Dryland crops are grown in resource poor environments. Cost of cultivation is an important factor in crop management in these areas. Hence, pest management interventions should necessarily take into account the extent of natural regulation of pests and diseases underway in any given field. Efforts to conserve and augment biocontrol agents including pathogens, parasites and predators should be envisaged in this context. Among the various options, microbial biopesticides have an excellent scope for management of pests in dryland crops when used intelligently. Releases of parasites or predators in conjunction with bio-pesticide sprays offers greater chance of their survival and perpetuation of the released agents compared to use of synthetic chemical pesticides. Biocontrol options also perform well when combined with other control measures such as use of resistant or tolerant crop varieties for crop pests. Biocontrol agents are density dependent factors and hence their seasonal activity starts after an initial incidence of crop pests.

Features of some selected bioagents and their field use recommendations in several crops are presented in this paper. Trichogrammatids are egg parasitoids of several insect pests such as pod borer and bollworm, Helicoverpa armigera; defoliators such as Achaea janata and army worm, Spodoptera litura; stem borers such as Chilo sp. In addition to natural parasitisation in the field, Trichogramma parasites can be released argumentatively in the field through releases of parasitized and sterilized eggs of Corcyra cephalonica pasted on paper cards. Among the predators, field releases can be made with Coccinellids: Coccinella septumpunctat, Cryptolaemus montrouzeri, Scymnus sp. (adult beetles or grub stages) and grubs of Chrysoperla carnea (Chrysopid).

Biopesticides based on Bt, NPV and GV have now been brought under the ambit of the Central Insecticide Act, 1968. Commercialization of microbial pesticides is possible only after registration with the Central Insecticide Board (CIB). At present, the following NPVs have been registered with the CIB in India: NPVs of Helicoverpa armigera and Spodoptera litura. While regulation is good for quality control of commercial products, this has led to higher pricing making their field use expensive. Currently, commercial NPV price ranges between Rs 150-200 for 100 ml product (ca 1 x 10^9 viral bodies ml-1) for NPVs infecting H. armigera and S. litura. Protection cost for one spray in cotton at 500 LE (larval equivalents) ha^-1 costs Rs 950 and in chickpea at 250 LE ha^-1 costs Rs 475. One spray with Bt at 0.25-0.3% concentration costs Rs 300-500. It is possible that communities or agencies engaged in organic farming or low-external input agriculture can produce locally both NPV (Jayaraj et al., 1989, Ramakrishnan et al., 1976) and Bt (Vimala devi et al., 2005; Vimala devi and Rao, 2005). The local production can result in reduction of protection cost and leads to internalization of expenditure within the community which goes well with the principles of using local resources.
i) Viral biopesticides (NPV and GV)

Majority of insect viruses used as biological control agents belong to the baculovirus group. These viruses are characterized by the presence of rod shaped nucleocapsid (hence ‘baculovirus’, from baculum, meaning rod) and the ability to form proteinaceous occlusion bodies within infected cells. Baculoviruses are of two types: Nucleopolyhedroviruses (NPVs) and Granuloviruses (GVs) based on the type of occlusion body formed. NPVs have the following advantages for consideration in BIPM initiatives: Species-specific action and hence safe to non-target organisms; non-pathogenic to most beneficial insects and hence fit admirably into bio-intensive IPM (BIPM) initiatives especially in food crops where pesticide residues are a major problem and fit well into organic farming. Use of NPVs is possible in several crops (Prasad and Prabhakar, 2005) and is provided in Table 2.

<table>
<thead>
<tr>
<th>Baculovirus type</th>
<th>Crop</th>
<th>Crop stage</th>
<th>Dosage (LE ha(^{-1}))</th>
<th>Number of applications per crop season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Helicoverpa armigera</em> (gram pod borer /American bollworm) NPV</td>
<td>Red gram</td>
<td>Flower initiation, 50% flowering and peak flowering</td>
<td>250-500</td>
<td>2-3 at 10-14 days interval</td>
</tr>
<tr>
<td>Chickpea</td>
<td>30 DAS and flowering</td>
<td>250</td>
<td>2-3 at 7-12 days interval</td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>Fruiting stage</td>
<td>250</td>
<td>3 at 7 days interval</td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>Fruiting stage</td>
<td>500-750</td>
<td>1-2 at 10 days interval</td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td>Flower head</td>
<td>250</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Groundnut</td>
<td>Flowering onwards</td>
<td>250-500</td>
<td>3-4 at 7-10 days interval</td>
<td></td>
</tr>
<tr>
<td><em>Spodoptera litura</em> (tobacco caterpillar or leaf worm) NPV</td>
<td>Tobacco Vegetables</td>
<td>Need based</td>
<td>250-500</td>
<td>1-3 applications at 7-14 days interval</td>
</tr>
<tr>
<td>Groundnut Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Achaea janata</em> (semilooper) GV</td>
<td>Castor</td>
<td>35-75 days after sowing</td>
<td>500</td>
<td>2 sprays first applied between 35-50 days and second at 60-75 days crop age based on pest incidence</td>
</tr>
</tbody>
</table>

ii) *Bacillus thuringiensis*(Bt) biopesticide

Bt is a naturally occurring soil bacterium that produces crystal proteins toxic to several insect species during the sporulation stage of its multiplication cycle. The crystalline protein inclusion constitutes 20-30% of the dry weight of sporulated cell allowing for commercial exploitation as a biopesticide. The potential of this bacterium in the management of several caterpillars causing serious damage to the cultivated crops world over is well documented over the last fifty years. There are currently more than a hundred products of Bt registered for the management of important lepidopteran insect pests such as *H. armigera* (bollworm), *Plutella xylostella*
(diamond back moth), *Trichoplusia ni* (looper) and *A. janata* (Vimala devi et al., 1996). Bt occupies 95% share of the microbial bio-pesticide market. The principal reasons for the success of Bt include the high efficacy and insect specificity of its insecticidal crystal proteins (ICPs) and their bio-degradability. Bt has a good scope for use by organic farmers especially on fruits and vegetables. The commercial Bt products are powders containing a mixture of dried spores and toxin crystals. Bt is applied as a foliar spray best against young caterpillars less than 2 cm long at concentrations between 0.2-0.3% giving a good coverage on plant surfaces. As Bt is deactivated by sunlight, spraying in late afternoon or evening or on cloudy days is most effective. Alkaline water (pH of 7.8) or acid water will deactivate the crystals. Generally repeat applications may be required under high pest pressure.

**iii) Insect pathogenic fungi**

Among the insect pathogenic fungi which can be used for insect pest control, important ones are Beauveria bassiana, Verticillium lecanii, *Metarhizium anisopliae* and Nomuraea rileyi. B. bassiana has a wide host range and can be used for control of caterpillars, beetles and bugs. *Metarhizium* is mainly used for control of grasshoppers and soil borne pests such as white grubs. *Verticillium* is used for control of sucking pests such as thrips and whitefly. *Nomuraea* is used for control of caterpillar pests on several crops. *Paecilomyces* is used for control of nematodes and mites while *Hirsutella* is mainly used for the control of mites in several crops. Fungal biopesticides are most effective when applied under high humidity conditions and immediately after rain or irrigation under cool weather conditions. Infective unit of fungal agents is spore and about 1 x 10^{12} spores are required to treat 1 ha. Generally talc based formulations are available in the market.

**iv) Inundative releases of bio-agents**

Apart from conserving native natural enemy populations which are density dependent mortality factors regulating pest populations in a given agro-ecosystem, another bio-intensive IPM option available for organic farmers is augmentative release of natural enemies that multiply during the growing season. Augmentative release may be made with either short- or long-term expectations depending on the target pest, the species of natural enemy and the crop involved and can be cost-effective. The two most commonly released bioagents are: egg parasitoids, *Trichogramma* wasps and the predatory lacewing, *Chrysoperla carnea*. *Trichogramma chilonis* is the dominant species of wasps in India. It has been used for the biological control of several pests in sugarcane, paddy, cotton and maize (Jallali and Singh, 1993; Prabhakar and Prasad, 2005) (Table 3).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Stage</th>
<th>Pest</th>
<th>Natural enemy species</th>
<th>Dosage per hectare</th>
<th>Number of releases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed paddy</td>
<td>30 days after transplanting</td>
<td>Stem borer</td>
<td><em>T. japonicum</em></td>
<td>50000 eggs</td>
<td>6 at weekly interval</td>
</tr>
<tr>
<td>Castor</td>
<td>30 days after sowing</td>
<td>Semilooper</td>
<td><em>T. chilonis</em></td>
<td>20000 parasitized eggs</td>
<td>3 releases at weekly intervals</td>
</tr>
<tr>
<td>Cotton</td>
<td>45 days onwards</td>
<td>Bollworms</td>
<td><em>T. chilonis</em></td>
<td>150000</td>
<td>6 at weekly interval</td>
</tr>
<tr>
<td></td>
<td>80 days</td>
<td>Spodoptera</td>
<td><em>Telenemus</em></td>
<td>50000 eggs</td>
<td>3 releases at weekly intervals</td>
</tr>
</tbody>
</table>

Table 3: Field use recommendations for bio-agents
<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Days After Event</th>
<th>Pests/Insects</th>
<th>Species</th>
<th>Number Released</th>
<th>Releases</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>45 days onwards</td>
<td>Stem borer</td>
<td><em>T. chilonis</em></td>
<td>75000</td>
<td>6 at 10 days interval</td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>45 days after transplanting</td>
<td>Fruit borer</td>
<td><em>T. brasiliensis</em></td>
<td>50000</td>
<td>6 at weekly interval</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top shoot borer</td>
<td><em>T. japonicum</em></td>
<td>50000</td>
<td>4-6 at 10 days interval</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>30 days onwards</td>
<td>Aphids, Whitefly, Thrips, Spodoptera</td>
<td><em>C. carnea</em></td>
<td>5000 grubs</td>
<td>3-4 at 15 days interval</td>
<td></td>
</tr>
</tbody>
</table>

References:


