The use of economic thresholds in pest management: apples in South Africa

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MONITORING SYSTEMS AND ECONOMIC thresholds can be used to determine the necessity for and timing of measures to control herbivorous arthropods which attack agricultural crops, particularly high-value ones such as apples. The data obtained from these monitoring systems, however, have far wider applications than just determining whether or not control measures are required. They can be used to decide the pest status of herbivorous arthropods, whether or not sporadic pests require attention during a particular season, to refine the timing of actions against perennial pests and to determine the effectiveness of measures applied to control chronic pests. Optimum use of monitoring data can help local exporters to supply unblemished fruit with the minimum use of insecticides to South Africa's main foreign markets, the European Union and the United States.

Introduction

The discovery of the insecticidal properties of DDT (diphenyltrichloroethane) in 1932 by Mueller heralded the widespread use of organic insecticides in agriculture.[1] After the initial success of chemical control, however, a crisis arose as a result of the exclusive use of this pest control tactic. This was due to the development of resistance to insecticides, pest resurgence and the development of secondary pests, all of which undermined the effectiveness of chemical control. In addition, adverse effects on the environment and human health started emerging. As alternatives to chemical control two paradigms were formulated. The one was integrated pest management (IPM) and the other, total pest management (TPM),[1] now more commonly known as areawide pest management.[2] IPM is based on the control of local arthropod pest populations by applying measures where and when necessary, whereas areawide control is based on continuously applied, preventative measures to the entire habitat of the arthropod pest. Central to IPM is the use of economic thresholds in order to determine where and when control measures should be applied. However, economic thresholds can be applied only if suitable pest monitoring systems are available. These monitoring systems, in turn, are based on sampling plans, in which the sampling units and sampling procedures are clearly defined.

Most of the local apple crop is exported, the most important markets being the European Union and the United States. These markets require high quality, unblemished fruit and minimum insecticide use. Optimum use of data obtained from monitoring systems can facilitate compliance with these requirements. In this article I examine the underlying principles of monitoring systems and the optimum use of data obtained from them in apple orchards in the Elgin area of South Africa. While applied entomologists are familiar with these principles, local exporters and overseas importers, being marketers, are usually not well versed in the application of economic thresholds (see later for definition). This article is therefore also an attempt to clarify these principles to marketers, both local and abroad.

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Some practical aspects of sampling arthropod pest populations

When sampling for decision making in pest management, the sampling error should be known, so that it can be taken into account when comparing the population level recorded in the sample with the economic threshold. The standard error relative to the sample mean is commonly used as an expression for sampling error (for example, see refs 3, 4):

$$D = \sqrt{\frac{S^2}{\bar{x}.n}}, \qquad (1)$$

where D is the sampling error, S^2 is the variance, $\bar{x}$ is the average number of organisms and n is the number of sampling units. An assumption when using this expression is that S^2 is constant. However, in the case of insect counts this is seldom the case. The variance is usually related to the mean. This relationship is described by Taylor's power law:[3,4]

$$S^2 = a(\bar{x})^b, \qquad (2)$$

where a and b are regression constants which can be estimated using

$$\ln(S^2) = \ln(a) + b.\ln(\bar{x}). \qquad (3)$$

Substituting (2) into (1) produces an expression for sampling error based on only the average number of organisms per sampling unit and the number of sampling units:

$$D = \sqrt{\frac{a(\bar{x})^b}{\bar{x}.n}}. \qquad (4)$$

If $\bar{x}$ in (4) is set at the economic threshold and then solved for a range of values of n, a graph similar to that in Fig. 1A is obtained.[5] This shows that at low numbers of sampling units, sampling error is high. However, sampling error is not significantly reduced by increasing n beyond a certain point. There is an optimum sample size, therefore, for obtaining a reasonable degree of precision with the minimum amount of effort. If the number of sampling units is kept constant, say, at the optimum sample size, and the average number of organisms, $\bar{x}$, is varied, a graph similar to that in Fig. 1B is obtained. This shows that at low population levels the sampling error is high. When sampling for arthropod pests which are damaging at low population levels, therefore, high levels of sampling error can be expected. Large samples then will improve the sampling error only up to a point, beyond which increasing the sample size will not significantly reduce the sampling error.

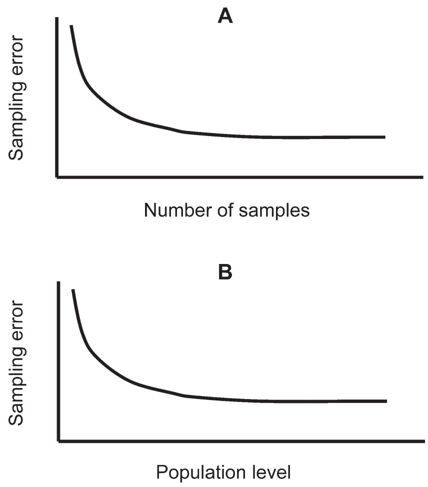

Fig. 1. Schematic representation of trends in sampling error plotted against (**A**) sample size and (**B**) population level when sampling for arthropod pests.

Thresholds

The importance of defining and using economic thresholds was first recognized during the late 1950s.[6] Stern *et al.* defined the economic-injury level (EIL) as the 'lowest population density that will cause economic damage'. By economic damage they meant, 'the amount of injury that will justify artificial control measures'. They also defined the economic threshold

(ET) as the 'density at which control measures should be determined to prevent an increasing pest population from reaching the economic-injury level'. Some years later, the suggestion was made that the word 'determined' could also mean 'initiated'.[7] Although these definitions have been criticized, they are still widely used. The main criticism is that they oversimplify the crop/pest interaction.[7] For example, in ref. 6 no distinction is made between 'damage' and 'injury'.[7] Pedigo *et al.*[7] defined injury as 'the effect of pest (insect) activities on host physiology that is usually deleterious' and damage as 'the measurable loss of host utility, most often including yield quantity, quality or aesthetics'.

From the definitions of EIL and ET given by Stern *et al.*,[6] it is clear that the former is always lower than the latter. In addition to these two definitions they defined the general equilibrium position (GEP) as the 'average density of a population over a period of time (usually lengthy) in the absence of permanent environmental change'. The GEP is therefore an ecological concept. Theoretically, it should be possible to manipulate the GEP by manipulating the environment by, for example, providing refuges for natural enemies, thereby increasing the levels of biological control. The GEP can also be changed by introducing insect-resistant plant material. However, in the case of perennial crops insect biotypes can develop which overcome the resistance mechanisms. This happened during the 1960s when a biotype of *Eriosoma lanigerum* (Hausman) (Hemiptera: Aphididae), that had overcome the resistance mechanisms in Northern Spy, Merton and Malling-Merton rootstocks, appeared in South African apple orchards.[8]

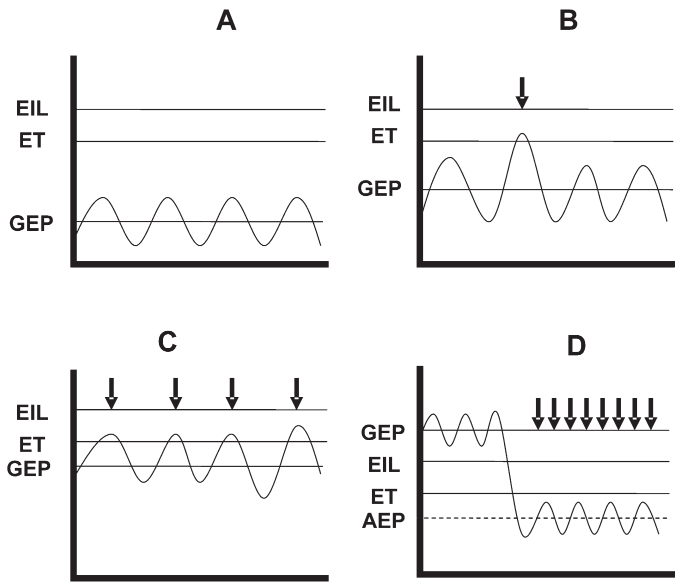

Fig. 2. Schematic representation of the relationship between the economic injury level (EIL), economic threshold (ET) and the general equilibrium position (GEP) for (**A**) non-pests, (**B**) sporadic pests, (**C**) perennial pests, (**D**) chronic pests. Arrows indicate the application of control measures; AEP = adjusted equilibrium position.

Arthropod herbivores of crops relative to the GEP, ET and EIL

Herbivorous arthropods that feed on crops can be classified according to four categories, depending on the relationship between their population levels and the GEP, ET and EIL.[6]

(A) *Non-pests* (Fig. 2A). These arthropods feed on the crop, but the GEP is well below the ET. Their numbers never exceed the ET, so treatment is not required to control them. In the Elgin apple growing area of the Western Cape province, the biological control of the phytophagous mites, *Panonychus ulmi* (Koch) (Prostigmata: Tetranychidae) and *Tetranychus urticae* Koch (Prostigmata: Tetranychidae), by *Neoseiulus californicus* (McGregor) (Mesostigmata: Phytoseiidae) is extremely successful.[9,10] Over a nine-year period, phytophagous mite populations declined from a peak of more than 30 mites per leaf to almost non-detectable levels.[10] Control measures are now no longer required.

(B) *Sporadic pests* (Fig. 2B). The GEP is below the ET. The population level is usually below the economic threshold, but sometimes it exceeds it and control measures are required to prevent it from exceeding the EIL. In South African apple orchards the African bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), is such a pest. It appears to reach damaging levels approximately every third season (Brown and Pringle, unpublished). During the intervening two seasons, the population levels remain below the ET. This is an example of a temporally sporadic pest. Spatially sporadic pests also occur. In such cases the GEP is below the ET, but in certain areas the latter is regularly exceeded, requiring intervention to prevent the EIL from being reached. However, this does not occur throughout the production area. The fruit weevil, *Phlyctinus callosus* (Schonherr) (Coleoptera: Curcullionidea), an indigenous, flightless beetle is such a pest. It regularly causes severe damage in certain areas, but elsewhere no damage is recorded.

(C). *Perennial pests* (Fig. 2C). The GEP is slightly below the ET and population levels regularly exceed the ET, requiring regular intervention to prevent the EIL from being reached. During spring *E. lanigerum* crawlers migrate up the trunks of apple trees from the roots. They establish colonies in the leaf axils, where they destroy the developing buds, reducing the following season's crop.[11, 12] In most local apple orchards this pest requires control measures every season as was demonstrated by Heunis and Pringle.[13]

(D) *Chronic pests* (Fig. 2D). The GEP of these pests is above the EIL. They therefore require constant, preventative treatment so as to create an adjusted equilibrium position (AEP) (the modified average density of ref. 6). In most apple producing areas throughout the world, codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is a chronic pest. It requires constant attention so as to force the GEP below the ET, creating an AEP. The measures applied locally for the control of this pest are not only chemical treatments, but also involve the use of pheromones to disrupt mating.[14]

Using thresholds to decide on intervention

The conditions that determine whether or not thresholds can be used are briefly summarized in Table 1.

For some pests reliable monitoring systems are not available. In the case of

Table 1. Conditions that determine whether or not thresholds can be used.

Can use thresholds	Cannot use thresholds
Reliable monitoring system available	No reliable monitoring system available
Sporadic pests and perennial pests	Chronic pests – control measures preventative
Economic threshold high	Economic threshold low

P. callosus, collars of single-faced corrugated cardboard are tied around the trunks of apple trees. The weevils shelter in the corrugations during the day, when they can be counted. However, this is not an accurate procedure.[15] This pest is currently monitored using fruit damage assessments, which provide information on activity only after damage has been caused.

Chronic pests are present every season and need to be controlled preventatively. In most local apple orchards, *C. pomonella* is presently controlled using pheromones to disrupt mating supplemented with chemical control.[14] The pheromone dispensers are placed in the trees during spring before moth activity starts. Thresholds cannot therefore be used to determine whether or not this form of intervention is required during a particular season. Pheromone-baited traps can still be used to monitor flight activity, but they are less reliable for decision making in pheromone-treated orchards than in orchards not so treated.[14]

As pointed out above, sampling error is high at low pest population levels. There is also an optimum sample size. Sampling precision can therefore be improved only to a limited extent by increasing the sample size (see Figs 1A, B). This makes it difficult to apply thresholds to pests which cause damage at low population levels. Such insects are usually direct pests (those which attack the marketable part of the crop) of high-value crops such as apples. For example, in Washington State apple orchards in the U.S.,[16] 0.2% of fruit damaged by codling moth represented a high population. This is an extremely low level of damage, and a large sample would be required to detect it with a reasonable degree of precision. Taking this into account, as well as the reduced sampling precision of pheromone-baited traps in orchards under mating disruption,[14] monitoring data cannot be used for short-term decisions regarding chemical intervention.

Using monitoring data

(A) *Non-pests.* Including this category of arthropod herbivores in monitoring systems is important. If the population level of one of these arthropods exceeds the ET, the reasons for the change in pest status need to be identified as soon as possible so that they can be rectified.

(B) *Sporadic pests.* Monitoring is the only way in which outbreak seasons of temporally sporadic pests can be identified. This enables growers to intervene only during these seasons and not preventatively on a routine basis. The activity of *H. armigera* can be monitored using pheromone-baited traps, and examining shoot tips and fruit for damage. Moths are caught in the traps before damage is recorded. However, there is no relationship between numbers caught in traps and damage. After the initiation of trap catches, damage to shoot tips is recorded, followed by that to fruit. Young larvae are easily controlled using a minimum of chemical sprays, but the older larvae (beyond the second instar) are difficult to control. Outbreak seasons can be identified using pheromone-baited traps, and inspecting for tip and fruit damage. Intervention can then be applied in good time and its success can be determined.

Phlyctinus callosus is a highly damaging direct pest, which is spatially sporadic. The most effective control measure is currently the use of barriers applied to the trunks of apple trees.[17,18] But applying these barriers is expensive and extremely labour intensive. Inspecting fruit damage can identify areas on a farm in which damage occurs, and so would benefit from the use of trunk barriers. After application, fruit damage inspections can assess the success of the control measure.

(C) *Perennial pests.* These require regular intervention. Monitoring can be used to refine the timing of the intervention, which may take the form of, for example, parasitoid releases (e.g. ref. 19) or chemical applications (e.g. refs 12, 13). In addition, monitoring can be used to determine the frequency or intensity of the intervention, which may have to be varied from year to year.

(D) *Chronic pests.* Monitoring the activity of chronic pests is of vital importance for determining the success of control measures. It can also be used to identify localized outbreak areas which require extra attention. Because of the preventative nature of the control measures used against these pests and the low economic thresholds (see above), monitoring cannot be used to determine the necessity of intervention from week to week or in specific locations. However, the data obtained from monitoring can be used to plan control measures from season to season[14] on a small or a large scale.

Chronic pests are usually the key scourge of a crop. An areawide pest management initiative was started in 1995 in the U.S., in which the main pests of several crops were targeted, including codling moth on apples and corn rootworms in the genus *Diabrotica* on corn (maize).[20] Areawide pest management practices have certain features which separate them from IPM systems.[20,21] First, they are conducted over large geographical areas.[20,21] Second, they are coordinated by organizations and not by individual growers.[20,21] Third, they are designed to reduce and maintain pest populations at low levels over the entire geographical area,[20,21] including non-cropping areas. Fourth, a high level of compliance is required, which may involve a mandatory component.[21]

The areawide American campaign against codling moth in 1995 was based on mating disruption.[21] However, factors such as open spaces, slopes and wind reduce the effectiveness of interrupted mating.[22] All these conditions are present in the Elgin apple growing area.[14] Mating disruption on its own will not be successful therefore in an areawide programme locally. It will have to be supplemented with other pest management tactics, such as the sterile insect technique if an areawide approach is to be adopted in South Africa. Reliable monitoring systems are essential for determining the success of areawide programmes over an extended time and for the early detection of reduced levels of control.

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