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> *No problem can be solved from the same level of consciousness that created it.*
> *Albert Einstein*

> *Truth is lived, not taught.*
> *Hermann Hesse*

Species Diversity and Abundance of Zoophages as a Basic Resource of the Ecological Pest Management Program for Suppression of the Codling Moth *Cydia pomonella* (L.) (Lepidoptera, Tortricidae) and Secondary Arthropod Pests in the Apple Orchard Agroecosystems of Southern Russia

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Abstract—The species diversity and number of zoophagous arthropods as estimated by Margalef's *d* index (1958) are the main biological sources of agroecosystem stability. This fact forms the basis of the ecological pest and its enemy management (EPEM) program, which has demonstrated high technical and ecological efficiency, the former referring to the main task of pest control, and the latter, to survival of the natural enemies of the pest and reducing the level of ecological hazard in orchards. Complete and reduced EPEM programs involving five (EPEM-5), four (EPEM-4) and three (EPEM-3) treatments per season with environment friendly synergistic compounds were tested in the ecological and organic apple orchards in the North Caucasus. The results confirm the possibility to protect the orchards by complete (6 treatments) and reduced (4 treatments) versions of EPEM using ecopreparations (bioregulators: Insegar, Match, Dimilin; biopesticides: Fitoverm™, Fermovirin™, Lepidocide™, etc.) to suppress the codling moth and secondary pests while increasing the activity of natural enemies. The EPEM-4 treatment cost in Krasnodar Territory, Northwestern Caucasus is on average half that of the conventional orchard protection measures.

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In this communication we consider the results and prospects of the program of ecological management of the populations of beneficial and harmful arthropods, aimed at drastic reduction of the pesticide load and the level of damage due to phytophages, obtaining organic fruit, and lowering the costs of protective measures. This is done by the example of our ecological method[1] of suppression of the arthropod apple pests and preservation of species diversity and abundance of their natural enemies.

The main factor that stimulated our work at development of an ecological approach to orchard protection was acknowledgement of inefficiency of the conventional "complex management"[2] program involving

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[†] Deceased.

[1] The basic concept of "ecological plant protection" was proposed by V.B. Chernyshev (2001, 2012).

[2] This approach is also known as "integrated management" but, as can be seen from the notes in this communication, this term is not totally appropriate.

the use of ecologically antagonistic measures, i.e., those with opposite effects on the orchard agroecosystem (Sugonyaev et al., 2008, 2010a). Such measures strongly reduce the beneficial function of the natural enemies and lead to “recovery outbreaks” of the orchard pests, first of all phytophagous mites (Sugonyaev, 2009; Sugonyaev et al., 2010b). We concluded that attempts to improve the “complex management” program would be futile, and that a new strategic approach should be used instead: namely, the development of an *ecological pest and enemy management* (EPEM) program.

The development of the “ecological apple orchard” and EPEM concepts proposed by the first author, and successful testing of the corresponding schedules and biotechnological schemes for 7 years in the south of Russia (Sugonyaev et al., 2008, 2010a, 2010b, 2010c, 2010d, 2011a, 2011b, 2013; Sugonyaev, 2009) brought to the fore the task of studying the activity of the natural enemies as the principal biological resource of the balanced apple orchard agroecosystem.

In view of this, we had to analyze the current concepts of protection efficiency and the adequate ways of its assessment, with respect to both the degree of suppression of the target pest and its safety for the beneficial species, i.e., natural enemies of this pest in the given agroecosystem.

The Concept of Technical or “Biological” Efficiency of Protective Measures and Its Criticism

As of now, the result of a protective measure is mainly evaluated by its **technical efficiency** (*Handbook of Plant Protection*, 1985), which corresponds to the **mortality rate** (%) of the target pest calculated by the formula:

$$C = (a - b) / a \times 100, \qquad (1)$$

where C is the mortality rate, a is the abundance of the pest or damaged fruits before treatment, and b is their abundance at a certain time after treatment.

In our opinion, an essential drawback of the technical efficiency concept as described in the *Handbook of Plant Protection* (1985) and more recent manuals is the absence or scarcity of information on the effect of the given pesticide on the beneficial fauna. Thus, plant protection experts are from the very beginning compelled to ignore the presence of zoophages and their potential role in suppressing arthropod pests, i.e., ecological stabilization of the agroecosystem.

The Concept of Ecological Efficiency and Ways of Its Assessment

Along with the target pest, the beneficial zoophagous species represent an integral component of EPEM. Therefore, assessment of technical efficiency of protective measures should be accompanied by simultaneous assessment of its **ecological efficiency** (the concept was proposed by the first author), which corresponds to the survival rate of zoophages in the given agroecosystem after treatment.

It can be assumed that broad-range pesticides have high technical efficiency but low ecological efficiency of suppression of the target pest; in other words, they destroy the natural enemies of the pest thus creating the prerequisites for its repeated outbreaks.

The ecological efficiency of protective measures can be estimated by the diversity index (d) of Margalef (1958), calculated by the formula:

$$d = S - 1 / \log N, \qquad (2),$$

where S is the number of species and N is the total number of individuals of these species.

Given the basic knowledge of the beneficial orchard fauna, the necessary data can be obtained by surveying the species diversity and abundance of the natural enemies in orchard agroecosystems with different levels of pesticide load:

(1) **organic**, in which all the synthetic compounds including the low-hazardous bioregulators (Match, Insegar, etc.) and biopesticides (Fitoverm) are prohibited[3], whereas preparations based on natural agents (bacterial, viral, and other similar biopesticides), techniques increasing the efficiency of zoophages, and physical methods (light traps) are allowed;

(2) **ecological**, in which hazardous broad-range chemical pesticides are prohibited, whereas low-hazardous synthetic bioregulators and target-specific biopesticides alternating with biopesticides based on natural agents (collectively referred to as *ecopreparations*), and techniques increasing the abundance and activity of zoophages are allowed;

(3) **conventional** or **standard**, in which the “environment friendly management” usually involves treatments with differently acting compounds: both

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[3] With the sole exception of synthetic sex pheromones.

low-hazardous selective preparations and dangerous broad-range chemical pesticides.

The above characteristics of crop protection schemes in these three types of orchards suggest a considerable gradient of toxic land, which, according to the first author, can be described by different *levels of environmental hazard* (LEH). These levels correspond to the classes of toxicity distinguished in the official *State Catalogue of Pesticides and Agrochemicals Allowed for Use in the Russian Federation* (2012): maximum (1), considerable (2), inconsiderable (3), and minimum (4). The intermediate variants are designated by decimal fractions.

To simplify the calculations, each preparation or technique used in the seasonal treatment schedule is recorded together with its LEH value (in parentheses) only once, without regard for its repeated applications.

Let us consider two examples. The biotechnological scheme EPEM-5 realized in an ecological orchard in 2007 can be recorded as follows: Insegar (3) + Match (3) → Match → Fitoverm (2.5) + Lepidocide (4) → Fitoverm + Lepidocide → Dimilin (2.5). The sum of the values in parentheses divided by the number of variants (5) yields the total LEH value of 3, which is quite low.

The biotechnological scheme EPEM-4 realized in an organic orchard in 2010 was based on two types of protective measures: (I) treatment with Fermovirin (4) + Lepidocide (4) + Bacicol (2.5) → Fermovirin → Fermovirin + Lepidocide → Fermovirin + Lepidocide + Fitoverm (2.5); (II) triple installation of dispensers with codling moth pheromone for male disorientation (no LEH value). The sum of the values in parentheses divided by the number of recorded variants (4) yields a comparable LEH value, namely 3.2.[4]

For comparison, let us consider the "environment friendly management" system of apple orchard protection recommended for Krasnodar Territory (Pralya, 2007). This system is based on alternation or even simultaneous use of antagonistically acting compounds, i.e., low-hazardous (+) and hazardous (–) insecticides: Insegar (+) (3) → Calypso (+?) (2.5) → Chlorpyrifos (–) (1.5) → Match (+) (3) in tank mixture with Zolone (–) (1.5) → Calypso (+?) → Bi 58 New (–) (1). The resulting sum (13.5) divided by the number of variants (6) yields 2.25, i.e., a relatively high LEH value indicating considerable mortality of natural zoophages in the orchard agroecosystem.

The outcome of this approach can be considered by the example of the "environment friendly system" of apple orchard protection from arthropod pests, developed in 2002–2008 by the Laboratory of agrocenotic management, All-Russia Institute for Biological Plant Protection (IBPP) and based on alternation of differently acting compounds. Application of this system in the environs of Eisk led to degradation of the orchard ecosystem, mass reproduction of the brown fruit mite *Bryobia redikorzevi*, and the rates of fruit damage by the codling moth steadily growing from 2.5% in 2003 to 34.2% in 2008, despite the doubled number of pesticide treatments: from 6 to 12 a season (Sugonyaev et al., 2010a, 2010d).

Another similar example is the scheme realized in 2007: Insegar (+) (3) → Cipi Plus (–) (1.5) → Dimilin (+) (2.5) → Fosban (–) (1.5) → Bi 58 New (–) (1) → Diazinon (–) (1.5) → Cipi Plus (–) → Match (+) (3) → Lepidocide (+) (4). This system had a fairly high LEH value of 2.2; as a result, the rate of fruit damage by the codling moth exceeded 19% while the outbreak of phytophagous mites became persistent.

The above data clearly demonstrate the need for development of the ecological method of apple orchard protection. Of primary importance is assessment of ecological efficiency of EPEM based on Margalef's *d* index for zoophages and the LEH value for the agroecosystem.

To increase the efficiency of field surveys of zoophages in apple orchards, we recommend that the survey should cover about 30 conspicuous and easily recognizable **indicator species**, including groups of species from certain taxa, such as spiders (Table 1). A single survey record includes the data on all the zoophages found on 50 shoots of the current and preceding years (two shoots from each tree, taken from the illuminated and shaded sides of the crown). Three surveys are carried out during the season: at the end of May, in the middle of July, and in the middle of August. Their results are pooled to obtain the mean value of the *d* index for the season.

We performed such surveys in 2008–2012[5] in the environs of Krasnodar, in organic and ecological apple orchards of the Kuban test farm of Kuban State Agri-

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[4] Fitoverm and Bacicol were not regularly used in the EPEM schemes during 5 seasons; the former was used twice, the latter, only once.

[5] In 2008 the surveys were carried our by E.S. Sugonyaev and I.V. Balakhnina, in the subsequent years, by I.V. Balakhnina.

Table 1. Indicator species of the natural enemies of apple orchard pests in Krasnodar Territory

Species	Feeding type	Abundance		Notes
		mass	common	
1	2	3	4	5
Order Coleoptera (beetles), family Coccinellidae				
Two-spotted ladybird *Adalia bipunctata* L.	pred.	+		An active predator attacking aphids on trees
Seven-spotted ladybird *Coccinella septempunctata* L.	pred.		+	Occurs on trees, but more often on herbaceous plants
Fourteen-spotted ladybird *Propylea quatuordecimpunctata* L.	pred.		+	A generalist predator consuming aphids, psyllids, and moth eggs
Ladybirds *Scymnus* spp., adults	pred.		+	In aphid colonies
Ladybirds *Scymnus* spp., larvae with wax cover	pred.		+	In aphid colonies
Stethorus punctillum Wse.	pred.		+	In spider mite colonies
Order Hymenoptera				
Ichneumonid wasp *Pimpla turionellae* L.	par.		+	A pupal parasite of codling moth
Pteromalid wasp *Dibrachys cavus* Walk.	par.		+	A pupal parasite of codling moth
Garden ant *Formica cinerea* Mayr	pred.?	+		A predator but protects aphid colonies
Black garden ant *Lasius niger* L.	pred.?		+	A predator but protects aphid colonies
Chalcid wasp *Brachymeria* sp.	par.		+	A pupal parasite of tortrix and other moths
Eulophid wasp *Colpoclipeus* sp.	par.		+	A pupal parasite of tortrix moths
Braconid wasp *Ascogaster* sp.	par.		+	A larval parasite of codling moth
Sceleonid wasp *Telenomus* sp.	par.		+	An egg parasite of lackey and gypsy moths
Order Heteroptera (true bugs)				
Mullein plant bug *Campylomma verbasci* M.-D.	pred.	+		A predator of aphids and brown apple mite
Minute pirate bug *Orius* sp.	pred.		+	A predator of small arthropods
Broad-headed bug *Camptopus* sp.	pred.		+	A generalist predator
Order Neuroptera				
Green lacewing *Chrysopa carnea* Steph.	pred.	+		A predator of aphids and spider mites
Order Diptera				
Aphid midge *Aphidoletes aphidimyza* Rond.	pred.	+		Orange-colored larvae are common in aphid colonies
Silver fly *Leucopis* sp.	pred.		+	More robust, whitish-pink larvae are common in aphid colonies
Flower flies Syrphidae genn. spp.	pred.	+	+	Large flattened larvae are common in aphid colonies
Tachinid fly *Bessa* sp.	par.		+	A larval parasite of lepidopterans
Tachinid fly *Neoplectus* sp.	par.		+	A larval parasite of codling moth
Dance flies Empididae, *Empis* sp.	pred.		+	Predators of small dipterans and phytophagous mites
Long-legged flies Dolichopodidae genn. spp.	pred.		+	Predators of small soft arthropods

Table 1 (Contd.)

Species	Feeding type	Abundance		Notes
		mass	common	
1	2	3	4	5
Order Thysanoptera (thrips)				
Aeolothrips intermedius Bag.	pred.		+	Predators of small soft arthropods
Order Acarina (mites)				
Red velvet mites Trombidiidae	pred.		+	Attack arthropods
Order Aranei (spiders)				
Running crab spiders Hilodromidae genn. spp.	pred.		+	Generalist predators attacking insects
Sheet weavers Linyphiidae genn. spp.	pred.		+	Generalist predators attacking insects
Wolf spiders Lycosidae genn. spp.	pred.		+	Generalist predators attacking insects
Jumping spiders Salticidae genn. spp.	pred.		+	Generalist predators attacking insects
Crab spiders Thomisidae genn. spp.	pred.		+	Generalist predators attacking insects

Notes: pred. means predator, par. means parasite.

cultural University (KSAU) (5 ha) and in a traditional orchard of IBPP (5 ha) positioned 3 km south of the ecological orchard. The results are shown in Fig. 1.

The *d* index values were considerably high, stable, and similar in the organic and ecological orchards, whereas the corresponding values in the traditional orchard were much lower (Fig. 1). Plotting of the mean *d* and LEH values for the entire observation period in the three types of orchards (Fig. 2) revealed a distinct trend: the higher the LEH value, the lower the *d* index.

These data demonstrate a high level of ecological efficiency of EPEM realized in the organic and ecological orchards owing to the reduced impact on the zoophages. This is manifested, in particular, by the stable low abundance of phytophagous mites and the San Jose scale *Diaspidiotus perniciosus*, which were actively suppressed by their natural enemies and did no detectable damage (Sugonyaev et al., 2010b, 2011a, 2013). The opposite situation was observed in the orchard with the conventional management system, where outbreaks of the spider mite *Tetranychus urticae* and the brown fruit mite took place in 2008 (Sugonyaev et al., 2010b, 2013)[6] while the population of the San Jose scale reached high abundance in 2011 (unpublished data of L.A. Vasilyeva). In all those cases, the outbreaks of pests led to additional treatments with highly toxic broad-range pesticides, such as Preparat 30.

To conclude this section, it should be noted that the ecological efficiency of the regulatory ecopreparations used in EPEM is also manifested by the noticeable decrease in the total pesticide load. According to the data of Ryabchinskaya and Kharchenko (2006), LD_{50} of these preparations exceeds 5–10 g/kg; in other words, they are three orders of magnitude less toxic than the majority of chemical insecticides.

Development, Testing, and Evaluation of the Biotechnological Epem Schemes in an Ecological Apple Orchard

The problem of suppressing the target pest and increasing the regulatory role of its natural enemies can be solved by developing the biotechnological schemes of EPEM combining the minimum anthropogenic impact, i.e., a small number of treatments with ecopreparations, with the maximum technical efficiency.

The main results of field testing of various biotechnological schemes of codling moth suppression in the ecological orchard of the Kuban test farm during 7 years in 2007–2013 are shown in Fig. 3. It can be concluded that the tested EPEM schemes with 5 or 4 treatments a season showed high or acceptable levels of technical efficiency: only 0.3–2.5% of the harvested fruits were damaged by the codling moth, whereas the conventional economic threshold of damage (ETD) in ecological agriculture is 5%. The results of testing of

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[6] No leaf damage by mining moth larvae was recorded in these orchards.

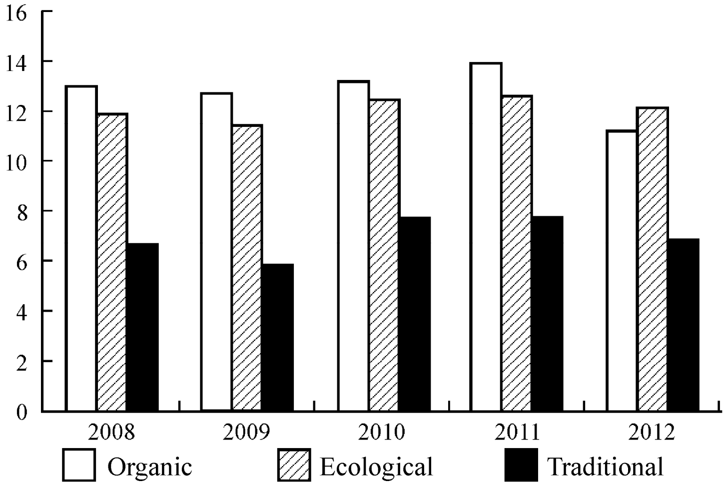

Fig. 1. The values of Margalef's *d* index in the organic, ecological, and traditional apple orchards in the environs of Krasnodar (IBPP and the Kuban test farm) in 2008–2012. Abscissa: years; ordinate: Margalef's *d* index.

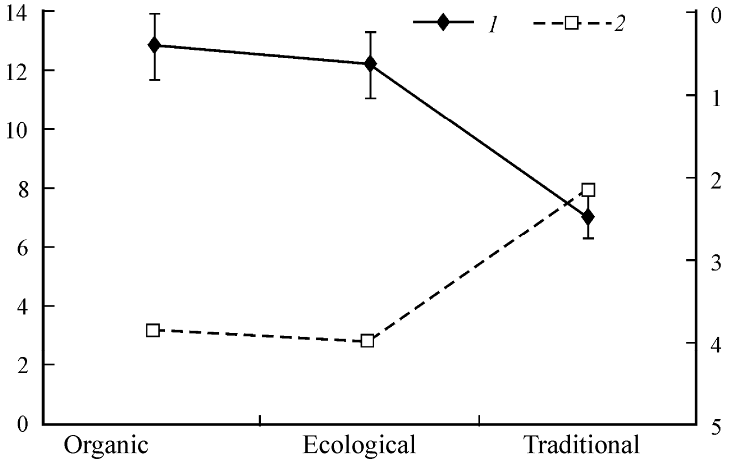

Fig. 2. The mean values of Margalef's *d* index and the level of ecological hazard (LEH) in the organic, ecological, and traditional apple orchards (IBPP and the Kuban test farm). Abscissa: orchard type; left ordinate: Margalef's *d* index (1); right ordinate: level of ecological hazard (2).

EPEM-3 schemes were not as definite; they will be considered below.

It should be noted for comparison that in the season of 2006, preceding our tests, 62.5% of the harvest of this orchard was damaged by the codling moth in spite of 5 treatments with broad-range organophosphoric insecticides (Fig. 4). In the following season (2007), realization of the biotechnological scheme EPEM-5 (five treatments with ecopreparations) reduced the harvested fruit damage rate to 1.2% (Fig. 4). High technical efficiency of EPEM based only on ecopreparations was demonstrated for the first time in this experiment (Sugonyaev et al., 2008).

The results of testing of the biotechnological EPEM schemes in 2007–2013 are shown in Fig. 3. The EPEM-5 scheme tested in 2007 was aimed at suppressing the codling moth and such secondary pests as the apple aphid *Aphis pomi* and the rose leafhopper *Typhlocyba rosae* and included the following tank mixtures and individual ecopreparations: (treatment I) Insegar with Match (halved dosages); (II) Match; (III) Fitoverm with Lepidocide; (IV) Fitoverm with Lepidocide; (V) Dimilin. The level of fruit damage by the codling moth varied during the season within the range of 0–3%, and the mean damage to harvested fruit was 1.2% (Fig. 3); thus, the technical efficiency of this scheme was sufficiently high.

During the cold May and June of 2008 (mean temperatures 15.9 and 20.6°C, respectively), the flight intensity of males of the overwintered codling moth

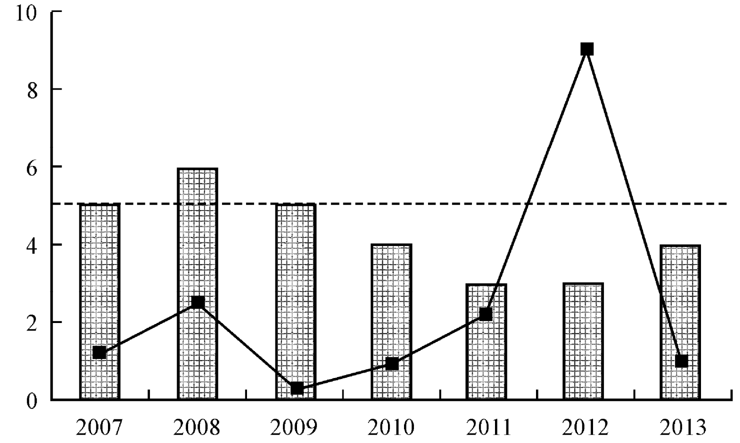

Fig. 3. Results of development and testing of biotechnological EPEM schemes aimed at suppressing the codling moth in the ecological apple orchard of the Kuban test farm in 2007–2013. Abscissa: years; ordinate: broken line: level of damage of harvested fruit by codling moth larvae, %; histogram: number of treatments with ecopreparations; dashed line: economic threshold of damage (ETD) of the codling moth. Fruit yield (Liberty variety, tons/ha): 14.9 in 2007; 12.0 in 2008; 10.1 in 2009; 16.8 in 2010; 18.0 in 2011; 17.9 in 2012; 18.1 in 2013.

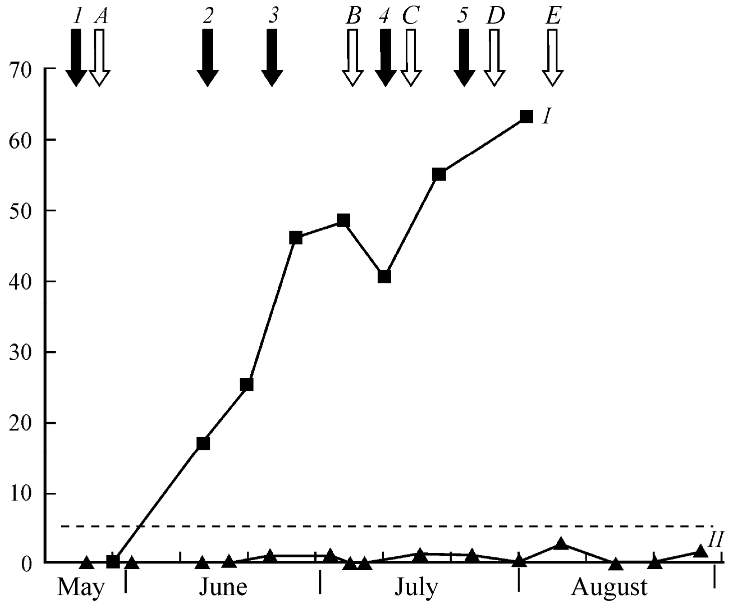

Fig. 4. Dynamics of fruit damage by the codling moth in the stock apple orchard of the Kuban test farm in 2005–2007. Abscissa: months; ordinate: levels of damage of harvested fruit by codling moth larvae, %. (*I*) implementation of the conventional "pest management system" in 2006; dark arrows: (*1*) Carbophos, (*2*) Actellic, (*3*) Zolone, (*4*) Zolone, (*5*) Rogor; (*II*) implementation of EPEM-5 in 2007; *light arrows*: (*A*) Insegar + Match (halved dosages), (*B*) Match, (*C*) Fitoverm + Lepidocide, (*D*) Fitoverm + Lepidocide, (*E*) Dimilin. Dashed line: economic threshold of damage of the codling moth.

generation did not exceed 4 ind. per trap per week; this value was below the two-level (dynamic) economic threshold of damage (TETD) used in our research (Fig. 5). In this situation, we decided to test the risk of deviation from the EPEM-5 scheme by replacing bioregulators with bioinsecticides in the first two treatments. The targets were the codling moth, San Jose scale, and rose leafhopper; the treatments were as follows: (I) Fitoverm in tank mixture with Lepidocide; (II) Fitoverm and Lepidocide; (III) Insegar mixed with Match (halved dosages); (IV) Fitoverm and Admiral; (V) Dimilin.

Replacement of bioregulators with bioinsecticides in the first two treatments proved to be technically inefficient: the damage of growing fruits by the codling moth larvae of the 1st summer generation reached 10.0%. This situation called for two treatments with Insegar and Match (halved dosages) instead of only

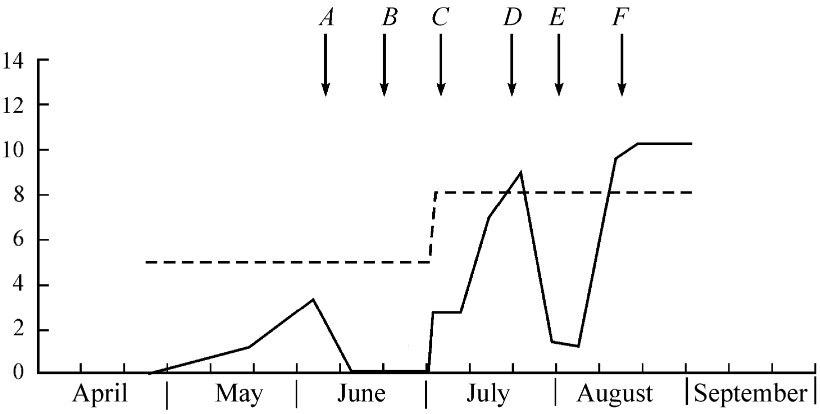

Fig. 5. Flight dynamics of codling moth males in the ecological apple orchard of the Kuban test farm in 2008. Abscissa: months; ordinate: dynamics of male captures (mean number of ind. per trap per week). Arrows: treatments with ecopreparations: (*A* and *B*) Fitoverm + Lepidocide, (*C* and *D*) Insegar + Match (halved dosages), (*E*) Fitoverm + Admiral, (*F*) Dimilin. Dashed line: two-level (dynamic) economic threshold of damage (TETD).

one treatment that had been originally planned (Fig. 5). As a result, the fruit damage level dropped to 0–3% while the mean number of larvae caught in belt traps on the apple tree trunks decreased from 4 ind. per belt in the 1st generation to 0.2 ind. per belt in the 2nd generation. Thus, control of the codling moth population was reestablished but at a price of increasing the number of treatments to 6 a season (Fig. 3). The mean damage to harvested fruit was 2.5% (Fig. 3), which corresponded to acceptable technical efficiency.

At the same time, low abundance of males of the overwintered generation (Fig. 5) was followed by a considerable level of fruit damage by larvae of the 1st summer generation, confirming the absence of distinct correlation between these parameters in the codling moth (Trapman et al., 2008).

In 2009, the biotechnological scheme of EPEM-5 was developed with the preceding results taken into account and realized under the conditions of more favorable temperatures of May and June (16.2 and 23.7°C, respectively) and active flight of codling moth males, noticeably exceeding the TETD (Fig. 6). The scheme was aimed at suppressing the codling moth, the gypsy moth *Ocneria dispar*, the peach weevil *Rhynchites bacchus*, and the leaf beetle *Luperus xanthopoda*, and included the following treatments with tank mixtures and individual preparations: (I) Insegar in tank mixture with Match (halved dosages) and Lepidocide; (II) Insegar with Match (halved dosages), Lepidocide, and Bacicol; (III) Match with Lepidocide (a halved dosage); (IV) Insegar; (V) Dimilin.

The level of fruit damage by the codling moth varied during the season within the range of 0–2%; the damage to harvested fruit was 0.3% (Fig. 3), indicating high technical efficiency of this biotechnological scheme.

To test the reduced variant of EPEM presuming a more intensive function of the zoophages, in 2010 we implemented the biotechnological scheme of EPEM-4 to suppress the codling moth, the peach weevil, the leaf beetle *L. xanthopoda*, the apple aphid, San Jose scale, and the rose leafhopper. It included the following tank mixtures: (I) Insegar with Dimilin (halved dosages), Lepidocide, and Bacicol; (II) Insegar with Match (halved dosages), Lepidocide, Fitoverm, and Admiral (halved dosages); (III) Insegar with Dimilin (halved dosages), Fitoverm, and Lepidocide; (IV) Insegar with Dimilin (halved dosages), Fitoverm, and Lepidocide. The level of fruit damage by the codling moth varied during the season within the range of 0–2.5%; the damage to harvested fruit was 0.9% (Fig. 2), which corresponded to high technical efficiency of EPEM-4.

Following the trend for reducing the number of treatments in the biotechnological schemes of EPEM, in 2011 we tested the scheme of EPEM-3 aimed at suppression of the codling moth and the apple sawfly *Hoplocampa testudinea* and using tank mixtures of the following ecopreparations: (I) Insegar with Dimilin (halved dosages), Fitoverm, Lepidocide, and Bacicol; (II) Insegar with Match (halved dosages), Fitoverm, and Lepidocide (halved dosage); (III) Insegar with Match (halved dosages) and Lepidocide. The level of fruit damage by the codling moth varied during the season within a somewhat broader range of 0–5%; the damage to harvested fruit was 2.2%

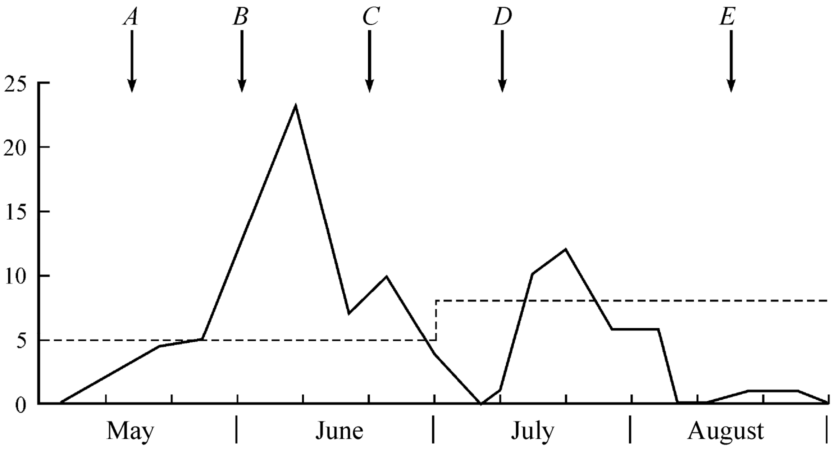

Fig. 6. Flight dynamics of codling moth males in the ecological apple orchard of the Kuban test farm in 2009. Abscissa: months; ordinate: dynamics of male captures (mean number of ind. per trap per week). Arrows: treatments with ecopreparations: (*A*) Insegar + Match (halved dosages) + Lepidocide, (*B*) Insegar + Match (halved dosages) + Lepidocide + Bacicol, (*C*) Match + Lepidocide (a halved dosage), (*D*) Insegar, (*E*) Dimilin. Dashed line: two-level (dynamic) economic threshold of damage.

(Fig. 3), which still showed acceptable technical efficiency though the value was noticeably greater than that in other EPEM schemes.

The results of testing of EPEM-3 should be considered in greater detail. The specificity of this biotechnological scheme is the presence of large intervals of 35–50 days between treatments with ecopreparations, which creates two factors reducing its efficiency: first, the protective action of bioregulators may attenuate by the end of the intervals; second, some adults and larvae of the codling moth may avoid the action of bioregulators while some moths may immigrate from the nearby orchards. According to the data of control pheromone traps installed along the ecological orchard perimeter about 200 m away from its boundaries, the greatest number of immigrants was observed in the northwestern sector, where from 7 to 40 moths were captured weekly in one trap.

A survey of the abundance of the codling moth larvae and pupae in the ecological orchard of the Kuban test farm in 2011 showed that in the EPEM-3 variant, 46 larvae were captured in 10 belt traps by September 13 (Sugonyaev et al., 2013). Thus, the density of the overwintering larvae was 4.6 ind. per trap, i.e., twice the assumed TETD.

It seemed that the biotechnological scheme of EPEM-3 could ensure an acceptable level of harvest protection from the codling moth in the given year but at the same time facilitated population growth and potential damage of the pest in the following season. To test this assumption, we repeated the biotechnological scheme of EPEM-3 in the ecological apple orchard in 2012. The density of flying males at the beginning of the season exceeded the TETD (Fig. 7) due to a considerably high abundance of the overwintered larvae. In this case, the technical efficiency of EPEM-3 proved to be too low to suppress the pest: the fraction of damaged fruits increased gradually and reached 9.0% by the moment of harvesting (Fig. 8). Thus, the scheme of EPEM-3 should be generally avoided; it may be used only as an inexpensive interim measure of orchard protection but it should always be replaced by EPEM-4 (in a critical case, even by EPEM-5) in the following season.

In 2013, when we returned to the biotechnological scheme of EPEM-4, the following situation was observed in the ecological apple orchard. The early and intense flight of adults of the overwintered generation reached its peak in the middle of May and then declined steadily (Fig. 9). The level of fruit damage varied during the season within the range of 0–3%; the damage to harvested fruit was 1%, i.e., EPEM-4 once again demonstrated its high technical efficiency (Fig. 10). It should be noted, however, that the harmful activity of the codling moth was generally low in 2013: the fraction of damaged fruits on the control trees at the end of the season was only 9.8%, i.e., much smaller than in the preceding years (see below). In sum, we can characterize EPEM-4 as the best scheme in terms of both harvest protection and *economic viability*. The recommended dates of treatment and dosages of ecopreparations in all the biotechnological EPEM schemes are given in our manual of the

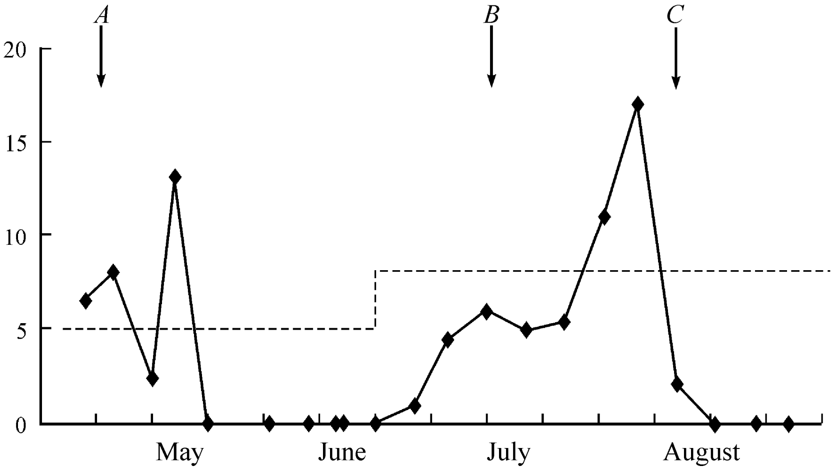

Fig. 7. Flight dynamics of codling moth males in the ecological apple orchard of the Kuban test farm in 2012. Abscissa: months; ordinate: dynamics of male captures (mean number of ind. per trap per week). Arrows: treatments with ecopreparations: (*A*) Insegar + Dimilin (halved dosages) + Fitoverm + Lepidocide + Bacicol, (*B*) Insegar + Match (halved dosages) + Fitoverm + Lepidocide (a halved dosage), (*C*) Insegar + Match (halved dosages) + Lepidocide. Dashed line: two-level (dynamic) economic threshold of damage.

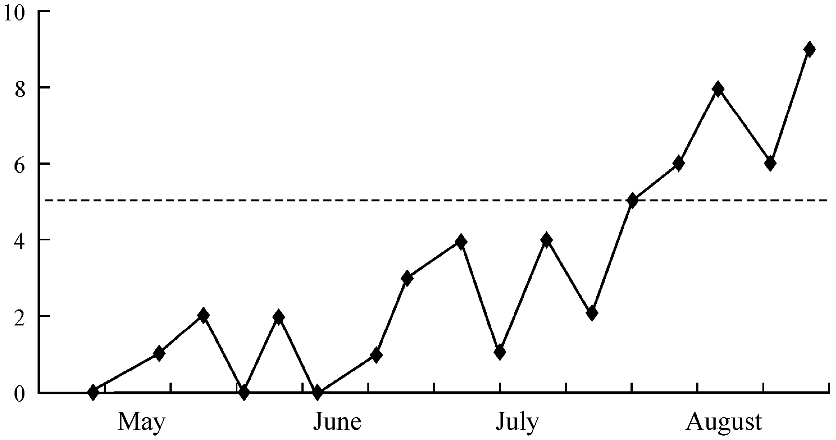

Fig. 8. Dynamics of fruit damage by the codling moth in the organic apple orchard of the Kuban test farm in 2012. Abscissa: months; ordinate: level of fruit damage by codling moth larvae, %. Dashed line: economic threshold of damage.

ecological method of apple orchard protection (Sugonyaev et al., 2013).

Simultaneously with our observations in the ecological orchard, fruit damage by the codling moth was monitored in the control group of apple trees not subjected to any treatment, which grew very close to the ecological and organic orchards. The level of fruit damage in the control at the end of the season was 28.8% in 2008, 25.4% in 2009, 42.4% in 2010, 83.1% in 2011, and 9.8% in 2013; there was no harvest in 2012. These data indicate high potential harmfulness of the codling moth in the orchards of the Kuban test farm, which can be realized if the protective measures are absent (as in the control group) or inefficient (as in the ecological orchard in 2006 when the level of fruit damage reached 62.5%).

Our experience of development and testing of the various biotechnological schemes of EPEM can be summarized as follows.

(1) Of fundamental importance is the fact that the EPEM schemes based on synergistic selective ecopreparations (bioregulators and bioinsecticides) can provide sufficient means of keeping the codling moth and secondary pest populations below the level of economic significance without the need for polytoxic chemical pesticides which are traditionally regarded as the only guarantee of crop protection.

(2) Ecopreparations, i.e., bioregulators of growth and development of the codling moth (the juvenoid Insegar, the chitin inhibitor Match, etc.) should **always** be included in the mixtures used against the larvae and

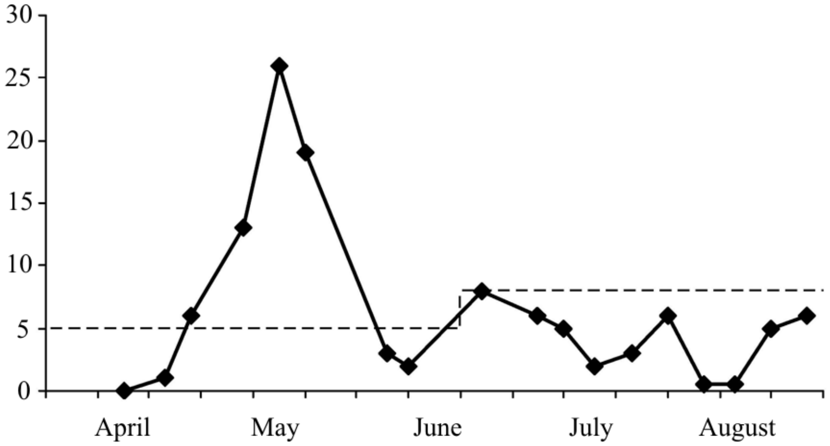

Fig. 9. Flight dynamics of codling moth males in the ecological apple orchard of the Kuban test farm in 2013. Abscissa: months; ordinate: dynamics of male captures (mean number of ind. per trap per week). Dashed line: two-level (dynamic) economic threshold of damage.

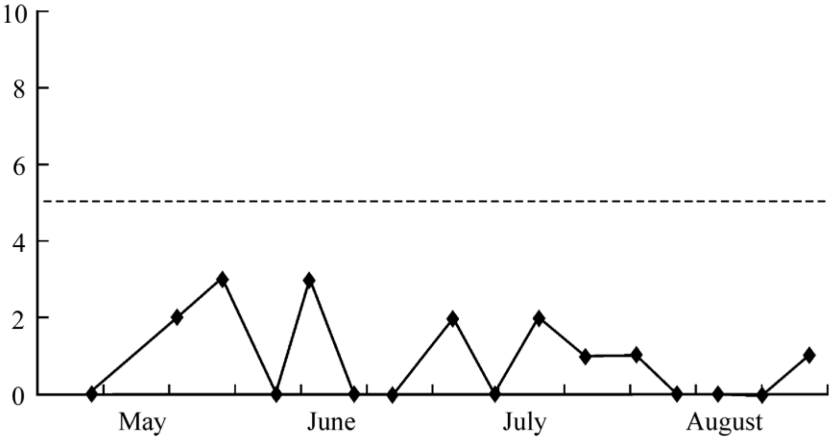

Fig. 10. Dynamics of fruit damage by the codling moth in the organic apple orchard of the Kuban test farm in 2013. Abscissa: months; ordinate: level of fruit damage by codling moth larvae, %. Dashed line: economic threshold of damage.

adults of all the generations, regardless of the number of males captured in pheromone traps and that of larvae found in fruit samples (since these parameters are not consistently correlated).

(3) The high protective capacities of EPEM and the specific regime of an ecological apple orchard allow one to develop an EPEM scheme with fewer treatments per season: EPEM-4 and EPEM-3. Of these, EPEM-4 is the optimum variant.

(4) The smallest possible number of treatments in the North Caucasus is three, which corresponds to the number of the codling moth generations in that region. The minimum number of treatments in the natural zones where the pest develops in two or one generations is still to be determined.

(5) In the control group of untreated apple trees, the level of fruit damage by the codling moth at the end of the season varied from 9.8 to 83.1% in 2008–2013, indicating high potential harmfulness of the pest in the study region.

(6) The five years of observations did not reveal any acquired tolerance of the codling moth populations to the bioregulators used in the EPEM schemes.

(7) The absence of such acquired tolerance may be the result of using a combination of bioregulators with different biological mechanisms (juvenoids, chitin inhibitors).

The Cost of Different EPEM Schemes in an Ecological Apple Orchard

The cost of the orchard protection measures is the main criterion of their **economic efficiency**. The conventional “management systems” suppress the target pest without considering the beneficial activity of its natural enemies in the orchard agroecosystem and destroy these enemies by highly toxic broad-range pesticides acting by the "scythe principle" (see Bey-Bienko and Sugonyaev, 1970). Thus, they waste a valuable biological resource which would ensure low abundance and negligible harmfulness of phytophagous mites, mining moths, and San Jose scale. As mentioned above, elimination of the natural enemies of potential pests facilitates an increase in the pest activity. This invariably leads to more intensive use of chemical pesticides, increasing the production cost and reducing the total profitability.

Let us consider the present state of the pesticide market and the common practice of apple orchard protection in Russia.

Ecopreparations manufactured by foreign companies (Syngenta, Crompton, Sumitomo Chemical) and imported in Russia, such as Insegar, Dimilin, Match, and Admiral, as well as some domestic ecopreparations, such as Fitoverm and Agrovertin, are quite expensive and show the negative tendency of constantly rising in price. According to our calculations based on the price lists of domestic sellers (Agrotech, Sober-Argo, Agriplant, Alsiko-Agroprom), the prices of the principal ecopreparations (per 1 kg or 1 l) grew from 2007 to 2011 by 650 rubles for Insegar, 90 for Dimilin, 332 for Match, and 330 rubles for Fitoverm. At the same time, the price of the polytoxic insecticide Zolone grew by mere 50 rubles during the same period. In the absence of state subsidies stimulating purchase and use of low-hazardous pesticides, the Russian agricultural producers experiencing the common shortage of funds would evidently prefer the seemingly less expensive "standard pest management." The possible risk of getting on the "pesticide treadmill" which may bring the farm to disaster due to the pesticide syndrome (Doutt and Smith, 1971) is usually overlooked.

As of 2011, most farms of Krasnodar Territory implementing "standard pest management," i.e., treatments with insecticides, acaricides, and fungicides, had to spend 28–30 thousand rubles per 1 ha of orchard; specialized apple producers spent up to 48–50 thousand rubles per 1 ha (Taranenko, 2011). Although the cited author did not specify the exact number of pesticide treatments in these farms, it is known that up to 12–14 treatments per season are used in typical apple orchards, and 20 treatments and more, in "specialized" ones.

Based on our long-term experience, we can state that the biotechnological schemes of EPEM, selectively suppressing the target pest and sparing the beneficial natural enemies of this pest by the "rapier principle" (Bey-Bienko and Sugonyaev, 1970), constitute a valid alternative to the growing costs of orchard protection. These schemes ensure the functioning of local entomophages in the orchard agroecosystem, increasing its total stability and reducing the costs of crop protection.

Our calculations based on the available price lists of 2009–2011 yielded the following estimated costs of orchard treatment in the different variants of EPEM (not counting the fungicides):

EPEM-5: 16 584 RUB/ha;

EPEM-4: 14 622 RUB/ha;

EPEM-3: 11 721 RUB/ha.

It can be seen from these estimates that implementation of EPEM schemes is less expensive than "standard pest management": by approximately 1.5 times for EPEM-5, by 2 times for EPEM-4, and by almost 2.5 times for EPEM-3. Thus, the high price of bioregulators and biopesticides are compensated for by the limited number of treatments in the EPEM schemes. Demonstration of the advantages of the biotechnological EPEM schemes, based on the achievements of fundamental science, stands in contrast with the narrow-mindedness of agricultural authorities and some agricultural research institutions which still rely on the futureless "standard pest management," i.e., intensive use of highly toxic broad-range pesticides.

The Product Purity

The purity level of the ecological orchard product is determined by a considerably lower toxic load on its agroecosystem due to the hazardous chemical pesticides being replaced by ecopreparations, and also due to the limited number of treatments per season. Chemical analysis of apples of Florina variety from the ecological orchard harvest of 2010 (Table 2) showed that the concentration of toxicants in them was an order of magnitude below the permissible values, so that these apples could be classified as "green" or ecologically pure.

In 2013, a more precise analysis of apples of Liberty variety (similar to Florina) from the ecological orchard of the Kuban test farm (Table 3) confirmed the results of 2010. Moreover, this analysis showed

Table 2. Analysis of apples of Florina variety from the ecological orchard, performed at the toxicological laboratory of the North Caucasian Zonal Research Institute for Gardening and Viniculture. Test record sheet 132 of 01.XII.2010

Standard toxicants tested	Regulatory document defining the testing methods	Permissible concentration, mg/kg	Test results, mg/kg	Measurement error
Lead	State Standard 30118-96	0.4	0.008	± 0.001
Cadmium	State Standard 30178-96	0.03	0.003	± 0.001
Mercury	State Standard 26927-86	0.02	< 0.001	± 0.0001
Arsenic	State Standard 26938-86	0.02	< 0.001	± 0.0001
HCH (isomers)	State Standard 30349-96	0.05	< 0.001	± 0.001
DDT (metabolites)	State Standard 30349-96	0.1	0.002	± 0.001
Cuproxat	State Standard 26931-86	5.0	1.69	± 0.004

Table 3. Analysis of apples of Liberty variety from the ecological orchard, performed at the toxicological laboratory of the North Caucasian Zonal Research Institute for Gardening and Viniculture. Test record sheet 123 of 26.IX.2013

Standard toxicants tested	Regulatory document defining the testing methods	Permissible concentration, mg/kg	Test results, mg/kg	Measurement error
Lead	State Standard 30178-96	0.4	0.009	± 0.001
Cadmium	State Standard 30178-96	0.03	0.002	± 0.001
Mercury	State Standard 26927-86	0.02	not found	
Arsenic	State Standard 26927-86	0.2	not found	
Copper	State Standard 26927-86	5.0	2.06	± 0.005
HCH (isomers)	Operations Manual 1541-76	0.05	not found	
DDT (metabolites)	Operations Manual 6129-91	0.1	< 0.001	± 0.0001
Bi 58 New	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.02	not found	

that the concentrations of toxicants in the fruit continued to decrease: four of the toxicants that had been present in 2010 were not detected at all in 2013 (Table 2). By contrast, apples of the local Gala variety (Agronom agroindustrial firm) obtained from the retail chain revealed a broader range and higher concentrations of chemical pollutants (Table 4).

The Results of EPEM Development for an Organic Aplle Orchard

The status of an organic orchard permits the use of a very limited number of EPEM components, especially bioregulators. According to our results, the viral bioinsecticide **Fermovirin** (EuroFerm, Germany) in a dosage of 2 standard capsules per 1 ha (tank mixture) can be the principal ecopreparation in such orchards. A small batch of Fermovirin was obtained by IBPP for testing.

As the result of field experiments with various combinations of ecopreparations in an organic apple orchard of the Kuban test farm in 2007–2013, we were able to reduce the number of treatments in the EPEM schemes from 8 to 4, whereas the total damage to harvested fruit by the codling moth dropped below the ETD in 2010 (Fig. 11) (Doroshenko et al., 2011; Sugonyaev et al., 2011a). We implemented a reduced biotechnological scheme of EPEM-4 with triple installation of dispensers with the female sex pheromone to disorient the codling moth males. The dispensers (in the total number of 160) were fixed with rubber bands on the branches, one on each tree. Besides the codling moth, EPEM-4 was aimed at suppressing the peach weevil and the rose leafhopper. It comprised the following treatments: (I) Fermovirin in tank mixture with Lepidocide and Bacicol + dispensers against males of the overwintered generation; (II) Fermovirin in tank mixture with Lepidocide; (III) Fermovirin in tank mixture with Lepidocide + dispensers against males of the 1st summer generation; (IV) Fermovirin in tank mixture with Lepidocide and Fermovirin (halved dosage) + dispensers against males of the 2nd summer generation (Fig. 11).

Table 4. Analysis of apples of Gala variety (Agronom agroindustrial firm, obtained from the local retail chain), performed at the toxicological laboratory of the North Caucasian Zonal Research Institute for Gardening and Viniculture. Test record sheet 124 of 26.09.2013

Standard toxicants tested	Regulatory document defining the testing methods	Permissible concentration, mg/kg	Test results, mg/kg	Measurement error
Lead	State Standard 30178-96	0.4	0.023	± 0.003
Cadmium	State Standard 30178-96	0.03	0.007	± 0.001
Mercury	State Standard 26927-86	0.02	< 0.001	±0.0001
Arsenic	State Standard 26927-86	0.2	0.003	± 0.001
Copper	State Standard 26927-86	5.0	3.25	± 0.003
HCH (isomers)	Operations Manual 1541-76	0.05	< 0.001	± 0.0001
DDT (metabolites)	Operations Manual 6129-91	0.1	0.004	± 0.001
Bi 58 New	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.02	0.01	± 0.008
Khorus (Cyprodinil)	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.4	0.17	± 0.003
Topsin-M	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.5	0.13	± 0.002
Komfort	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.05	0.02	± 0.005

The observed dynamics of damage to the growing fruits by the codling moth was largely the same as in the preceding years: low or zero damage in May–June, a gradual increase in July, and the maximum in the middle and the second half of August (Fig. 14). However, as the result of EPEM-4, the damage to the ripening fruits in the middle of August 2010 did not exceed the ETD and constituted 4.6% (Fig. 11), including the apples containing the pest larvae with arrested development. If the latter group were excluded, the level of damage to harvested fruit would drop to 2.2%, indicating acceptable technical efficiency of EPEM-4 (Fig. 11).

Testing of EPEM-3 that involved 3 treatments with Fermovirin combined with other ecopreparations and triple installation of pheromone dispensers in the season of 2011 revealed an insufficient level of technical efficiency: the damage of harvested fruit by the codling moth reached 8.1% (Fig. 11). Testing of EPEM-4 in the season of 2012 failed because Fermovirin lost its virulence, possibly due to prolonged storage (2 years). In spite of other control measures (treatment with Lepidocide, installation of dispensers), the pest activity started to grow noticeably and the damage of harvested fruit by the codling moth increased to 12% (Fig. 11).

Having considered this situation, in 2013 we tested an enhanced EPEM variant consisting of 6 treatments with high-quality Fermovirin in combination with Bitoxybacillin and Lepidocide and 4 installations of pheromone dispensers (Fig. 12). This biotechnological scheme, which may be conditionally called EPEM-6, allowed us to keep the fruit damage by the codling moth within the range of 0–3% during the season and to reduce the damage of harvested fruit to zero (Figs. 11, 12), i.e., it had a high level of technical efficiency.

According to our data, EPEM-4 and EPEM-6 with bacterial preparations can be recommended for use in organic apple orchards in southern Russia. Another conclusion from the results obtained is that no less that 4 treatments with Fermovirin (EPEM-4) and 3 installations of sex pheromone dispensers should be used each season; deviation from this scheme may reduce the technical efficiency of crop protection. Ecological efficiency of EPEM-4 proved to be the highest in the organic orchard, as can be seen from the maximum values of Margalef's *d* index (see Figs. 1, 2). The activity of zoophages maintains the permanently low abundance of phytophagous mites (Sugonyaev et al., 2010c), the apple aphid (in the absence of the ants *Formica cinerea* in the tree crowns; see Sugonyaev and Balakhnina, 2009), the pear lace bug *Stephanitis pyri*, San Jose scale, the peach weevil, and other sec-

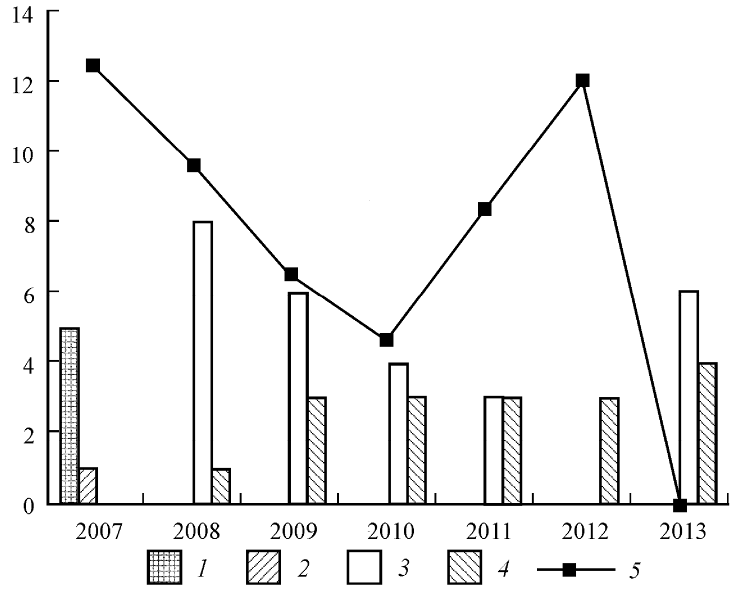

Fig. 11. Results of development and testing of EPEM (combined with installation of pheromone dispensers) in the organic apple orchard of the Kuban test farm in 2007–2013. Abscissa: years; ordinate: histograms: number of treatments with ecopreparations and other measures: (*1*) Fitoverm + Lepidocide, (*2*) installation of 100 pheromone traps per ha to deplete the codling moth male pool, (*3*) Fermovirin + Lepidocide, (*4*) installation of pheromone dispensers on each tree to disrupt mating of the codling moth; broken line (5): level of damage of harvested fruit by codling moth larvae, %; Fruit yield (Liberty variety, tons/ha): 8.9 in 2007; 23.2 in 2008; 18.0 in 2009; 24.4 in 2010; 19.0 in 2011; 25.0 in 2012; 20.1 in 2013.

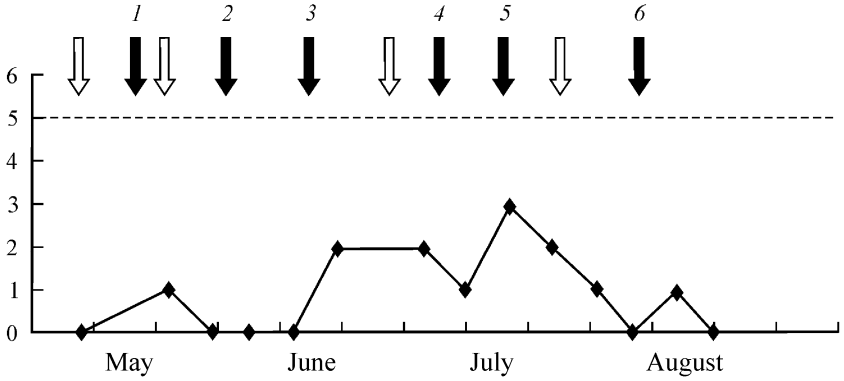

Fig. 12. Dynamics of fruit damage by the codling moth during testing of the EPEM-6 scheme with 4 installations of pheromone dispensers in the organic apple orchard of the Kuban test farm in 2007–2013. Abscissa: months; ordinate: level of fruit damage by codling moth larvae, %; dark arrows: treatments with ecopreparations: (*1*–*3*) Fermovirin + Bitoxybacillin; (*4*–*6*) Fermovirin + Bitoxybacillin + Lepidocide; *light arrows*: installation of pheromone dispensers; Dashed line: economic threshold of damage.

ondary pests, a trend worth developing. The codling moth shows characteristic dynamics of abundance and harmfulness, which are low in the first half of the season and increase in the second half (Figs. 13, 14). This pattern, observed in all the 6 seasons, probably reflected immigration of adult moths from the orchards positioned northwest of the Kuban test farm. These migrations require a special study (planned for 2014–2015) using pheromone and light traps, to determine the dynamics of both sexes. This phenomenon seems to be responsible for an increased harmfulness of the codling moth despite the high values of *d* index. It should be noted that the abundance of another species capable of immigration, the rose leafhopper, also shows weak dependence of the index. To suppress this pest, we included a halved dosage of Fitoverm in the tank mixture of the IV treatment of EPEM-4. As concerns the ecological purity of experiments in the organic orchard, it was the highest, no traces of chemical pollutants being found in the fruits in 5 out of 8 cases (Table 5).

The Legislative Support of Development and Introduction of EPEM in the Ecological and Organic Apple Orchadrs in Russia

Despite the advantages of EPEM considered above, the decisive factor in choosing between EPEM and conventional measures by Russian agricultural pro-

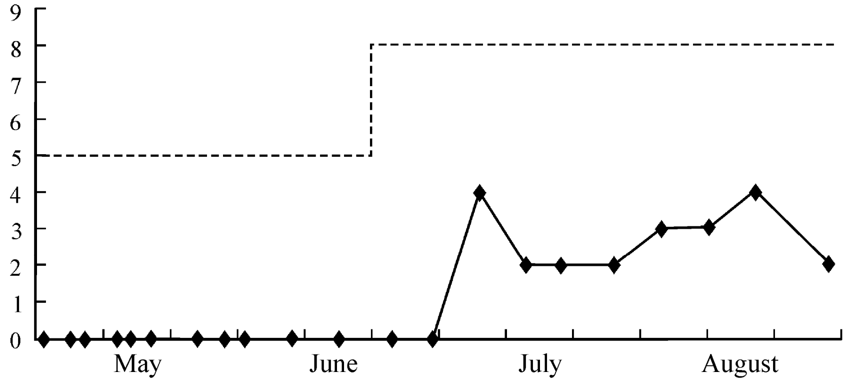

Fig. 13. Flight dynamics of codling moth males in the organic apple orchard of the Kuban test farm in 2010. Abscissa: months; ordinate: dynamics of male captures (mean number of ind. per trap per week); dashed line: two-level (dynamic) economic threshold of damage.

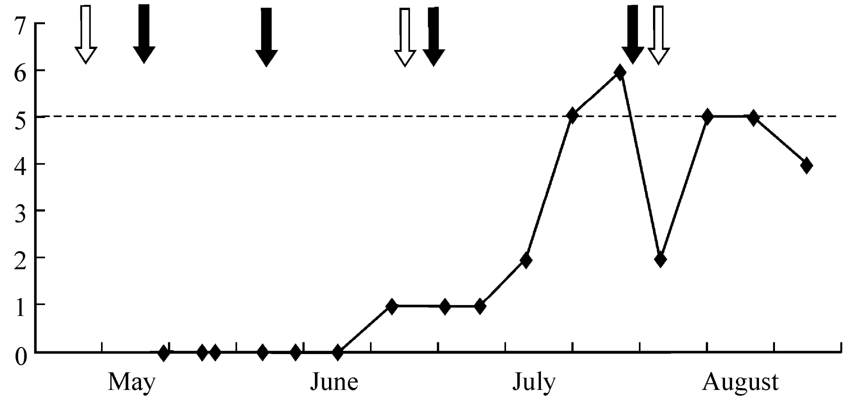

Fig. 14. Dynamics of fruit damage by the codling moth in the organic apple orchard of the Kuban test farm in 2010. Abscissa: months; ordinate: level of fruit damage by codling moth larvae, %; dark arrows: treatments according to the EPEM-4 scheme; light arrows: installation of 160 pheromone dispensers; dashed line: economic threshold of damage.

Table 5. Analysis of apples of Liberty variety from the organic orchard, performed at the toxicological laboratory of the North Caucasian Zonal Research Institute for Gardening and Viniculture. Test record sheet 125 of 26.IX.2013

Standard toxicants tested	Regulatory document defining the testing methods	Permissible concentration, mg/kg	Test results, mg/kg	Measurement error
Lead	State Standard 30178-96	0.4	0.005	± 0.001
Cadmium	State Standard 30178-96	0.03	not found	
Mercury	State Standard 26927-86	0.02	not found	
Arsenic	State Standard 26927-86	0.2	not found	
Copper	State Standard 26927-86	5.0	1.84	± 0.002
HCH (isomers)	Operations Manual 1541-76	0.05	not found	
DDT (metabolites)	Operations Manual 6129-91	0.1	< 0.001	± 0.0001
Bi 58 New	*Manual of Identification of Trace Quantities of Pesticides in Foods* (1992)	0.02	not found	

ducers is likely to be the absence of formalized position of the state favoring the use of more expensive but low-hazardous and efficient ecopreparations, which would allow the farmers to use fewer treatments, produce ecologically pure crops, and reduce the level of environment pollution. By contrast, the EU states provide legislative support of development of ecological agriculture, in particular gardening. Of considerable importance is the higher price of officially certified "green" products as compared to those grown under heavy pesticide load. Among the CIS states, legislative acts in support of ecological agriculture have been adopted so far only in Moldova (Voloshchuk, 2010).

CONCLUSIONS

(1) The species diversity and abundance of beneficial zoophagous species, estimated by Margalef's *d* index, is the principal biological resource of the agroecosystem that determines the intensity of stabilization processes in it.

(2) The ecological efficiency of protective treatments can be assessed by the survival rates of zoophagous species, i.e., by changes of Margalef's *d* index following the treatment.

(3) The conventional pest management systems, including the "ecology-oriented" ones, involve the use of differently acting (antagonistic) preparations. They have high technical efficiency but at the same time they eliminate the natural enemies of the pests and thus disturb the orchard agroecosystem. Their ecological inefficiency increases the number of chemical treatments needed to suppress the "recovery outbreaks" of pests, up to the level at which farming becomes unprofitable.

(4) The programs of ecological management of pests and beneficial species (EPEM) are based on similarly acting (synergistic), low-hazardous ecopreparations. They successfully suppress the pests but preserve the beneficial arthropod fauna, i.e., they have high technical and ecological efficiency and can reliably protect the crops with a limited (5 or even 4) number of treatments.

(5) The EPEM schemes considerably reduce the toxic load on the apple orchard agroecosystem estimated by the level of ecological hazard (LEH), thus facilitating its stabilization and yielding ecologically pure products.

(6) The innovative nature of EPEM consists in rejecting the outdated and ecologically unsound, mostly chemical methods of orchard protection and advancing to the new strategic level of management of harmful and beneficial arthropod populations.

(7) Simple implementation of EPEM in the ecological apple orchard and its relatively low cost (on average half that of conventional treatments) are the prerequisites of its large-scale introduction into practice, which is an essential condition of increasing domestic production of ecologically pure fruit.

(8) Implementation of EPEM-4 in the organic apple orchard, involving 4 treatments with Fermovirin combined with other ecopreparations and additional use of the male disorientation method (3 installations of dispensers per season) kept the fruit damage done by the main and secondary pests below the ETD, i.e., had an acceptable level of technical efficiency. In critical situations, EPEM-6 can be used to protect the crops.

(9) EPEM as an essential element of ecological agriculture requires legislative support which would create a solid organizational basis for its introduction and increase its commercial appeal.

ACKNOWLEDGMENTS

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