Chapter 15
IPM Programs in Commonwealth of Independent States and Russia

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Abstract Main principles of ecological approach to pest and its enemy management both in annual and perennial agro-ecosystem are discussed. The author's approach to cotton protection is orientated towards an elaboration of pest and its natural enemy management strategy. It is based on the usage of environment friendly means for cotton pest management, conservation and augmentation of natural enemy populations in a cotton agro-ecosystem. Correlation between arthropod species diversity, numbers of generalist predators, resistance of plant, and cotton pest population fluctuations laid the foundation of two main parameters for decision making: (a) the minimal zoophage efficiency level, and (b) the dynamic threshold of main pest species, particularly bollworm. The full or partial replacement of broad-spectrum chemical pesticides by bacteria compound and other environment friendly means is a basic demand of the elaborated cotton pest and its enemy programs in Turkmenistan and Tadjikistan. The significant achievements of its implementation in both the countries during 1970s–1980s demonstrate an effectiveness and benefits of an ecological approach to cotton protection.

At present in the southern Russia the typical feature of conventional programs of insecticide treatment in apple orchards is an arbitrary combination of chemical compounds of different characteristics in ecological sense, i.e. use of environment hazardous chemicals after environment friendly one and vice versa. Such alternation of insecticides of opposite vector will never stabilize an apple orchard agro-ecosystem. In the experimental apple pest and its natural enemy program the alternation of only environment friendly compounds have been used, namely, bioinsecticides: Lepidocide^{TM}, Phytoverm^{TM}, and bioregulators: Insegar, Match, Dimmilin which all work in the same direction – stabilization of an orchard agro-ecosystem, i.e. they have equal vector. Under a trial of the suggested program apple fruit damaged by codling moth has been 1.2% in the harvest (ET is 5% of damaged fruit).Thus the possibility of codling moth management without the use of broad-spectrum chemical pesticides in practically possible.

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R. Peshin, A.K. Dhawan (eds.), *Integrated Pest Management: Dissemination and Impact,* DOI 10.1007/978-1-4020-8990-9_15,

Keywords Cotton bollworm · codling moth · economic threshold · species diversity · natural enemy · monitoring · ecological stabilization

15.1 Introduction

In 1970s–1980s of the last century in the Union of Soviet Socialist Republics (USSR) a classical biological control occupied a considerable sector in plant protection system in the country covering an area of 20–25 million hectares annually. The bio-plants network has provided cooperative farms and other agricultural enterprises with living natural enemies (*Trichogramma* spp. mainly) and bacteria compounds in very large quantities.

However, integrated pest management (IPM) program based on mass rearing and release of natural enemies and microbiological insecticide application only has been used in some large–scale greenhouses. As an exception, in the same period of time, the significant progress in development of cotton pest management program was achieved in some Central Asian republics – the process in which the author was involved for a long time. I suppose my own experiences will be useful for the further interpretation of attained results.

Data obtained in an apple orchard in North-West Caucasus recently will be interesting for an understanding of pest and its natural enemy management problems under the condition of perennial agro-ecosystem.

15.2 Part I: Cotton pest and Its Natural Enemy Management

Evolution of integrated pest management concept and its derivative ecological versions (Tshernyshev 2001; Sugonyaev and Monastyrskii 1997, and suggested in this chapter) is closely aligned with cotton insect pest problems and the widespread use of pesticides on the crop. Cotton is a real model for development of ecological approach to a solution of crop pest and its natural enemy management tasks in annual crops.

The Cotton Belt in the Commonwealth Independent States (CIS) occupies an arid territory stretching along the border of Iran in Transcaucasica in the west and Afghanistan in Central Asia in the east.Climatic condition for a cotton growing determines both the production system and the spectrum of arthropod pests. Spring frosts often destroy cotton seedlings, necessitating resowing. Late-sown cotton fields (in half of May) are common in many areas. In general, the growing season begins in early April and ends in late August. Severe winters and short season influence the range of insect pests. Some subtropical specialized cotton pests [*Pectinophora gossypiella, Earias insulana* (Lepidoptera), etc] are absent while generalists are common. The dominant and regular pests are: sucking species – *Tetranichus telarius* (Tetranichidae), *Thrips tabaci* (Thripidae), *Bemisia tabaci* (Aleyrodidae), *Aphis craccivora, A. gossypii, Acyrthosiphon gossypii* (Aphididae), *Lygus gemellatus*

(Miridae), gnawing species – *Agrotis segetum, Spodoptera exigua, Helicoverpa armigera* (Noctuidae). The last species is a key pest, which causes highest losses. The dynamic of population density of cotton bollworm is characteristic of two peaks: the first one is in the middle – late June (the 1st generation), the second is in the middle of July and the beginning of August (the 2nd generation). The 3rd generation takes place in August – September. Moreover, it is known that caterpillars of the 2nd generation are most injurious (see below) while caterpillars of the 3rd generation do not cause any injury. The numbers of cotton aphids complex and spider mite are most in the beginning – middle of July and in August – September while other sucking species (tarnished plant bugs, cicadellids) reach the maximum in middle of August and in the beginning of September, i.e. in the end of the growing season.

15.2.1 The History of the Cotton Pest and Its Enemy Management Conception Development

From the 1950s to the 1980s cotton pest management in the USSR passed through a series of phases (Sugonyaev 1977; 1994). During late 1950s and 1960s chemical control was a single method of the crop protection. A combination of artificially low economic threshold (ET) of cotton bollworm – 2 to 3 caterpillars per 100 cotton plants–provoked frequent, universal, broad-spectrum insecticide treatments, gradual selection of resistant strains of the bollworm and other cotton pests, and suppression of natural enemies activity. This created a system of increasing dependence on pesticides that resulted in up to 10–12 applications per season (Sugonyaev 1977; Kovalenkov and Aleshev 1977). As a result, the pesticide load per hectare in cotton-growing areas was 10 times higher (about 30 kg/ha) than the mean index throughout the country (Sugonyaev, 1994). But the heavy usage of pesticides did not prevent harvest losses caused by pests (Narzikulov and Kovalenkov, 1977). General harvest losses were estimated at about 30%. In addition, pesticide pollution seriously threatened the environment and health of the people.

An unfavourable situation in cotton production prompted Agricultural Ministry of USSR to find causes of such development of events. In 1966 on the initiative of Mr. L.S. Drozdov, Head Department of Outward Plant Quarantine, Dr. M. V. Stolyarov, entomologist of All-Union Institute of Plant Protection, Leningrad, and the author investigated the situation in cotton production in Afghanistan. The objective was to find an answer to the question – why cotton bollworm does not damage cotton seriously at the left bank of Amu-Dariya River, in Afghanistan, as it does at the right bank, in the USSR?

The study of the cotton arthropod community in North Afghanistan (The National Agriculture Station in Baglan-city, Baglan Province) in 1966–1968, where no treatments with pesticides were done, revealed a great share of insect zoophagous species in the cotton field (Sugonyaev et al., 1968, 1971; Sugonyaev, 1969, 1979; Stolyarov et al. 1974a). From approximately 120 dominant and common regular arthropod species inhabiting in cotton field in North Afghanistan, 20% of species fall into plant–feeding category (including 2% of injurious species), 49.1% of species are predators and parasites, and 30.9% of species are so called «indifferent» ones. Species of natural enemies form a specific complex characteristic for the given agro-ecosystem during the whole season. Field surveys showed that initial situation information of the cotton arthropod community in a given field during a definite period of time determines a pattern of species population fluctuation. Total abundance of arthropods is higher in the early-sown cotton field (middle April) (left part of dotted curve in Fig. 15.1) than the same in the field with a late sowing time (middle May) (left part of unbroken curve). As a result, the total number of species (mostly cotton aphid, *Aphis gossypii*) in the late-sown field was 12 times higher than the same in the early-sown one i.e. the former may be characterized as an unsteady field while the latter is a steady one (Fig. 15.1). More detailed analysis has revealed the higher population density of potential aphidophagous species in the early-sown cotton fields with their mild microclimate towards middle half of June (Fig. 15.2A) after their migration from the withering wild landscape. The opposite picture is observed in the late-sown cotton field (Fig. 15.2B). The ratio of natural enemies to that of aphids in an initial period of growing season in fields of both types determines the aphid population fluctuations and absence or presence of injury (Fig. 15.2A, B, the aphid numbers in relation of ET).

Similar course of events was observed regarding the population fluctuations of the spider mite (*Tetranicus telarius*) and the big cotton aphid (*Acyrthosiphon gossypii*). Eventually the important role of aphidophages and general predator's

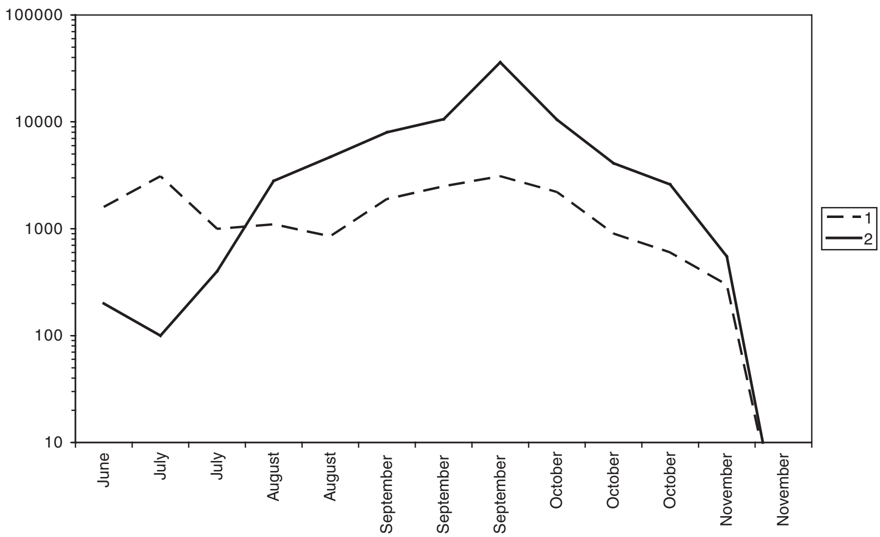

Fig. 15.1 The dynamics of total numbers of harmful and beneficial insects both in early (1) and late sown (2) cotton fields (see in text also). On ordinate axis – numbers, logarithm scale; on abscissa axis – date

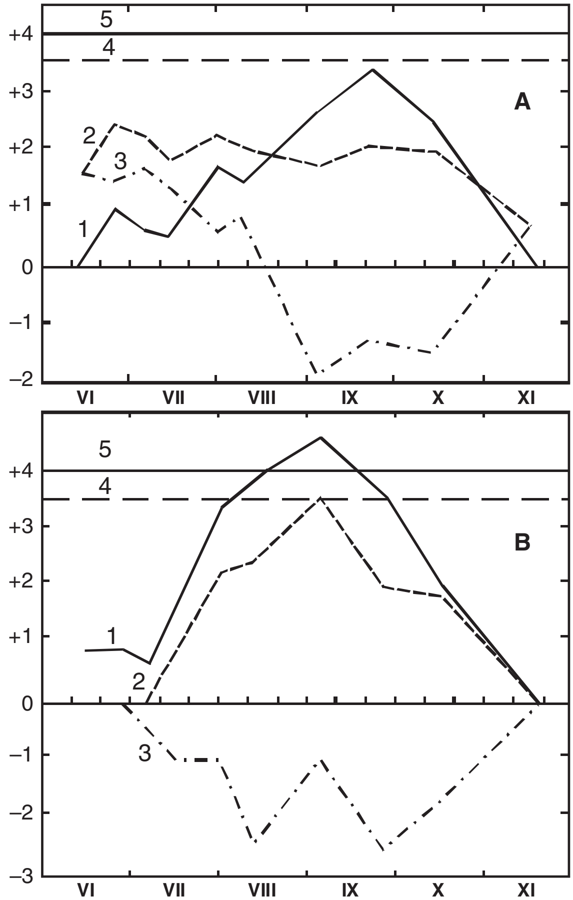

Fig. 15.2 The dynamics of cotton aphid (*Aphis gossipii*) (1) and its natural enemy (2) population density both in the early (**A**) and late-sown (**B**) cotton fields, 3 – the ratio aphidophages: aphids, 4, 5 – the threatening and operative levels of the ET, respectively. On ordinate axis – logarithm of population density and ratio aphidophages: aphids; on abscissa axis – date

activity for aphid population regulation were proved by the field check experiment when natural enemies in half of the plot were eliminated with DDT treatment (Stolyarov et al. 1974b). Cotton bollworm, during of whole period of investigation in North Afghanistan did not attain the status of potential pest (Table 15.1) as a result of natural enemies pressure (Stolyarov et al. 1974b).

Thus, in North Afghanistan population density fluctuations in cotton ecosystem was associated with arthropod species that were determined by factors of natural control, particularly by general predators activity, where pesticides were not applied for cotton protection on a large scale. In general terms, a constant relation of certain natural enemies with a biotope, their polyphagy and considerable numerical

Table 15.1 The damage potential of cotton bollworm in the Baglan area, Afghanistan (1966–1968)

Year	Plants examined	Quantity of generative organs	Damaged by cotton bollworm caterpillars		Number of caterpillars
			Number	%	
1966	2000	26650	72	0.27	13
1967	1300	13030	62	0.52	24
1968	1350	14300	31	0.21	8

abundance determine their important function as «a biological barrier» preventing pest species reproduction (Sugonyaev, 1969).

The data obtained in North Afghanistan showed that an activity of natural enemy populations is an important natural resource which must be conserved for future cotton pest management program. This stimulated a formation of my concept of pest and its enemy management. Pests and its natural enemies are the links of a single food chain in a given agro-ecosystem, and there is a necessity of their maintenance in a definite quantitative frame acceptable from the economic point of view. Thus, definite ground for an agro-ecosystem stabilization is created.

At present, conventional IPM programs are successive series of operations based on an economic threshold (ET) of a given key pest and do not take into account natural enemies activity. As fast as a pest population density reaches ET one perceives this event as a signal for the treatment of a given crop with pesticide, i.e. ET works as a trigger. However, such approach to plant protection contradicts the ecological principles of the early IPM conception orientated on an use of natural enemy activity as an important component of IPM (Bartlett, 1956; Huffaker and Messenger, 1964; Stehr, 1975; DeBach and Rosen, 1991). That is why emphasis on including in the definition the concept of the word «enemy» – pest and its enemy management (PEM).

But in 1968, High Board of Agriculture Ministry of USSR, the official plant protection circles did not accept my concept of cotton pest and its enemy management on ecosystem basis. Their rejection was motivated by the premise: that a plant protection innovation has been developed under the condition of private small farms, thus not suitable for «an industrial socialistic agriculture» (Sugonyaev, 1977). Nevertheless in Zoological Institute of the USSR Academy of Sciences where an intellectual independence and fundamental knowledge development takes place, our data from Afghanistan and my conception found comprehension and further development.

The prerequisites of our ecological approach to a development of cotton pest and its enemy management are: (a) the known data on great extent of natural enemies activity that occurs naturally in agro-ecosystem; (b) the circumstance that 98–99% of all potential pests are already under a natural enemies pressure; (c) some so called «dangerous pests» are a result of destruction of their natural enemies by use of pesticides; (d) the optimization of established natural enemies in a given agro-ecosystem through conservation and augmentation practices which are most real means of decreasing insecticidal treatments, environment pollution and reducing pest control costs.

The data and information obtained in other areas of Turkmenistan are typical of all areas of the cotton belt of CIS. It is important that data on the great intensive cotton fields in the Murgab Oasis demonstrated a universality of ecological regularities which were revealed by us for the first time in Afghanistan on small farmer fields. Several years of observation on the cooperative farm «Teze durmush» (about 2000 hectares) showed that when chemical pesticide treatments were reduced by 80% in 1972 and then stopped altogether in 1973, the index of species diversity ***d*** and mean population density of general predators per single cotton plant increased noticeably. On the whole, an increase in both the species diversity of the arthropod community in general (***d*** ranged from 220 in 1971 to 270 in 1975) and number of predator complex (densities per single plant ranged from 0.9 in 1971 to 3.6 in 1976) was relatively stable and changed slowly over several observation years (Sugonyaev et al., 1977; Alexeev and Niyazov, 1977).

However, under the condition of Baglan Province in North Afghanistan and in the Murgab Oasis the species diversity can change dramatically during the growing season as a result of arthropod species movement both from neighbourhood localities and surrounding fields, particularly from alfalfa fields. Observations in early-sown fields (middle of April) and late-sown ones (middle of May) showed differences in the cotton arthropod community. The temperature and humidity in rows under cotton canopy in the experimental fields explain this phenomenon as a result of the different power of both field types in their attractiveness for a settling with insect species, particularly predators. In the early-sown field a fast growth of cotton creates an optimal microclimate and results in abundant plant exudates secreted by cotton leaves, which attracts adult predators, for example, lacewings (*Chrysopa carnea*) and coccinellid beetles. As a consequences of which, the cotton arthropod community in the early-sown field develops rapidly during late May, resulting in diversity peak in late June (Fig. 15.3(1)). During the same period in the late–sown fields, because of the weak growth of cotton and an unfavourable microclimate, development of the arthropod community takes place very slowly and is ultimately less diverse (Fig. 15.3(2)). Thus, the characters of crop establishment and the abundance of natural enemies in the agro-ecosystem determine a steady or unsteady states of field, which was confirmed by direct surveys (Sugonyaev and Kamalov, 1976).

Significant correlation between diversity index values, a number of generalist predators, and population fluctuation of cotton pests indicate that the diversity index may be used to predict general trends in change of species numbers in a given field. These diversity–index data have been the basis for calculations of the minimal *zoophage efficiency level* (ZEL) required to give acceptable control of pest populations. Narzikulov and Umarov (1977) studied cotton agro-ecosystem in Tadjikistan and concluded that the density of 250–300 natural enemies per 100 cotton plants is enough in order to suppress all pest populations in a given field. They named this density «the entomophage effeciency level». Similar observations were made by Sugonyaev et al., (1977) in Turkmenistan. The generalist predators, zoophages

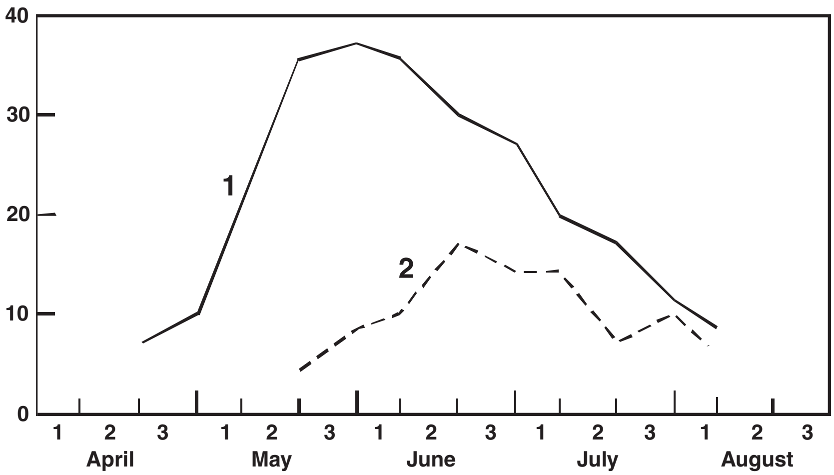

Fig. 15.3 The change in the specific diversity index ***d*** on cotton fields sown in the half of April (1) (every point on the *solid curve* represents a mean index value over 5 years) and those sown during late May (2) (every point on the *broken curve* represents a mean index value over 2 years). $\boldsymbol{d} = \frac{S-1}{\lg N}$, where S – the total quantity of insect species, N – the total quantity of specimens. On ordinate axis – significance of the index ***d***; on abscissa axis – date

attack both insect and mite pests. The ZEL has been found empirically during long-term observation of population fluctuations of both beneficial and harmful arthropod species in cotton fields in different areas of Turkmenistan and determined as the average density of 3 ± 0.5 indicative zoophagous species per 1 cotton plant for management of pest complex in cotton (Sugonyaev, et al., 1977; Sugonyaev, 1994).

In practice, quality of indicative species of zoophages, the most common and easily recognized in the field, are general predators and parasites and these includes predaceous bugs *Nabis palifer* (Nabidae), *Deraeocoris punctulatus, Campylomma* spp. (Miridae), *Orius* spp. (Anthocoridae), ledy beetles *Adonia variegata, Synharmonia conglobata, Stethorus punctillum* (Coccinellidae), lacewings *Chrysopa carnea* (Chrysopidae), predaceous thrips *Aeolothrips intermedius* (Aeolothripidae), *Scolothrips acariphagus* (Thripidae), parasitic wasp *Habrobracon hebetor* (paralysed cotton bollworm caterpillans of 2nd–3rd instars) (Braconidae), wasp *Polistes gallicus* (Vespidae). The population dynamics of predatory species during growing season plays a significant role. The most diverse predatory bug complex (*Orius* spp., *Campylomma* spp., *Deraeocoris punctulatus*) reaches the highest level in the first half of July and remains in stable state before the beginning of September. The numbers of lacewings (larvae) are not high but it is distinguished with stability during June – August period. Lady beetles reach the peak of their numbers in the first half of June and after that stay in a low and stable numbers for rest of the season. On the whole, predator populations density runs to ZEL commonly in middle – last 10 days of July (2.8 specimens per 1 cotton plant), and fluctuates at this level upto the end of August when it reaches the highest value (3.6) (Sugonyaev et al., 1977).

A precise calculation of natural enemies density during twenty four hours indicate that at 9 o'clock the number of predatory bugs *Orius* spp., *Campylloma* spp., *Deraecoris punctulatus* and lady beetls *Adonia variegata* and other species increases in cotton plant canopy, noticeably, and increases or remains at the same level at 12 o'clock. At 15 o'clock the number of most predatory species decreases, but at 18 o'clock it increases again. The exception is the predatory bug, *Nabis palifer* which reaches its quantitative maximum in cotton canopy at 3 o'clock and minimum at 15 o'clock (Tshernyshev et al., 1992). The correct coefficient suggested by Tshernyshev et al. (1992) allows getting more exact information on the predator density at definite times during the twenty four hours (Table 15.2) that has importance for the determination of real ZEL and corresponding decision making.

The effect of the above mentioned indicative zoophagous species on cutworm (*Agrotis segetum*) is insignificant in contrast with cotton bollworm. But the former is infested with the complex of specific parasitic wasps mainly *Apanteles telengai, Rogas dimidiatus* (Braconidae), etc, which parasitized caterpillars at the beginning of summer on a lower scale (on average 8.6%) which is not enough (Eremenko and Ulyanova, 1977; Jumanov, 1977).

The economic threshold (ET) of pest species is the second important parameter in monitoring and decision making process. Fixed ET for any pest species is unreal value. During the plant growth the capacity of plant for compensation of pest damage changes considerably. So, during development of caterpillars of 1st cotton bollworm generation (June – the first 10 days of July) a natural fall of cotton flowers and buds in early (optimal) sown field is about 50–60%, but during of 2nd one (July-August) – 10–15% only (Boldyrev and Kovalenkov, 1977; Sugonyaev unpublished data). That is why the injury of bollworm caterpillars of 1st generation is minimal. Contrary to that the injury caused with cotton bollworm caterpillars of 2nd generation cause maximum losses because the grade of compensation of damaged bolls is low. Clearly a predetermined static ET is not suitable for our case while a dynamic one is a necessity. In accordance with the known data the dynamic ET for bollworm are:

(a) 1st generation – 25 caterpillars or 40 injured fruit per 100 plants for medium staple varieties, and 12 caterpillars or 20 injured fruit for long staple varieties; (b) 2nd generation – 10 caterpillars per 100 plants for medium staple varieties, and 5

Table 15.2 Coefficient for a calculation of real predator population density per 1 cotton plant (in relation of its density at 9 o'clock taken as an unit)

Predaceous species	Time of survey (o'clock)							
	21	24	3	6	9	12	15	18
Deraeocoris unctulatus	1.5	1.3	1.2	1.2	1	1.1	1.8	1.3
Adonia variegate	1.2	1.4	1.2	1.2	1	1.2	1.3	1.5
Coccinella 11-*punctata*	1.2	1.5	1.1	1.1	1	1.4	1	1.7
Propylaea 14-*punctata*	1.7	1.9	1.1	1.1	1	1.7	1.5	1.9
Chrysopa carnea (larvae)	1.6	1.1	2.3	2.3	1	1.7	1.4	2.3

caterpillars per 100 plants for long staple varieties (Tansky, 1969, 1988; Sugonyaev, 1994).

The ET of cutworm (*Agrotis segetum*) changes and dependes on broad-leaf weed density per 1 m^2 or a lack of them in cotton field: (a) no broad-leaf weeds present – 1 caterpillar per 1 m^2; (b) broad-leaf weeds present – 3 caterpillars per 1 m^2. There are two points explaining of this ET variance: first, presence of broad-leaf weeds which distract caterpillars from cotton sprouts, and they concentrate and feed under them; second, in case broadleaf weeds are absent caterpillars attack cotton sprouts. There are economic thresholds for other the major cotton pests but they are static and tentative (Sugonyaev, 1994).

15.3 Accomplishment of Survey, Monitoring and Decision Making

A field survey is the operative ground of PEM program, observations of seasonal changes in species composition and population density of phytophagous and zoophagous species in a given cotton field are made once every week or 10 days. The general sampling scheme includes: a) visual examination of 50 ($p < 0.05$) or 100 ($p < 0.01$) cotton plants, recording the indicative zoophagous species, main cotton pests, and from the beginning of June – caterpillars of cotton bollworm and injured fruit at four points around the field margin (5–25 m from the edge), and sampling of 25 plants (five groups with five plants in the row) at each point; b) the use of pheromone traps attractive for cotton bollworm male moths (1 trap per 2 ha) with the ET an average 3 specimens per 1 trap during a week.

Routinely, only 50 cotton plants are surveyed and simultaneously pheromone traps are checked. In the course of time the cotton bollworm only maintains its status of a pest while other phytophagous species no longer remain pests of any consequences. For example, in Turkmenistan outbreaks of cotton bollworm still occur in favorable years even if predator numbers reach ZEL. However, on average such outbreaks occur once every three years. During two years from three year cycle, cotton bollworm population is controlled by natural enemies, and it is very important to determine when the pest population indicates a tendency to increase.

Late-sown cotton fields attributes to the unsteady type and is more subject to outbreaks of cotton bollworm, cotton aphids and spider mite. More careful survey is desirable, i.e. examination of 100 cotton plants once every week. At farm level, the demonstration of advantages of cotton pest and its enemy management program in the field is essential i.e. in farmer's school, for further extension of the innovated technology of the crop protection. Training of scout personnel from the members of given cooperative or state farms has a decisive and significant role for implementation and adoption of the cotton pest and its enemy management methods. In a given farm trained scouts (who are provided with motorcycles) inspect about 20 ha daily or ~200 ha during every one 10 days' cycle. The field (or plot) where the population of cotton bollworm, for instance, reaches ET marks, the scout puts up a small flag. The scouts pass all information to the supervisor who decides whether control measures are needed. Thus, all data on the cotton field type and population of both pest and zoophage populations are available, and one needs to take it into consideration for decision making. Undoubtedly, a decision making process is most important for implementation of the cotton pest and its enemy program, and it requires to pay attention to some additional question.

The principle of the cotton pest and its enemy management program is the that any broad-spectrum chemical pesticide treatment in a given agro-ecosystem will result in ecological catastrophe by destroying natural enemies activity. Moreover, it provides some positive trends in natural enemies establishment. Balance between ecological and economic expediency is a starting point, and ET must not work as a trigger. In fact every dynamic ET has its economic value which is variable and estimated to cause 5 and 7% yield loss which is acceptable (Tansky, 1988; Sugonyaev and Monastyrskii, 1997). A yield loss compensated should justify the costs, which either does not repay the expenses of protection measure or gives insignificant returns with respect of probable ecological preferences, for example, preservation of natural enemies population density. In other words 5% yield loss is admissible, which is the pay off costs for ecological stability of a cotton agro-ecosystem. If an economic threshold consists of two levels – threatening and operative ones (see below) then the cost of the former is 5% yield loss and of the latter 7%.

This conclusion laid the foundation of the monitoring system for observation of both beneficial and injurious species density on cotton fields with different sowing times. Instead of the conventional monitoring system oriented on a fixed number of cotton bollworm caterpillars per 100 cotton plants for decision making, this innovative system emphasizes the priority of ZEL in a decision making process.

It is obvious that concept of pest and its enemy management (PEM) regard all natural enemy activity in a given agro-ecosystem as a basic and essential component of decision making process. Either we should take into consideration natural enemies activities as a natural part of pest control, or we reject their regulative role as unimportant from practical point of view, and rely on use of broad-spectrum chemical pesticide applications. "Ecologization" and similar unscientific attempts to unite into single IPM program, a natural enemy activity with strong broad-spectrum chemical pesticide application, i.e. use of opposite vectors, when the latter destroys achievement of the former, will never create an ecological stabilization of a given agro-ecosystem.

Thus, there is an urgency to develop IPM program with alternation of environment friendly compounds/measures working in the same direction, i.e. means of equal vector and there is considerable probability to develop an effective PEM program (Sugonyaev, 1994; Sugonyaev and Monastyrskii, 1987) instead of recent interpretation of IPM concept which is based on the use of ET as a trigger for pesticide application. So, a rational decision is based on experienced estimation. If the ZEL is equal 1.0–1.5 indicative species of zoophages per 1 plant then the ET for cotton bollworm, cotton aphids and spider mite remains unchanged. However, if the ZEL is equal to 3 ± 0.5 then the ET for cotton bollworm increases by 50%, e.g. 15 caterpillars per 1 plant on medium staple varieties for the 2nd generation. Thus, two levels of the ET are defined, namely the lower, or *threatening* one (10 caterpillars) and upper, or *operative* one (15 caterpillars). In case of pheromone trap the operative level is 6 adults per trap during a week. Observation of a threatening level calls for a repeat of the inspection of the field after 3–4 days in order to make a definite decision. In the same situation for cotton aphids and spider mite, their ET are increased by 25%. This method of applying variable thresholds related to predator density, i.e. ZEL allows rapid implementation of cotton pest and its enemy management principles among farmers. There are two alternatives: first, if the density of zoophages reaches ZEL or greater than that, and the densities of cotton bollworm and other main pests are lower than ET or nearby it in a given field, then some interventions in natural process must be rejected. Second, if the density of zoophages reaches ZEL, and at the same time the density of cotton bollworm is equal or higher than operative level of ET (15 caterpillars) in a given field a need for immediate pest managing action arises. As the conservation of zoophagous species is one of the primary aims of the pest and its enemy management concept, a choice of some environment friendly measures is a very important part of decision making.

15.3.1 Biological Control Component

Biological control that occurs naturally in cotton agro-ecosystem would be regarded as the backbone of the cotton pest and its enemy management program. An augmentation of established natural enemies in a given field and its role in pest population regulation is a paramount task. Application of bacteria compounds based on *Bacillus thuringiensis*(Bt), or bioinsecticide (BI) is a more perspective way of cotton bollworm suppression without negative impact on both natural enemy populations and diversity of the arthropod community.

The experiments with Bitoxibacillin^{TM} (BTB-202) (1%) and Entobacterin^{TM} (2%) indicated: the biological effectiveness of BTB-202(68.2% against mortality on the second day after application of BI, and 79.5% on the whole). Similar result was obtained with Entobacterin^{TM} (62.1 – and 90.0%, respectively) (Davlyatow, 1977). In other experiments the applications of BTB-202 and Lepidocid^{TM} caused larval mortality of 86 and 88 per cent, respectively after 10 days (Niyazov, 1992). All BI do not kill natural enemies (Davlyatow, 1977; Sukhoruchenko et al., 1976), and they are good tools for cotton pest and its enemy management. From formal toxicological point of view, the above mentioned biological effectiveness of BI is rather low but is satisfactory tool for change of number between prey and predator, in favour of the latter. Thus, an impact of predator activity on a prey population increases significantly without the release of some quantity of predators reared in laboratories. Thus, biological control component of the cotton pest and its enemy management program is a harmonious combination of microbiological and biological agents, thus increasing their effectiveness reciprocally in suppression of pest population.

Augmentation of natural enemies by means of release of parasitic wasps *Trichogramma* spp. and/or *Habrobracon hebetor* for suppression of cotton bollworm eggs and caterpillars, respectively, in Tadjikistan showed unstable effectiveness. As a consequence of *Trichogramma* release at the rate 200000 numbers per 1 ha the quantity of infested cotton bollworm eggs varied from 0.0 to 12.9% on the fourth day after release. The infestation of cotton bollworm caterpillars with *H. hebetor* was 5.3–29.5% (at the rate 200 numbers per 1 ha) (Tashpulatov, 2007). But the same parasitic wasps used at high rates: 600000 specimens per ha for *Trichogramma* sp. and 3000 specimens per ha for *H. hebetor* infested their hosts by 30 and 56%, respectively (Kovalenkov and Aleshev, 1977; Hamraev and Abdel-Kavi, 1977).

15.3.2 Chemical Component

Conventional pesticides are an effective tool for pest population suppression in Tadjikistan but its use is limited in Turkmenistan. The desired characteristics of pesticide based pest management are: (a) selective action on target species, (b) relative harmlessness for natural enemies, and (c) narrow spectrum of action. As a rule, the need for chemical pesticide arises under the condition of late-sown cotton field, an agro-ecosystem of which is more "crumbly", and it is mainly predisposed for sucking pests outbreaks. Selective acaricids, such as chlorfensulfide, dinobuton, dicofol, bromopropylate, halektron, propargite, tedion, and cyhexatrin, are toxic to spider mite (LD_{50} is 0.0006–0.001%) but have minimal impact on natural enemies (Sukhoruchenko et al., 1976; Niyazov, 1992; Sugonyaev, 1994). On the basis of experimental results, phosalone has been chosen for suppression of sucking pest on cotton because its impact on natural enemies is minimal (Table 15.3) (Sukhoruchenko et al., 1976).

Insecticide like carbaryl (carbamate) showed that this compound changes the relation between phytophages and entomophages -: 2.8/1 – before treatment; 16.1/1 – 5 days after treatment, and 237.0/1 – 20 days after treatment, respectively (Sukhoruchenko et al. 1976). A negative influence of this kind of insecticide on the initial ecological situation in the cotton field, i.e. the violation of natural equilibrium between phytophagous and zoophagous species, compelled to recommend bacteria compounds, instead of chemical ones, for example, BTB-202 and Lepidocid^{TM}, which cause bollworm caterpillars mortality about 70–80% (in comparation with carbaryl which has similar effect – 82.2%) without suppression of natural enemies activity in a given agro-ecosystem. It is important to note, the high summer temperature (more 33 °C) may decrease of biological effectiveness of BI that is why these compounds are more effectively applied during the evening hour (Niyazov, 1992). Unavailability of biological means of control is the main reason for chemical pesticide application. In any case, aerial application of chemical pesticide, and so called "prophylactic" application of these must be rejected. Local use of insecticide in a damaged plot or spot application of plot is obligatory.

15.3.3 Agronomic Component Including Environment Manipulation

Several agronomic factors stimulate the rapid growth and closing of the cotton plant canopy, which is needed to produce rapid development of beneficial community

Table 15.3 An impact of phosalone on the number of spider mite, cotton aphids and their natural enemies

Time of survey (Days after treatment)	Population per infested plant and P/PD*											
	Phosalone			Control			Phosalone			Control		
	Spidermite	Acariphage	P/PD	Spidermite	Acariphage	P/PD	Cotton aphids	Aphidophage	P/PD	Cotton aphids	Aphidophage	P/PD
0	116.8	1.86	62.7/1	191.1	1.6	119.4/1	9.0	1.6	5.7/1	4.4	1.8	2.4
9	1.1	2.4	0.4/1	13.0	3.6	3.7/1	2.1	1.5	1.5/1	4.7	5.2	0.9/1
20	6.5	2.5	2.6/1	108.8	3.1	35.1/1	7.9	1.8	4.5/2	12.2	2.3	5.4/1
30	1.2	2.1	0.6/1	177.0	3.7	47.8/1	32.4	3.14	10.3/1	34.4	4.2	8.2/1

* P/PD – prey/predator.

and general stabilization of the agro-ecosystem. These factors include: (a) use of stimulants as seed treatment to accelerate growth of seedlings, (b) optimal sowing season (∼middle of April), (c) sowing on narrow rows (60 cm between rows), (d) sowing on ridges, and (e) precise irrigation scheduling.

The differences in canopy closure between optimal and late plantings can influence the relative humidity and temperature on the soil surface and in the canopy. These differences can influence the development of the beneficial community, which generally prefers a milder microclimate. The unattractive late-sown field microclimate discourages immigration of natural enemies and thereby increases late pest problems.

The frequent alternation of cotton and alfalfa fields in a rotation is desirable because of the similarity between entomophage communities in the two crops (Jaccard's index of similarity: 41.3%) during the first and second years after alfalfa sowing particularly (Niyazov, 1992).

A weed management in cotton field during seedling growth period is a way for decreasing cutworm injury because the destruction of broad leaf weeds provokes passage of caterpillars from weeds to cotton plants. Hence, desirable time for cultivation is conditioned by beginning of cutworm pupation. Suppression of weeds outside the fields must be prudent because many zoophagous species are reproduced in wild grasses in spring and at the beginning of summer.

A fertilization scheduling and composition of fertilizer are important matter for increasing the cotton plant immunity particularly to sucking pest. Periodical use of a balanced NPK compound (without nitrogen surplus) during cotton planting is recommended.

Selection of cultivars resistant to pest is an important measure in increasing of general build up and it provides insurance to the crop against pest attack. As it was ascertained in Tadjikistan the long staple varieties: 9883-I, 6249-V are not attractive for population establishment of cotton bollworm and lygus bug (*Lygus pratensis*). The medium staple variety Mehrgon does not attract cotton bollworm and cotton whitefly (*Bemisia tabaci*) but is highly preferred by lygus bug (Tashpulatov, 2007).

15.4 Impact of Cotton Pest and its Enemy Management Programs

The achievement of cotton pest and its enemy programs development in Turkmenistan and Tadjikistan during the1970s–1980s demonstrates the benefits of an ecological approach to cotton protection. The number of chemical pesticide-treated cotton fields in Turkmenistan in general, and the Murgab Oasis in particular, have decreased: in Turkmenistan, from a high of 850000 treated ha in 1970 to a low of 900 treated ha in 1990, and in the Murgab Oasis, from a high of 120000 treated ha in 1980 to a low of 90 treated ha in 1990, i.e. 13 times and many fields were increasingly left untreated. This is due to natural control forces, natural enemies activity mainly work in these cotton fields. But it is not a return to subsistence (extensive) phase (Doutt and Smith, 1971) as in Afghanistan in the1960s (Sugonyaev, 1969). It is as a result of decision of two basic problems; (a) stopping of natural enemies destruction, (b) finding the methods of their conservation and increasing their regulative role. As a result, over the same period, the use of biological control agents (bacteria compounds mainly) on cotton has increased from 54.8% in 1986 to 85.3% in 1990. Considerable economic benefits took place also – the mean yield of raw cotton in the Murgab Oasis increased by 0.26 tons/ha from 1981 to 1990. In addition, introduction of cotton pest and its enemy management principles in the 1980s–1990s at most cotton plantations in Turkmenistan produced saving about $ 4–5 million annually from reduction in pesticide expenses alone (Sugonyaev, 1979, 1994; Niyazov, 1992; Sugonyaev and Niyazov, 2004).

The decreased threat of pesticide pollution is a major benefit of cotton pest and its enemy management programs that are based on an ecological approach and is a significant step in environment preservation. So, upto 1990 the mean load of pesticides was 0.2 kg/ha throughout Turkmenistan, and 0.1 kg/ha in the Murgab Oasis (Niyazov, 1992) which is considerably lower than amounts previously recorded for Central Asian republics on the whole (Narzikulov and Kovalenkov, 1977).

In Tadjikistan, where more conventional scheme of IPM permitting use of universal, broad-spectrum chemical pesticides has been implemented, the decreasing of the number pesticide-treated cotton fields has decreased 3.5 times from 1967 to 1976 (2000000 hectares in 1967 and 570000 hectares in 1976) (Kovalenkov and Aleshev, 1977). This trend was maintained from 1980 to 1989 (Vanyants, 1991). Economically, cotton IPM program has been very effective, and yield of raw cotton has increased by about 30%. Ultimately the return of expenditure on cotton protection has been 13–14 times higher in the IPM areas, and additional income has equaled $ 1100–1200/ha. Simultaneously, ecological effectiveness of cotton IPM has been significantly high because the mean load of pesticides per hectare has decreased 6.8 time (from 35.2 kg/ha to 5.2 kg/ha) over 20 years.

The characteristic feature of the cotton IPM program in Tadjikistan during 1970–1990 was the combination of *Trichogramma* spp. release, Dendrobacillin™ and broad-spectrum pesticide applications, i.e. biological means and chemical compounds of opposite vectors that resulted in pest outbreaks locally. The cotton pest and enemy management program in Turkmenistan has been based on alternation of environment friendly compounds only working on conservation of natural enemy populations and stabilization of the agro-ecosystem, i.e. means of equal vector. As a result of the number of chemical pesticide-treated cotton fields has decreased more essentially here, and pest density has fluctuated lower ET during long-term time while a high profit of cotton production has been maintained.

General trends in cotton IPM development throughout the world shows that there are two main directions: (a) IPM program based on mathematical simulation model and computer-generated expert system oriented on a wide area; (b) pest and its enemy management (PEM) program based on an empirical data adapted for individual farmer's use.

(a) The main aim of the first, area-wise approach is the development of the model simulated on basic relationships in to the ditrophic system consisting of a plant and its consumer. The ditrophic system is manageable for assimilation of both information on pest population fluctuation in relation to ET and phases of plant growth data necessary for prediction and decision making. However, some attempts of modeling of multitudinous relationships in the tritrophic system consisted of plant, phytophage and its natural enemy on an agro-ecosystem level have been found inoperable. Probably, Thompson (1939) has been the first who showed that "there is no way of developing a method (mathematical, E.S.) that can reduce to manageable form the appalling complexity of natural factors".

The USA and Australia have been pioneers in developing of simulation model and computer-generated expert system for cotton and cotton insects (Luttrell et al., 1994). In 1979 in Albany, Department of Biological Control, University of California, the author had the opportunity to acquaint himself with the work of the operative computer – generated expert system based on the ditrophic system model, which was the great achievement in cotton protection at that time. The use of the ditrophic system model in relation of ET was responsible for the spreading of usage of ET as a trigger for pesticide treatment, commonly in order to prevent increasing pest population from reaching the economic injury level. As a result of this, IPM concept has turned gradually into well regulated program of chemical pesticide applications with all the typical features as the ecological narcotics (DeBach and Rosen, 1991). In spite of the significant progress in the philosophy of integrated pest management in the USA, chemical pesticide applications averaged about 6 in 1992, and in some localized areas, 15 or more applications. In Australia, cotton growers apply 10–12 applications of insecticides to cotton; some apply upwards of 16–18 applications (Luttrell et al., 1994). Similarity of situation with cotton protection in the USA and Australia show inadequacy of the usage of the ditrophic system model oriented on ET as a trigger operation instead of real cotton pest and its enemy management on an ecosystem basis. High number of pesticide treatments will never allow to create an ecological stabilization of a given agro-ecosystem, but are the precursor of unsteady ecological situation, and, in future there is every possibility of the crop failure (Bottrell and Adkisson, 1977; DeBach and Rosen, 1991). Ehler and Bottrell (2000) consider significant difficulties in IPM implementation in the USA as «predicting pest and natural enemy population trends is difficult because of "chaos" in agro-ecosystem». As the above-mentioned authors state, absolute predominance of chemical pesticides in IPM programs, and often, an ignorance of natural enemy populations' activity by many pest consultants are common for contemporary situation in plant protection in the USA (Ehler and Bottrell, 2000).

(b) The second approach in development of cotton protection is based on the FAO principle «a farmer as an expert in his own field», and oriented on elaboration of pest and its enemy management (PEM) program. Apparently, typical features of PEM are:

First- A maximal simplicity in any recommended management strategy (on condition that it is based on thorough fundamental research).

Second- The knowledge of cotton grower about the main harmful and useful arthropod species in cotton field.

Third-The use the zoophage efficiency level (ZEL) as a basic parameter of the systems approach to cotton insect management, and decision making process.

Fourth-The use of the dynamic economic threshold (DET) (different for different generations of target species, and type of cotton plant) for the key insect pests e.g. cotton bollworm.

Fifth-The use of environment friendly compounds only, e.g. bacteria, virus and selective pesticides.

Sixth- The adoption of agronomical measures for creation of an ecologically stable field, e.g. optimal sowing (early) time, right weed management, resistant variety, etc.

Possible criticism of the PEM concept approach can be leveled at the method of decision making process because it is subjective and imperfect. Ehler and Bottrell (2000) mentioned the problems with implementation of IPM in the USA as discussed above. The requirement for precise method results in some additional difficulties. "The monitoring schemes developed for pest and natural enemy populations may be too sophisticated and expensive to be a practical tool for the pest consultant," as highlighted by Ehler and Bottrell (2000). Meanwhile the empirical data of 20 years in different areas of Turkmenistan and Tadjikistan show the ZEL in relation to ET is the reliable method of monitoring and decision making that is the cause for significant decrease of cotton pest injury, and increasing of additional income. Ehler (2000) shared the ZEL concept actually when showed two predatory bugs per plant is enough for beet protection in Northern California.

Any approach to cotton pest and its enemy management must be developed under the different conditions of developed and developing countries and if they reply to one basic arrangement: work on an utilization of the great natural resource – natural enemy populations activity, and stabilization of the agro-ecosystem.

15.5 Part II: Apple Pest and its Enemy Management on an Ecosystem North-West Caucasus, Russia

At present broad-spectrum chemical pesticides cover about 95% of all apple orchards in the south of Russia, nevertheless harmfulness of apple pests, particularly the codling moth (*Cydia pomonella*), remains very high (Storchevaya, 2002). It is known that the great fauna of beneficial arthropod – about 1000 species of natural enemies including 100 ones attacking codling moth – is common for orchards in the south Europe (Zerova et al. 1992). However, this productive natural resource is destroyed recklessly with broad–spectrum pesticides. An urgent search of alternative strategies of orchard protection, an elaboration of apple pest and its enemy management program in orchards based on conservation of natural enemy populations and stabilization of the agro-ecosystem are our research priorities. The research is being conducted in cooperation with All Russian Institute of Biological

Control and Kuban Agriculture University in the Krasnodar area. Two pest species – the codling moth and the green apple aphid (*Aphis pomi*) are the subjects of our examination.

15.5.1 Codling Moth

There is a serious problem with suppression of this key pest which is a real barrier to the development of ecological approach in apple orchards protection in the south of Russia. The cause of failure is an arbitrary alternation of pesticides with different properties in the conventional IPM programs of orchard protection. The official published recommendations on apple orchard protection are: (a) for the Stavropol area (Central Caucasus) in 2003 were alternation of environment friendly (+), and broad–spectrum environment dangerous (−) compounds namely, Insegar (+) → Carhate (−) → Zollon (−) → Phuri (−) → Summiton (−) → Match (+) → Bileton (−); (b) for the Krasnodar area in 2007 – Insegar (+) → Calipso (+−) → Chlorpirhiphos (−) → Match (+) → Zollon (−) → BI58 (−). Typically, the ecological consequences of application of either are ignored. Meanwhile, the use of biological based compounds, e.g. natural hormone analogist (Insegar, Match, etc) and biopreparation (Lepidocid^{TM}, Biotoxibacillin^{TM}, etc), are not harmful for natural enemy populations and promote the agro-ecosystem stabilization. Contrary to this, broad–spectrum chemical pesticides destroy most of arthropods, and in the first turn, natural enemies, thus destabilizing the apple ecosystem.

The conventional pesticide treatment programs are commonly based on compounds of opposite trend, or vector (in ecological sense) when the broad spectrum pesticides negate the gains of biological compounds. From this point view, IPM programs based on alternation of both chemical pesticides and biological based compounds with opposite ecological effects will never create an ecological stabilization of a given agro-ecosystem, and, hence, there is a necessity to develop a program which is only based on environment friendly compounds, working in the same direction, i.e. preparations of equal vector. Thus, the question of the possibility of the use bio-compounds only as a mean of codling moth management came up for research. In 2007, two experimental programs with different alternations of compounds both in the commercial (№.1) and the experimental (№.2) farms have been tried.

In the first conventional apple pest management program the alternation of compounds with different properties, i.e. environment friendly (+) and environment dangerous (−) ones have been used in the succession: Insegar (+) → Cipi plus (−) → Dimmilin (+) → Phosban (−) → BI58 (−) → Diasol (−) → Cipi plus (−) in combination with Match (+) → Lepidocid^{TM}(+) – in all 8 treatments per season (Fig. 15.4). The average number of moth males trapped in pheromone traps exceeded ET in all cases. As a consequence the mean damage of apple fruit by codling moth in all orchards in farm №.1 reaches 18% at the time of harvest (the ET is 5% of damaged fruit) (Fig. 15.4).

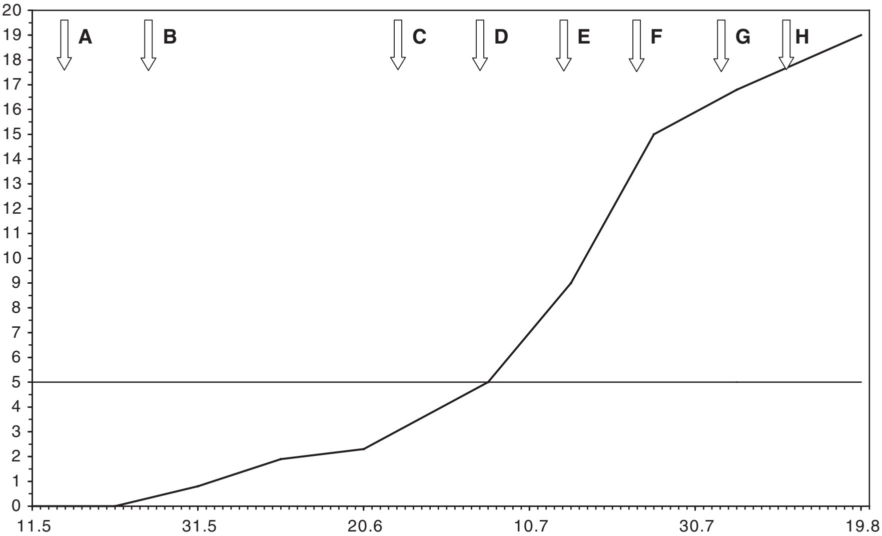

Fig. 15.4 The dynamics of apple fruit damages by codling moth caterpillars in the farm N 1 orchards during summer of 2007 (*curve*). The *arrows* show the treatments with definite compounds (see in text). Horizon line – the ET. On ordinate axis – quantity of damage fruit, %; on abscissa axis – date

In the second experiment, apple pest and its enemy management program the alternation of environment friendly (+) compounds only have been used in the succession: Insegar (+) in combination with Match (+) → Match (+) → Phytoverm^{TM}(+) in combination with Lepidocid^{TM}(+) → Phytoverm^{TM}(+) in combination with Lepidocid^{TM}(+) → Dimmilin (+) – in all 5 treatments per season (Fig. 15.5). During the experiment the monitoring of codling moth population fluctuation carried out with pheromone traps (four traps per hectare).The ET is 8 codling moth male specimens per 1 trap during 1st week. The average number of the hibernated moth males of the 1st and the 2nd generations had exceeded ET, and were twice the number(16 codling moths).

The mean damage of apple fruit by codling moth in two experimental orchards in farm $\mathcal{N}$o. 2 was 1.2% at the time of harvest (Fig. 15.5). The results indicated that; (a) an alternation of environment dangerous and environment friendly compounds in the same insecticide treatment program is not effective, besides (or owing to) its ecological incompatibility; (b) an alternation of environment friendly compounds only in the same insecticide treatment program is effective, ecologically compatible, thus showing the principle possibility of apple pest and its enemy management program as was done in case of cotton crop.

15.5.2 Green Apple Aphid

A high population density of green apple aphid on shoots of apple tree for prolonged time period (April–July) makes it necessary for repeated organophosphorus

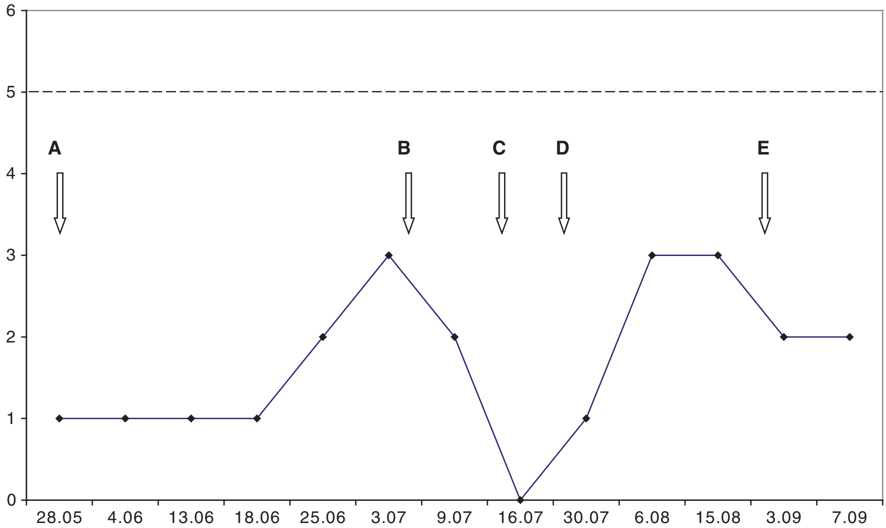

Fig. 15.5 The dynamics of apple fruit damages by codling moth caterpillars in the farm N 2 orchards during summer of 2007 (*curve*). The *arrows* show the treatments with different compounds (see in text). Horizon line – the ET. On ordinate axis – quantity of damage fruit, %; on abscissa axis – date

insecticide treatments. The observations showed a high density of aphid and ants' activity which attended aphid colonies for food and at the same time provided protection against of aphidophages. In this case, the ant species *Formica* sp. was the most in number and aggressively attacked predaceous bug, lady beetle and other entomophages both in aphid colony and outside of it. Novogorodova and Gavrilyuk (2007) have found that many species from the genus *Formica* are most active protectors of aphids. In the aphid colonies protected by *Formica* spp., aphidophages were 5–11 times less than in ones protected by ant species from other genera. Hence, a removal of ant from aphid colony will allow in creating situation favourable for aphidophage activity.

In the experiment where the sticky ring has been made of tree trunk the numbers of the predaceous bug, *Campylomma verbaci*, increased by 4.3 times within fifty days (Table 15.4) while ants disappeared. Simultaneously, the numbers of other species (aphidophages) also increased significantly (Table 15.4). Later in the season, after appricable decrease of aphid population on experimental trees; *C. verbasci* began to migrate from experimental trees and settle on trees infested with aphid. That is peculiar natural insectaries – the phenomenon noted by DeBach and Rosen (1991).

In general, the tree apple system presents a more complicated perennial agroecosystem to manage because of its greater persistence than annuals, as former allows development of a more evolved community of arthropods. Definite obstacle for development of an ecological approach to apple orchard protection is based

Table 15.4 Populaion of green apple aphid, *Formica* ant and aphidophages onexperimental (with sticky ring) and control (without sticky ring) apple trees

Experimental or control trees	Date of survey	Population of aphid counted on 10 shoots 25 cm long/tree, in grade of aphid number per 1 shoot					Number of *Formica* ant	Number of aphidophages				
		I 1–10	II 11–25	III 26–50	IV 51–100	V >100		*Campylomma* bug	Lady beetle	Lace-wing	Syrphyd fly	Cecidomyiid fly
Exp	17.07	3	8	6	8	19	491	25	1	–	–	3
Cont		9	9	8	9	–	143	30	3	–	–	2
Exp	22.07	5	3	2	2	–	–	108	13	–	14	28
Cont		6	5	5	4	–	124	49	–	–	2	11
Exp	30.07	1	–	–	–	–	–	12	–	3	–	–
Cont		5	3	2	3	1	97	18	–	–	–	3
Exp	06.08	2	–	–	–	–	–	14	–	–	–	–
Cont		7	4	3	–	–	48	12	2	–	–	–
Exp	14.08	1	–	–	–	–	–	16	–	–	–	–
Cont		6	2	–	–	–	28	15	–	–	–	1

on the concept of direct or indirect injury of insects (Turnbull and Chant, 1961). But the previous assertion that, codling moth population cannot be controlled with natural enemies because it damages apple fruit directly required reconsideration. At present bio-compounds particularly natural hormone analogs, allow to keep codling moth population lower than ET (Fig. 15.5) without suppression of natural enemies activity that will increase their useful role step by step. The pest species with indirect injury are more manageable with biological control as rise of aphidophage activity in suppression of green apple aphid has demonstrated (Table 15.4).

Acknowledgments Many thanks for supporting our development on ecological approach in apple orchard protection in Krasnodar area, North-West Caucasus to Prof. T.N. Doroshenko (Cuban State Agrarian University) and Dr. V.Ya. Ismailov (All-Russian Institute of Biological Control). My special compliments to my colleagues Dr. V.A. Jakovuk and I.V. Balakhnina (All-Russian Institute of Biological Control), and to Dr. Radjinder Peshin (Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu) for editing the chapter text.

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