPM and NIPM categories of farmers. The difference between the two represents the amount of risk avoided due to adoption of IPM practices. The formula for eco-rating can be expressed as

$$ES_{ij} = (IS_j) \times (AI_i) \times (Rate_i)$$

Where, ES_{ij} is the eco-rating score for active ingredient i and environmental category j , IS_j is the pesticide risk score for environmental category j, AI_i is the percent active ingredient in the formulation, and $Rate_i$ is the application rate per hectare of ith active ingredient. The present analysis covers only a single year and pesticide use may vary considerably depending on weather conditions, and this holds true for both IPM adopters as well as non-IPM adopters.

To examine the farmers' preference for use of safer pesticides, the values of willingness to pay (WTP) were obtained through contingent valuation (CV) method using a survey of 40 farmers practicing vegetable IPM and 40 farmers of paddy IPM of the surveyed area. The respondents were asked to provide WTP values for different formulations of their favorite pesticides. Five formulations were asked, one that avoiding risk to each of the five environmental categories. The farmers were asked to rank those five categories whose presence they would be willing to pay more. They were then asked how much if anything they were willing to pay per kg of active ingredient for their most preferred category and their least preferred category. The other categories were valued between the upper and lower bounds of these values. The respondents were given the chance of rearranging their ranks until they were completely satisfied that the rankings and WTP values were representative of their preferences.

Results and Discussion

Table 1 shows that pesticide use on paddy sample farms was estimated to be 2.07 and 2.42 kg active ingredient per ha respectively on IPM adopted and non IPM adopted farms. On an average, paddy crop was treated four times with pesticide, one application each of herbicide and fungicide and two applications of insecticide. Among major insecticides used in paddy farms include the Endosulfan, Monocrotophos, Chlorpyriphos, Phorate, Diclorvos and Pyrethroids such as lamdacyhalothrim etc. All of these insecticides are classified as highly hazardous to moderately hazardous (Category I and II) according to the WHO classification.(Table 2). In case of vegetables, on an average, pesticide consumption in tomato was found much higher than that of cabbage on both types of farms. On an average, tomato and cabbage crops were treated four times with pesticides on IPM farms, whereas, the frequency increased to 9 and 7 times respectively on non IPM farms. Among pesticides, only insecticides and fungicides were used that too almost in equal proportions. The major insecticide used are cypermethrin, chlorpyriphos, monocrotophos and quinalophos whereas, mancozeb and copper oxichloride are the major fungicides used in tomato and cabbage cultivation in the study area.

Table 1: Pesticide use pattern on sample farms

State	Districts	Crops	Average No. of sprays		Quantity (active ingredient. / per ha)	
			IPM	NIPM	IPM	NIPM
Haryana	Karnal and Kaithal	Paddy	4	4	2.07	2.42
Western Uttar Pradesh	Ghaziabad	Tomato	4	9	2.02	3.71
Western Uttar Pradesh	Ghaziabad	Cabbage	4	7	1.61	2.63

A majority of respondents considered that the use of pesticides brings down the pest population, and thereby increases crop yield. However, many of the non IPM adopters are of the opinion that the prescribed doses in the package of practices are not effective in controlling insects and diseases. On the other hand, some IPM farmers were also found to spray either no chemical pesticides or in lower concentration. The source of pesticide supply was mainly private pesticide dealers and the distance from where pesticides were bought was with in 1-3 km in the study area. Since pesticides have detrimental effects on non-target organisms many of the respondents reported a significant decline in population of beneficial organisms especially, birds, earthworm etc.

The respondents in the study area were concerned about increasing crop losses due to insects and diseases. Some of the major pests and diseases causing economic loss are shown in Table 3. In paddy crop, insects such as yellow stem borer and leaf folders are causing major damage whereas, among diseases blast and false smut are gaining prominence in the study area. Indiscriminate usage of pesticide coupled with mono-cropping and high fertilizer usage had further aided the problem. In vegetables, fruit borer, white fly and tomato leaf curl virus are becoming serious problem in tomato, whereas, cabbage borer and diamond back moth are found as major insects in cabbage crop in the study area.

Table 2: Types of chemical pesticide used in paddy and vegetable cultivation

Pesticides	Safety hazard level*
Organochlorines	
Endosulfan 35% EC	Class II
Organophosphates	
Monocrotophos 35% SL	Class I b
Dichlorvos (DDVP) 76% EC	Class I b
Phorate 10 %G	Class I a
Quinalphos 25% EC	Class II
Dimethoate 30 % EC	Class II
Triazophos 40 % EC	Class I b
Profenofos 50 % EC	Class II
Chlorpyrifos 20 % EC	Class II
Methyl parathion 50 % EC	Class I a
Synthetic pyrethroids	
Lambda-cyhalothrim 5% EC	Class II
Alpha-cypermethrin 10 % EC	Class II
Cypermethirin 25% EC	Class II
Others	
Cartap hydrochloride 50% SP	Class II
Butachlor 50% EC	Class U
Streptocycline	Class U
Anilofos 30 % EC	Class II
Carbandazim 25 % DS	Class U
Pretilachlor	Class U
Propiconazole 25 % EC	Class II
Tricyclazole 75% WP	Class II
Imidacloprid	Class II
Fipronil	Class II
Copper oxichloride 50 % WP	Class III
Mancozeb 75 % WP	Class U
Hexaconazole 5 % SC	Class U

* WHO classification: Class I a - Extremely Hazardous; Class I b - Highly Hazardous; Class II - Moderately Hazardous; Class III - Slightly Hazardous; Class U - Unlikely to present acute hazard in normal use

Table 3 : Major Insects and Diseases

Crops	Insects	Diseases
Tomato	Fruit borer	Tomato leaf curl Virus
	White fly	Damping off
	Aphids	Stem and Fruit cracker
Cabbage	Cabbage borer	Club rot
	Diamond back moth	Ring rot
	Aphids	Cabbage yellow
	Termite	Soft rot
		Root rot
Paddy	Stem borer	Blast
	Leaf folder	False smut
	White-backed plant hopper	Sheath blight
	Rice Hispa	Zinc deficiency
	Gundhi bug	

Willingness to Pay

Table 4 shows that in case of paddy cultivation, 41 percent of the sample farmers ranked first the safer pesticides for human beings as the most preferred category. The were willing to pay upto 30 percent price premium for those formulations that are certified to have no or least harmful effects on human health. The average willingness to pay for those pesticides was estimated as 10 per cent over the present value. However, more than 50 percent respondents rated pesticide safer for beneficial insects as the most preferred one. For that characteristic, they were found to be ready to pay a maximum of 33 percent higher prices.

Similarly in case of vegetable cultivation in western Uttar Pradesh, more than two third sample farmers expressed their first choice towards safer pesticides formulations for beneficial insects. For that, farmers were ready to pay on an average around 30 percent higher prices than what they are paying today. Those who had ranked human health as first category were found to be willing to pay a maximum of 40 percent. Aquatic, animals and birds are the least preferred environment category as regards the willingness to pay is concerned in both the crop regimes. These results confirm that a market exists for safer or environment friendly pesticides in the study area.

Table 4: Rank and Willingness to Pay for risk avoidance to each environment category

Environmental category	% of sample opting first number choice	Average WTP (%)	Average WTP (%) opting first number choice	Max WTP (%)
Paddy				
Human	41.38	10.00	17.91	30.00
Animal	3.45	2.24	0.00	12.00
Birds	0.00	0.17	0.00	5.00
Beneficial insect	55.17	13.96	20.00	33.00
Aquatic species	0.00	0.00	0.00	0.00
Vegetables				
Human	30.00	16.38	28.33	40.00
Animal	0.00	3.75	0.00	14.00
Birds	2.50	2.38	0.00	12.00
Beneficial insect	67.50	21.75	29.07	38.00
Aquatic species	0.00	0.00	0.00	0.00

Environmental Impact of IPM

The risk scores for most commonly used pesticides in the study region for each environment category i.e. human beings, animals, birds, aquatic and beneficial insects is presented in Table 5. As mentioned earlier, the information regarding hazard rating as well as toxicity database for each pesticide was obtained from data bases such as EXTOXNET, Pesticide Manual and previous studies. Higher values indicate high risk associated with respective pesticide.

The scores assigned to each pesticide active ingredient were combined with usage data to arrive at an overall ecological rating for each pesticide. These estimates are presented in Table 6 by each category of pesticide. These results show higher aggregate eco- ratings for each environment category on NIPM farms as compared to IPM farms demonstrating a higher environmental concerns. The estimates also show that eco-ratings were reduced from 20 to 30 percent as a result of adoption of IPM practices by IPM adopters in each paddy growing season. Similar results were also reported in Western Uttar Pradesh where IPM is being practiced in vegetable cultivation. The estimates show that eco-ratings were reduced up to 39 to 46 percent as a result of adoption of IPM practices in tomato and vegetable cultivation in each season (Table 6 & 7). These reductions represent the percent pesticide risk avoided due to reduced pesticide application as well as judicious selection of environment friendly pesticides on IPM farms in crop cultivation in the study area.

Table 5: Risk Score for paddy and vegetables pesticide applied in the study area

Name of pesticides	Risk Scores				
	Human	Animals	Birds	Aquatic	Beneficial
Cartap	3	3	1	3	1
Phorate	5	5	3	5	3
Endosulfan	5	5	3	5	1
Monocrotophos	5	5	5	3	5
Diclorvos	5	5	5	3	3
Cholorpyriphos	3	3	5	5	5
Lindane	5	5	5	5	5
Lambdacyhalothrim	3	3	1	5	5
Carbandazim	3	3	5	5	1
Propiconazole	3	3	1	3	1
Tricyclazole	3	3	3	1	1
Butaclore	1	1	1	5	3
Anilofos	3	3	1	3	3
Pretilachlor	1	1	1	3	1
Quinalphos	3	3	3	3	3
Cypermethrin	3	3	1	1	3
Dimethoate	3	3	3	3	3
Alpha-cypermethrin	3	3	1	1	1
Copper oxichloride	3	3	1	3	1
Mancozeb	1	1	1	3	1
Hexaconazole	1	1	1	3	3

Table 6: Environmental risk associated with pesticide use in paddy by NFFS and FFS farmers

Category	Types of pesticide	Eco-ratings		Aggregate % risk avoided to each environment category
		NIPM farmers	IPM farmers	
	Herbicide	42.89	40.64	
Human beings	Insecticide	214.90	138.32	30.08
	Fungicide	6.86	6.06	
	Herbicide	42.89	40.64	
Animals	Insecticide	214.90	138.32	30.08
	Fungicide	6.86	6.06	
	Herbicide	39.35	35.62	
Birds	Insecticide	143.11	100.46	26.10
	Fungicide	9.44	5.74	
	Herbicide	187.62	171.01	
Aquatic species	Insecticide	208.54	144.00	20.72
	Fungicide	9.73	6.78	
	Herbicide	112.47	105.78	
Beneficial insects	Insecticide	131.75	90.62	19.51
	Fungicide	2.29	2.02	

Table 7: Environmental risk associated with pesticide use in vegetables by Non-IPM and IPM farmers

Category	Types of pesticide	Eco-ratings Non-IPM	IPM	Aggregate % risk avoided to each environment category
Human beings	Insecticide	238.38	137.10	39.16
	Fungicide	96.36	66.57	
Animals	Insecticide	238.38	137.10	39.16
	Fungicide	96.36	66.57	
Birds	Insecticide	196.70	117.52	40.64
	Fungicide	96.67	56.62	
Aquatic species	Insecticide	219.69	133.58	40.35
	Fungicide	191.21	111.52	
Beneficial insects	Insecticide	230.83	121.67	46.13
	Fungicide	57.40	33.59	

Note: No herbicide use was reported by sample farmers in vegetable cultivation

Conclusions

The study estimated the farmers' willingness to pay for pesticides hazard reduction for five environmental categories. These results show that a market exists for environment friendly pesticides in the study area and farmers are willing to pay a price premium. Data bases were also compiled for assessing risk levels to eight environment categories, for more than 20 pesticides used in the study area. These risk values may be used by researchers and farmers while recommending or using different pesticides in the field. It has also been estimated that current use of IPM technology has potential of avoiding pesticide risk hazards to different environment categories by 20-30 percent in paddy cultivation and 39 to 46 percent in vegetable cultivation. Hence, developing farmers' own capacity by imparting information, knowledge and skill through in-depth and intensive training as well as awareness programmes about pesticide hazards would go a long way in enhancing environmental benefits due to IPM adoption.

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Appendix I: Pesticide Impact Scoring System

Environmental categories	Indicators	Score		
		High Risk = 5	Moderate risk = 3	Low risk = 1
Human Health				
1.Toxicity				
Acute Toxicity	Pesticide Class (WHO Criteria)	Ia; Ib	II	III
	Signal Word (EPA Criteria)	Danger / Poison	Warning	Caution
Chronic toxicity	Weight of Evidence of chronic effects	Conclusive Evidence	Probable Evidence	Inconclusive Evidence
Aquatic Species				
1. Toxicity	95 hr LC50 (fish) mg/L Fish / other aquatic Species Toxicity	<1 ppm	1-10 ppm	> 10 ppm
2. Exposure	Runoff Potential Score	High	Moderate	Low
Beneficial Insects				
1. Toxicity	Insect Toxicity Ratings	Extreme / High	Moderate	Low
2. Exposure	Plant Surface Residue Half life	> 4 weeks	2-4 weeks	1-2 weeks
Mammalian Farm Animals	For animals and human beings, same level of risk has been assumed.			
Birds				
1.Toxicity	Birds Toxicity Ratings	High/Extreme	Moderate	Low
	8 days LC 50	1-100 ppm	100-1000 ppm	> 1000 ppm