# Optimization of Chemical Pesticide use in Rice

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## SUMMARY

Pesticide is an indispensible part of modern agriculture. Over the years, new researches from private and public organization are towards developing new molecules or new formulations which are easy to use, economic and environmentally safe. The pesticide poisoning and pollution are two major negative effects of pesticides. Awareness programme should be included to obtain the optimize pesticide use. Proper pest monitoring, protective clothing, application of pesticide at right time at right dose and at right quantity should be integral part of pesticide application. Integrated pesticide resistance management should be included in farm practices and both private and public organization should take active participation in managing the problem. Otherwise, there is a great chance that we may not have any pesticide option left in pest management in near future. Genuine concerns on consumer and environmental safety of pesticide uses should be dealt with scientific findings. Need of the hour is to have a readymade pesticide detection kit at affordable price. Long term pesticide uses and its effect on flora and fauna should be investigated and should be included in cost-benefit ratio calculation.

## 1. INTRODUCTION

In India, around 40 per cent of the total cultivated area is treated with the pesticides. Approximately, 65-70 per cent of the cultivated area treated with pesticides is irrigated. The production of pesticides started in India in 1952 and at present, India is the fourth largest global producer of agrochemicals after the US, Japan and China. These pesticide industries had a value of USD 4.4 billion in financial year 2015 and are expected to grow at 7.5% per annum to reach USD 6.3 billion by financial year 2020 (FICCI report 2016). Approximately 50% of the demand comes from domestic consumers while the rest goes towards exports. Consumption of technical grade pesticides in India had a steady growth over the years (Fig. 1). Andhra Pradesh (including Telangana), Maharashtra and Punjab are top three states contributing to 45% of pesticide consumption in India. Pesticides consumption in India is amongst the lowest in the world at 0.6 kg/ha against ~13 kg/ha in China. Pesticide consumption is biased towards insecticides (60% of the pesticide used is insecticide) in India as against 40% globally. Among the crops, cotton and rice consume 57% of the total pesticide consumption. Rice, a prevalent crop in south-east Asia is attacked by number of pests (Fig. 2) due to favourable climatic conditions. 15-25% potential of rice production is lost due different pests, weeds and diseases (Table 1). It compels farmers to use a major chunk of pesticides to prevent/recover from pest attack. In India, Central Insecticide Board and Registration Committee has recommended 90 pesticides or combination product to tackle wide range of pest problems. Most benefits of pesticides are based only on direct crop returns. Pesticide requirement/demand and import in India is presented in Table 2.

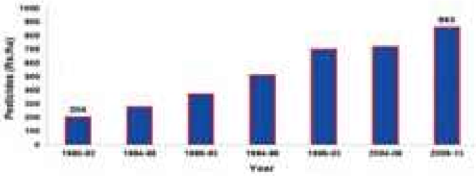
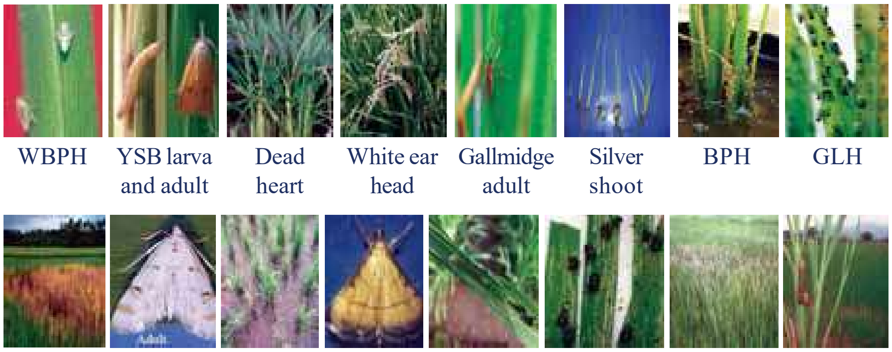


Fig. 1. Pesticide use scenario over the years in value term (The expenditure on pesticide use was Rs.863 at all India level at constant 2013-14 price with highest use in the state of Punjab (Rs.3340/ha) and lowest use in Jharkhand)



WBPH · YSB larva and adult · Dead heart · White ear head · Gallmidge adult · Silver shoot · BPH · GLH

Hopper burn · Case worm · Case worm damage · Leaf folder · Leaf folder damage · Hispa · Hispa damage · Swarming caterpillar

Fig.2. Insect pest in rice and damage symptoms.

**Table 1. Losses due to pest attack.**

| Crop | Actual production (milliontonnes) | Approximate estimated lossin yield Percent | Approximate estimated lossin yield In milliontonnes | Monetary value of estimated losses (millionRs.) |
|---|---|---|---|---|
| Cotton | 44.03 | 30 | 18.9 | 339660 |
| Rice | 96.7 | 25 | 32.2 | 240138 |
| Maize | 19 | 20 | 4.8 | 29450 |
| Sugarcane | 348.2 | 20 | 87.1 | 70667 |
| Mustard | 5.8 | 20 | 1.5 | 26100 |
| Groundnut | 9.2 | 15 | 1.6 | 25165 |
| Other oilseeds | 14.7 | 15 | 2.6 | 35851 |
| Pulses | 14.8 | 15 | 2.6 | 43551 |
| Coarse cereals | 17.9 | 10 | 2.0 | 11933 |
| Wheat | 78.6 | 5 | 4.1 | 41368 |
| Total/Average |  | 17.5 |  | 863884 |

*(Dhaliwal et al.2010)*

**Table 2. Requirement/demand of pesticides and import of pesticides in India.**

| Pesticide demand MT(Tech. Grade) | | | | | |
|---|---|---|---|---|---|
| 2010-11 | 2011-12 | 2012-13 | 2013-14 | 2014-15 provisional | 2015-16 projected |
| 54637 | 58368 | 53882 | 61153 | 64966 | 63154 |
| Pesticide consumption MT(Tech. Grade) | | | | | |
| 55540 | 52979 | 45619 | 60282 | 57353 | - |

*Source: Standing Committee on Agriculture (2015-2016) Sixteenth Lok Sabha Ministry of Agriculture and Farmers Welfare (Department of Agricultural Research and Education) Twenty Ninth Report*

Post harvest losses were estimated from 9 per cent in developed countries to 20 per cent or more in developing countries due to stored product insects. Concepts of "a grain saved is a grain produced" and "hidden harvest" should be an integral part to achieve food security. The most used fumigants are methyl bromide and phosphine. Methyl brome is being phased out by many countries for its ozone-depleting nature. Several reports pointed out that due to repeated use of phosphine led to the development of pest resistance. Lack of new discoveries and strict fumigant registration has added more challenges. There is an urgent need to evaluate and find the most effective dose of fumigant against rice storage pests.

Despite the beneficial effects, there is genuine concern over the use of pesticides and its impact to non-target organisms especially human being. This is because small amounts of pesticide residues may remain in the crops, either resulted from the direct use of pesticides on the crops or environmental contamination. In India problems resulting from unregulated and uncontrolled usage are quite alarming. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields.Runoff and wind may cause non-point pesticide pollution and affecting other species. It is relevant to know the concentration of pesticides presents in different matrices and if there is certain scope to avoid the pesticide contamination.

### *1.1. Objectives*

i. To generate baseline susceptibility data for the newer chemistry molecules against insect pests and diseases.

ii. To study the mechanism of pesticide resistance and management of resistance.

iii. `To investigate long term effect of pesticides on soil flora and fauna

iv. To check pesticide related food and environmental safety issues

## 2. STATUS OF RESEARCH KNOWLEDGE

### *2.1. New molecules and assessing their effectiveness against insect-pests*

Researchers are working tirelessly to develop safer molecules which could undergo photo-degradation, microbial degradation as well as chemical degradation leaving very less amount of residues in the environment. Accordingly, many conventional pesticides have been replaced by newer insecticides. These new group of insect control insecticides includes neonicotinoids, spinosyns, avermectins, oxadiazines, IGR's, fiproles, pyrroles, pyridine azomethine, ketoenols and benzenedicarboxamides. Most of these groups of pesticides play an important role in managing many arthropod pests with good bioefficacy, high selectivity and low mammalian toxicity, which make them attractive replacement for synthetic organic pesticides. These novel groups of pesticides are likely to play an important role in IPM programme in future. Classification and mode of action of new chemistry insecticides is presented in Table3.

**Table 3.Classification and mode of action of new chemistry insecticides as per IRAC (Insecticide Resistance Action Committee) (IRAC2015).**

| Chemical class | Active ingredients | Mode of action |
|---|---|---|
| Avermectins, milbemycins | Abamectin, Emamectin benzoate, Lepimectin, Milbemectin | Glutamate-gated chloride channel allosteric modulators |
| Spinosyns | Spinetoram, Spinosad | Nicotinic acetylcholine receptor allosteric modulators |
| Diamides | Chlorantraniliprole, Cyantraniliprole,Flubendiamide | Ryanodine receptor modulators |
| Formamidines | Amitraz | Octopamine receptor agonists |
| Neonicotinoides | Acetamiprid, Clothianidin, Dinotefuran, Imidacloprid, Nitenpyram, Thiacloprid, Thiamethoxam | Nicotinic acetylcholine receptor competitive modulators |
| Oxadiazines | Indoxacarb | Voltage-dependent sodium channel blockers |
| Phenyl pyrazoles | Ethiprole, Fipronil | GABA-gated chloride channel blockers |
| Pyridine azomethines | Pymetrozine, Pyrifluquinazon | Chordotonal organ TRPV channel modulators |
| Tetronic and tetramic acid derivatives | Spirodiclofen, Spiromesifen, Spirotetramat | Inhibitors of acetyl CoA carboxylase |

Pesticide mixtures may be more effective against various life stages of arthropod pests The primary benefits of mixed pesticide formulations are decreasing labour cost by reduction of rounds of application, higher mortality of different groups of arthropod pests having separate and distinct feeding habits and delaying resistance development against a particular pesticide by various pests. Additive or synergistic effects of insecticides in mixture with botanicals can be obtained to control insect pests (Table 4). Efficacy of insecticides as seedling root dip for YSB in dry season rice has been worked out as effective and low cost technology (Jena 2004). Chemical control of YSB has also been worked out, particularly, the oviposition deterrent activity. Thus the evolution of materials continued with new chemical families discovered and utilization of them in different formations will offer increased pest protection, reduced persistence and less polution. Pesticide tested at ICAR-NRRI against insect pest are presented in Table5.

**Table 4.Status of insecticide mixtures in controlling insect pests.**

| Pests | Chemicals | Authors |
|---|---|---|
| *Nilaparvatalugens* (Brown planthopper) | Buprofezin 23.1% + fipronil3.85% SC | Chakraborty et al. 2017 |
| Yellow stem borer | Lowest per cent of dead heart recorded in tricyclazole + chlorpyriphos combination and white ear in azoxystrobin + chlorpyriphos combination | Neelakanth et al. 2017 |
| Yellow stem borer | Least per cent of dead heart (1.7%) in application of tricyclazole + fipronil | Prasannakumar et al. 2011 |

**Table 5. Pesticides tested at ICAR-NRRI.**

| Pests | Chemicals | Authors |
|---|---|---|
| Hispa,leaf folder and yellow stem borer | Phorate, carbofuran, beta cyfluthrin, thiacloprid, phosphamidon, monocrotophos | Rath 2002 |
| Termite, yellow stem borer and Gundhi bug | Carbofuran, fenvalerate | Rath 2005 |
| Termite, yellow stem borer and gundhibug | Pyriphos,cypermethrin, phosphamidon, monocrotophos, thiamethoxam, imidacloprid, endosulfan, carbofuran and phorate | Rath 2006 |
| Yellow stem borer and gundhibug | Flubendiamide + buprofezin, monocrotophos, acephate, flubendiamide,dinotefuron,buprofezin | Rath 2011; Rath 2012 |
| Yellow stem borer and gundhibug | Carbofuran,phorate,cartap,chlorpyriphos and monocrotophos | Rath 2013; Rath 2014 |
| Yellow stem borer and gundhibug | Sulfoxaflor,acaphate, dinotefuron, thiamethoxam, triazophos, buprofezin, imidacloprid and monocrotophos | Rath et al. 2014;<br>Rath et al . 2015 |
| Rice hispa, BPH, ear cutting caterpillar, leaf folder and gundhi bug | Imidacloprid, bifenthrin, thiamothoxam, indoxacarb | Jena and Dani 2011;<br>Jena et al. 2000 |
| Yellow stem borer | Chlorantraniliprole | Jena et al 2001 |

## 3. NEW MOLECULES AND ASSESSING THEIR EFFECTIVENESS AGAINST DISEASES

Rice diseases cause crop losses about 12.2% of the attainable yield. A wide range of rice diseases affect rice, like blast, sheath blight, bacterial blight, brown spot, false smut and several virus diseases, including rice tungro, are of primary concern. As the major rice diseases are caused by fungus, fungicides are important tool to control rice diseases.Globally 8.4% of fungicides market share is for rice.The rice fungicides can be broadly classified in two categories viz., seed treating and foliar fungicides. Seed treating fungicides have narrow to moderate spectrum of control. Major advantage of seed treating fungicides is its high level of control at low dose and with low residue. Tricyclazole at 0.2g/kg of seed effectively controlled leaf blast. Foliar fungicides are highly effective in managing foliar diseases and those are grouped as per their mode of action and chemical class.(a) Melanin biosynthesis inhibitors are highly effective against rice blast disease; prevent melanin biosynthesis in appressoria of *P. oryzae* and penetration to rice plants forming appressoria (e.g. tricyclazole, pyroquilon, chlobenthiazone etc.) or scytalonedehydratase enzymes (carpropamid, dichlocymetetc.).(b) Benzimidazole group fungicide (e.g. carbendazim, thiophanate, thiabendazole etc.) was introduced during 1960s and early 1970s are single site inhibitors of fungal microtubule assembly during mitosis, via tubulin-benzimidazole-interactions. (c) Triazole fungicides (e.g. propiconazole, tebuconazole, hexaconazole, difenconazole etc.), the largest class are highly systemic with mobility through xylem and are known to have broad spectrum activity against major diseases like sheath blight, sheath rot, grain discoloration etc. (d) MET II inhibitors (eg. thifluzamide and flutalonil etc.) inhibit succinate dehydrogenase in fungi and highly effective against sheath blight. These fungicides are systemic (Xylem mobile) and have good residue. (e) Strobilurins, first synthetic group fungicides originally derived from mushroom fungi, called Strobilurustenacellus. These fungicides are referred to as QoI fungicides (Vincelli2002). Some of the other commonly used strobilurins against rice diseases are fenamidone, kresoxim methyl, pyraclostrobin and trifloxystrobin either as stand-alone or mixed with other multi-site inhibitor fungicides or triazoles like propiconazole.

As per Central Insecticide Board, Govt. of India, more than 30 fungicides have been registered for use in rice and several new molecules are under testing. Isoprothiolene and Tricyc1azole 75WP were more effective in controlling the blast disease in nursery in comparision to Isoprothiolene, Tricyclazole, Edifenphos, Hexaconazole and Mancozeb as seed treatment.In rice, strobilurin fungicide trifloxystrobin in combination with tebuconazole are used against blast, sheath blight and other foliar diseases (Bag et al. 2016). Tricyclazole and isoprothiolane are found highly effective resulting in 87.9 and 83.8% reduction in neck blast and 33.8 and 29.9% increase in grain yield over check, respectively (Sachin and Rana 2011).

Optimum rate of azoxystrobin @ 125 g/ha are highly effective. Biswas and Bag (2010) reported new QoI fungicides Kresoxim methyl, azoxystrobin, metaminostrobinand trifloxystrobinand combinations with other groups were highly effective against sheath blight of rice. Copper hydroxide fungicides reduced false smut balls in harvested rice by 80% but yield was also often reduced significantly while Bag et al (2010) reported effectiveness of new formulation of copper hydroxide. Application of Metaminostrobin 20% SC + hexaconazole 5% SC was effective against leaf blast and neck blast. Different pesticide tested against rice diseases are presented in Table 6.

**Table 6. Literature on efficacy of fungicides in managing rice diseases.**

| S.No. | Diseases | Fungicides | References |
|---|---|---|---|
| 1 | Blast | Tricyclazole and Isoprothiolane | Sachin and Rana (2011) |
| | | Kresoxim methyl,metaminostrobin and trifloxystrobin | PrasannaKumar et al. (2011) |
| | | Tricyclazole and azoxystrobin | Kunova et al. 2013 |
| | | Tetrachlorophthalide 30 WP, tebuconazole + trifloxystobin and difenoconazole | Ghazanfaret al. 2009 |
| | | Azoxystrobin and kresoximmethyl | Chen et al.2015 |
| | | Propiconazole | Fang et al. 2009 |
| 2 | Sheath blight | Azoxystrobin and propiconazole | Parsons et al.2009 |
| | | Kresoxim methyl,metaminostrobin and trifloxystrobin | PrasannaKumar et al.2011 |
| | | Thifluzamide | PrasannaKumar et. al. 2012 |
| | | Trifloxystrobin 25% + tebuconazole50% | Bag2009 |
| 3 | Brown spot | Captan 70% + hexaconazole5% WP @ 0.2% | Kiranand Prasanna 2011 |
| 4 | False smut | Zineb and thiophanatemethyl | Kannahi et al. 2016 |
| | | Trifloxistrobin + tebuconazole | Raji et al. 2016 |
| | | Copper hydroxide | Bag et al. 2010 |
| 5 | Bakanae/ Foot rot | Carbendazim | Bagga et al. 2006 |
| 6 | Seedling blight | Carbendazim 12% + mancozeb63%, trifloxystrobin50% + tebuconazole25%. | Raghu et al. 2017 |

## 4. PESTICIDE RESISTANCE-IT CAUSES, HOW TO OVERCOME IT

Pesticide resistance is a reduction in the ability of an insecticide in achieving the desired control. This is reflected in repeated failure of a pesticide expected level of control of pests when used according to the product label recommendations. When a pesticide is first used, a small proportion of the pest population may survive exposure to the material due to their distinct genetic makeup. These individuals pass along the genes for resistance to the next generation. Subsequent uses of the pesticide increase the proportion of less-susceptible individuals in the population. Through this process of selection, the population gradually develops resistance to the pesticide. It may be behavioral, penetration,metabolic or/and altered target-site resistance.In addition, failure to adhere to good farming practice such as crop rotation and cleaning of farm equipment, which helps prevent the spread of pest seeds and spores, can exacerbate the spread of resistance. Fungicides having single site action are more prone to develop resistant mechanisms in the pathogen compared to those having multi cite action. Status of insecticide resistance in India and world is given in Table 7.Thus, industry has given emphasis in the research particularly areas of mode of action, resistance risk, field monitoring for baseline sensitivity and sensitivity variations in treated fields.

**Table 7.Status of insecticide resistance in India and world.**

| S. No. | Resistance status | Authors |
|---|---|---|
| 1 | In China field-collected populations of *Nilaparvatalugens* had developed high levels of resistance to imidacloprid (resistant ratio, RR = 233.3–2029-fold) and buprofezin (RR = 147.0–1222). Furthermore, *N. lugens* showed moderate to high levels of resistance to thiamethoxam (RR = 25.9–159.2) and low to moderate levels of resistance to dinotefuran (RR = 6.4–29.1), clothianidin (RR = 6.1–33.6), ethiprole (RR = 11.5–71.8), isoprocarb (RR = 17.1–70.2), and chlorpyrifos (RR = 7.4–30.7). | Zhang et al. 2016 |
| 2 | Most strains of *N. lugens* (except FQ15) collected in 2015 had developed moderate resistance to dinotefuran, with resistance ratios (RR) ranging from 23.1 to 100.0 folds. | Mu et al. 2016 |
| 3 | Field populations collected from different locations of Karnataka (Gangavati, Kathalagere, Kollegala, Soraba and Mandya) were studied for their susceptibility or resistance to the insecticides and found that the populations from Gangavati, Kathalagere and Kollegala exhibited higher resistance to some of the old insecticides and low resistance to new molecules. | Basanth et al. 2013 |
| 4 | Brown plant hopper population collected from east Godavari district of Andhra Pradesh exhibited 5- to 35-fold resistance to neonicotinoid insecticides like imidacloprid, thiamethoxam and clothianidin. | Krishnaiah et al. 2006 |
| 5 | Moderate levels of resistance were detected in the field populations to acephate, thiamethoxam and buprofezin (resistance factors 1.05–20.92 fold, 4.52–14.99 fold, and 1.00–18.09 fold, respectively) | Malathi et al. 2017 |

### *4.1. Major factors that influence resistance development*

- Continued and frequent use of one pesticide or closely related pesticides on a insect pest population
- Use of application rates that are below or above those recommended on the label
- Poor coverage of the area being treated
- Frequent treatment of organisms with large populations and short generation times
- Failure to incorporate non-pesticidal control practices when possible
- Simultaneous treatment of larval and adult stages with single or related compounds.

### *4.2. Steps to be taken to overcome it*

The best strategy to avoid insecticide resistance is prevention. More and more pest management specialists recommend insecticide resistance management programs as one part of a larger integrated pest management (IPM) approach. Monitoring is one of the key activities in the implementation of an insecticide resistance management strategy. Monitoring insect population development in fields to determine when control measures are warranted. Monitor and consider natural enemies when making control decisions in some cases. Insecticides should be used only if insects are numerous enough to cause economic losses that exceed the cost of the insecticide plus application. It is better to have an integrated approach to managing pests.Use as many different control measures as possible. Avoid broad-spectrum insecticides when a narrow-spectrum or more specific insecticide will work. Apply insecticides when the pests are most vulnerable. Use application rates and intervals recommended by the manufacturer Thus in nutshell the successful management of insecticide resistance requires monitoring the levels of resistance and understanding the mechanisms involved. Such studies are necessary to enhance the control efficiency by alternating appropriate insecticides.

## 5. UNDERSTANDING ROLE OF PHOSPHINE IN RICE STORAGE PESTS MANAGEMENT

Phosphine has been in commercial use as a grain fumigant since the mid 1950s. However, Phosphine (from aluminium phosphide tablet and powder formulations) is the only fumigant used for grain protection in India since 1970s. More recently its use has expanded due to the phase-out of methyl bromide as they create ozone depletion. Multiple phosphine applications (every 3 months during a storage period of 1 to 3 years) of grain stacks are common. Inadequacies in current fumigations such as use of substandard gas proof sheets and sand stacks, shorter exposure periods (3 to 5 days), failure to measure gas levels, and poor maintenance of gas concentrations during exposure period are major constraints of successful fumigation.

Phosphine fumigation is an effective method of eliminating insects in stored commodities in many countries worldwide. It should be noted that there is little to be gained by extending the exposure period if the structure to be fumigated has not been carefully sealed and insects are not subjected to lethal concentration of phosphine. It has been found that as regards technical performance, Quickphos (phosphine source), when applied either in single or double dosage, exhibited in the control of stored-product insects such as *Rhyzopertha dominica*, *Sitophilus* spp., and *Tribolium castaneum,* yielding 100% mortality.Toxic hydrides produce by phosphine cause changes to cellular and organismal physiology, including disruption of the sympathetic nervous system, suppressed energy metabolism and toxic changes to the redox state of the cell. It was recommended that at 1.0, 0.3, and 0.2 mg $l^{-1}$ complete control can be expected in 5, 10 and 14 days, respectively for field trial and eventual registration.

The main disadvantages of phosphine fumigant are that the treatment confers no residual protection against re-infestation, once the commodity is again exposed, and the fact that the most effective fumigants are all highly toxic to humans and other non-target organisms. There is no doubt that good fumigation practices also prevent insect survival, which is assumed as preventing further insect resistance. Phosphine resistance in grain beetle pests particularly in *Rhyzopertha dominica*, *Tribolium castaneum, Cryptolestes* spp., has been elaborated. To prevent the development of resistance, it is essential to avoid applications with sub-lethal doses. Depending on fumigation circumstances, in particular low temperature and poor gas-tightness of the container, it is important to use longer exposure to achieve pest mortality in all parts of the fumigated commodities.In addition it is necessary to achieve a minimum of 500 ppm for the control of normal insects and at least 1000 ppm when phosphine-resistant insects are present as target end concentrations.

## 6. EFFECT OF PESTICIDES ON SOIL MICRO FLORA AND FAUNA

In the present situation, pesticides application in agriculture becomes a necessary evil which resulted in contamination of aquatic and soil ecosystems and thus affected the microbial community inhabit of those ecosystems. Microbial communities are one of the key drivers of assessing soil health and therefore for the advancement of sustainable agriculture a proper understanding is to be required to visualize the changes of soil microflora change under influence of chemical pesticides. Application of higher dose of chemicals and fertilizers in agriculture actually warrants us to know the real effect on soil microflora, but complete data are not available to justify the actual impact of these on soil microbial communities. Besides, there are still multiple issues which need to be addressed to estimate the effect of pesticides on microbial communities in the soil in the future, and to make a broadly accepted agenda for risk assessment in agro-ecosystems that include microbial indicators.

According to guidelines for the approval of pesticides, carbon or nitrogen mineralization is the most important functional parameters to judge the side-effects of pesticides on soil microorganisms under any systems (Kumar et al. 2017a). Some microbial groups use applied pesticides as a source of energy and nutrients, whereas other groups may be affected by toxic nature of the pesticides. A variation of soil microbial community under influence of pesticides is a complex phenomenon and thus provides an insight of two important implications of microbial diversity. Firstly, a decrease in diversity must have resulted in the risk of alteration of their biological response in a particular system. Secondly, alteration of microbial diversity itself provides information about the intensity of such stressed ecosystem. Therefore, it is necessary to be examined the non-target effect of pesticide on soil microflora and its diversity under a particular system. Thus, we need to have a wider method to enumerate soil microflora under pesticide exposure, and usage of latest molecular tools such as qPCR and metagenome for better understanding the abundance and diversity of soil microbial community under influence of long-term exposure of pesticides in agricultural crops including rice.

In the past, a different array of cultivation-dependent and independent methods were used to analyze the effects of pesticide exposure on soil microflora in the different ecosystem, however, under rice soils, it has been nominally investigated (Kumar et al.2017b; Kumar et al. 2017c). Among all pesticides, 82% of the data refer to insecticides and on an average, pesticide exposure resulted in the increased and decreased of bacterial population by 17% and 25%, respectively, whereas, 58% of the cases no significant change was noticed. The same trend continued to the actinomycetes population, whereas results indicated that fungal groups were found to be most sensitive to pesticides. Some reports also indicated that among the different groups, nitrogen mineralization bacteria (ammonium oxidizers, denitrifiers, and nitrite oxidizers) were seemed to be the negatively affected by the continuous application of chlorpyrifos (insecticide) (Kumar et al. 2017a), while other bacteria were relatively less frequently inhibited. The absence of inhibitory effect on populations of diazotrophs is in agreement with a very low record of negative effects of pesticide application on nitrogen fixation in soil (Table 8).

**Table 8. Summarization of the data from published reports on the effects of pesticides on microflora and microbial activities in wetland rice fields (Source: Dey 2012).**

| Population/Activity | Pesticide tested* | | | Effect** | | |
|---|---|---|---|---|---|---|
| MICROBIAL POPULATIONS | F | H | I | - | = | + |
| Actinomycetes | 0 | 5 | 26 | 4 | 19 | 7 |
| Fungi | 0 | 1 | 25 | 7 | 18 | 1 |
| Bacteria | | | | | | |
| Total bacteria in soil | 0 | 5 | 15 | 4 | 13 | 3 |
| Total bacteria in Phyllosphere | 0 | 0 | 7 | 0 | 7 | 0 |
| Total bacteria in rhizosphere | 0 | 0 | 7 | 0 | 7 | 0 |
| N cycle other than BNF | 0 | 9 | 5 | 6 | 3 | 5 |
| $N_2$-fixing bacteria | 0 | 1 | 20 | 1 | 15 | 6 |
| Various Physiological groups | 0 | 5 | 5 | 1 | 2 | 7 |
| Miscellaneous groups | 0 | 2 | 4 | 3 | 3 | 1 |
| Total of Bacterial counts | 0 | 22 | 63 | 15 | 50 | 22 |
| SoilProperties(N,P,Kavailability) | 3 | 7 | 0 | 1 | 0 | 8 |
| Specific Enzymatic Activities | | | | | | |
| Amylase | 0 | 1 | 8 | 0 | 8 | 1 |
| Cellulase | 0 | 0 | 8 | 0 | 8 | 0 |
| Dehydrogenase | 1 | 4 | 3 | 0 | 6 | 3 |
| Dextranase | 0 | 0 | 7 | 0 | 7 | 0 |
| Invertase | 0 | 1 | 14 | 0 | 15 | 0 |
| Phosphatase | 0 | 0 | 13 | 0 | 13 | 0 |
| Urease | 0 | 4 | 1 | 0 | 4 | 1 |
| â-glucosidase | 0 | 0 | 13 | 4 | 9 | 0 |
| Others | 0 | 0 | 2 | 0 | 2 | 0 |
| Total of enzymatic activities | 1 | 10 | 69 | 4 | 72 | 5 |

*Contd....*

| Population/Activity | Pesticide tested* | | | Effect** | | |
|---|---|---|---|---|---|---|
| MICROBIAL POPULATIONS | F | H | I | - | = | + |
| Microbiological activities | | | | | | |
| $O_2$ uptake or $CO_2$ Production | 0 | 5 | 2 | 2 | 1 | 3 |
| OMdecomposition/mineralization | 1 | 2 | 1 | 0 | 4 | 0 |
| Nitrification | 2 | 6 | 15 | 14 | 6 | 2 |
| Denitrification | 9 | 9 | 12 | 4 | 16 | 0 |
| $N_2$-fixation (soil) | 8 | 9 | 24 | 1 | 3 | 28 |
| $N_2$-fixation (rhizosphere) | 0 | 0 | 32 | 13 | 10 | 9 |
| Total microbiological activities | 20 | 31 | 86 | 34 | 40 | 42 |
| Grand total | 24 | 76 | 269 | 65 | 199 | 85 |

I: insecticide; H: herbicide; F: fungicide; *Summary per microbiological groups and microbial activities; ** - inhibition, =: no effect, +: enhancement

## 7. EFFECT OF CHEMICALS ON THE ABUNDANCE AND DIVERSITY OF SOIL ARTHROPODS IN RICE ECOSYSTEM

Though not apparent to the naked eye, soil is actually one of the most diverse and species rich habitats of the terrestrial ecosystem. The total number of described species on earth (1,500,000) and 23 per cent are soil animals. Historically, most of the efforts on biodiversity studies focused, especially on above ground plant and animal species. However, the below ground biota supports much greater diversity of organisms than does the above ground biota. The under agro-ecosystem, earthworms were the most dominant organism in terms of biomass, while in terms of numbers, ants and termites predominated.External agricultural inputs such as mineral fertilizers, organic amendments, herbicides, fungicides and pesticides are applied with the ultimate goal of maximizing productivity and economic returns, while side effects on soil organisms are often neglected. Pesticides and fertilizers are integral part of agriculture and studies related to their impact are well documented. Pesticides like Aldrin and DDT, metal pollutants, Zn have adverse impact on soil fauna. Chlorpyriphos application adversely affected beneficial arthropods like non-Sminthurid Collembolans, ants, spiders and parasitic hymenoptera. Fertilizer application, pre emergence and post emergence herbicides had some negative impact on the faunal activity. In Kentucky blue grass turf, chlorpyriphos and isofenphos had the greatest impact on predacious arthropods.

## 8. PESTICIDES RESIDUES IN SOIL-PLANT-WATER SYSTEM

Upon application, pesticides undergo a very complex series of events. It may reach to target site to kill the organisms or it may be transported into environmental matrices through the air or water. Sometimes it may reach into the ground. Distribution of pesticides depends on its nature and pertaining environment. It has been observed that there is a significant knowledge gap about movement of pesticide and its fate in the environment. Proper pesticide residue analysis across the globe in a network will help to minimize the pesticide pollution. Every steps to be taken to release minimum quantity of pesticides to save our environment.

Despite the health risks from pesticides, farmers believe it is indispensable for higher production. It has been observed at farm level improper use of pesticides has further contributed to the environmental and health problems resulting from pesticides. Improper uses may be in the form high dosages, use of non-recommended pesticides, inadequate pre-harvest intervals and cocktailing of pesticides. Untrained pesticide shopkeepers play a critical role for improper and more use of pesticides. Most of developing countries are unsuccessful to regulate the pesticide use and its market despite its stringent laws.

Pesticides sprayed in field have a less chance to be quantified in rice grains. De-husking and milling can remove residues at various extent as pesticides are mostly contained in outer layer of grain i.e. bran. Pesticides are lipophilic in nature and there is a greater chance they are contained in rice bran. There are very few pesticides can translocate into the flour. But during grain storage, rice is invariably sprayed with insecticides to reduce losses. This leads to pesticide contamination in food. In rice ecosystem, large amount of standing water creates the probable problems of pesticides contamination in ground and surface water. Leaching or runoff depends not only on soil properties (clay content, organic matter content etc.) but also on pesticides properties like solubility, residual half-life, etc. However, to maximize the benefits of pesticide use at minimum human, environmental and economic cost, pesticides must be strictly regulated and used judiciously by properly trained and appropriately equipped personnel, ideally in tight integration with other complementary technologies.

Continuous application of chlorpyrifos for 7 years did not affect most of soil microbiota except nitrogen mineralizing microflora (Kumar et al. 2017a). Chlorpyriphos degradation was faster under elevated $CO_2$ (Adak et al. 2016). Changes in microbial diversity indices confirmed that imidacloprid application significantly affected distribution of microbes. The extent of negative effect of imidacloprid depends on dose and exposure time (Mahapatra et al. 2017). Pretilachlor did not harm the soil microbes at field dose but affected at higher dose (Sahoo et al. 2016). In-vitro experiment has been carried out for number of pesticides namely butachlor, bispyribacsodium, chlorantraniliprole, fipronil etc. to check their distribution in different environmental matrices and effects on soil microbes.

## 9. KNOWLEDGE GAPS

In India, work on pesticide resistance and its management have not been given much emphasis compared to developed countries. Recent reports of pesticide resistance should be deeply understood to overcome the problem. Consumers are concerned about the pesticide residue on their food. Simple but exhaustive analytical method should be developed to quantify minimum quantity of pesticides. Short term studies of pesticide poisoning were reported elsewhere. Our study on long term effect of pesticide will provide inputs on structural and functional changes of soil flora and fauna upon pesticide application.

## 10. RESEARCH AND DEVELOPMENT NEEDS

Based on the above observation, generation of baseline information of newer chemicals about their effectiveness and variation in location should be investigated. In addition to that, pesticide mixtures should be tried to overcome the resistance problems. The mechanism of insecticide resistance should be studied for future research. Impact of long-term pesticides on rice insect pests, soil fauna, microbes and AM fungal associations in rice-rice cropping system should be determined. Loads of pesticides in soil- plant- water system should be quantified to make a rice cropping system more sustainable and eco-friendly.

## 11. WAY FORWARD

### 11.1. Managing pesticide resistance

The main purpose of resistance management is to prevent or at least slow down the accumulation of resistant individuals in insect pest populations, so as to preserve the effectiveness of available pesticides. The challenge is to reduce the selection pressure for resistance while providing the necessary level of crop protection. There is unfortunately no single resistance management prescription that can be applied globally to all pesticides, insect pests and crops. Nor is resistance solely a technical problem that can be readily overcome with the right new pesticide with a new mode of action, or an adjustment in the way conventional pesticides are used. Managing resistance requires: first, the use of rational pest control strategies based on the principles of integrated pest management, which reduce pesticide use and hence the selection pressure for resistance; and second, the implementation of a comprehensive and tailor-made Resistance Management Plan (RMP) that is adapted to the pest, the crop and the region.

### 11.2. Alternative of phosphine fumigations

Alternative to phosphine such as ethylformate, sulfurylfluoride and $CO_2$-rich atmosphere have been studied both at laboratory and field levels and efficacy proven. However, these have not been used yet for grain preservation in India. Several plant compounds have been studied but at laboratory level only. Overall, while there is an appreciable change in Indian grain storage system by the use of silo bags substituting CAP storage and by expanding storage capacity by erecting more metal silos across the county, rigorous changes in fumigation of food grains are yet take place.

### 11.3. Cheaper methods to detect pesticide residue

Till date pesticides have been quantified through chromatographic methods coupled to selective detectors, for example, GC-MS, LC-MS-MS. These methods are efficient, sensitive and reliable. Major limitation of these techniques is time-consuming and costly and need trained technicians. Cheap and easy methods which can reliably detect pesticides in different food products into the homes have to be developed. Considerable attention has been given to the development of biosensors for the detection of pesticides as a promising alternative. Ready to use device like Electronic-nose (e-nose) methods should be tested for rapid detection of pesticides. This will be at low cost of detection. Scientists already developed an electronic nose gas-sensing device. It was based on intrinsically conducting polymer (CP)-type. This device could identify eleven insecticides representing eight different classes as well as can discriminate them. Steps have been taken to have in-build library into the e-nose based on electronic vapor signature patterns.

### *11.4. Moving towards greener chemicals and green practices in pesticide usage*

In recent years, neonicotinoids and diamides have been the fastest-growing class of insecticides in modern crop protection, with widespread use against a broad spectrum of sucking and certain chewing pests. This provides room for more innovative technology to be developed in application of newer molecule pesticides. Of such the technologies are 1) Employing pesticides as seed treatment to provide protection to seedlings against insect pests, and 2) Using insecticides mixtures having independent mode of action. Dermacor-X-100® (active ingredient, chlorantraniliprole) seed treatment could be used as a valuable component of integrated pest management program for stem borers in rice. Research for refined use of seed treatments is anticipated. Status of insecticide seed treatment in controlling stem borers is presented in Table 9.

**Table 9. Status of insecticide seed treatment in controlling stem borers**

| Pests | Chemicals | Authors |
|---|---|---|
| *Chilopartellus* and *Sesamiainferens* | Chlorpyriphos 20 EC (Seed treatment-ST + Foliar spray-FS) was found best among all the treatments | Hedge et al. 2017 |
| Stem borer complex in rice in Texas (*Eoreumaloftini* and *D. saccharalis*) | Dermacor-X-100® (0.1 mg a.i per seed) seed treatment provided complete control. | Way et al. 2009 |
| *Chilopartellus* | Seed treatment with Spinosad 45%SC spray @ 200ml/ha | Vishvendra et al. 2017 |

## 12. CONCLUSIONS

Proper pest monitoring, protective clothing, application of appropriate pesticide at right time at right dose and target species should be integral part of pesticide application. Genuine concerns on consumer and environmental safety of pesticide uses should be dealt with scientific findings. Need of the hour is to have a readymade pesticide detection kit at affordable price. Long term pesticide uses and its effect on flora and fauna should be investigated. Mass awareness among end users about optimization of chemical pesticide use in rice is the need of the hour.

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