Integrated Pest Management (IPM) for Reducing Pesticide Residues in Crops and Natural Resources

G. V. Ranga Rao, B. Ratna Kumari, K. L. Sahrawat and S. P. Wani

Abstract

Investigation on the pesticide residues during 2006–2009 in various crops and natural resources (soil and water) in the study village (Kothapally, Telangana State (TS)) indicated the presence of a wide range of insecticidal residues. Pooled data of the 80 food crop and cotton samples, two rice grain samples (3 %) showed beta endosulfan residues, and two (3 %) soil samples showed alpha and beta endosulfan residues. In vegetables of the 75 tomato samples, 26 (35 %) were found contaminated with residues of which 4 % had residues above MRLs. Among the 80 brinjal samples, 46 (56 %) had residues, of these 4 % samples had residues above MRLs. Only 13 soil samples from vegetable fields were found contaminated. The frequency of contamination in brinjal fields was high and none of the pulses and cotton samples revealed any pesticide contamination. IPM fields showed substantial reduction sprays which in-turn reflected in lower residues. Initial studies on water analysis indicated the presence of residues in all water sources with higher in bore wells compared to open wells, however, by 2009 the water bodies reflected no residues above the detectable level.

Keywords

IPM · Natural Resources · Residues

Introduction

Ever increasing demand for food, feed, and fiber, due to increased population, requires increased productivity on a sustained basis. With the advent and adoption of improved technologies such as high-yielding crop varieties and the use of fertilizers and pesticides, considerable progress has been achieved in boosting agricultural production (Foley 2011). However, during this process of enhancing productivity, the use of agrochemicals became an integral part of the present day agriculture. Globally, approximately 2.5 million tons of pesticides are used annually in agriculture. Latest information on pesticide use across

G. V. Ranga Rao (✉) · B. R. Kumari · K. L. Sahrawat · S. P. Wani
International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Telangana State, 502 324 India
e-mail: g.rangarao@cgiar.org

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the world clearly indicated an increase from about US$7 billion to US$12 billion from 2000 to 2012 with a similar trend across the globe (Plumer 2013).

Worldwide, approximately 9000 species of insects and mites, 50,000 species of plant pathogens, and 8000 species of weeds damage crops. Insect pests cause an estimated loss of 14 %, plant pathogens cause 13 % loss, and weeds cause another 13 % loss (Pimentel 2009). Pesticides use is indispensable in agricultural production. About one-third of the agricultural products are produced by using pesticides. Without pesticide application, the loss of fruits, vegetables, and cereals from pest injury would reach 78, 54, and 32 %, respectively 2008). In view of the world's limited croplands and growing population; it is necessary to take all measures to increase crop production in order to ensure food safety (Zhang et al. 2011). On the other hand, Knutson and other researchers pointed out that if the consumption of pesticides is prohibited, the food production in the USA would drop sharply and the food prices would soar.

Drivers of food security and crop protection issues are discussed relative to food losses caused by pests. Insect pests globally consume food estimated to feed an additional one billion people. Key drivers include rapid human population increase, climate variability, loss of beneficial on-farm biodiversity, reduction in per capita cropped land, and water shortages. The use of integrated pest management (IPM) in agriculture is urgently needed, and is also being widely adopted globally. IPM offers a 'toolbox' of complementary crop- and region-specific crop protection solutions to address these rising pressures. IPM aims for more sustainable solutions by using complementary technologies. The applied research challenge now is to reduce selection pressure on single solution strategies, by creating additive/synergistic interactions between IPM components. IPM is compatible with organic, conventional, and genetically modified (GM) cropping systems and is flexible, allowing regional fine-tuning. It reduces the pest levels below economic thresholds utilizing key 'ecological services', particularly bio-control. Landscape scale 'ecological engineering', together with genetic improvement of new crop varieties, will enhance the durability of the pest-resistant cultivars (conventional and GM). The IPM will also promote compatibility with the use of semio-chemicals, bio-pesticides, precision pest monitoring tools, and rapid diagnostics. These combined strategies are urgently needed; and are best achieved via multi-disciplinary research, including complex spatio-temporal modeling at the farm and landscape scales. Integrative and synergistic use of existing and new IPM technologies will help meet the future food needs more sustainably in the developed and developing countries. The aim of this chapter is to provide further evidence to show that IPM indeed can reduce pesticide use without sacrificing the yields of the major crops studied.

Status on Pesticide Related Issues

There have been many studies on determining the ill effects of pesticide exposure (McCauley et al. 2006). The World Health Organization and the UN Environment Programme estimate that each year, 3 million farm workers in the developing world experience severe pesticide poisoning of whom about 18,000 were fatal (Miller 2004). A study with 23 school children who were shifted to organic food from normal diet, a dramatic reduction in the levels of organo-phosphorus pesticides in their system was observed (Lu et al. 2006).

Excessive and non-judicious use of insecticides has led to the degradation of environmental quality, pest resistance, pest resurgence and the contamination of agricultural products and natural resources. Most of the studies on pesticides conducted in Asia reflect the presence of pesticide residues in significant amounts in food and agricultural commodities, and pesticide pollution does exist in the country; and is a cause of concern for public health (Kumari et al. 2002, 2003, 2004, 2005, 2006). Pesticides applied to the soil or that eventually end in the soil in agricultural areas can contribute to the contamination of surface and ground waters (Gilliom et al. 2006; McMahon et al. 2006).

Information from India showed that about 51 % of the food material is contaminated with residues in comparison to 21 % worldwide, of which 20 % were above MRL prescribed by FAO standards (Anon 1999). The contaminated food is generally not discarded in the developing countries, but enters the food chain out of ignorance, innocence and equally importantly out of lack of affordability by the consumers. Lack of awareness of the consequence of pesticide- contaminated food could be one of the reasons for increased incidences of cancers in developing world. Besides the damage to human health, an indiscriminate use of chemical pesticides adversely affects the natural bio-diversity that results in the reduction of natural enemies (Ranga Rao et al. 2005).

Exposure of humans to the hazardous chemicals directly in the fields and indirectly through contaminated diet resulted in the occurrence of residues of organo-chlorines in human blood (3.3–6.3 mg per L) and milk (3.2–4.6 mg per L) samples from lactating women. High levels of pesticide residues (15–605 times) were observed in blood samples of cotton farmers from four villages in Punjab (Anon, 2005). In the past few decades with the benefits of synthetic pesticides being clearly recognized, the usage has steadily increased from 2.2 g ha^{-1} active ingredient (a.i.) in 1950 (David 1995) to 381 g ha^{-1} by 2007 i.e., about 270- fold increase (Anon 2009).

Various inappropriate practices in the use of pesticides cause possible poisoning symptoms generally among farmers who do not wear protective clothing (Ntow et al. 2006). Perceptions by farmers of pesticide efficacy were found to play a major role in farmers' behavior towards the use of pesticides and the adoption of alternative methods of pest control such as IPM (Hashemi and Damalas 2010). For example, pesticide use on any crop depends on the farmer's attitude whether to enhance the productivity to meet the market demands in search of enhanced income or subsistence farming for livelihood (Erbaugh et al. 2000).

For maintaining the quality of a commodity, it is essential to keep the produce free of pesticide residues. A zero level residue in the finished product is not only desired but also needed for eco-preservation and human health as well. The necessity of pesticide residue analysis in various agro-based commodities has become more relevant in the present context. Implementation of IPM strategies will help to reduce the dependence on toxic pesticides associated with agriculture to enhance productivity of healthy products and profitability.

The chemical residues from the soil find their way to the aquatic systems or get accumulated in the plant products (grain, root, stem etc.). Farmer field schools organized in India on cotton situation brought out the importance of IPM in reducing pesticide-induced risks at the farm level without sacrificing the yields (Mancini 2006). The constraints in the adoption of protective clothing in tropics were discussed by Kishi (2005).

Integrated Pest Management (IPM)

Globally, there is an increasing pressure on the agriculture sector to produce more food to meet increased demand of the growing populations all around the world. This has increased the need for intensive plant protection with increased use of pesticides, leading to complex environmental implications. Several national and international agencies and nongovernmental organizations are presently engaged in supporting research and the use of eco-friendly approaches for crop protection practices for the sustainable environment.

The basic concept of IPM is the containment of pests below economically damaging levels, using a combination of control measures. Two fundamental principles are: (1) that as individual pest control methods are often not successful alone and (2) that pests only need to be managed when present at populations high enough to cause economic damage. The IPM relies on the integration of various plant protection options with a selective use of insecticides in a regulated program. This refers to an active program of monitoring pest and natural enemy population levels. Four primary components of IPM include: host plant resistance, manipulation of the farming system, enhanced bio-control, and selective use of biorational and/or synthetic pesticides.

IPM is the most environment-friendly approach of crop-protection and prescribes the use of chemical pesticides as the last resort. However, most of the farming communities in India are not much educated. Therefore, they are averse to adopt the program. Implementation of the IPM strategies reduces toxic pesticides in agriculture to enhance productivity of healthy products and profitability. The inclusion of eco-friendly IPM packages in the plant protection measures is the need of the hour to save the crop losses from the biotic stresses and to sustain and improve the agricultural production, soil health, and overall environmental quality. Insecticide residues in non-IPM vegetable fields were higher than those recorded for the IPM fields (Arora and Singh 2004; Sardana et al. 2005). The insecticide residues in the IPM-managed vegetable (tomato and cucumber) fields ranged from 0.004 to 0.027 mg kg^{-1}, while the residues ranged from 0.005 to 0.106 mg kg^{-1} in the non-IPM fields (Ranga Rao et al. 2009a).

On-Farm Experience

Under integrated watershed management program and bio-intensive pest management (BIPM) technologies were initiated in farmer participatory approach during 2000 in Kothapally village of TS to alleviate the plant protection problems in crops like cotton, pigeonpea, and chickpea. During 2000–2001, pigeonpea BIPM farmers applied one spray each of neem fruit extract and HNPV, followed by manual shaking (3–5 times) and did not apply any chemicals. Non-IPM farmers sprayed 3–4 times with chemicals. During the 2001–2002 season, BIPM farmers used one spray each of neem and HNPV followed by manual shaking (2–4 times), while the non-IPM farmers used 2–3 rounds of chemical sprays. In chickpea, during the post rainy season 2000–2001, the BIPM plots received 1–3 sprays of HNPV, while the non-IPM farmers did not take any plant protection measures for their crops. During 2001–2002, BIPM farmers applied one spray of neem fruit extract and two sprays of HNPV, while non-IPM farmers used two sprays of chemicals.

The larval population in BIPM pigeonpea plots was always found lower than those of non-IPM plots, where farmers applied 3–4 sprays of chemicals. BIPM interventions resulted in the substantial decrease in borer damage to pods and seeds with 34 % and 21 % pod and seed damage compared to 61 and 39 % pod and seed damage in non-IPM plots. This lower pod borer damage in the BIPM plots also reflected in higher yield of 0.77 t ha^{-1} compared to 0.53 t ha^{-1} in farmer practice treatment. The observations on egg and larval population during 2001–2002 indicated similar trend as in the previous season. The BIPM interventions resulted in 33 and 55 % reduction in pod and seed damage, respectively. The BIPM plots yielded 0.55 t ha^{-1} compared to 0.23 t ha^{-1} yield in non-IPM plots, even although the overall yield levels were low (Ranga Rao et al. 2007).

In chickpea, egg and larval population during 2000–2001 indicated the onset of the pests during the first fortnight of November when the crop was around 30 d old (with one egg $plant^{-1}$), and the number continued to increase until the first fortnight of December when the crop attained podding stage and later declined by the end of January. The difference in plant protection practices between BIPM and non-IPM plots was clearly reflected in the lower larval population in BIPM fields throughout the vulnerable phase of the crop. The BIPM farmers also harvested three times higher yields of 0.78 t ha^{-1} compared to 0.25 t ha^{-1} in non-IPM fields, which was primarily due to an effective pest management and the adoption of improved variety (ICCV 37) developed at the International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT).

Chemical Usages on Different Crops

Detailed crop surveys on the use of chemicals on different crops during 2005–2006 in India brought out the following proportion of pesticide inputs in various crops: cotton: (51 %), rice (10 %), pigeonpea (6 %), maize (2 %), chickpea

Table 1 Quantity of common used pesticides, used by farming community and the recommended doses

Chemical (No. of farmers)	Chemical group	Quantity of chemical used (ml ha^{-1})		
		Mean	Range	Recommended
Endosulfan (185)	Organochlorine	1580	375–5000	1000
Monocrotophos (251)	Organophosphate	1590	250–3750	750
Indoxacarb (169)	Chloro-nicotil	418	63–1250	250
Spinasod (133)	Microbial	213	50–500	125
Cypermethrin (82)	Pyrethroid	1753	250–2500	500
Imidacloprid (51)	Neonicotinoid	305	63–750	125

(1 %), groundnut (2 %), and chilly (28 %) of the total pesticides usage in the selected project locations (World bank DM ICRISAT, final Report Anon 2007). In Asian agriculture, about 80 % of the plant protection chemicals utilized were in cotton and vegetables, although the area was only about 5 % of the total. Similar trend was also noticed in India with 75 % of the chemical use in these crops covering only 5 % of the cultivated area (Vasantharaj David 1995). Of these, chilly was found to be highly intensive crop with 15–20 sprays in a 6-month period, contributing to heavy residues on the products, hindering its export. Results from Table 1 clearly show the use of excess dosage of plant protection chemicals by farmers. This could be due to their ignorance, low confidence on the efficacy of chemicals, lack of effectiveness due to the occurrence of insecticidal resistance in key species, and inappropriate application. Since intensive plant protection in a limited area was responsible for major residues and environmental issues those areas should be given the priority to reverse the ill effects caused by the use of chemicals.

The studies related to pesticide use the following implementation of IPM in 17 selected villages, indicated substantial reduction in pesticide application from 11 sprays to 4 sprays in cotton, 2.1 to 1.6 in rice, 2.9 to 2.2 in pigeonpea, and 2.9 to 2.3 in chickpea during 2005 and 2007 (Table 2). This impact was due primarily to the periodic farmer researcher interactions, training imparted to the farmers and their keenness on judicious use of chemical pesticides. Mancini (2006) also described similar results with about 75 % reduction in pesticide use in contact villages compared to 28 % in the noncontact villages without compromising crop yields through farmer field schools.

The crop samples analyzed for pesticide residues in 15 contact (41 samples) and 5 noncontact (15 samples) villages revealed presence of pesticide residues in all samples of which 38 samples had residues below 0.001 ppm (Anon 2007). However, one sample each of *Dolichos* and tomato only had residues of monocrotophos and chlorpyriphos above the maximum residue limits (MRLs) prescribed by the FAO. According to Peter Melchett (2008), the level of pesticide residues in juice drinks in the UK was on an average 34 times more than those permitted in drinking water and sometimes up to 300 fold. Studies conducted by Yaong Bai et al. (2006) in vegetables in the Shaanxi area of China revealed the occurrence of residues of five organophosphorus pesticides ranging from 0.004 to 0.257 ppm; and in 18 of 200 samples, the residue levels exceeded MRLs. The occurrence of pesticide residues in the in samples in the study clearly indicated the status of residues and the need for developing strategies for their management.

Bio-Rationals

The term covers a range of alternatives to synthetic chemical pesticides of biological origin. Their main feature is specificity to avoid nontarget mortality and associated problems. The use of bio-pesticides is an important component of IPM strategy for all major crops. The best-known examples are the neem-based products, which have shown to be effective against a number of pests, NPV being used for the control of important

Table 2 Comparison of pesticide use on selected crops in villages before and after the implementation of IPM

Village (No. of farmers)	No. of insecticidal sprays											
	Cotton			Paddy			Pigeonpea			Chickpea		
	2005	2007	Reduction (%)	2005	2007	Reduction (%)	2005	2007	Reduction (%)	2005	2007	Reduction (%)
Daulatabad (11)	–	–	–	2.0	1.7	15.0	3.3	3.3	0.0	–	–	–
Mudireddypalli (19)	–	–	–	2.3	2.1	8.7	3.1	3.3	−6.5	–	–	–
Peddaravelli (11)	7.9	2.2	72.2	1.5	0.8	46.7	2.0	1.3	35.0	–	–	–
Pullagiri (14)	6.9	3.6	47.8	2.6	2.3	11.5	2.7	1.8	33.3	–	–	–
Indrakal (17)	7.5	4.1	45.3	2.3	2.1	8.7	2.7	2.0	25.9	–	–	–
Musapet (9)	–	–	–	1.8	0.8	55.6	–	–	–	–	–	–
Addakal (11)	–	–	–	2.5	2.1	16.0	–	–	–	–	–	–
Chandapur (16)	16.5	6.8	58.8	2.7	1.7	37.0	3.0	2.3	23.3	2.9	2.4	17.2
Kamalpally (15)	9.5	3.1	67.4	–	–	–	2.8	2.5	10.7	2.7	2.6	3.7
Gundlamachnur (17)	13.7	3.6	73.7	2.2	1.7	22.7	2.9	1.7	41.4	3.0	2.6	13.3
Lingapur (18)	10.3	4.0	61.2	2.1	1.6	23.8	2.5	1.6	36.0	2.7	1.8	33.3
Kyasaram (21)	14.7	4.2	71.4	2.4	2.1	12.5	3.1	2.3	25.8	2.7	2.4	11.1
Alirajpet (15)	10.9	3.3	69.7	2.1	1.7	19.0	3.0	2.4	20.0	2.9	2.2	24.1
Kukunurpally (16)	16.4	3.2	80.5	1.7	1.4	17.6	3.0	1.9	36.7	–	–	–
Vattimeenapally(16)	8.1	3.4	58.0	–	–	–	2.9	2.1	27.6	3.6	2.6	27.8
Medipallykalam (20)	15.5	3.9	74.8	1.8	1.5	16.7	3.5	2.9	17.1	2.8	2.0	28.6
Kummera (15)	9.9	3.4	65.7	1.8	0.5	72.2	2.6	1.6	38.5	2.6	1.9	26.9
Mean	11.4	3.8	65.1	2.1	1.6	25.6	2.9	2.2	24.3	2.9	2.3	20.7

Absence of crop in the village; Obtained from Ranga Rao et al. 2009; Obtained from ICRISAT World Bank DM project final report 2007

pests like *Helicoverpa armigera* and *Spodoptera* spp. In addition, *Bacillus thuringiensis* (Bt) has gained importance in suppressing pest populations in crops like cotton and vegetables.

There are several bio-pesticides commercially available for use by farmers. There were approximately 175 registered bio-pesticide active ingredients in India and 700 products globally (Ranga Rao and Goplakrishnan 2009). Awareness of the need for safer agents has grown with an increasing concern for the toxicity of synthetic pesticides. Hence, biorational pesticides have immense potential. A number of neem-based formulations are being produced by small-scale formulators and marketed as insecticides. Most of them are made from neem oil and contain varying amounts of Azadirachtin. There have, however, been problems with the maintenance of consistent quality. To overcome this, farmers are encouraged to procure neem seeds and prepare their own spray containing 5 % neem-fruit-powder extract using the prescribed procedure.

Hence, several integrated pest management (IPM) programs have adopted neem as one of the prime options for creating greater stability and sustainability in crop production. In the present IPM module, the use of neem during the vegetative phase, followed by the application of Helicoverpa Nucleo Polyhedrosis virus (HNPV), a popular insect pathogen at flowering and need-based application of chitin inhibitors (novaluron, flufenoxuron) instead of conventional insecticide (endosulfan) during pod formation phase in pest management would be of immense help in augmenting the natural enemies in the chickpea ecosystem (Ranga Rao et al. 2008).

Effect of IPM Options on Soil Inhabiting Natural Enemies

Studies to assess the effects of select treatments on soil inhabiting natural enemies during 1998–2000 postrainy seasons revealed that their population started building up during the vegetative phase (302 trap^{-1}) and attained the peak during the flowering phase (455 trap^{-1}) and subsequently there was a gradual decline during pod formation and preharvested phases of the crop. Observations on the effects of various treatments on soil inhabiting natural enemies at vegetative phase revealed that plots treated with endosulfan had significantly lower populations (107.7 trap^{-1}) with 64 % reduction compared to the control (302.3 trap^{-1}). The plots treated with HNPV showed minimum disturbance to natural enemies with a catch of 267.1 trap^{-1}, on par with the control (Ranga Rao et al. 2008).

These studies clearly indicated the population dynamics of soil inhabiting natural enemies and their potential in suppressing the pod borer. Considering the preference by insect pests and their associated natural enemies live and feed on chickpea than other legume crops (Ranga Rao and Shanower 1999), it is necessary to integrate safer and effective pest management options in the chickpea IPM programs in order to obtain maximum advantage from the natural enemies. Hence, one should be cautious in the selection and sequencing of control measures to maintain the ecological balance and healthy environment. The results from these investigations have provided further insight to the earlier studies on the effective use of IPM options in the management of key pests and their natural enemies with less deleterious effects on natural enemies.

Effect of IPM Options on Aerial Natural Enemies in the Chickpea Canopy

Using a De Vac® at 22, 54, 76, and 99 DAS during the 1998–1999 season assessed the impact of various IPM options on aerial natural enemies. The results from these studies at 22 DAS revealed lower number of natural enemies in plots treated with endosulfan (39.5) compared to plots treated with HNPV (69.7), IPM (51.0) and control (87.1). Observations at 54 DAS 2 days after the third spray suggested a similar trend with a significant reduction (58 %) in the number of natural enemies in the plots treated with endosulfan. However, there was no significant reduction in the number of natural enemies in the plots treated with either neem (20.8) or HNPV (21.5) compared to the control (23.8). Perusal of the data at 76 DAS revealed that the plots treated with endosulfan recorded the less number of aerial natural enemies (18.0) while neem, HNPV, and IPM treatments had populations of 25.3, 28.8, and 27.3, respectively, compared to control (32.2). At 99 DAS, the natural enemy populations in plots treated with endosulfan were found significantly low (9.5) and the other treatments were on par with each other. The overall effect of endosulfan, neem, and HNPV indicated 52, 29, and 14 % reduction in population of aerial natural enemies, respectively, over control. (Ranga Rao et al. 2008)

Effect of IPM options on larval parasitoids of H. armigera. During the study period, the larval parasitization *of H. armigera* was mainly by *Campoletis chlorideae*. Apart from *C. chlorideae,* the other larval-pupal parasitoid, *Carcelia illota* Curron, a tachinid was recorded only in control plots, however, its incidence was only 2 %. Two years study during 1998–2000 at ICRISAT fields, the overall effect of endosulfan, neem, HNPV, and IPM treatments indicated 35, 20, 16, and 21 % reduction, respectively.

In subsequent studies during 2003–2004, post-rainy season in chickpea revealed the overall effect in two samples of larval collections (at 26 and 56 DAS) lower parasitization in plots treated with endosulfan (2.3 %) with 60 % reduction over control. The larval parasitization from plots treated with neem fruit extract (4.7 %) and neem oil (5.2 %) indicated 17 and 11 % reduction in population, respectively, over control. The bio-pesticide HNPV-treated plot recorded higher number of parasitized *H. armigera* larvae (5.7 %) with 2.8 % reduction in population, which was on par with control.

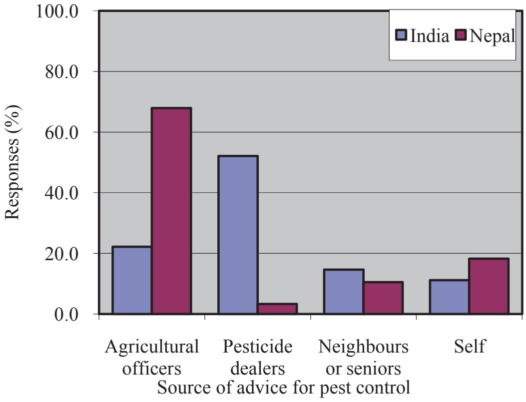

Fig. 1 Sources of advice to farmers in pest control in India and Nepal. (Obtained from Ranga Rao et al. 2009b)

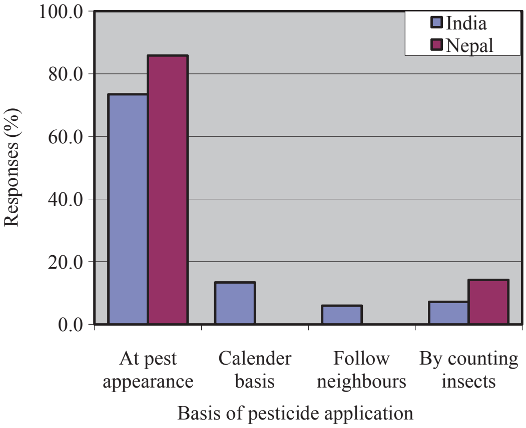

Fig. 2 Basis of pesticide application by farmers in India and Nepal. (Obtained from Ranga Rao et al. 2009b)

Farmer Perception of Plant Protection

Participatory rural appraisal (PRA) was undertaken in 70 villages in India and Nepal, covering 1185 farmers to generate baseline information on the current plant protection practices. The study revealed that 93 % of the farmers in India and 90 % in Nepal had adopted chemical control for the management of various insect pests in different crops. However, less than 20 % of the farmers expressed confidence on the efficacy of the current plant protection measures. In India, 52 % farmers get their plant protection advice from pesticide dealers. While in Nepal, majority of the farmers (69 %) make their plant protection decisions through agricultural officers (Fig. 1). A majority of the farmers (73 % in India and 86 % in Nepal) initiate the plant protection based on the first appearance of the pest, irrespective of their population, crop stage, and their damage relationships (Fig. 2). About 50 % of the farmers in India and 20 % in Nepal were not using any protective clothing while spraying. Health problems associated with the application of plant protection chemicals were reported by farmers. The cost of plant protection on various crops ranged from 7 to 40 % of the total crop production cost. Although IPM has been advocated for the past two decades, only 32 % in India and 20 % of farmers in Nepal were aware of the IPM practices. IPM implementation in selected villages brought 20–65 % reduction in pesticide use on different crops (Ranga Rao et al. 2009b).

Knowledge on Integrated Pest Management (IPM)

Though IPM has been advocated for over two decades, only 32 % farmers in India and 20 % in Nepal were aware of IPM practices. Among the various bio-pesticides, majority of the farmers (76 % in India and 93 % in Nepal) have adopted neem in their pest management programs. Though the farmers in India and Nepal were aware of bio-pesticides and natural enemies, their integration into the IPM was only 32 % in India and 20 % in Nepal. This low adoption of IPM in various crops was primarily due to the non-availability of IPM inputs at the farm level, the complexity of the IPM modules for different crops, lack of information on the ill effects of toxic chemicals and the existing insufficient extension networks.

Insecticide Residue Monitoring: A Case Study

Pesticide residue monitoring was taken up at Kothapally and Enkepally villages of Ranga Reddy district, TS in food crops (rice, maize, pigeon-

Table 3 Pesticide residues in vegetable samples collected from farmers' fields, Kothapally village, Ranga Reddy district during 2007

Crop (No. of samples)	Range of pesticide residue level (mg kg^{-1})			
	Monocrotophos	Chlorpyrifos	Endosulfan	Cypermethrin
Brinjal (10)	0.003 (<0.001–0.007)	0.008 (<0.001–0.040)	0.019 (<0.001–0.089)	0.052 (<0.001–0.283)
Cucumber (10)	0.004 (0.001–0.011)	0.066 (0.001–0.330)	0.019 (0.002–0.030)	0.010 (0.001–0.034)
Okra (10)	0.013 (<0.001–0.044)	0.605 (0.001–5.154)	0.130 (0.001–0.784)	0.025 (<0.001–0.112)
Ridgegourd (6)	0.015 (<0.001–0.041)	0.050 (0.001–0.223)	0.021 (0.002–0.061)	0.086 (0.001–0.352)
Tomato (23)	0.005 (<0.001–0.025)	0.035 (<0.001–0.151)	0.032 (<0.001–0.466)	0.024 (<0.001–0.141)

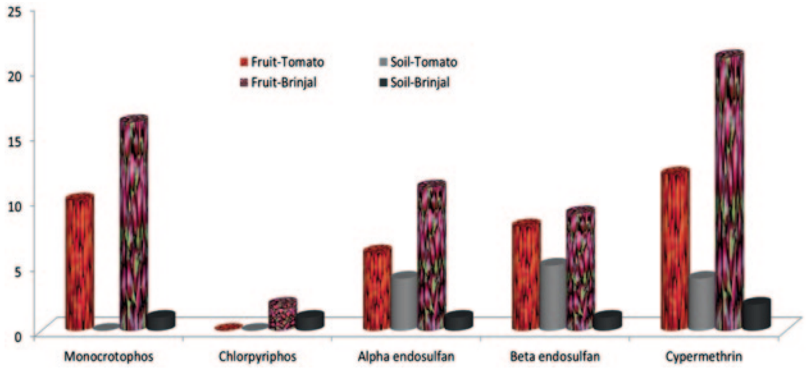

Fig. 3 Frequency distribution of insecticide residues in vegetable crops and soil samples from their respective fields

pea), vegetables (tomato and brinjal), and cotton besides soil and water during 2006 and 2009 seasons. The pesticide residue analysis during 2006 and 2007 revealed the presence of residues of chlorpyriphos and cypermethrin above MRL in 10 % of the samples of brinjal and tomato. In fact, most of the water samples from bore as well as open wells showed considerable level of residues though they are below the MRLs (Table 3).

Pesticide Residues in Food Grains and Cotton

Analysis of food grains, cotton, and soil samples showed that out of all grain samples analyzed, one sample of rice grain was contaminated with beta endosulfan (0.5 µg g^{-1}). Alpha (0.02 µg g^{-1}) and beta endosulfan (0.02 µg g^{-1}) residues were detected in one soil sample collected from maize field during 2008 season. Only two samples contained beta endosulfan residue— one rice grain sample (0.008 µg g^{-1}) and one soil sample collected from rice field (0.03 µg g^{-1}) during the 2009 season. However, none of the pigeonpea grain and cotton lint samples were contaminated with insecticide residues. The presence of endosulfan residues in rice grain and soil from rice field could be attributed to the fact that farmers used endosulfan for pest control in various fields (Fig. 3). Detection of endosulfan residues in maize cultivated fields and cobs was in consonance with the study conducted by Singh et al. (1992). Senapati et al. (1992) reported the absence of residues in pigeonpea grain at harvest. Samant et al. (1997) and Nayak et al. (2004) also reported nondetectable levels of chlorpyriphos and endosulfan in the black gram and green gram seeds. The nondetection of residues in soils from pigeonpea fields are in agreement with the results of Tanwar and Handa (1998). A shift in cotton cultivation from traditional varieties to Bt varieties, which requires less number of sprays according to our survey, might be one of the reasons for nondetectable residues in cotton lint. Suganya Kanna et al. (2007) also did not observe any resi-

Table 4 Insecticide residues in tomato and brinjal and in respective soil samples from the fields observed in Kothapally and Enkepally villages during 2008–2009 and 2009–2010 cropping seasons

No. of samples analyzed/ contaminated	Insecticides detected	Frequencies	Residue range (µg g^{-1})	MRL (µg g^{-1})*
In Tomato				
Fruit 75 (26)	Monocrotophos	10	0.006–0.2	0.2
	Alpha endosulfan	5	0.01–0.2	2.0
	Beta endosulfan	8	0.008–0.07	2.0
	Cypermethrin	11	0.06–0.5	0.5
Soil 40 (13)	Monocrotophos	–	–	–
	Alpha endosulfan	4	0.05–0.8	–
	Beta endosulfan	3	0.02–0.2	–
	Cypermethrin	3	0.01–0.3	–
Brinjal				
Fruit 80 (46)	Monocrotophos	17	0.01–0.2	0.2
	Chlorpyriphos	2	0.009–0.01	0.2
	Alpha endosulfan	15	0.009–1.0	2.0
	Beta endosulfan	10	0.006–3.0	2.0
	Cypermethrin	21	0.01–0.2	0.2
Soil 40 (5)	Monocrotophos	1	0.06	–
	Chlorpyriphos	1	0.03	–
	Alpha endosulfan	1	0.1	–
	Beta endosulfan	1	0.01	–
	Cypermethrin	1	0.02	–

*Maximum residue limit

dues of imidacloprid and acetamiprid in cotton lint.

Insecticide Residues in Vegetables and Soil

Studies organized on the pesticide residues in vegetable (brinjal, cucumber, okra, ridge gourd, and tomato) and water samples collected from Kothapally Adarsha watershed in Rangareddy district, TS, India during 2007 revealed the presence of monocrotophos (range 0.001–0.044 mg kg^{-1}), chlorpyrifos (0.001–5.154 mg kg^{-1}), cypermethrin (0.001–0.352 mg kg^{-1}) and endosulfan (0.001–0.784 mg kg^{-1}). The residues of monocrotophos and endosulfan were below MRL in all the 59 vegetable samples, while the residues of chlorpyrifos were above MRL in four samples and cypermethrin in two samples.

The data on insecticide residues in tomato fruits and soil are presented in Table 4. Out of the 15 tomato fruit samples analyzed during the 2008 summer season from two villages, eight (53 %) samples were found to be contaminated with all the insecticide groups under study, except for chlropyriphos; and the residue concentration ranged from 0.01 to 0.3 µg g^{-1}. However, one sample showed monocrotophos residue above the MRL. During the *Kharif* 2008 season, 40 % of the samples (6 out of 15) were contaminated (0.006 to 0.3 µg g^{-1}). One (0.07 µg g^{-1}) out of the 15 samples contained insecticide residues during the *Rabi* 2008 season. During the 2009 summer season, low concentrations of residues in 7 out of 15 samples (47 %) were detected showing monocrotophos as the major insecticide. Four samples out of 15 contained residues during the 2009 *Kharif* season, however they were below MRLs. (Table 4). Out of the 10 soil samples 3 (33 %) contained cypermethrin residues (ranging from0.1 to 0.3 µg g^{-1}) in the 2008 summer season. Alpha and beta endosulfan residues (0.02 to 0.07 µg g^{-1}) in 5 out (55 %) of 10 samples were detected during 2008 *Kharif* season. During the 2008 *Rabi*, only 1 out of 10 soil samples

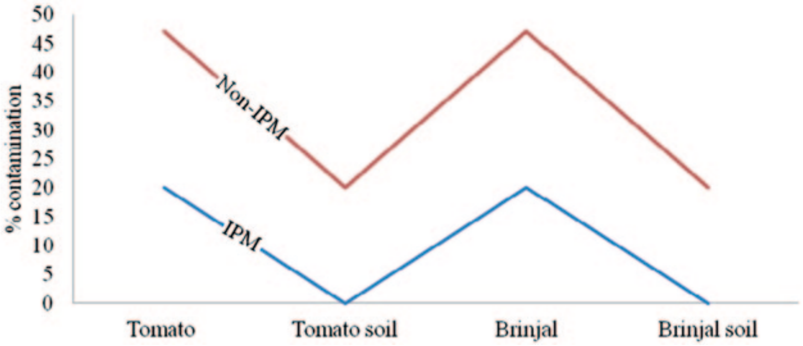

Fig. 4 Impact of IPM in reducing insecticides residues in tomato and brinjal crops and soils

contained beta endosulfan residue (ranging from 0.03–0.2 µg g^{-1}). Three out of ten soil samples contained alpha endosulfan and cypermethrin residues (ranging from 0.04 to 0.8 µg g^{-1}) during the 2009 *Kharif* season.

In brinjal during 2008 summer season, the frequency of contamination with cypermethrin (0.009 to 3.0 µg g^{-1}) was higher, and it was in 9 out of 16 brinjal fruit samples. Beta endosulfan was present in greater concentration (3.0 µg g^{-1}) and was above the MRL (Table 6). A contamination level of 69 % (11 out of 16) with monocrotophos and cypermethrin as the main contaminants (residue concentration ranging from0.006 to 0.2 µg g^{-1}). In 7 out of 16 samples, residues of monocrotophos, alpha endosulfan and cypermethrin (44 % contamination) were detected during 2008 *Rabi* season, (0.009 to 0.1 µg g^{-1}). Sixty nine per cent (11 out of 16) of the samples were found contaminated during 2009 summer season, and the residue concentration ranged from 0.006 to 0.2 µg g^{-1}. In 8 out of 16 samples (0.01–2.0 µg g^{-1}) insecticide residues were detected during the 2009 *Kharif* season. The results of soil analysis are shown in Table 3. Monocrotophos (0.06 µg g^{-1}) and chlorpyriphos (0.03 µg g^{-1}) residues were detected in the samples collected in 2008 summer season. During the 2008 *Kharif* season, insecticide residues were not detected in the samples. One out of the eight (13 %) samples collected contained the residues of different insecticides (ranging from 0.01 to 0.1 µg g^{-1}) during the 2008 *Rabi*, 2009 summer, and 2009 *Kharif* seasons. The presence of monocrotophos in selected vegetable samples in concentrations above the MRL probably was due to unauthorized sale by pesticide dealers and their use by farmers, although this insecticide was banned for use on vegetables as per the Insecticide Act, 1968 as on 28th December, 2006 (Sharma 2007). The contamination of soil samples with insecticide residues from the field planted with brinjal was lower as compared to the samples from the field planted with tomato. This could be attributed to greater canopy cover under brinjal and longer duration of the crop as suggested by Jayashree and Vasudevan (2007) in paddy canopy and the movement of residues to the soil and in the run-off water.

Considering overall all samples, of the 80 food crop and cotton samples, only two rice grain samples (3 %) showed beta endosulfan residues and two (3 %) out of 80 soil samples showed alpha and beta endosulfan residues. In vegetables, of the 75 tomato samples, 26 (35 %) were found contaminated with residues and 4 % had residues above MRLs. In soil samples (Fig. 5), 13 samples (26 %) out of the 50 samples from tomato fields had residues. Among the 80 brinjal samples, 46 (56 %) had residues; and out of these 4 % samples had residues above MRLs. Only 13 % of the soil samples from brinjal fields were contaminated (Fig. 3 and 4).

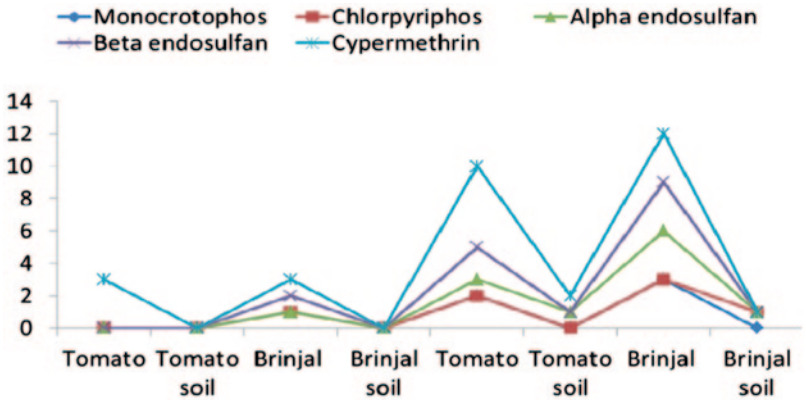

Fig. 5 Frequency distribution of insecticide residues in crops and soil samples taken from the IPM and Non-IPM fields planted with vegetables

Table 5 Pesticide residues in two vegetable samples collected from IPM and farmers practice plots, Kothapally village, Ranga reddy district, TS, 2007

Crop	Treatment (No. of samples)	Residue levels (mg kg^{-1})			
		Monocrotophos	Chlorpyrifos	Endosulfan	Cypermethrin
Tomato	IPM (18)	0.005	0.034	0.012	0.023
Tomato	Non-IPM (5)	0.005	0.041	0.101	0.028
Cucumber	IPM (5)	0.004	0.027	0.011	0.009
Cucumber	Non-IPM (5)	0.005	0.106	0.026	0.012

Insecticide Residues in Water

The pesticide residue analysis during 2006 and 2007 revealed the presence of residues of chlorpyriphos and cypermethrin in most of the water samples from bore as well as open wells showed considerable level of residues though they are below the MRLs. During 2006–2007, residues of all the four pesticides were found higher in bore well water compared to open well samples (Table 6). Residues of endosulfan were higher by 300 %, cypermehrin by 89 %, monocrotophos by 50 %, and chlorpyrifos by 9 % in bore wells compared to samples collected from the open wells. The total residue concentrations of all the four pesticides were high in water samples from bore wells (0.036 mg kg^{-1}) than water samples from the open wells (0.023 mg kg^{-1}). Low levels of residues in open wells could be due to greater exposure to the environment thereby more scope for degradation. These studies brought about the status of selected conventional pesticides used for farming activities. Though the levels of toxicity in several samples were below MRL's considering their occurrence in all samples one should critically look into the eco system to make sure the crops and the agro ecosystem were free from the toxicants.

Water analysis during 2009 from food crop fields and vegetable fields did not reveal any insecticide residues. According to the WHO (2004), most of the organochlorine pesticides are practically insoluble in water. Our results are in agreement with the findings of Jagdishwar Reddy et al. (1997) who reported no insecticide residues in river, tank and canal water. However, most of the documented review on pesticide residues in water in India indicated the presence of highly persistent organochlorines like DDT, HCH, lindane, and heptachlor and endosulfan in different water sources. The suspended residues were probably quickly decomposed by sunlight through photo degradation reaction and hence pyrethroids did not persist longer on the surface or sub-surface

Table 6 Pesticide residue levels in water samples collected from open and bore wells of Kothapally village, Ranga Reddy district during different phases of IPM (2006-09)

Source of water sample	Residue levels (mg kg^{-1})[a]				Total
	Monocrotophos	Chlorpyrifos	Endosulfan	Cypermethrin	
Initial phase of IPM upto 2006					
Bore well	0.003 (<0.001–0.004)	0.012 (<0.001–0.018)	0.004 (<0.001–0.005)	0.017 (<0.001–0.029)	0.036
Open well	0.002 (<0.001–0.002)	0.011 (0.004–0.017)	<0.001 (<0.001)	0.009 (<0.001–0.009)	0.023
During 2009					
Bore well	ND	ND	ND	ND	ND
Open well	ND	ND	ND	ND	ND

ND Not detected

[a] Mean of four open and two bore wells (Values in the parenthesis denote the range)

water samples (Awasthi 1997; Nwankwoala and Osibonjo 1992) studied the organochlorine pesticide residues in surface waters in Ibadan (Nigeria). This may be due to the indiscriminate use of chemicals and perhaps could be contamination from local as well as upstream areas.

Impact of Integrated Pest Management in Minimizing Insecticide Residues

To understand the impact of IPM modules in the reduction of insecticide residues, samples of crop, soil, and water were monitored from selected IPM farmers and the results compared with the samples collected from the nonIPM farmers from two villages, *viz.,* Kothapally and Enkepally of Ranga Reddy district, Andhra Pradesh. As vegetables are the major source of chemical use, tomato and brinjal were covered in this study. Five tomato and five brinjal farmers were selected from Kothapally village and IPM schedule was given to them. studies organized on the pesticide residues in vegetable (brinjal, cucumber, okra, ridgegourd, and tomato) and water samples collected from Kothapally Adarsha watershed in Rangareddy district, Andhra Pradesh, India during 2007 revealed the presence of monocrotophos (range 0.001–0.044 mg kg^{-1}), chlorpyrifos (0.001 to 5.154 mg kg^{-1}), cypermethrin (0.001 to 0.352 mg kg^{-1}) and endosulfan (0.001 to 0.784 mg kg^{-1}). The residues of monocrotophos and endosulfan were below MRL in all the 59 vegetable samples while the residues of chlorpyrifos were above MRL in four samples and cypermethrin in two samples. The water samples also revealed the presence of pesticide residues but were below MRLs (Table 6). Among the food crops and cotton analyzed for the insecticide residues (monocrotophos, chlorpyriphos, alpha endosulfan, beta endosulfan, and cypermethrin), one rice grain sample (0.5 µg g^{-1}) out of five samples collected from Kothapally was contaminated and among the soil samples, residues were detected in one soil sample (0.02 µg g^{-1}) collected from maize field during 2008 in Enkepally. Only two samples were contaminated—one rice grain sample (0.008 µg g^{-1}) and one soil sample (0.03 µg g^{-1}) collected from rice field during 2009 from Enkepally. Out of the total 45 tomato fruit samples analyzed from Kothapally for insecticide residues over a period of five seasons in 2008 and 2009, 11 samples (24 %) were found to contain residues. In Enkepally, the residues were observed in 50 % of samples (15 out of 30 samples) during this period. However, none of the samples from Kothapally and 7 % of contaminated samples from Enkepally had residues above MRLs. Overall, out of the 30 soil samples collected from tomato fields during 2008 and 2009, only six samples (20 %) contained insecticide residues compared to 35 % in Enkepally. Among the 40 brinjal samples analyzed during 2008 and 2009 seasons, 17 (43 %) samples from Kothapally and 29 (73 %) samples from the Enkepally contained insecticide residues. The overall residue levels in brinjal during the study period indicated 7 % of samples in Enkepally above MRLs.

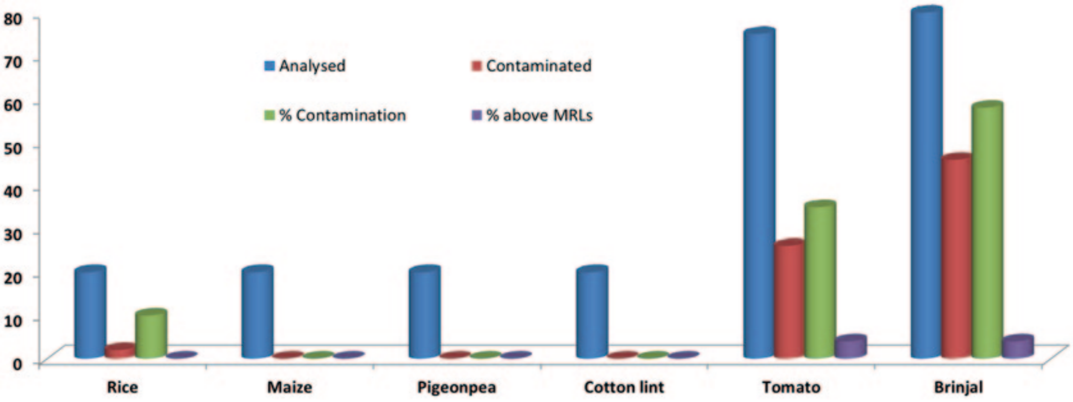

Fig. 6 Percent contaminated samples of various food, fiber, and vegetable crops from Kothapally village during 2008–2010

Soil analysis in five various seasons showed that only 10 and 15 % of the samples collected from brinjal fields were contaminated in Kothapally and Enkepally, respectively; and none of the water samples collected from food crops, cotton, and vegetable crops were contaminated (Fig. 6 and Table 4).

As a result of close interactions with researchers and farmers covering various activities on natural resources and crop improvement, the farmers are familiar and adopting the good agricultural practices. The awareness in farmers on various aspects, particularly efficient use of water, the importance of improved cultivars and plant protection practices has increased substantially and most of the senior farmers are presently at the forefront in spreading the technologies to others.

With the introduction of transgenic cotton in this village during 2005, the adoption presently is 100 %, which has facilitated farmers in reducing the pesticide use; for example, from 20 (while using traditional varieties) to at present 3–4 sprays. Though pesticides are still in use in this village (mostly on vegetables), the farmers are quite aware of the bio-pesticides such as neem, vermiwash, and HNPV; and they strictly follow the need-based application of plant protection options. The data obtained in 2008–2009 on pesticide residues clearly indicated a down word trend in the occurrence of beta endosulfan, monocrotophos and cypermethrin in only 4 % of brinjal and tomato samples. After thorough implementation of IPM, the water samples from various fields in Kothapalli village were found free from residues. This clearly emphasizes the impact of intensive implementation of the IPM in this village during the past one decade (Figs. 4 and 5). This is one example in which there is a remarkable turnaround from a bad situation which was rectified, through a greater level of education followed by adoption of eco- friendly approaches.

Thus, by adopting the IPM strategies in their village (Kothapally), senior farmers including Mr Narayana Reddy, Mr Narsimha Reddy, and Ms Laxmi are very comfortable in sharing their knowledge in the use of BIPM approaches in addressing the environmental and health issues. In this process, now the whole farming community of the village adopted the protective clothing and took the oath that they see no one sprays any plant protection chemicals without a protective gear. At present, this village is a role model for sustainable improvement of natural resources with improved productivity and environment.

The world has long produced enough calories, around 2700 per day per human, more than enough to meet the United Nations projection of a population of nine billion by 2050, up from the current seven billion. There are hungry people not because food is lacking, but because not all of those calories go to feed humans (a third go to feed animals, nearly 5 % are used to produce biofuels, and as much as a third is wasted, all along the food chain, Mark Bittman 2013).

The Way Forward

An adequate support for plant protection research is essential to meet the challenges of producing healthy food from the available land with minimal adverse effect on the environment. Technologies such as developing resistant varieties, enhancing natural enemies, improving the cultural control, judicious use of chemical pesticides and IPM will have a significant role to play in the future. Indeed most operational IPM systems have a relatively simple, yet effective beginning. In this way, even where resources may be quite limited, an effective IPM system can often be developed and adopted to suit the local situations. Biological control of pests through the use of natural enemies is an important component of the IPM strategy due to its environmental soundness and wide acceptability. Interest in biological control of pests in agricultural crops is increasing. Apart from the harm from the chemicals to human health and environment, pesticides can easily disrupt the natural control of pests and diseases by killing their natural enemies. Without these beneficial organisms, farmers become more dependent on the use of pesticides. Without the progress in the recent plant protection research, the hunger and poverty alleviation would have been worst but need to be taken further. This cannot be achieved through the individual research agenda of any one organization; and hence appropriate research partnerships including the international organizations, national institutes, non-governmental agencies and farmers should work together to make the dream of safe food and safe environment true.

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