Chapter

14

Biological Options for Crop Health (Nutrition, Pest and Disease) Management-Sanguine to Sustainable Agriculture

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ABSTRACT

Interest in biological control of plant insect pests and pathogens has been stimulated in recent years by trends in agriculture towards greater sustainability and public concern about the use of hazardous pesticides. Microorganisms have the capability to synthesize many different biologically active secondary metabolites such as antibiotics, herbicides, pesticides, anti-parasitic and enzymes like cellulase, chitinase and xylanase. Microbial collection at ICRISAT, Patancheru, India has over 2000 accessions of bacteria and actinomycetes isolated from various sources and/or niches of composts, rhizosphere and rhizoplane soil samples of sorghum and rice. These accessions possess at least one of six agriculturally beneficial traits studied viz. phosphate solublization, siderophore production, cellulose degradation, nitrogen fixation, antagonism to disease causing fungi and fluorescent Pseudomonas. In addition to that ICRISAT has also identified 28 entomopathogenic bacteria and actinomycetes capable of managing the most

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devastating insect pest of many crops (such as cotton, pigeonpea, chickpea etc.) viz. Helicoverpa armigera. A long-term rain-fed field experiment conducted between June 1999 and April 2010 at ICRISAT where use of plant biomass, compost and bio-fertilizers as soil building elements and crop nutrients, whereas microbial and botanical bio-pesticides as plant protection methods yielded comparable to conventional agriculture treatment, receiving chemical fertilizers and pesticides. Such efforts could lead to improve the ongoing plant protection system by introducing eco-friendly biological options to minimize operational hazards and to improve the environment through natural resource management leading to improvement in livelihood and food security. Factors that influence efficient use of various biological options include production, efficacy, availability, shelf life, narrow host range, genetic enhancement, compatibility, trainsition period, rate of decomposition, competing technology, traditional knowledge products, quality control and collaboration with private sector. This chapter discussed various aspects of the process leading to identification, evaluation and sharing of bio-products for encouraging eco-friendly pest management for sustainable agriculture.

Key words: Plant growth, Microorganisms, Soil health, Sustainable agriculture

1. INTRODUCTION

Over reliance on chemical pesticides and fertilizers has generated panoply of problems including safety risks, outbreaks of secondary pests (normally held in check by natural enemies), environmental contamination, decrease in biodiversity and insecticide resistance. Money spent on chemical pesticides can be 50% of the total input cost of production of some crops, especially for pests that attack crops like cotton and pigeonpea (Rupela, 2006). Majority of the farmers in semi-arid tropics by virtue of their small holdings cannot afford expensive inputs such as pesticides and fertilizers (for instance 75% of Indian farmers own less than 2.4ha; Chadha *et al*., 2004). Pest related damages result in an estimated Rs. 50,000 crore loss annually in the field and storage in India, for instance nearly half of the potential yield of rice is lost due to pests (Ignacimuthu, 2002). With an ever increasing awareness about a clean and safe environment and the potential dangers from pollution, particularly the health hazards associated with the use of the man-made synthetic plant protection and plant production agrochemicals, the demand for products and technologies based on microorganisms and plants has been increasing steadily worldwide. Natural enemies of insect pests play a key role in reducing the levels of pest populations. Both natural and applied biological control tactics are important in successful management of pest populations. After nearly two decades of intensive field level training, farmers have just started understanding the values of biological control. Of the total insecticide use in India, biopesticides such as botanicals and microbials cover around 1% compared to that of 12% globally. The major reason behind this lower adaptation of eco-friendly techniques was primarily due to the non-availability of the efficient quality products at affordable cost. This chapter briefly describes the research carried out at ICRISAT on biological options for crop health management for the last one decade.

2. BIOLOGICAL OPTIONS

Helicoverpa armigera is the key production constraint in several crops such as chickpea, pigeonpea, peas, lentil, chilies, sunflower, tomato, tobacco and cotton. Global crop losses due to *H. armigera* have been estimated to be over US$ 2 billion annually whereas 80% of this loss occurs in India causing wide spread misery to the farmers who face the risk of frequent crop failures (Grzywacz *et al*., 2005). Viable and sustainable management of *H. armigera* using the conventional approach of relying primarily on chemical pesticides has become costly and also, increasing resistance, environmental impact, safety and residues has been primary cause of concern. These concerns necessitated the idea of biological options of crop protection with stable production. Various biological options such as entomopathogens, antagonistic microbes and botanicals serves as an alternative to chemical pesticides for the management of major *H. armigera.* The various potential biological options considered were as follows:

3. VIRAL AND FUNGAL BIOCONTROL AGENTS

Among the viruses, it has been shown that nuclear polyhedrosis virus (NPV) is highly effective in controlling *H. armigera* on a range of crops including legumes, however, apart from Australia, their use by farmers is restricted only to high value horticultural crops (Cherry *et al*., 2000). Production of *Helicoverpa armigera* nuclear polyhedrosis virus (HaNPV) is a significant constraint not only on volume and cost but also for the quality of the products. The cost of HaNPV products is still higher than the synthetic chemicals and reduction in production costs will be crucial to any expansion of the market (Lisansky, 1997). Among the fungi, *Metarhizium anisopliae*, *M. flavoviride*, *Beauveria bassiana*, *Nomuraea rileyi* and *Paecilomyces farinosus* have been reported to kill *H. armigera* and other important insect pests. However, adhesion of fungal spores to host cuticle and their germination is a prerequisite for enhancing the efficacy of fungal pathogens and also 90% relative humidity is required for germination of fungal spores, a big handicap in widespread use of such bio-pesticides (Pawar, 1998).

4. BACTERIA, ACTINOMYCETES AND THEIR METABOLITES

Secondary metabolites from microbes, particularly bacteria and actinomycetes, are known to kill various insects including *H. armigera*. Among the bacteria *Bacillus thuringiensis* (Bt) is the most researched and focused on the toxins (cry toxins) it produces, and the proteins are isolated, purified and studied for their efficacy to kill insect larvae (Kaur, 2000). The major disadvantage of using Bt products are its narrow host range and effectiveness only on early instar larvae (Navon, 2000). The actinomycetes, mainly those belonging to the *Streptomyces* spp, make up an important group of soil bacteria from actinobacteria class. Several species of the Streptomycetaceae family are widely studied because of their ample capacity for production of secondary metabolites and extracellular enzymes. Spinosad (a product of the soil actinomycete *Saccharopolyspora spinosa* (Thompson & Hutchins, 1999); a mixture of spinosyn A and spinosyn D as active ingredients) when applied to first instar larvae of *H. armigera* caused significant reduction in the population (Mandour, 2009; Wang *et al*., 2009). At this stage, spinosad has become so popular and even used widely by the organic farmers of Europe and America to control *H. armigera*.

5. PLANT GROWTH PROMOTERS (PGP)

PGP stimulate growth of host plants directly by nitrogen fixation (Han *et al*., 2005), solublization of nutrients (Rodriguez & Fraga, 1999), production of growth hormones, (Correa *et al*., 2004) and indirectly by antagonizing pathogenic fungi by production of siderophores, chitinase, β-1, 3-glucanase, antibiotics, fluorescent pigments and cyanide (Pal *et al*., 2001). Majority of the PGP are isolated from rhizosphere (Khalid *et al*., 2004). Incorporation of crop residues and application of PGP microbial inoculants can have a direct impact not only on soil health and crop productivity but also can be an alternative for the chemical fertilizers and pesticides (Hameeda *et al*., 2006).

6. ENDOPHYTES

Endophyte is an endo-symbiont, often a bacterium or fungus that lives within a plant for at least part of its life without causing apparent disease. Endophytes may benefit host plants by preventing pathogenic organisms from colonizing, for *e.g*. *Neotyphodium* spp (a fungus) that lives in Italian rye grass kills rice leaf bug (Shiba *et al*., 2007), or by producing mycotoxin, for *e.g*. *Bacillus mojavensis* in maize produces mycotoxin which is antagonistic to *Fusarium moniliforme* (Bacon & Hinton, 2002). Endophytes induce systemic resistance in the host plant, so that plants can take care of themselves against pests and pathogens.

7. NATURAL PLANT PRODUCTS AND CROP RESIDUES

Some of the natural plant products such as custard apple seed extract, extracts of *Gliricidia sepium*, karanj oil and neem products are known to kill various insect pests of crops including *Helicoverpa*. Neem products available in the market are effective in killing *Helicoverpa* (Vyas *et al*., 1999). Ranga Rao and Gopalakrishnan (2009) reported the larvicidal activity of 18 different botanical extracts against *S. litura* with the range of mortality between 52% and 86% with the maximum found in neem fruit powder. Crude extracts of Annona, Jatropha and Pongamia vermicompost bio-wash were reported to kill *H. armigera* and *Spodoptera litura* (Gopalakrishnan *et al*., 2009). Crop residues are not only the important source of organic matter but also can have a direct impact on soil health, productivity and be an alternative to chemical pesticides but it is burnt in many parts of the world. In India, Punjab alone, crop residues are burnt worth 15M US$ annually, compost can be produced instead of burning these valuable crop residues (Sidhu *et al*., 1998). Compost contains many antagonistic, entomopathogenic and PGP microbes.

8. BIOLOGICAL OPTIONS AVAILABLE AT ICRISAT

ICRISAT has identified over 2000 accessions of bacteria and actinomycetes isolated from composts and rhizosphere soil samples, which possess at least one of six agriculturally beneficial traits studied viz. phosphate solublization, siderophore production, cellulose degradation, nitrogen fixation, antagonism to disease causing fungi and fluorescent production (*Pseudomonas fluorescens*; Table 1). In addition to that ICRISAT has also identified 28 entomopathogenic bacteria and actinomycetes (*Streptomyces albus* CAI-21, *S. champavatii* CAI-26 and *S. roseoviolaeus* MMA-32) capable of killing *H. armigera*. Recently, actinomycete isolates CAI-21, CAI-26 and MMA-32 were partitioned against ethyl acetate and the resultant organic and aqueous phase were evaluated for their efficacy on 2^{nd} instar larvae of *H. armigera*. The results showed that organic phase of the isolate MMA-32 showed 67–79% mortality in 3 days (Fig. 1). This result was highly reliable as the whole experiment was repeated four times (with 15 replications), hence it can be concluded that the isolate MMA-32 contains some secondary metabolites that are capable of killing *H. armigera* that may be separated and used as bio-pesticide.

In an another experiment ICRISAT used 25 different herbal composts (*Jatropha curcas*, *Annona squamosa*, *Parthenium hysterophorus*, *Oryza sativa*, *Gliricidia sepium*, *Adhatoda vasica*, *Azadirachta indica*, *Capsicum annuum*, *Calotropis gigantea*, *Calotropis procera*, *Datura metal*, *Allium sativum*, *Zingiber officinale*, *Ipomoea batatas*, *Momordica charantia*,

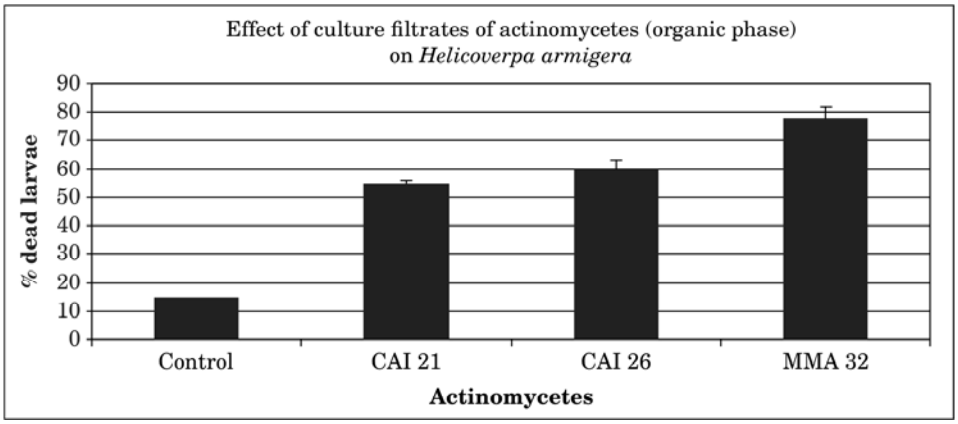

Fig. 1: Effect of culture filtrates of actinomycetes, after partitioning against ethyl acetate and the resultant organic phase, on the mortality of *H. armigera*

Table 1: Characterization of microbes on the basis of agriculturally important beneficial traits

S. No	*Category*	*No of potential strains **
1	Cellulose degrading bacteria and fungi	119
2	Antagonistic bacteria and actinomycetes	405
3	Phosphate solubilizing bacteria	143
4	Nitrogen fixing bacteria	590
5	Siderophore producing bacteria and actinomycetes	580
6	Fluorescent *Pseudomonads*	260
7	Entomopathogens	38
	Total	2135

* On the basis of in vitro lab test results

Moringa oleifera, *Argyranthemum frutescens*, *Nerium indicum*, *Allium cepa*, *Curcuma aromatica*, *Pongamia pinnata*, *Abacopteris multilineata*, *Nicotiana tabacum*, *Tridax procumbens* and *Vitex negundo*) for isolating antagonistic actinomycetes against *Macrophomina phaseolina* (causes charcoal rot in sorghum) and *Fusarium oxysporum* f. sp. *ciceri* (FOC; causes wilt in chickpea), *Fusarium udum* (causes wilt in pigeonpea), *Sclerotium rolfsii* (causes collar rot in chickpea) and studied on various biocontrol and PGP traits including production of siderophore, indole acetic acid (IAA), rock-phosphate, cellulase, chitinase, lipase and protease and phosphate solubilization. Of the 137 isolates studied, 73%, 67%, 35% and 53% of the isolates were found producing siderophore, IAA, chitinase and protease respectively, whereas none of the 137 isolates were able to solubilize rock phosphate and produce cellulase and lipase (Table 2). The results of biocontrol studies indicated that 79% and 53% of the isolates inhibited *M. phaseolina* and FOC, respectively, while none of the isolates inhibited *F. udum* and *S. rolfsii* (Table 2). All the 137 actinomycetes, isolated from 25 different herbal vermicomposts, and another 360 bacteria, isolated from rhizosphere of a "system of rice intensification" (SRI) fields, were further characterized for their antagonistic potential against *Fusarium* wilt, collar rot, dry root rot and *Botrytis* grey mould diseases of chickpea, and charcoal rot disease in sorghum by dual culture assay, blotter paper assay, greenhouse evaluation and further evaluated in the field. From these studies, a total of 20 antagonistic actinomycetes and bacteria against *Fusarium* wilt of chickpea and charcoal rot of sorghum were identified up to the species level by 16S rDNA analysis and samples submitted to National Bureau of Agricultural Important Microorganisms (NBAIM) gene bank (Gopalakrishnan *et al*., 2009; Kiran *et al*., 2009; Ranga Rao & Gopalakrishnan, 2009; Gopalakrishnan *et al*., 2010a, b; Gopalakrishnan *et al*., 2011a, b, c, d, e). These results open the new avenue for evaluating hundreds of PGPR microbes lying in microbial germplasm at ICRISAT for potential entomopathogenic and antagonistic traits.

Table 2: Screening of actinomycetes isolated from 25 different herbal composts for antagonistic and plant growth promoting (PGP) traits

PGP and Biocontrol traits	*Total number of screened isolates*	*% Positive isolates*
Siderophore	137	73
Indole acetic acid	15	67
Rock phosphate solubilization	137	0
Phosphate solubilization	137	7
Cellulase (cellulose degradation)	137	0
Chitinase (chitin degradation)	137	35
Lipase (lipid degradation)	137	0
Protease (protein degradation)	137	53
Macrophomina phaseolina	100	79
Fusarium oxysporum f sp. ciceri	62	53
Fusarium udum	137	0
Sclerotium rolfsii	137	0

9. ON-STATION EVALUATION OF LOW COST BIOLOGICAL OPTIONS

A long-term rain-fed on-station experiment (on a vertisol =black soil, rich in clay) was conducted between June 1999 and April 2010, at ICRISAT, Patancheru, with a focus on low-cost and biological options of crop protection and production. It contained four treatments: T1 = Low cost system 1, T2 =

low cost system 2, T3 = Conventional and T4 = Conventional + plant biomass. Each treatment was of 30M width and 60M length that contained 6 replications of 30 X 9.5 m, 0.2 ha for each treatment, with a total area of 1.02 ha including non-cropped area. This experiment was conducted on a 1.5 m deep Vertisol with pH in the top 15 cm ranging from 8–8.2.

Inputs for T1 and T2 treatments: These had not received any tillage, chemical fertilizers and pesticides all along. Sowing was always done by seed drill method. Rice straw was used as surface mulch in T1 whereas crop residues were used in T2 for the first 3 years, thereafter it remained same for both the treatments. Only crop residues and weeds generated from this field and Gliricidia lopping (*Gliricidia sepium*; N_2 fixing legume tree planted on the boundaries during first year; leaves of this plant contains 2.4% N, 0.1% P and 1.8% K; 700 M long bunds provided 30 Kg N_2/ha/year) were used as surface mulch. In addition to that 1.5 to 1.7 t/ha of compost was also added every year. Manual weeding was done if required and retained in the field. Pest management was only by bio-pesticides. Table 3 shows different plant protection materials that ICRISAT used in this experiment. Before application in the field, all the botanicals and entomopathogens listed in Table 3 were evaluated for their potency. Among the botanicals, Pongamia, Datura and neem foliage and fruit powder were found to have the maximum mortality (more than 60%) against *H. armigera* and *S. litura*. Some botanicals viz. Marigold, Melia and cow urine were sprayed at 10% in water, which acted as good repellents. When adjacent fields were about to be chemically sprayed, prior to that 50% cow urine was applied on the soil surface (not on the plants), which perhaps effected the migration of larvae thereby less damage in treated plots. Sucking pests such as aphids and mealy bug were controlled by using 0.5–0.8% khadi soap solution (very mild soap) or vegetable oils. Entomopathogens such as *Bacillus subtilis, B. megaterium, B. pumilius, Serratia marcescens* and *M. anisopliae* were also used when necessary.

Inputs for T3 and T4 treatments: Tillage was always done by bullock plough. Crop residues were not added in T3 whereas it was added in T4. Compost was added once in two years to both the treatments @ 1.5 to 1.7 t/ ha. 80 kg N as urea and 20 kg P as SSP were added to both the treatments. Manual weeding was done, if required, but not retained (discarded) in the field. Pest management was done only by chemicals, where monocrotophos was sprayed for sucking pests such as aphids whereas Quinalphos or Methomyl for *Helicoverpa* and *Spodoptera*. Details of all the four treatments were shown in Table 4 (Rupela *et al*., 2005).

Crops were changed every year but were same in all the four treatments in a given year. For *e.g*. in year 2 it was sorghum/pigeonpea intercrop, year 3 was cotton/ cowpea intercrop. Detailed cropping pattern can be viewed in

Table 3: List of various biological options used in the on-farm evaluation trials

Botanical/ Microorganisms	***Scientific names***	***Conc.***	***Against***	***Percent mortality***	***Remarks***
Anona foliage	*Anona squamosa*	1%	HA	40	Repellent and insect killing ability
Calotropis	*Calotropis gigantea*	1%	HA	14	Insect killing property
Datura	*Datura metal*	1%	HA	46	Insect killing property
Marigold	*Targetus erecta*	1%	HA	NA	Repellent
Melia	*Melia azedarach*	1%	HA	NA	Repellent
Neem foliage	*Azadirachta indica*	1%	HA	48	Insect killing property
Neem Fruit Powder	*Azadirachta indica*	1%	HA	74	Repellent and insect killing ability
Pongamia	*Pongamia pinnata*	1%	HA	72	Insect killing property
Tridax	*Tridax procumbens*	1%	HA	34	Insect killing property
Curd recipe	NA	NA	NA	NA	To attract beneficial insects
Cow urine Foliar spray	NA	10%	HA	NA	Repellent
Cow urine mixed with botanical	NA	5% Cow urine; 1% botanical	HA	NA	Repellent
Cow urine spray at plant base	NA	50%	HA	NA	To prevent insect migration
Cactus	*Cactus sp*	1%	HA	NA	Repellent
Soap solution	NA	0.8%	Aphids and Mealy bug	NA	Phytotoxic on young leaves
Vegetable oil emulsified with soap	NA	1.5% oil; 0.5% khadi soap	Aphids	NA	–
Bacteria	*B. subtilis* BCB19	$3x10^6$ cfu/ml	HA	28	Entomopathogen
Bacteria	*B. pumilus* SB 21	$3x10^6$ cfu/ml	HA	38	Entomopathogen
Bacteria	*B. megaterium* SB9	$3x10^6$ cfu/ml	HA	30	Entomopathogen
Bacteria	*Serratia marcescens* HiB 28	$3x10^6$ cfu/ml	HA	87.9	Entomopathogen
Fungus	*M. anisopliae*	$3x10^6$ cfu/ml	HA	52	Required >75% humidity

NA = not applicable; HA = *Helicoverpa armigera*

Table 4: Details of the four different treatments used in the on-farm evaluation trials

	Treatment plots			
Act/Inputs	***LC 1***	***LC 2***	***MA***	***MA+ BM***
Tillage	Zero-tillage	Zero-tillage	Conventional (bullock plough)	Conventional (bullock plough)
Sowing	Seed-drill	Seed-drill	Seed-drill	Seed-drill
Microbial inoculants*	+	+	–	–
Biomass ($t\ ha^{-1}\ yr^{-1}$ first 3 years only)	10 Rice straw as surface mulch	10 Farm-waste, stubble and hedgerow foliage as surface mulch	None	10 Farm-waste, stubble and hedgerow foliage incorporated
Compost ($t\ ha^{-1}$)	1.5–1.7 annual	1.5–1.7 annual	1.8 (1 in 2 year)	1.8 (1 in 2 year)
Fertilizer (N) Urea ($kg\ N\ ha^{-1}$)	0	0	80	80
Fertilizer (P) $kg\ P\ ha^{-1}$ (1 in 2 year)	20 (RP)	20 (RP)	20 (SSP)	20 (SSP)
Pest management	Biopesticides¤	Biopesticides	Chemical pesticides	Chemical pesticides
Weeding	Manual, weeds retained	Manual, weeds retained	Manual, weeds discarded	Manual, weeds discarded

LC1 = Low-cost system 1, No tillage, Rice straw as surface mulch + biological inputs for plant growth and pest management. LC2 = Low-cost system 2, No tillage, farm waste as surface mulch + biological inputs for plant growth and pest management. MA = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. MA + BM (Biomass) = Same as MA + Farm waste as biomass as in LC2.

* = Microbial inoculants applied were *Bacillus circulans* EB 35, *Serratia marcescens* EB 67, and *Pseudomonas* sp. CDB 35 (Hameeda *et al*., 2006) along with other inoculants like Rhizobium and Azotobacter.

¤ = Biopesticide formulation (microorganisms, herbal extracts and vermi wash) developed at ICRISAT.

RP = rock phosphate; SSP = single super phosphate

Fig. 2. As few years are needed for the agriculturally beneficial microorganisms to build up in soil and probably this was the reason for poor results in the first year. Upon comparing the yield of T1 and T2 with T3 and T4 from year 2, yield in T1 and T2 were either higher or at least equal to the yields of T3 and T4 on all the occasions except year 6 and 8 (Fig. 2). Hence, it can be concluded that without compromising on yield it was possible to grow crops without chemical fertilizers and pesticides at a

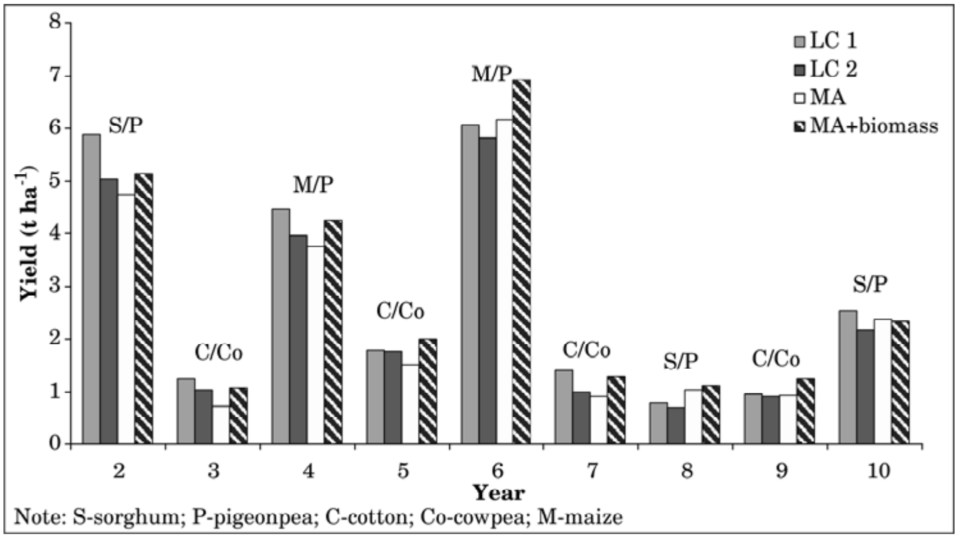

Fig. 2: Yield (t ha^{-1}) in organic plots (LC1 and LC2) in comparison with non-organic plots (MA and MA + biomass) in an on-station evaluation trial over 10 years

reasonable productivity level. ICRISAT had done similar kind of demonstration experiment in farmer's field on cotton at Kothapally, Ranga Reddy district, Andhra Pradesh and showed bio plots yielded 30% more cotton than chemical plots (Rupela, 2006).

10. LIMITATIONS OF BIOLOGICAL OPTIONS

The following issues need to be addressed in order to efficiently use various biological options.

10.1. Production

Production of the bio-pesticides has limitations both in volume and cost. For *e.g.* the *in vivo* production of NPV in live insects is still alien to most agrochemical companies and so they are reluctant to adopt it, and the in-vitro tissue culture is still under the development. Also NPV products are much costlier than synthetic chemicals (Grzywacz *et al*., 2005).

10.2. Efficacy

On some crops entomopathogens perform well, so low doses can be used. For *e.g.* HaNPV is effective at low dozes on sorghum whereas not on cotton and chickpea. Thus, much research is needed to identify the precise mechanisms that cause the problem (Murray *et al*., 2000)**.**

10.3. Availability

Many efficient bio-pesticides are not available easily. For *e.g* NPV products are available only in USA, Australia, India, china and Thailand but not in any other developing countries. Also, apart from Australia, their use by farmers is still restricted only to horticultural crops (Cherry *et al*., 2000).

10.4. Shorter Shelf-Life

Most of the bio-pesticides available today has shorter shelf life and needs to be refrigerated, where as many poor farmers and dealers do not have such facilities.

10.5. Narrow Host Range and Effectiveness

Many Bt products have been indicated to have a narrow host range and are most effective only on early instar larvae, necessitating frequent sprays (Navon, 2000).

10.6. Genetic Enhancement

It provides an alternative means of enhancing the speed of action of entomopathogens. For *e.g*. the median lethal time (LT_{50}) for *H. zea* NPV strain expressing an insect-selective scorpion toxin was demonstrated at 2.5 days compared to 6 days for the unmodified virus (Treacy *et al*., 2000).

10.7. Compatibility

Entomopathogens and botanicals should be tested for their compatibility to know whether entomopathogens are not killed by the botanicals and vice versa.

10.8. Transition period

When a field is converted from conventional farming to organic farming yield of the crops is reduced, at least in the initial few years, as few years are needed to build the agriculturally beneficial microorganisms in soil. It should be possible to reduce this period to less than one year with scientific understanding of organic farming.

10.9. Rate of Decomposition

Decomposition of applied biomass is faster in tropical than in temperate climates. Thus in tropical climates, biomass can serve as an important source of crop nutrition and protection and thus aid crop production. We should promote and do more research on degradation of organic residues.

10.10. Competing Technology

In the absence of mechanization and research and development (R&D) investments by the governments, globally, several protocols of organic farming are indeed labor intensive. So we need to invest more money on R&D to develop commercially viable products.

10.11. Traditional Knowledge Products

We should explore the traditional knowledge products such as curd recipe. It involves mixing specific quantities of curd, Jaggery and bread yeast in water and sprayed, which is an attractant to friendly insects such as wasps that feeds on *Helicoverpa*.

10.12. Quality Control

It is very important to produce and maintain high quality product of the bio-pesticides in order to gain the confidence of the farmers. So quality of the bio-pesticides available in the market should be monitored regularly.

10.13. Collaboration with Private Sector

Many bio-pesticide researchers have adequate skills in the bio-agent isolation, characterization and evaluation but lack the skills needed to develop promising bio-agents into a successful commercial product. The real progress can only be achieved by having strong public-private sector collaboration.

11. CONCLUSIONS

Biological options are highly relevant to poor farmers as several of these can be produced on farm while some will be needed from market. Crop protection and nutrients needs could be met through plant biomass, composting, mulching, liquid manures, bio-pesticides and natural plant products. These options are a potential solution to global warming! Further research and extension toward improving biological means and economic competitiveness is required!

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