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Review Article

Bioremediation and Biodegradation of Pesticide from Contaminated Soil and Water - A Noval Approach

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A B S T R A C T

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The world population is going to increase in tremendous rate. To feed and clothe this population from exhausted land and fast depleting water resources would be the great concern and challenge to the future generation. Moreover the use of genetically modified crops, hybrid seed, fertilizers and pesticide in the agricultural field is major concern today. Pesticide at present is an indispensable tool to increasing the yield and to protect the economically important crops from pest, insects, fungi, nematode and weeds. There are three primary approaches to bioremediation; biostimulation, bioaugmentation and phytoremediation. Biodegradation of pesticide by bacteria, fungi, algae and other organisms is ecofriendly, most efficient and economical method of detoxification. Another approach is genetically modified microorganism i.e. recombinant strain for degradation would be boon to soil bioremediation processes.

Introduction

Pesticides are a large and varied group of substances that are specifically designed to kill biological organisms including weeds, insects, and rodents. However, the extensive use of pesticides may result into their accumulation in the agricultural produce. Their low biodegradability has classified these chemicals as persistent toxic substances (Tayade *et al.*, 2013). Fungicides, herbicides, insecticides, nematicides, rodenticides, fumigants, disinfectants, wood preservatives, and antifoliants are examples of pesticides (Puget Sound Water Quality Authority (PSWQA), 1991). About one third of the world's agricultural production is lost every year due to pests despite the pesticide consumption which is more than two million tons. In India pests cause crop loss of more than Rs 6000 crores annually, of which 33 per cent is due to weeds, 26 % by diseases, 20 % by insects, 10 % by birds and rodents and the remaining 11% is due to other factors (Rajendran, 2003). Pesticides are also used in industrial, domestic and marine environments. Pesticides are used globally and extensively for the control of pests (Bakiyaraj *et al.*, 2014). The regular monitoring and control of pesticide usage in agriculture is very important because of the risks posed by pesticides on human, animal, plant health and on the environment (Oozbe and Fidan, 2009).

Degradation of water quality

Agricultural, domestic and industrial wastes are the major sources of water pollution. Sewage is the biggest pollutant of fresh water when discharged into rivers. The immediate consequence is drop in the amount of dissolved oxygen and the Biological Oxygen Demand (BOD) reduces. The flora and fauna of the rivers experience change and reduction in number due to death by suffocation. Another source of water pollution is the discharge of hot water from cooling engines in the industries. This increases water temperature and lowers the metabolic rate of organisms. . Excess fertilizer, herbicides and pesticides when washed by rain into rivers causes serious danger to life. Excess phosphorus in fertilizer cause serious eutrophication (Owa, 2014) 98% of the pesticides imported were classified as acutely toxic for fish and crustaceans and 73% for amphibians. Approximately 8.4 kg of a.i. were imported per hectare of protected areas and 24.3 kg of a.i. per hectare of wetlands (Elba *et al*., 2014). Water pollution causes approximately 14,000 deaths per day, mostly due to contamination of drinking water by untreated sewage in developing countries. An estimated 700 million Indians have no access to a proper toilet, and 1,000 Indians children's die of diarrhea every day and so many other countries too. Nearly 500 million Chinese lack access of safe drinking water (Owa, 2014).

Degradation of soil quality

Waste can be classified into four types: agricultural, industrial, municipal and nuclear waste. Agricultural wastes include a wide range of organic materials, animal wastes, and timber by-products. Many of these, such as plant residues and livestock manure, are very beneficial if they are returned to the soil. However, improper handling and disposal may cause pollution. Industrial waste products may be in gas, liquid or solid form. The most important gases are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Food processing plants produce both liquid and solid wastes. Another urban waste is municipal garbage. This is made up of materials discarded by homes and industry. It contains paper, plastic and organic materials (Undang Kurnia *et al.*, 2011). Excess heavy metals in the soil originate from atmospheric deposition, sewage irrigation, improper stacking of the industrial solid waste, mining activities, the use of pesticides and fertilizers (Zhang *et al.*, 2011). Detrimental effects of contaminants on soil micro biota may be directly related to loss of biodiversity and functions such as the recycling of nutrients. However, this direct negative effect is still debated among microbial ecologists because microbial communities may be surprisingly resilient (i.e. able to recover from contamination effects) and/or functionally redundant (Valentı´n *et al*., 2013). Microbial activity is inhibited significantly by Cu, Zn, Pb etc. (Su *et al.*, 2014).

Status of Pesticides in India and World

According to Abhilash and Nandita, 2009 about two million tons of pesticides are consumed per year throughout the world and among the two million tones, 24 % is consumed in USA, 45 %in Europe and 25 % in rest of the world. Among the Asian countries, pesticide consumption is highest in China followed by Korea, Japan and India. The usage of pesticide in India is about 0.5 kg/ha of which major contribution is from organochlorine pesticides. This is due to increased insect pest attack caused mainly by the prevailing warm humid climatic condition (Bhat and Padmaja, 2014). Due to their biological stability and higher degree of lipophilicity in food commodities pesticides pose a significant effect on human and animal health (Tayade *et al.,* 2013) thus their continuous use leads to their accumulation in soil as well as in water (Rajendran, 2003). The main cause of increasing demand of pesticides is the promotion of High Yielding Varieties that marked the green revolution has led to large scale use of chemicals as pesticides (Bag, 2000). Green revolution has led to large scale use of pesticides to promote high yielding varitiesso it is the main cause of increasing demand of pesticides. At present, India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides with an annual production of 90,000 tonnes (Government of India, 2007). India had adopted the environment friendly integrated pest management (IPM) approach for combating pests and diseases as a cardinal principle of its plant protection strategy (Dhanraj et al., 2012).

Pesticides

Organophosphorus (OP) pesticides are a broad-spectrum insecticide used on a wide range of crops including vegetables, fruits, grains and ornamentals. They are designed to kill or repel pests but may be harmful and fatal to other organisms, including humans. Pesticides contribute significantly to cancer mortality (Gilmo Yang et *al.*, 2008). OP pesticides all act by inhibiting the nervous system enzyme acetylcholinesterase (AChE) and as such are termed anticholinesterase insecticides (Laschi *et al.,* 2007). The phosphorylation of AChE and the resultant accumulation of acetylcholine are responsible for the typical symptoms of acute poisoning with OP compounds. In addition to acute health effects, OP compound exposure can result in chronic, long-term neurological effects (Johnstone *et al.,* 2010).

Harmfull effects of pesticides:

Increase in the use of pesticides can result in various health and environmental problems like poisoning of farmers and farm workers, cardiopulmonary, neurological and skin disorders, fetal deformities, miscarriages, lowering the sperm count of applicators, etc. (Bag, 2000). Continuous application of synthetic pesticides has also contributed to the extinction of useful organisms present in the soil. Besides contaminating the environment, including the soil, pesticide residues also affect useful organisms like earth worms, bees, spiders, plants and like to natural decay, which otherwise would have contributed towards preventing harmful pests (Singh *et al.,* 2014). This negative impact of pesticides is mainly due to the high toxicity, stable nature, less soluble active ingredients of pesticide. Among the various pesticides used, much problematic are organochlorine pesticides. (Odukkathil and Vasudevan, 2013).

Among these pesticides, chlororganic compounds, aldrin, heptachlor, endosulphan, DDT, are of deep concern, due to their tendency to accumulate (Das *et al.*, 2003) in living tissues causing serious diseases to human beings. These have detrimental effect on soil flora and fauna (Daisy Bhat and P.Padmaja, 2014). The food we eat today contains a concoction of banned and restricted chemicals like DDT, benzene hexachloride (BHC), aldrin, dieldrin, lindane etc. which result in functional disorder and disease (Rangarajan, 2001).

Bioremediation is a process by which organic wastes are biologically degraded under controlled conditions to an innocuous state, or to levels below concentration limits. In other words It uses naturally occurring bacteria , fungi algae, plants to degrade or detoxify substances hazardous to human health or environment. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health or environment (Murali *et al.*, 2014). This technology includes various naturally occurring mitigation processes i.e. natural attenuation, biostimulation, and bioaugmentation. The hazardous wastes generated from the chemical processes are being treated using physico-chemical and biological methods by the respective industries to meet the prescribed standard as per the Environmental Protection Act, 1986 (Rajesh Sharma *et al.*, 2014). Biodegradation of a compound is often a result of the actions of multiple organisms. When microorganisms are imported to a contaminated site to enhance degradation the process is known as bioaugmentation (Murali *et al.*, 2014). Contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes and thus clean-up of polluted water and land areas. The commonly used biopesticides which are pathogenic for the pest of interest are biofungicides (Trichoderma), bioherbicides (Phytopthora) and bioinsecticides (Bacillus thuringiensis) (Maheshwari *et al*., 2014).

Factors on which Bioremediation depends

The control and optimization of bioremediation processes is a complex system of many factors. These factors include: the existence of a microbial population capable of degrading the pollutants; the environment factors (type of soil, temperature, pH, the presence of oxygen or other electron acceptors, and nutrients). Microbes will adapt and grow at subzero temperatures, as well as extreme heat, desert conditions, in water, with an excess of oxygen, and in anaerobic conditions, with the presence of hazardous compounds or on any waste stream. The rate of biodegradation in soil depends on four variables are as follows:

(i) Availability of pesticide or metabolite to the microorganisms

(ii) Physiological status of the microorganisms

(iii) Survival and/or proliferation of pesticide degrading microorganisms at contaminated site

(iv) Sustainable population of these microorganisms (Dileep K. Singh 2008).

There are three main approaches in dealing with contaminated sites: Identification of the problem, assessment of the nature and degree of the hazard, and the best choice of remedial action. The need to remediate these sites has led to the development of new technologies that emphasize the detoxification and destruction of the contaminants (Kulkarni et al., 2008; Busca *et al.,* 2008) rather than the conventional approach of disposal.

Mechanism of Heavy Metal Decontamination

The metals are required by all life forms even today in minute amounts for normal cell metabolism. The intake of the metals is subject to intricate homeostatic mechanisms that ensure that sufficient, but not excess quantities are acquired. While some metals are useful and selectively acquired by the microbes, many other metals that serve no biological role but cause damage to their avidity for the sulfhydryl groups of proteins need to be avoided. Different organisms exhibit diverse responses to toxic ions. Eukaryotes in particular are more sensitive to metal toxicity than bacteria .and they typically regulate intracellular metal ion concentrations by the expression of metallothioneins (MTs), which is a family of metal chelating proteins. Bacteria also have MTs that are functionally homologous to the MTs of eukaryotes. Prokaryotic MTs have been studied in detail only in the cyanobacterium Synechococcus. In this cyanobacterium they confer resistance to Zn^{2+} and Cd^{2+} However, the use of these MTs only as the main mechanism of tolerance to metals (as in Synechococcus) is rarely seen in bacteria. (Murali and Mehar, 2014)

Bioremediation of pesticide from contaminated soil

The waste generated by the pesticide has become a big problem due to insufficient and ineffective waste treatment technology involving physico-chemical and biological treatment. The data indicates that pesticide residues remain in surface soil, leading to toxicity in the soil-water environment. Commonly used pesticides namely chlorpyrifos, cypermethrin, fenvalerate, and trichlopyr butoxyethyl (Fulekar and Geetha, 2008). Bioremediation is advantageous due to capability of microbes and some plants for detoxification of the environmental pollutants. Microbes which were commonly reported in pesticides bioremediation include *Pseudomonas sp., Bacillus sp, Klebsiella sp, Pandoraea sp, Phanerochaete Chrysosporium, Mycobacterium* sp. The pesticide thus transformed or degraded by the microorganism is used as a carbon source, nitrogen source, any other mineral source or a final electron acceptor in respiratory chain .For example *Achromobacter xylosoxidans* strain CS5 was able to utilize both endosulfan and endosulfan sulfate as sulfur as well as carbon source and energy source resulting in complete mineralization of endosulfan via hydrolytic pathway (Wen *et al.,* 2009).

Role of fungi: Fungi degrade pesticides by introducing minor structural changes to the pesticides rendering it non toxic and are released to soil, where it is susceptible to further biodegradation by bacteria (Gianfreda and Rao, 2004). Several fungi such as *Agrocybe semiorbicularis, Auricularia auricula, Coriolus versicolor, Dichomitus squalens, Flammulina velupites, Hypholoma fasciculare, Pleurotus ostreatus, Stereum hirsutum, and Avatha discolor* have shown their ability to degrade various pesticide groups like phenylamide, triazine, phenylurea, dicarboximide, chlorinated and organophosphorus compounds (Bending *et al.,* 2002). According to Quintero *et al.*, 2007 Several classes of pesticides such as lindane, atrazine, diuron, terbuthylazine, metalaxyl, DDT, gamma-hexachlorocyclohexane (g-HCH), dieldrin, aldrin, heptachlor, chlordane, lindane, mirex, etc. have been degraded to different extent by white-rot fungi. Fungi isolated from oil spill environment can reduce oil pollution (Das and Chandran, 2011).

Role of bacteria: Most bacterial species which degrade pesticides belong to the genera *Flavobacterium, Arthrobacter, Azotobacter, Burkholderia and Pseudomonas*. The nature of degradation varies among species and the target compound. *Pseudomonas sp. and Klebsiella pneumoniae* have been shown to possess hydrolytic enzymes that are capable of breaking down s-triazine herbicides, such as atrazine. Similarly, a number of enzymes such as oxygenases, hydroxylases, hydrolases and isomerases present in *Pseudomonas* and *Alcaligenes* sp. have been shown to degrade herbicide 2, 4-D (Mulbry and Kearney, 1991). In soil environment, due to the limiting environmental conditions, and nature of the pesticides, most of the pesticides undergo partial degradation leading to the formation and accumulation of metabolites in the soil system. These metabolites are sometimes more toxic and less soluble than the parent compound which may inhibit the microbial population in the soil and further reduce the degradation of the pesticide resulting in the partial degradation of the pesticide. For example, degradation of endosulfan in soil by fungi and bacteria follows such a pathway via oxidation and hydrolysis leading to the formation of toxic endosulfan sulfate and less toxic endosulfan diol (Weir *et al.*, 2006). Best example for partial degradation is DDT, which undergoes degradation to form metabolites like DDD and DDE that are toxic and more persistent than the parent compound (Foght *et al.*, 2001). Introducing microbial population which can degrade the pesticides completely and by optimizing the environmental condition can enhance the degradation of pesticides and its metabolites in the soil. Microbial degradation of most of the recalcitrant organic compounds is limited by the presence of anionic species in the compound. The anions like chloride, sulphate etc. are strongly bonded to the hydrocarbon ring which prevents the microbes from attacking the ring structure. This may be due to increased toxicity of anionic group (Julia *et al.*, 2001).

Role of cow dung bacteria: When a solution of cow dung is sprinkled over oil spillage in oceans, it has the capacity to soak the oil. Naturally occurring bacteria in cow dung have the capability to degrade crude oil into simple and harmless compounds. Cow dung microflora was assessed for aerobic heterotrophic bacteria and petroleum-utilizing bacteria as well as the degradation potential of petroleum-utilizing bacterial isolates. *Acinetobacter* sp, *Bacillus* sp, *Pseudomonas* sp, *Alcaligenes* spp, and *Serratia* spp. were found as aerobic heterotrophs, and *Pseudomonas* spp. and *Bacillus* spp. were identified as petroleum utilizers in cow dung. Petroleum utilizers in total aerobic heterotrophs ranged from 6.38% to 20% (Akinde and Obire, 2008).

Role of Enzymes: enzymes have a great potentiality to effectively transform and detoxify polluting substances because they have been recognized to be able to transform pollutants at a detectable rate and are potentially suitable to restore polluted environments (Rao *et al.*, 2010). Enzymes are also involved in the degradation of pesticide compounds, both in the target organism, through intrinsic detoxification mechanisms and evolved metabolic resistance, and in the wider environment, via biodegradation by soil and water micro-organisms (Shapir *et al.*, 2007). *P. putida* theortical oxygen demand (TOD) enzyme is a representative of a much larger family of enzymes with application in the biocatalysis of environmentally relevant reactions. (Ferraro *et al.*, 2005). Fungal enzymes especially, oxidoreductases, laccase and peroxidases have prominent application in removal of polyaromatic hydrocarbons (PAHs) contaminants either in fresh, marine water or terrestrial (Balaji *et al.*, 2013).

Phytoremediation

Phytoremediation is the biotechnological application of plants to detoxify pollutants, and is an ideal and modern technique for environmental clean-up (Ziarati and Alaedini, 2014). More than 2400 plant species are reported to possess pest control properties, while some plants kill through poisonous exudates, others control through non killing activities like repellency, feeding deterrence and growth inhibition without adverse effects on environment and human health (Rajendran, 2003). Plant products can also be used as a major biopesticides . Plant-incorporated protectants include substances that are produced naturally on genetic modification of plants. Such examples are incorporation of Bt gene, protease inhibitor, lectines, chitinase etc into the plant genome so that the transgenic plant synthesizes its own substance that destroys the targeted pest (Kandpal 2014), Some natural, biodegradable compounds, such as exogenous polyamines, allow the plants to tolerate concentrations of pollutants 500 times higher than untreated plants, and to absorb more pollutants (Maheshwari *et al*., 2014).

The main advantages of phytoremediation are that: it is far less disruptive for the environment, (Ahn, 2006) it has better public acceptance, and it avoids the need for excavation and heavy traffic (Macek *et al.*, 2002). The most important aspect of phytoremediation is to find accumulator plants that show effective uptake of target contaminants (Emiko Matsumoto *et al.*, 2009). There are already many examples of the use of genetically modified plants in pesticide phytoremediation; glyphosate oxidase, cytochrome P450 enzymes, a Rieske non-heme monooxygenase (named DMO) that converts dicamba to 3,6-dichlorosalicyclic acid that has been expressed in *A. thaliana*, tomato, tobacco and soybean plants (Behrens *et al.,* 2007) and aryloxyalkanoate dioxygenase enzymes (TfdA) that have been expressed in corn (patented for the degradation of 2,4-D and pyridyloxyacetate herbicides) (Colin Scott *et. al*., 2008).

Bioremediation as cost-effective and environment friendly: Mats have been shown to sequester heavy metals and radionuclides as well as degrade recalcitrant toxic organic contaminants (Bender *et al.*, 2000). To remediate and restore functions of soil polluted by HCHs and DDX, effective technologies are necessary. Conventional treatments for organochlorine-contaminated soils include excavation and incineration, thermal desorption (Foght *et al.,* 2001), microwave- enhanced thermal treatment (Kawala and Atamanczuk, 1998), soil washing with surfactants (Kile and Chiou, 1989), supercritical fluid extraction (Sahle-Demessie and Richardson, 2000) and biological treatment (Yao *et al.*, 2006). Among these treatment technologies, bioremediation was more cost-effective and less destructive (Foght *et al.,* 2001).

Many pesticides, such as b-HCH and DDX are normally considered persistent in aerobic environments, are not persistent under anaerobic conditions (Van Eekert *et al.,* 1998). Therefore, generating a reduced environment in water, soils and sediments may facilitate the degradation of organochlorine pesticides (Satapanajaru *et al.,* 2006). Zerovalent iron (Feo) is a good reducing agent and can generate a reduced environment in water, soils and sediments .Some studies observed zerovalent iron can facilitate the degradation of DDT in water and soil freshly spiked with DDT (Yao *et al.,* 2006). However, there is a lack of knowledge about the potential of zerovalent iron to stimulate the degradation of HCHs and DDX in contaminated site soils. There are many differences between soil freshly spiked with organochlorine pesticides and contaminated sites soil which have been polluted by organochlorine pesticides for several years.

Firstly, organochlorine pesticides such as DDT and HCHs in contaminated sites soil may have become less bioavailable after being naturally aged for many years

(Quintero *et al.,* 2005). Furthermore, soils from former organochlorine pesticides manufacturing plant may be impacted by more than one contaminant. Co-contaminants may complicate biodegradation (Foght *et al.,* 2001). They provide more readily utilized substrates for themicro flora, which can divert enzymatic activity from the contaminant of concern. Furthermore, they may have specific or nonspecific toxic effects on the soil micro flora and may affect the solubility or adsorption of the contaminant of concern (Odukkathil and Vasudevan, 2013).

Advantages and disadvantages of bioremediation: For bioremediation to be successful, the bioremediation methods depend on having the right microbes in the right place with the right environmental factors for degradation to occur. The right microbes are bacteria or fungi, which have the physiological and metabolic capabilities to degrade the pollutants. Bioremediation offers several advantages over conventional techniques such as land rolling or incineration. Bioremediation can be done on site, is often less expensive and site disruption is minimal, it eliminates waste permanently, eliminates long-term liability, and has greater public acceptance, with regulatory encouragement, and it can be coupled with other physical or chemical treatment methods.

Bioremediation has also its limitations. (Dileep K. Singh, 2008). Residues from the treatment are usually harmless products and include carbon dioxide, water, and cel biomass. Many compounds that are considered to be hazardous can be transformed to harmless products and transferring contaminants from one environmental medium to another (Dhewa, 2011).

How can increase the degradation capability: Another strategy is to add a specific gene that can confer specific degradation capability to indigenous microorganism. The addition of degradative genes relies on delivery and uptake of genetic material by an indigenous microorganism. There are two possible approaches that can be taken i.e. (i) the use of microbial cells to deliver gene via conjugation, (ii) to add naked gene in soil and allow its uptake via transformation (Dileep K. Singh, 2008).

The use of pesticides and insecticides increases day by day which pollute our air, soil, water and ultimately reach to us through food chain. It is very necessary to degrade these pollutants so that our environment does not degraded and we can live a healthy life in a healthy environment. Bioremediation is the most effective management tool to manage the polluted environment and recover contaminated soil and water. we should use bioremediation to treat contaminated soil and water because it is less harmful and less environmental load, it affect only a few target organisms and one specific pest, it is very effective in small quantities and often decompose quickly , It lower the exposures and largely avoiding the pollution problems. When used as a component of Integrated Pest Management (IPM) programs, biopesticides can contribute greatly. In future we can use genetic engineering to improve the efficacy of microorganisms to reduce the environmental burden of toxic substances.

Table.1 There is various processes which play an important role in the removal of pollutant are as follows

Process	Function	Pollutant	Medium	Plants
Phytoextraction	Remove metals pollutants that accumulate in plants. Remove organics from soil by concentrating them in plant parts	Cd, Pb, Zn, As, Petroleum, Hydrocarbons and Radionuclides	Soil & Groundwater	Viola baoshanensis, Sedum alfredii, Rumex crispus,
Phytotranformation	Plant uptake and degradation of organic Compounds, Plants and associated microorganisms degrade organic pollutants	Xenobiotic substances	Soil	Cannas
Rhizofiltration	Roots absorb and Zn, Pb, Cd, As. Groundwater adsorb pollutants, mainly metals, from water and aqueous waste streams	Zn, Pb, Cd, As	Ground water	Brassica juncea,
Phytostabilization (Immobilization)	Use of plants to reduce the bioavailability of pollutants in the environment	Cu, Cd, Cr, Ni, Pb, Zn	Soil	Anthyllis vulneraria, Festuca arvernensis

Table.2 Showing role of different organisms in bioremediation which are as follows

Process	Source	Pollutant	Microbes/Plants	References
Phytoremediation	Soil	Pb, Cd	Vetiveria zizanioides and Eichornia crassipes, plus applications of zeolite.	Undang Kurnia, 1997.
Biodegradation	Garden, beach and mud	Saw	Aspergillus sp Trichoderma sp,	Sivakumaran, 2014.
Degradation	Cellulosic materials such as corncobs, saw dust and sugarcane	Blue dye 2B	Bacillus sp	Bhoosreddy, 2014.
Phytoremidiation, Adsorption	Sewage irrigated soils wastwateer	Heavy metals lead, iron, manganese, copper and zinc etc.	Flagellate sp. of Dunaliella algae	Qari and Hassan, 2014
Adsorption	Soil	Cu, Mn, Zn, Pb, Cr and Pd	Three herbaceous plants (Plantago major L.,Taraxacum officinale L. and Urtica dioica L.) and one leguminou (Trifolium pratense L.)	Maliziad *et al.*, 2010.

Table.3 Plant products registered as biopesticides which has been shown below

Plant product used as biopesticide	**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.
Pyrethrum / Pyrethrins	Ants, aphids, roaches, fleas, flies, and ticks.
Rotenone	Leaf-feeding insects, such as aphids, certain beetles (asparagus beetle, bean leaf beetle, Colorado potato beetle, cucumber beetle, flea beetle, strawberry leaf beetle, and others) and caterpillars, as well as fleas and lice on animals.
Ryania	Caterpillars (European corn borer, corn earworm, and others) and thrips.
Sabadilla	Squash bugs, harlequin bugs, thrips, caterpillars, leaf hoppers and stink bugs.

Source: (Kandpal, 2014)

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