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BIOLOGICAL CONTROL: A VERITABLE NATURAL PEST MANAGEMENT STRATEGY

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ABSTRACT

The advent of synthetic pesticides in the 1950s makes the control of pests appeared easy and at hand. However, it soon became obvious that there were problems associated with pesticides use. Some pests became resistant, and some non-target organisms were adversely affected, pest resurgence occurred and environmental and human health concerns arose. There is also the problems of adulteration and leaving of poisonous residues in food after use. The much advocated Integrated Pest Management (IPM) strategy promotes non-chemical pest control tactics, like the use of pest-resistant crop varieties, cultural control methods and the use of biological control measure. In IPM, pesticides are used only when absolutely necessary, to prevent an economic loss and rarely to be used as a prophylactic option. These problems associated with synthetic pesticides usage had propelled researchers to look for alternative pest control measures that would be natural, safer, probably cheaper and more locally available, and also effective. This paper therefore, examines the biological control measure (known as the use of natural enemies), as a veritable alternative pest control strategy.

Keywords: Biological control, Pest, Integrated pest management, Bio-control agents.

INTRODUCTION

A pest by definition is any organism that is detrimental or harmful to man, animal or crops; be it is an insect, disease organism, weed, rodent, or any other organism. Biological control on the other hand, is an important aspect or a major component of the Integrated Pest Management (IPM) strategy, defined as the utilization of living organisms (called natural enemies), to control pests or reduce the damage caused by harmful organisms to tolerable levels, below the Economic

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Injury Threshold (EIT). It is a bio-effector method of controlling pests (including insects, mites, weeds and plant diseases) using other living organisms *(Flint and Dreistadt, 1998)*. It is understood to mean the use of living organisms to reduce pests. Organisms employed are the natural enemies of the pest species, or individuals of the pest species, modified, such that they destroy members of their own species (Cochrane, 1994). All pests have their natural enemies. The use of these organisms to manage pests is known as biological control (Hoffmann. and Frodsham, 1993). It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role (Wikipedia, 2016).

The Need For Biological Control

Today, the protection of food and fiber crops from insect, mite, disease, and weed pests in conventional agricultural systems still relies primarily on the use of chemical pesticides (Hoffmann. and Frodsham, 1993). In Africa, particularly Nigeria, farmers have depended over the years on the use of the mostly imported conventional (synthetic) insecticides like phostoxin and primiphos-methyl (actellic); which though are very effective for stored products protection, their use have several drawbacks like increasing costs, inconsistent supplies due to scarcity and hazards to human health and the environment, if carelessly and indiscriminately used; more so that most farmers in developing countries like Nigeria are poorly educated (Ofuya, 2003). The new and much advocated Integrated Pest Management (IPM) system promotes non-chemical pest control tactics .It is a strategy by which farmers draw from a range of pest control methods to achieve the most effective, economical and sustainable combination for a particular situation (Thomas and Waage, 1996). In IPM, the emphasis is placed on self-renewing pest subjugation tactics, such as the use of pest-resistant crop varieties, cultural control methods and the use of biological control measure. Insecticides are used only when absolutely necessary, albeit judiciously, to prevent an economic loss and rarely to be used as in a prophylactic manner. Judicious use of insecticides includes choosing selective ones (i.e. those that are less hazardous to natural enemies of insect pests) or minimum insecticide application (Hoffmann. and Frodsham, 1993, Longe, 2015). There is the need therefore, to develop alternatives to conventional pesticides.

TYPES OF OR APPROACHES TO BIOLOGICAL CONTROL

There are three basic types of biological pest control strategies: importation (sometimes called classical biological control), augmentation and conservation (University of Minnesota, 2012).

(1) Importation or Classical Biological Control:

Importation or classical biological control involves the introduction of a pest's natural enemies to a new locale where they do not occur naturally. This is usually from one country to another. The introduced pests are referred to as exotic pests. The process of importation involves determining the origin of the selected pest and quarantine, to ensure that they will work and that no unwanted organisms (such as hyper-parasitoids) are introduced with it. If these procedures are passed, the selected natural enemy is mass-produced and then released. Follow-up studies are conducted to determine if the natural enemy becomes successfully established at the site of release, and to assess the long-term benefit of its presence.

For best result in pest control, a biological control agent requires a colonizing ability which will allow it to keep pace with the spatial and temporal disruption of the habitat. Its control of the pest will also be greater if it has temporal persistence, so that it can maintain its population even in the temporary absence of the target species, or a non-host specific opportunistic forager, that will rapidly exploit available pest populations (Follett and Duan, 2000). The later is however dangerous, as it may affect other beneficial non-target organisms.

Importation or classical biological control is long lasting and inexpensive. Other than the initial costs of collection, importation, and rearing, little expense is incurred. When a natural enemy is successfully established it rarely requires additional input and it continues to kill the pest with no direct help from humans and at no cost.

There are many examples of successful importation programs. One of the earliest successes was the control of *Icerya purchasi*, the cottony cushion scale, a pest that was devastating the California citrus industry in the late 19th century. A predatory insect *Rodolia cardinalis* (the Vedalia Beetle), and a parasitoid fly were introduced from Australia by Charles Valentine Riley. Within a few years the cottony cushion scale was completely eradicated by the introduced natural enemies.

A recent example of classical biological control, was that of a small wasp, *Trichogramma ostriniae*, that was introduced from China to control the European corn borer (*Ostrinia nubilalis*), one of the most destructive insects in North America. Locally, cats and dogs can be 'imported' into an area, such as farms and farm stores to kill and drive away rodents. Importation however does not always work. It is usually most effective against exotic pests and less so against native insect pests. The reasons for this are not often known but may include the release of too few individual agents, poor adaptation of the natural enemy to environmental conditions at the release location, and lack of synchrony between the life cycle of the natural enemy and host pest (Wikipedia, 2016)

(2) Augmentation:

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Augmentation involves the supplemental release of natural enemies, boosting the naturally occurring population. Relatively few natural enemies may be released at a critical time of the season (*inoculative release*) or millions may be released (*inundative release*).

Inoculative releases usually occur in greenhouse production of several crops. For example, periodic releases of the parasitoid, *Encarsia formosa*, were used to control greenhouse whitefly, while the predatory mite *Phytoseiulus persimilis* was used for control of the two-spotted spider mite. Recommended release rates for lacewings, lady beetles and *Trichogramma* parasitoids in vegetable or field crops range from 5,000 to 200,000 per acre (1 to 50 per square metre) per week (inundative release) depending on level of pest infestation. Similarly, entomo-pathogenic nematodes were released at rates of millions and even billions per acre for the control of certain soil-dwelling insect pests. The convergent lady beetle, *Hippodamia convergens*is, is commonly used for the biological control of aphids. (Wikipedia, 2016).

Biological control involving the release of mass-produced natural enemies in laboratories (inoculation, argumentation and inundation) for *C. maculatus* control in granaries at the farm's level may be hindered by financial, technical and logistic problems (Arbogast, 1984). The isolation of strains of the bacterium *Bacillus thuringiensis* that are toxic to beetles (Hernstadt et al., 1986) accompanied by appropriate developments in biotechnology for increased toxicity of the specific strains (Evans, 1987) may facilitate their use for *C. maculatus* control. In an augmentation operation or application, the spraying of octopamine analogs (such as 3-FMC) has been suggested as a way of boosting the effectiveness of augmentation. Octopamine, is regarded as the invertebrate counterpart of dopamine, which plays a role in activating the insects' flight-or-fight response. The idea behind using octopamine analogues to augment biological control is that natural enemies will be more effective in their eradication of the pest, since the pest will be behaving in an unnatural way because its flight-or-fight mechanism has been activated. Octopamine analogues are said to do two things: (i) they affect insects at very low dosages; (ii) they do not have a physiological or negative effect in humans or other vertebrates (Roeder T., 2005).

(3) Conservation:

The conservation of existing natural enemies in an environment is the third method of biological pest control. It is probably the most important and readily available biological control practice to farmers. Natural enemies occur in all production systems and cropping systems can be modified to favour the natural enemies, a practice sometimes referred to as habitat manipulation. Providing a suitable habitat, such as a shelterbelt, hedgerow, or beetle bank where beneficial insects can live and reproduce, can help ensure the survival of populations of natural enemies.

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Simple things like leaving a layer of fallen down leaves or mulch in place provides a suitable food source for worms and provides a shelter for small insects, in turn also providing a food source for hedgehogs and shrew mice. Compost pile(s) and containers for making leaf compost also provide shelter, as long as they are accessible by the animals (not fully closed). A stack of wood may provide a shelter for rats, hedgehogs, shrew mice, some species of butterflies, Long grass and ponds provide shelters for frogs and toads (which themselves eat snails). Not cutting annual plants or other non-hardy plants during dry season, allows many insects to make use of their hollow stems (Pauline, 2005). Lacewings, lady beetles, hover fly larvae, and parasitized aphid mummies are almost always present in aphid colonies.

Provision of artificial shelters in the form of wooden caskets, boxes or flowerpots is also sometimes undertaken, particularly in gardens, to make a cropped area more attractive to natural enemies. For example, the stimulation of the natural predator *Dermaptera* is done in gardens by hanging upside-down flowerpots filled with straw or wood wool.

Green lacewings are given housing by using plastic bottles with an open bottom and a roll of cardboard inside of it (Pauline, 2005).

Bird houses provide housing for birds, some of whom eat certain pests; while letting certain plants (as *Helianthus* spp, *Rudbeckia* spp, *Dipsacus* spp, *Echinacea* spp) come into seed is also advised, to supply food for birds. Obviously for this to work these trees cannot be pruned/trimmed until after the birds and other animals have eaten all the beetle pests associated with them.

A flowerpot, filled with straw to attract *Dermaptera* spp. *Picture by Pauline Pears.*

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Besides the provisioning of natural or artificial housing, the providing of nectar-rich plants is also beneficial. Often, many species of plants are used so as to provide food for many natural predators. It should be mentioned that many natural predators are nectivorous during the adult stage, but parasitic or predatory as larvae. A good example of this is the soldier beetle which is frequently found on flowers as an adult, but whose larvae eat aphids, caterpillars, grasshopper eggs, and other beetles. The storage environment can also be manipulated in several ways to conserve and enhance numbers and species of natural enemies; such as providing food e.g. honey for parasitoids, changes in storage structure (e.g. illumination) and enhancement of searching efficiency of parasitoids with kairomones (Huis van, 1991). Caswell (1976) suggested that storage of cowpea in the pod and maize in shucks enable the parasitoids of *C. maculatus* and *S. zeamais* to overtake the fast developing population of the bruchid and the curculionidae at a shorter time than shelled in (threshed) cowpea and dehusked / shelled maize.

Another conservation method under the biological control measure and in the realm of habitat manipulation is the use of cover crops (Bugg and Waddington 1994), to attract natural predators of pests. For example, the predator mite *Euseius tularensis* (Congdon) is known to help control the pest citrus thrips. Researchers found that the planting of several different leguminous cover crops (such as bell bean and cowpea) provided sufficient pollen as a feeding source to cause a seasonal increase in *E. tularensis* populations, which with good timing could potentially introduce enough predatory pressure to reduce pest populations of citrus thrips (Grafton-Cardwell *et al.* 1999). The cover crops, known as "trap crops", can also be used to attract pests away from the crop of value (target crop), towards what the pest sees as a more favorable habitat (Shelton and Badenes-Perez 2006). Trap crop areas can be established within crops, within farms, or within landscapes. In many cases the trap crop is grown during the same season as the food crop being produced. The limited area occupied by these trap crops can be treated with a pesticide once pests are drawn to the trap in large enough numbers to reduce the pest populations. In some organic systems, farmers drive over the trap crop with a large vacuum-based implement to physically pull the pests off the plants and out of the field (Kuepper and Thomas 2002). This system has been recommended for use to help control the Lygus bugs in organic strawberry production (Zalom *et al.* 2001).

Other example of ‘trap crops’ are the nematode resistance White mustard (*Sinapis alba*) and Radish (*Raphanus sativus*). They can be grown after a main (cereal) crop and trap nematodes, for example the beet cyst nematode (*Lelivelt et al., 1993; Smith* et al., 2004) and Columbian root knot nematode (*Teklu et al., 2014)*. When grown, nematodes hatch and are attracted to the roots. After entering the roots they cannot reproduce in the root due to a hypersensitive resistance reaction of the plant. Hence the nematode polpuation is greatly reduced, by 70-99%, depending on species and cultivation time.

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BIOLOGICAL CONTROL AGENTS, THEIR EFFECTS AND SUCCESS STORIES

All organisms, including weeds, have other naturally occurring organisms and environmental factors that suppress them, with or without human effort. This is called natural control. Natural enemies of insect and other pests, known as biological control agents, include predators, parasitoids, and pathogens. Biological control agents of weeds include insects, herbivores, cover crops and pathogens; while the biological control agents of plant diseases are referred to as antagonists.

(1) Predators:

Predators are organisms (basically animals), that feed on other (usually lesser) organisms called preys. The larvae of Ladybugs for example, are voracious predators of aphids, and will also consume mites, scale insects and small caterpillars. Similarly, the larvae of many hoverfly or flower fly species in the family Syrphidae, principally feed upon greenfly. One overfly larva can devour up to fifty aphids in a day. They also eat fruit tree spider mites and small caterpillars. Adults feed on nectar and pollen, which spidermites require for egg production. Dragonflies are important predators of mosquitoes, feeding on both the mosquito larvae and adults; while *Polistes* wasps feed on bollworms or other caterpillars on cotton plants (Wikipedia, 2015).

Other useful garden predators include lacewings, pirate bugs, rove and ground beetles, aphid midge, centipedes, spiders, predatory mites, as well as larger fauna such as frogs, toads, lizards, hedgehogs, worms and birds. Cats and dogs kill mice, rats and other rodents, both on the field and in store; while several species of entomo-pathogenic nematodes feed on various insect pests (Beard, 2005).

Major Characteristics of Predators:

The major characteristics of predators include:

Adults and immatures are often generalists rather than specialists.

They are usually not host-specific.

They generally are larger than their prey.

They kill and consume their prey.

Preying mantid consuming insect prey. Picture by Jon Lelito, Dept. of Entomology, Penn State University

Lacewings: a notable bio-control predator insect. *Picture by Pauline Pears.*

(3) Parasitoids and Parasites:

A parasitoid is an organism (usually an insect) which lives and undergoes its development in or on the body of another organism (usually a single host), in a relationship that is basically parasitic; but unlike a true parasite, the parasitoid ultimately sterilizes or kills, and sometimes consumes the host.

A typically parasitic relationship on the other hand, is one in which the parasite and the host interacts without killing the host or hindering its reproductive process. In most such relationships, the parasite obtains its nutrients or other resources to thrive from the host's body without preventing the host from reproducing. In a "parasitoidal" relationship however, the parasitoid kills or sterilizes the host, before it can produce offspring. When a parasite prevents reproduction of the host, the effect is incidental and unusual, but various forms of systematic parasitic castration do occur among parasitoids. (Wikipedia, 2016).

It should be noted however, that many times, there is no clear distinction between the concepts of parasitism and parasitoidy. Many species of true parasites can cause the death of their host if for example they are present in overwhelming numbers or the host is in poor condition, or other compromising circumstances develop, such as secondary infections. In contrast, if a parasitoidal relationship is regarded as a form of parasitism, the parasitoid may be called a necrotroph; while a non-lethal parasite is termed a biotroph (*Academic Press, 2009)*.

Some organisms live as parasites during the early stages of their lives, by behaving as internal parasites, but end up their lives parasitoidally by killing or consuming the host and later emerge as free-living adults. These are called *proteleans*. Protelean organisms are widely regarded as a special class of parasites, or rather, parasitoids; and the most typical examples are the parasitoidal *Hymenoptera, Diptera* and *Strepsiptera* insect groups. Proteleans that do not necessarily kill the host, such as the *Strepsiptera*, may however be counted as parasitoids because they generally sterilize it and prevent reproduction of offsprings.

The behaviors and life cycles of natural enemies can be relatively simple or extraordinarily complex, and not all natural enemies of insects are beneficial to crop production. For example, hyper-parasitoids are parasitoids of other parasitoids.

Major Characteristics of Parasitoids:

They are usually host-specific (Specialized in their choice of host)

They are smaller and reproduce at a faster rate than their hosts.

The live in or on their hosts. Immatures parasitoids remain on or in host, while adults are free-living, mobile, and may be predaceous.

They usually sterilize and kill their host, but not so in parasitism, except under unusual situations *(Kaya, et al., 1993; Pauline, 2005; Gurr, 2016)*

Parasitoids examples include: Ichneumonid wasps: (5–10 mm), that prey mainly on caterpillars of butterflies and moths. Braconid wasps (iny wasps up to 5 mm) attack caterpillars and a wide range of other insects including greenfly. *Encarsia formosa*, a small predatory Chalcid wasps (<3 mm), parasitize eggs/larvae of greenfly, whitefly, cabbage caterpillars, scale insects and Strawberry Moth (*Acleris comariana*). Tachinid flies, parasitize a wide range of insects including caterpillars, adult and larval beetles, true bugs, and others. *Aphidius colemani* (against aphids) and *Eretmocerus* spp. (against white flies)[9] Also, *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae) has been introduced to control the glassy-winged sharpshooter *Homalodisca vitripennis* (Hemipterae: Cicadellidae) in French Polynesia and has successfully controlled ~95% of the pest density *(Hoddle et al., 2006).* True parasites examples include plants mistletoe and cuscuta.

Parasitic wasp *Cotesia congregata* on tobacco hornworm *Manduca sexta*.

Hippodamia glacialis, a predator of aphids. *Photo by J.Ogrodnic*

(4) Pathogenic Micro-organisms or Pathogens:

Pathogens are disease-causing micro-organisms which include bacteria, fungi, viruses, protozoans and nematodes; which kill or debilitate their host and are relatively host-specific. Various microbial insect diseases occur naturally, but may also be used as biological pesticides (called microbial pesticides).

(a) *Bacteria*:

Bacteria are microscopic single-celled plants, which exist in water, air, soil, air, plants and animal body. They are capable of surviving in places where most other living organisms will not survive. Bacteria used for biological control infect insects via their digestive tracts, so insects with sucking mouth parts like aphids and scale insects are difficult to control with bacterial biological control (Swan, 1994). *Bacillus thuringiensis* is the most widely applied species of bacteria used for biological control, with at least four sub-species used to control Lepidopteran (moth, butterfly), Coleopteran (beetle) and Dipteran (true flies) insect pests. The bacterium is available in sachets of dried spores which are mixed with water and sprayed onto vulnerable plants like some fruit trees. *Bacillus thuringiensis* has also been incorporated into crops, making them resistant to these pests and thus reducing the use of pesticides.

(b) *Fungi*:

Fungi are living plants without chlorophyll; so, they live either as *saprophytes* on dead plant bodies, or as *parasites* on other living organisms (plant or animal). They are the most common disease causing organisms in crop plants.

Fungi that cause disease in insects are known as entomo-pathogenic fungi, which include at least fourteen species that attack aphids (Hall and Dunn, 1997). Examples include *Beauveria bassiana* that is used to control a wide variety of insect pests such as whiteflies, thrips, aphids and weevils.

Trichoderma, with about 89 species are used in the control of certain plant pathogens. *Trichoderma viride* has been used to treat the spread of fungal and bacterial growth on tree wounds. *Metarhizium* spp. is used against beetles, locusts and grasshoppers, hemiptera, spider mites and other arthropod pests. *Lecanicillium* spp., against white flies, thrips and aphids; *Paecilomyces fumosoroseus*, against white flies, thrips and aphids; *Purpureocillium lilacinus* against root-knot nematodes, *Entomophaga* spp., Entomophthorales which includes *E. grylli* that infects Orthoptera and *E. muscae* that infects Diptera; etc.

(c) *Viruses:*

A virus is a sub-microscopic, infectious, parasitic protein coated particle, pathogen, or unit, in the borderline of living and non-living things; and which are only visible through electron microscope. Ordinarily, they are inert or inactive, but assumes life on entry into a living tissue of plant or animal.

The European Rabbit (*Oryctolagus cuniculus*) is seen as a major pest in Australia and New Zealand, and a viral biological control that can be introduced in order to control the overpopulation of the rabbit in Australia is the rabbit haemorrhagic disease virus that causes the rabbit haemorrhagic disease. Unlike chemical insecticides, microbial insecticides can take longer to kill or debilitate the target pest. This may limit their use to crops that can sustain some insect damage. To be effective, most microbial insecticides must be applied to the correct life stage of the pest, and some understanding of the target pest's life cycle is required. Some microbial insecticides must be eaten by the insect to be effective. Good spray coverage is therefore important (Hoffmann. and Frodsham, 1993).

General Characteristics of Pathogens:

They kill, reduce reproduction, slow growth, or shorten the life of pests

They are usually specific to target species or to specific life stages of pests

Their effectiveness may depend on environmental conditions or host abundance

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They are relatively slow acting; and may take several days or longer to provide adequate control

Figure 4. Uninfected Beet armyworm (bottom), and beet armyworm killed by a polyhedrosis virus (NPV). Photo credit: David Nanace, USDA ARS, Bugwood.org

(5) Smothering Plants or Cover Crops:

In the general definition of pests, weeds are classified as pests, as they affect crops life negatively. Leguminous plants, that are cover crops, such as *Mucuna pruriens*, are used in some countries like Benin Republic and Vietnam as a biological control agents for the problematic *Imperata cylindrica* grass; [22] while *Desmodium uncinatum* can be used to stop the spread of the parasitic plant called *Striga*.

ADVANTAGES OF BIOLOGICAL CONTROL METHODS:

<u>It is host-specific</u>. The control measure is directed against only one pest, with no negative impact on non-target organisms.

<u>It is non-toxic</u>. Its application leaves no harm in the environment, or creates any danger to the user or consumers of crop / crop products being protected.

It is a financially attractive option. Although initial costs are frequently high, biological control is in the long term cheaper and more beneficial to the economy.

It is permanent where natural enemies are introduced and established, with the aim of sustainably stabilizing the agricultural ecosystem.

It is compatible with other methods, even chemical method, provided the methods are employed selectively, so as not to damage the natural enemies introduced.

DISADVANTAGES OF BIOLOGICAL CONTROL METHODS:

(i) The establishment of 'natural enemies' of pest species is usually difficult because:

(ii) It requires a precise understanding of the ecological conditions of the area before application;

(iii) It requires the cooperation of and coordination among all farmers in the given area, for it to succeed.

(iv) When introducing natural enemies, extensive import and quarantine regulations must be observed, for it to succeed.

(v) It is usually a long term project, as its impact most often becomes apparent after a long period of time.

CHARACTERISTICS OF GOOD NATURAL ENEMIES FOR BIO-CONTROL

A successful natural enemy should have:

(i) High reproductive rate, A high reproductive rate is important so that populations of the natural enemy can rapidly increase when hosts are available

(ii) Good searching ability, The natural enemy must be effective at searching for its host and it should be searching for only one or a few host species. Spiders, for example, feed on many different hosts including other natural enemies.

(iii) Host specificity, A good natural enemy must be host specific, so that control measure can be directed against only one pest, with no negative impact on non-target organisms.

(v) Be synchronized with its host (The target pest). It is very important that the natural enemy occur at the same time as its host. For example, if the natural enemy is an egg parasitoid, it must be present when host eggs are available; and

(iv) Be adaptable to different environmental conditions. A good natural enemy should be able to survive under varying environmental conditions, as they are usually moved away from their natural habitat to other places where they are needed to exercise control on a target pest. It should be noted however, that no natural enemy has all these attributes, but those with several characteristics will be more important in helping maintain pest populations below economic damage or threshold level.

BIO-CONTROL ADOPTION AND FARMER EDUCATION

A potential obstacle to the adoption of biological pest control measures is farmers sticking to the familiar use of pesticides. Thacker, 2002, had claimed that many of the pests that are controlled today using pesticides actually became pests because pesticide use reduced or eliminated their natural enemies. Farmers therefore needs to be properly educated on the benefits of natural or biological control of pests and the easy and practical ways of doing so.

MEASURES AND PRE-CONDITIONS NECESSARY FOR BIO-CONTROL ADOPTION

When launching the programme of biological control, the following steps, pre-conditions and measures needs to be observed, before the natural enemies can be introduced:

(i) Determine the economic significance or threshold level of the pest organisms to be controlled.

(ii) Check the taxonomy of the pest organism and determine whether it is an exotic species or an indigenous one.

(iii) Gather information on the pest organisms to be controlled.

(iv) Identify the existing natural enemies in the environment and elsewhere and determine their efficacy.

(v) Analyze the conditions for introduction and establishment of natural enemies.

(vi) Determine the factors influencing pest population density.

(vii) Calculate the cost-benefit ratio of the planned biological control.

(vii) Finding and procuring the natural enemies.

(viii) Developing and adopting good rearing methods.

(ix) Determining host-specificity of the natural enemies.

(x) Determining the presence or absence of hyper-parasites and such other organisms in the area.

(xi) Measuring effects after the release of bio-control agents.

(xii) Determining the needs of the natural enemy species, so as to create ecological niches in which they can survive during unfavourable conditions

CONCLUSION

The importance of natural enemies in biological pests control cannot be over-emphasized and the future of biological control strategy in pest management is very promising. Educational and extension efforts however, have not provided farmers with the necessary information to help identify natural enemies or determine their presence in fields. Making educators, such as extension agents and farmers aware of the existence of these natural enemies is a very important and necessary step in the adoption and use of bio-control strategy.

Before biological control will advance therefore, much more emphasis needs to be placed on investigating indigenous natural enemies and making farmers to be aware of them and their impact on the pests they attack. With this information it may be possible to foster or enhance the efficacy of natural enemies through manipulation of the crop habitat, changes in cultural practices, or changes in pesticide application practices.

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