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Opportunities and Obstacles to Green Chemistry Innovations in Agriculture

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Abstract

During the last half century, the use of chemical pesticides and fertilizers dominated agricultural practice and manufacturing industries rapidly expanded their use of synthetic chemicals in the production of consumer and industrial goods. Adverse effects of chemical pesticides and fertilizers have been reported on both the abiotic and biotic components of the environment. The farmer are exemplified by residues in soil, air, water food etc. and the latter by phytotoxicity, residues, vegetation changes in plants and physiological deformities, diseases, mortality, population changes, genetic disorders etc In mammals, avian insects and other organisms. To escape from these harmful effects the concept of organic farming was emerged from the conference of authentic in 1981. Providing everyone with healthy food without harming environment will become increasingly challenging. Sustainable food production is a critical component to meeting the demands and challenges faced by agriculture worldwide Organic farming seeks to achieve three goals farm profitability, community prosperity and environmental stewardship. Fortunately there are many alternatives to chemical farming. Organic farming encompasses a wide variety of farming techniques and practitioners. The success of green chemistry depends on the training and education of a new generation of chemists. There are many unknowns in the details of how such an organic farming system would work, what inputs would supply it and what technologies to employ in the transition. The paper deals with the use of different types of bio-pesticides, bio fertilizers, genetically modified crops, types of environmental friendly farming, biological control on agriculture, biological catalysts. What are the opportunities and obstacles to green chemistry innovations in agriculture and what are some strategic suggestions for moving them forward?

Keywords: Sustainable, Organic Farming, Stewardship, Pesticides.

Introduction

Heavy use of synthetic chemicals for pest control started from 1940s. Thereafter Green Revolution Technology of crop production could increase food production in developing countries through the intensive use of inputs like chemical fertilizers and pesticides. After twenty years it was found that the level of synthetic pesticides and fertilizers were not biodegradable and their harmful effects started coming out. Entry of pesticides into the food chain coupled with their bioaccumulation and biomagnifications trigger effects of unforeseen consequences. Chemicals like methyl bromide, chlorofluorocarbon etc. are established culprits for depletion of the ozone layer. It has become important now to develop alternatives of these synthetic agro-inputs. Since the human and environmental safety is a global concern, we need to create awareness among the farmers, manufactures and the common man to switch over to organic agriculture. The paper deals with some methods to prevent use of harmful chemicals in the agriculture.

Use of Bio- fertilizers

Dependence on chemical fertilizers for future agriculture growth would mean further loss in soil quality and possibilities of water contamination. The Govt. of India has been trying to promote an improved practices involving use of bio-fertilizers along with fertilizers. The idea of using micro-organisms to improve land productivity has been around in India for at least 70 years but it was only in the 1990s that large scale production of various bio-fertilizers commenced. The promotion of bio-fertilizers in India is mainly carried out by the National Bio-fertilizer Development Centre (Ghaziabad), which was set up in 1987.

Major Bio-fertilizers and Target crops

Bio fertilizer	Target crops
Rhizobium	*Leguminous* crops (Pulses, oil-seeds, fodder)
Azatobacter	White rice, vegetables
Azospirillum	Rice, sugar cane
Blue green algae (BGA)	Rice
Azolla	Rice
Phosphate solubilising micro organisms (PSMs)	All

Estimated Total Potential Demand of Bio- fertilizer in India

Category of Bio-fertilizer	Amount in million tones
Rhizobium	35,730 mt
Azobacter	162,610 mt
Azospirillum	77,160 mt
BGA	267,510 mt
Phosphate solublizer	275,510 mt
Total	818,730 mt

Source : Abhay Phadke, 2001.

The reasons behind the poor performance of bio-fertilizers in India.

1. As agro-climatic conditions and soil characteristics vary widely, a large range of strains of each bio-fertilizer needs to be isolated for each area. Until strains which can tolerate wide variations in temperature can be identified, the performance of bio-fertilizers will remain uneven.
2. Throughout the process of production and packages extreme care is to be taken to maintain sterile conditions.
3. The storage and application of bio-fertilizers require special facilities and skill, which most producers, shopkeepers and farmers donot possers.
4. Bio-fertilizers of improved quality can be made available in adequate quantity.

Use of Bio-pesticides

Bio-pesticides are certain types of pesticides derived from natural materials as animals, plants, bacteria, fungus, virus and certain minerals or other safe biologically based active ingredient. Benefit of bio pesticides include effective control of insects, plant diseases and weeds as well as human and environment safety.

Types of Bio-pesticide

Bio Chemical pesticides	a. Insect pheromones
	b. Plant Extract & oils
	c. Plant growth regulators
	d. Insect growth regulators
Microbial Pesticides	a. Bacterial Bio-pesticides
	b. Fungal Bio-pesticides
	c. Viral Bio-pesticides

Bio Chemical Pesticides

There are almost 122 bio-chemical pesticide active ingredients registered with the EPA, which include 18 floral attractants, 20 plant growth regulators, 06 insect growth regulators, 19 repellent and 36 pheromones (Stein ward, 2008).

Insect Pheromones

Insect Sex Pheromones are used in pest management. They themselves donot kill a target pest, When used for pest management, two common uses are to attract an insect to a trap containing a lethal pesticides or to disrupt mating, thus confusing the males and decreasing their success at locating a female with which to mate.

Advantage

High species specificity. Relatively low toxicity. Thus maintains an ecological balance by leaving undisturbed population of other insect species and non-target organisms.

Disadvantage

Often must be used in combination with other pest management strategies to achieve the efficacy desired.

The blending of very similar molecules in particular combinations and ratio can be used as mating disruption for several species of insects, predominantly various Toxtix species. The specific mixture of isomers used to control a given species are displayed in the table below.

Sex Pheromones for Tortix species

Insects Species	Scientific Name	Acetate Isomers	Alcohol Isomers
Tea Tortix	*Homona magnanima*	Z	
Blackheaded fireworm	*Rhopobota naevana*	Z	
European corn borer	*Ostrinia nubilalis*	Z and E	
Omnivorous leafroller	*Platynota stultana*	Z and E	Z and E
Tufted apple moth	*Platynota idaeusalis*	E	E
Light brown apple moth	*Epiphyas postvittana*	E	

Plant Extracts and oils

Along with insecticides can also be used as herbicides. Act less directly and specifically. Some botanical extract such as floral essences attract insect to trap, while some directly interrupt the reproductive cycle of insects.

Ex. Cayenne can be used as deterrent. Lemon grass oil, strip the waxy coating of leaves of weeds to cause dehydration, coat the pest causing suffocation, enhance the natural immune system of a crop (systemic acquired resistance)

Pyrethrum

Extract from the species of *Chrysanthemum* is commonly used in organic agriculture yet it can be highly toxic. Pyrethrum quickly paralyze and kill insect, mode of action is similar to that of DDT.

Thymol

Naturally occurring mixture of compounds from the plant *Thymus vulgaris* is used to control the *Varroa mite* a species that is parasitic to bees.

Enzyme Extract

The extract turns on the natural immune system of the crop allowing the crop to protect itself from powdery midew.

(Powdery mildew **–** a group of numerous fungi that thrives under humid conditions). The enzyme extract is effective on a range of vegetable, fruit and fruit tree crops including grapes and cucumber (Ngvyen, 2008)

Plant growth Regulators

Plants produce hormones naturally, while humans apply growth regulators to the plants. Plant growth regulators may be synthetic compounds (eg.IBM and Cycocel) that mimic naturally occurring plant hormones or they may be natural hormones that were extracted from plants tissue (eg. IAA).

Plant growth regulators do not specifically target any type of pest, instead they are used to enhance crop yield, crop shelf life and the appearance of the crop. They do so by affecting flowering, ripening and aging stems and other parts, prevention or promotion of stem elongation, color enhancement of fruit, prevention of leafing and leaf fall and many other functions.

Plant growth regulator (Fishel, 2006)

Class	Function (s)	Practical Uses	Example
Auxins	Shoot elongation	Thin tree fruit, increase rooting and flower formation	Indole-3-butyric acid (IBA)'
Gibberellins	Stimulate cell division and elongation	Increase stalk length, increase flower and fruit size	Gibberellic acid (GA_3)
Cytokinins	Stimulate cell division	Prolonging storage life of flower and vegetables, bud initiation and root growth	Kinetin
Ethylene and Ethylene generators	Ripening	Induce uniform ripening in fruit and vegetables	Ethylene
Growth inhibitors and retardants	Stop growth (inhibitor) or slows growth (retardant)	Promote flower production by shortening internodes (inhibitor); or retards tobacco sucker growth (retardant)	Abscisic acid

Eg. – *California citrus*- A combination of three plant growth regulators is used prior to harvest on *California citrus* crops.

2,4 dichlorophenoxy acetic acid (2,4-D)

Used mainly to delay and reduce unwanted fruit drop.

Gibberellic acid (GA3)

Used to delay over ripening.

Naphthalene acetic acid (NAA)

Used to promote fruit drop of excess fruit

(Thinning to increase the size of the remaining fruit) and to inhibit the growth of suckers on the trunk (Lavati, 2008)

Advantage

Very small concentration can produce major growth changes.

Disadvantage

Might have unintended affects on non target species and ecological balance issues (Lavatt, 2008). Some plant growth regulators are known to be human carcinogens and endocrine disrupters. This category of compound needs much more study by environmental health specialists.

Insect Growth Regulators

Chemical compounds that alter the growth and development of insects. Thus they are specific to the control of insect pests. There are three key types of insect growth regulators.

1. **Juvenile hormone based insecticides**- disrupt immature development and the emergence of an adult.
2. **Precocenes** – interfere with normal function of the glands that produce juvenile hormone, thereby indirectly preventing the emergence of a reproductive adult.
3. **Chitin synthesis inhibiters** – limit the ability of the insect to produce a new exoskeleton after moulting .Thus chitin synthesis inhibiters leave the insect unprotected from the elements and from prey, drastically reducing its chances of survival.

Advantage

They are effective when applied at very minute quantities.

Disadvantage

Not species specific and impact arthropods generally including insect, spiders and crustaceans. Thus can result in large negative impacts on non target species population.

Like plant growth regulators, insect growth regulators need further investigation on environmental health specialists.

Eg. – *Azadirachtin* – Neem and its constituent azadirachtin are considered bio-pesticide. Neem materials can affect insect mites, nematodes, fungi, bacteria and even some viruses. Azadirachtin (limonoids) are effective in insect growth regulatory activitiy, Limonoids does not kill pests but alters the life processing behavior in such a manner that the insect can no longer feed, breed or undergo metamorphosis (Elahi, 2008)

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Some of the plant products registered as bio-pesticides

Plant product used as bio-pesticides	Target Pests
Limonene and Linalool	Fleas, aphids and mites, also kill fire ants, several types of flies, paper wasps and house crickets.
Neem	A variety of sucking and chewing insect.
Rotenone	Leaf feeding insects such as aphids, certain beetles (asparagus beetles, bean leaf beetle, Colorado potato beetle, cucumber beetle, strawberry leaf beetle and others) and caterpillars, as well as fleas and lice on animals.
Ryania	Caterpillars (European corn borer, corn earsworm and others) and thrips.
Sabadilla	Squash bugs, harlequin bugs, thrips, caterpillars, leaf hoppers, and stink bugs.
Pyrethrum/ Pyrethrins	Ants, aphids, roaches, fleas, flies, and ticks.

Microbial pesticides

Microbial pesticides come from naturally occuring or genetically altered bacteria, fungi ,algae, viruses or protozoans. Bacteria bio-pesticides claim about 74% of the market, Fungal bio pesticides about 10%, viral bio-pesticides about 5%, predater bio - pesticides about 8%, other bio - pesticides 3%. (Thakore, 2006) At present there are approximately 73 microbial active ingredient that have been registered by the US EPA.

Some success stories about successfully utilization of bio pesticides and bio control agents in Indian agriculture.

1. Control of diamondback moths by *Bacillus thuringiensis,*
2. Control of mango hoppers and mealy bugs and coffee pod borer by *Beauveria,*
3. Control of *Helicoverpa* on cotton, pigeon pea, and tomato by *Bacillus thuringiensis,*
4. Control of white fly on cotton by neem products,
5. Control of *Helicoverpa* on gram by N.P.V.,
6. Control of sugarcane borers by *Trichogramma* and
7. Control of rots and wilts in various crops by *Trichoderma*-based products.

Biopesticides Registered under Insecticides Act, 1968

S.No.	Name of Bio-pesticides
1	*Bacillus thuringiensis* var. israelensis
2	*Bacillus thuringiensis* var. kurstaki
3	*Bacillus thuringiensis* var. galleriae
4	*Bacillus sphaericus*
5	*Bacillus sphaericus*
6	*Bacillus sphaericus*
7	*Pseudomonas fluoresens*
8	*Beauveria bassiana*
9	NPV of *Helicoverpa armigera*
10	NVP of *Spodoptera litura*
11	Neem based pesticides
12	*Cymbopogan*

Bacterial Biopesticides and their Modes of Action

Example Bacteria	Primary Categories	Target pest (s)	Mode of action
Bacillus thuringiensis (Bt)	Insecticide	Butterfly & Moths *Lepidoptera*	Digestive System
Bacillus subtilis (Bs)	Bactericide	Bacterial & Fungal Pathogens such as *Rhizoctonia, Fusarium, Aspergillus*, and others	Colonizes on Plant root and competes
Pseudomonas fluorescens	Fungicide/ Bactericide	Several Fungal, Viral, and bacterial diseases such as frost forming bacteria	Crowds out and controls the growth of Pathogens

Bacillus thuringiensis

The most widely used microbial pesticides are subspecies and strains of *Bacillus thuringiensis (Bt)*, accounting for approx 90% of the bio-pesticides market (Chattopadhyay & others, 2004).

Fungal bio - pesticides

Fungal bio pesticides can be used to control insect, plant diseases including other fungi or bacteria, nematodes and weeds. The mode of action is varied and depends on both the pesticidel fungus and the target pest.

Fungal Biopesticides and their Modes of Action

Example Fungi	Primary Categories	Target pest (s)	Mode of action
Beauveria bassiana	Insecticide	Foliar feeding insects	White muscadine diasease
Trichoderma viride/harzianum	Fungicide	Soil borne fungal disease	Mycoparasitic
Muscodor albus	Fumigant	Bacteria and soil-borne pests	Releases volatile toxins

Viral bio pesticides

Baculoviruses (Viral bio pesticides) are pathogens that attack insect and other arthropods. The two types of baculovirus differ in the range of target pests as summarized in table.

Baculovirus target pest and mode of action

Virus Type	Primary Categories	Target pest (s)	Mode of action
Nucleopolyhedrosis Virus (NPV)	Insecticide	Species Specific for Species of *Lepidoptera* (88%), *Hymenoptera* (6%), and *Diptera* (5%)	Infect digestive cell in larvae gut
Granulosis Virus (GV)	Insecticide	Species Specific of Lepidoptera	Infect digestive cell in larvae gut

Advantage

Each virus only attacks particular species of insect and they have been shown to have no negative impacts on plants, mammals, birds, fish or non target insect (D` Amico, 2007).

Disadvantage

Baculoviruses include the need for the virus to be ingested, resulting in lower efficacy and their traditionally high cost of production. Histori cally the production of *baculoviruses* has required live hosts (*In vivo* production) making it costly.

Genetically Modified Crops

In the past two decades transgenic technology has been developed to generate insect resistant crops for reducing both yield loss and pesticide utilization. *Bacillus thuringiensis (Bt)* insect resistant crops are one of the most outstanding achievements in plant transgenic technology which have achieved significant success economically and ecologically. The **Bt-Crystal** (Cry) insecticidal protein (**δ endotoxin**) genes are highly selective and represent a class of numerous proteins with insecticidal action on larvae from various orders:

Gene	Toxic for
Cry 1& Cry 2	*Lepidopteron* pests
Cry 2A	*Lepidopteron* pests & *Dipterans* pests
Cry 3	*Coleopteron* pest

Bt-Cry protein is toxic to insects but non toxic to human animals. The first insect-resistant GM-Crops were tobacco produced in 1987. GM crop of japonica rice and indica rice was produced in 1988 and 1990 respactively.

Bt-transgenic plants expressing genes for insect resistance with slight modification

Plant	Gene	Resistance to
Tobacco	Magi[6] Peptide	*Spodoptera frugiperda*
Tobacco	Cryl A	*Helicoverpa zea*
Tomato	Cryl A	Pinworm
Potato	Cryl Ab, Cryl Ac,Cry5	Potato tuber moth
Potato	Cry3A	Colorado potato beetle
Cotton	Cryl 1A	Pink bollworm
Maize	Cryl A	European corn borer
Rice	Cryl Ab	Lepidopteron
Rice (Indica,Minghui 63)	Cry2A	Yellow stem borers
Rice (Indica, Minghui 63)	Cryl Ac, Cry2A, Cry9c	Yellow stem Borers and Asiatic Stem Borer

Conclusion

As environmental safety is a global concern, we need to create awareness among the farmers, manufacturing, government agencies, Policy makers and the common men to switch over to organic farming. Research in production, formulation and delivery may greatly assist in commercialization of bio pesticides, bio fertilizers and transgenic crops. More research is needed towards integrating biological agents into production system, improving capability of developing countries to manufacture and use of organic methods of farming. Developing of bio-pesticides and bio fertilizers industry has to be treated as a strategic, comprehensive and forward looking task. Transgenic crops are an additional tool to supplement conventional pest resistance programs. The increasing concerns of consumers and government on food safety has led growers to explore new environment friendly methods to replace or at least supplement the current chemical based practices.

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