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ECONOMIC THRESHOLD LEVELS FOR THE VELVETBEAN CATERPILLAR ON SOYBEANS IN BRAZIL: THE SOCIAL AND THE PRIVATE PERSPECTIVES

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Pest Control is treated as a economic problem. The social and the private perspectives differ due to the consideration of the environmental and social impacts as well as technical aspects such as resistance, resurgence and secondary pests. A mathematical model is developed to determine and compare the social and the private optimum control strategies (which define the Economic Threshold Levels) for the velvetbean caterpillar on soybeans in Brazil. The crop/pest system incorporates effects of predators and parasites, the soybean natural capacity to compensate for injury and the pesticide effects on both pests and its natural enemies; in the social case, the environmental and social impacts and the effects of pest resistance to the pesticide are incorporated. Consideration of density dependence, weather effects, randomnes of pest attack and risk aversion are discussed. The results can be compared with current control practices and IPM programme recommendations.

In the same way that agricultural production can be regarded as an economic activity, both at the micro and the macroeconomic level, pest control decision-making can also be treated as an economic problem. Decisions concerning the control of many vectors, pathogens and medical and veterinary pests are very similar to those of crop-pests. In both cases the decisions will often involve the choice of the best pesticide, the dosages to be sprayed, and the times of application, with the choice being made as the result of a balance between the pros and cons of each action, or in more economic terms, their respective costs and benefits. Measuring these costs and benefits is where the differences between the two problems become more evident.

The reason for these differences is that whereas in the crop-pests case the benefits of the control are usually gains in yields – thus marketable products – with non-crop pests the benefits are usually non-marketable, particularly when involving human health. Applying an economic framework to the non-crop pest control problem therefore becomes more difficult. Nevertheless, the control of crop-pests also involves non-marketable goods and the calculations of costs and benefits are not straightforward. If, for example, the control action involves the use of pesticides, effects other than the reduction in the pest population might occur. They include human intoxication, residues on food, environmental pollution, effects on neighbouring fields, in addition to "technical" consequences such as development of resistance and effects on non-target species, particularly beneficial predators and parasites. The difficulties of incorporating these aspects into a decision process are clear.

The incorporation of these aspects, however, will be dictated by the level at which the decision is being taken. This is why the social and the private perspectives of the problem can lead to different control strategies. Farmers have, in principle, no motivation to sacrifice their crops in exchange for greater environmental preservation, whereas a central authority must somehow incorporate the environmental costs. They also tend to be risk averse, usually causing them to overspray the crops; the central planner usually has better information about the system, is more concerned with the results of his action region rather than any specific micro-region or farm, having a different attitude towards risk. Farmers also have no foresight to apply lower dosages to maintain lower resistance levels, because the resistance level is not affected by a single farmer alone, but rather by the actions of all farmers within a region.

Other similar aspects could be added to illustrate that different optimum control strategies may exist under the same physical situation, depending on whether the problem is being analysed under the private or under the social perspective, and in the private case on farmers' knowledge and perception of the problems.

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This is not so much the case with non-crop pests, as both decisions and actions are usually taken at the social rather than at the private level.

The intention of the author is to analyse the differences between optimum control strategies when the environmental aspects are incorporated into the decision, including the possible development of pest resistance to the pesticides. In order to achieve that, a mathematical model for the determination of Economic Threshold Levels (ETLs) for the velvetbean caterpillar (*Anticarsia gemmatalis*, Hubner 1818) on soybeans was developed. This model is the object of interest of the present work. Before it can be introduced, the concept of ETLs and some aspects of the mathematical procedure are examined.

At the private (farm) level, the goal in the strictest economic sense is to maximise profits. However, it has long been recognised by agricultural economists that reducing the problem to a pure maximisation of profits would be unrealistic, because a number of other aspects determine his goals and his actions. The most important of these aspects is risk aversion, which is a way of expressing his lack of knowledge of all phenomena involved in the system, many of which are stochastic in nature.

Similarly to the private case, the goal in the social (regional) context should, in principle, be the maximisation of the social benefits (profits). Among those aspects to be incorporated into the decision at this level are the possible environmental effects and the development of resistance, which were referred to previously.

As to the "technical" constraints of the problem, they are studied in terms of biology, entomology, ecology and other related areas of basic research. We will not try to name the range of phenomena studied, although those aspects that could be incorporated into the model are presented and analysed.

Referring now to the concept of ETLs, a balance must be made between the theoretical definition and its applicability and feasibility. Irrespective of the level of knowledge of the constraints of the problem and the possibility to specify both these constraints and the objective function in mathematical terms, it is understood that a maximisation problem underlies the decision making process at both the private and the social levels. The maximisation consists of the determination of the (optimum) strategy that will give the maximum value of the objective function. This optimum strategy will consist of a series of actions – traditionally pesticide sprayings – which shall be implemented a number of times. The "signal" to the farmer that one of these actions must be initiated is the level of pest density of the system. At different points in time these levels may be different and they are dictated by the optimisation process. They are what we refer to in this paper as the Economic Threshold Levels.

The discussion about the practical applicability and thus the relevance of the above definition involves two basic aspects. The first, that even if the problem could be specified according to the above maximisation framework, could the optimum solution be attained in practice? i.e., could it be stated as a pragmatic rule to be followed by farmers? The second refers to the limitations of the mathematical models. Is it possible to translate all the information available (both the objective function and the constraints of the problem) in mathematical terms? Even with a positive answer, are the models manageable and the conclusions reliable?

The model to be introduced indirectly addresses both questions. The second one clearly poses the greatest difficulties. It must be added here that the eventual lack of knowledge about the phenomena involved in the physical system or even about the farmers' and decision markers' goals can not be remedied by economic methods. The models cannot be expected to give optimum solutions when great dificiencies in knowledge about the physical system remain. The following model pre-supposes that the level of knowledge is such that the mathematical approach is reliable and thus useful. This judgement is partly subjective, so the reader is left to decide for himself.

The case study

The choice of soybeans as the case-study is primarily due to the availability of data. It is also due to the original concern with the environmental aspects: the use of insecticides on the crop represented over 23% of total consumption of active ingredients (A.I.) of insecticides in Brazil in 1985. An average of three sprays of 120 g of A.I./ha each were made that year, as compared to the Embrapa's recommendations of only two sprays. Within the soybean system, the velvetbean caterpillar stands as the single major pest. For the caterpillar alone, a single spray is recommended. The economic and enviromental benefits from the adoption of the Embrapa's IPM programme would be significant. In particular, the existence of a biological control method could further improve this situation. Because of its importance, many studies have been developed, and the availability of data is extensive.

The model consists of two quite independent parts. The first is the physical description of the system and the second is the economic maximisation which determines the Economic Threshold Levels. Models aiming at the sole description of the physical system have been developed – Menke (1973), Gazzoni et al. (1984) and Wilkerson et al. (1986). Because of their purpose, some ecological and entomological aspects could be incorporated in greater detail. Our model is extremely flexible for the incorporation of most of these and other aspects about which there is adequate knowledge. But given our purpose, it is structured in such a way that only the basic characteristics are incorporated, with the introduction of various aspects being analysed by sensitivity analyses. It is therefore for field specialists to determine the most appropriate and realistic scenarios to be used, depending on the specificities of each particular situation.

The physical system

Detailed specialised literature on both plant and pest systems is extensive. We will make a brief description of both systems and their interactions based on data from the Embrapa's Centro Nacional de Pesquisas da Soja, which are summarised in Margulis (1988).

The life cycle of *Anticarsia gemmatalis* is composed of four stages – egg, larva, pupa, and adult (moth). The larval stage is the most relevant for this study and consists of 5 to 7 different instars, depending mainly on leaf availability and temperature. Leaf consumption rates vary according to the instar: nearly 90% of total consumption is concentrated in the last two instars. The final adult stage lasts nearly 16 days, during which the females can lay up to 1000 eggs each. Oviposition activity is very intense soon after mating, decreasing sharply afterwards. It is only during the larval stage that the insects feed on the soybean leaves.

The moths first arrive in the fields between 25 and 50 days after planting, and continue to do so for a variable period of time. Because the insect life cycle lasts only some 50 days, whereas leaves are present for 100 days or more, it is not uncommon to have two or even three generations of insects along the same crop.

In regard to the plant system, the seeds that develop in the mature stages of the soybean growth are the ultimate product of interest. The plant developmental stages can be broadly divided into the vegetative and the reproductive, which in turn can be sub-divided into a number of stages (Fehr et al., 1971). The capacity of the soybean to compensate for injury by pests varies considerably depending on the stage of growth (Turnispeed & Kogan, 1976), being much greater if defoliation occurs during the vegetative stages. If it occurs during or after blooming or pod filling stages, the yield losses can be significant. Emergence of leaves depends on the variety, but it typically occurs around 7 days after planting; flowering – after 45 days, pod filling – after 70 days and maturity 120-140 days after planting, when leaf availability becomes zero again. Harvest occurs 6 months after planting.

For the velvetbean caterpillar/soybean system, the relationship between pests and the injury caused, as measured in terms of yield losses (kg of beans/ha), is not direct, but rather a two step process: Pest – Plant Defoliation – Yield Loss. Both these relations are positive, although neither is linear. The relation between the number of pests and the level of defoliation depends on the number of pests per larval stage, as mentioned above, as well as on temperature and pest density. In addition to the growth stage, the relationship between defoliation and yield loss depends mainly on plant variety, location and seedling time. Other aspects are described in the following sections.

The Model

In the first part of the model, the system's development is "reproduced", beginning with the leaf availability on each day (natural plant growth), the arrival of pests, predators and parasites, the interactions of pests and these natural enemies and the total amount of leaf consumed. By taking into account the soybean natural capacity to recover from defoliation, the model then determines the defoliation before spraying, for all possible spraying days. After the pesticide has been applied, pests may still continue to arrive. The new arrival distribution is assumed to be the same as the original one. The residual pesticide toxicity – which affects both pests and the natural enemies – is incorporated into the model.

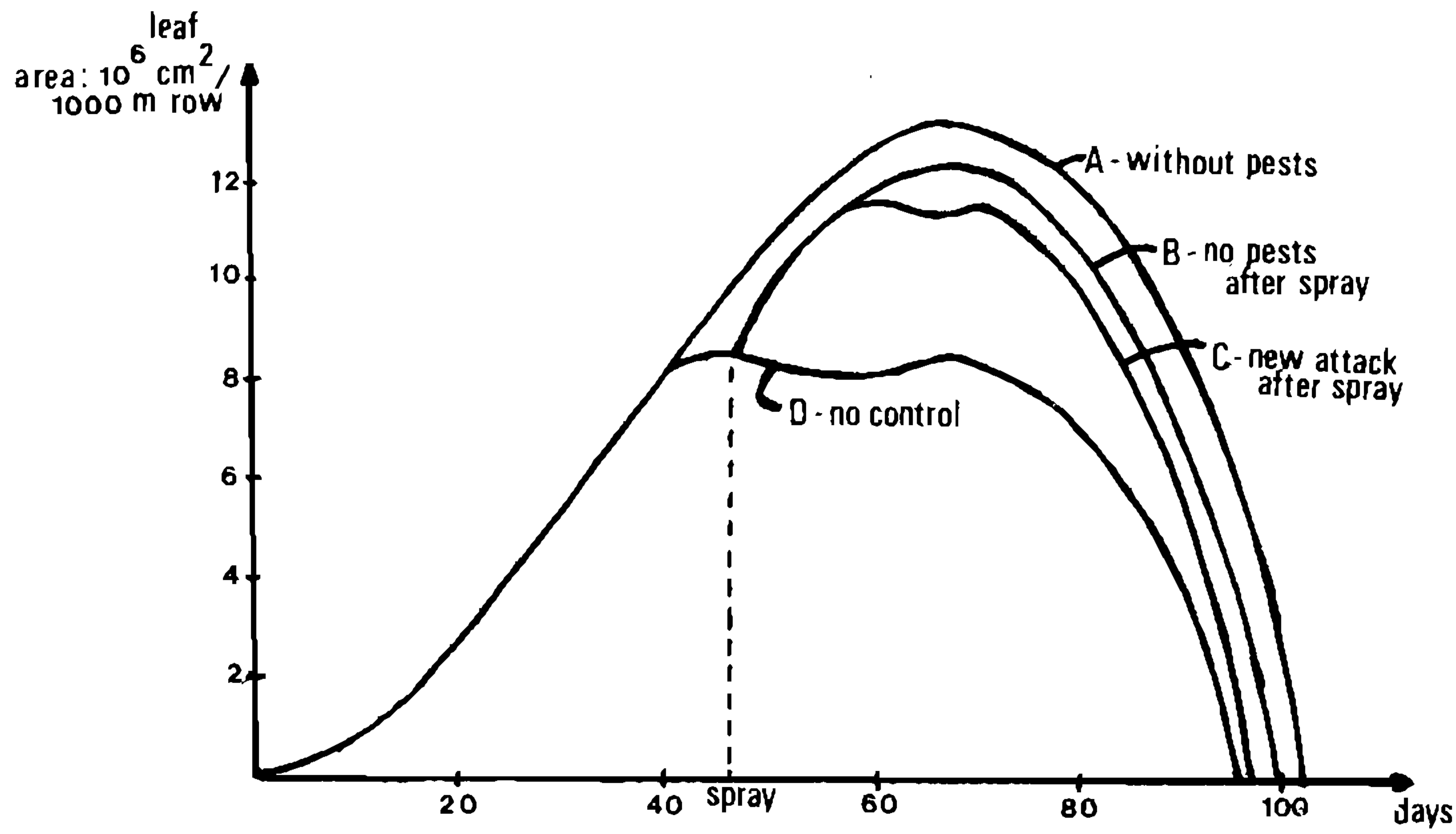

Fig. 1: Leaf availability without and with pest attack and a single spraying.

Before presenting the second part of the model, Figure 1 below illustrates the development of the system (the model) for the one season case with a single spraying allowed. Curve A shows the leaf availability as a function of time without pest attack (the actual curve used in the model). With the introduction of control, the population level drops to the number of survivors. After that, new pests may migrate into the system; only the cases where no pests arrive after spraying (curve B) and the one where the new arrival distribution is parallel to the original one (curve C) are depicted in the figure. Curve D shows the case of attack without control.

The optimisation part of the model consists of determining the strategy that maximises profits (or social benefits). This is the objective function. The strategy consists of the day of application and the dosage to be sprayed. From what has been said about the system, it can be concluded that the choice is based on a balance between the damages before and after spraying. Premature applications will cause great losses (defoliation) after spraying, and late applications will cause the defoliation before spraying to be too high. Therefore the time of application is crucial in the determination of the optimum strategy. Depending on the intensity of the attack and on the day of application, it is intuitive that different dosages should be used, and thus the choice of the dosage is also to be determined in the maximisation process.

Notice that the objective function has been assumed to be the maximisation of profits in one season. The incorporation of environmental costs – the social analysis – is reduced to a sensitivity analysis of the insecticide price, which can be increased by different pre-determined values. Also, the present Embrapa's control strategies can be reproduced by the model by substituting the optimisation part with the adoption of its fixed strategies (fixed dosages to be sprayed at pre-established pest population levels – the Embrapa's ETLs). The model's results are compared with those of the Embrapa's recommendations.

Specification of the Model's structure

The arrival rates – Five alternatives are considered for the day of pest outbreak, after which moths may continue to arrive for another 30 days. Because the larval stage lasts 15 days, the model assumes that larvae are present within the system for 45 days. The arrival of moths is assumed to follow a statistical distribution, and four distributions are considered (two Poissons, a Normal and an Uniform). An adjustment constant is used to make the level of pest density match those which are observed in practice. The resulting number of larvae using each of the distributions is presented later (Fig. 2b).

Oviposition – As mentioned previously, the oviposition rates vary according to moth's age.

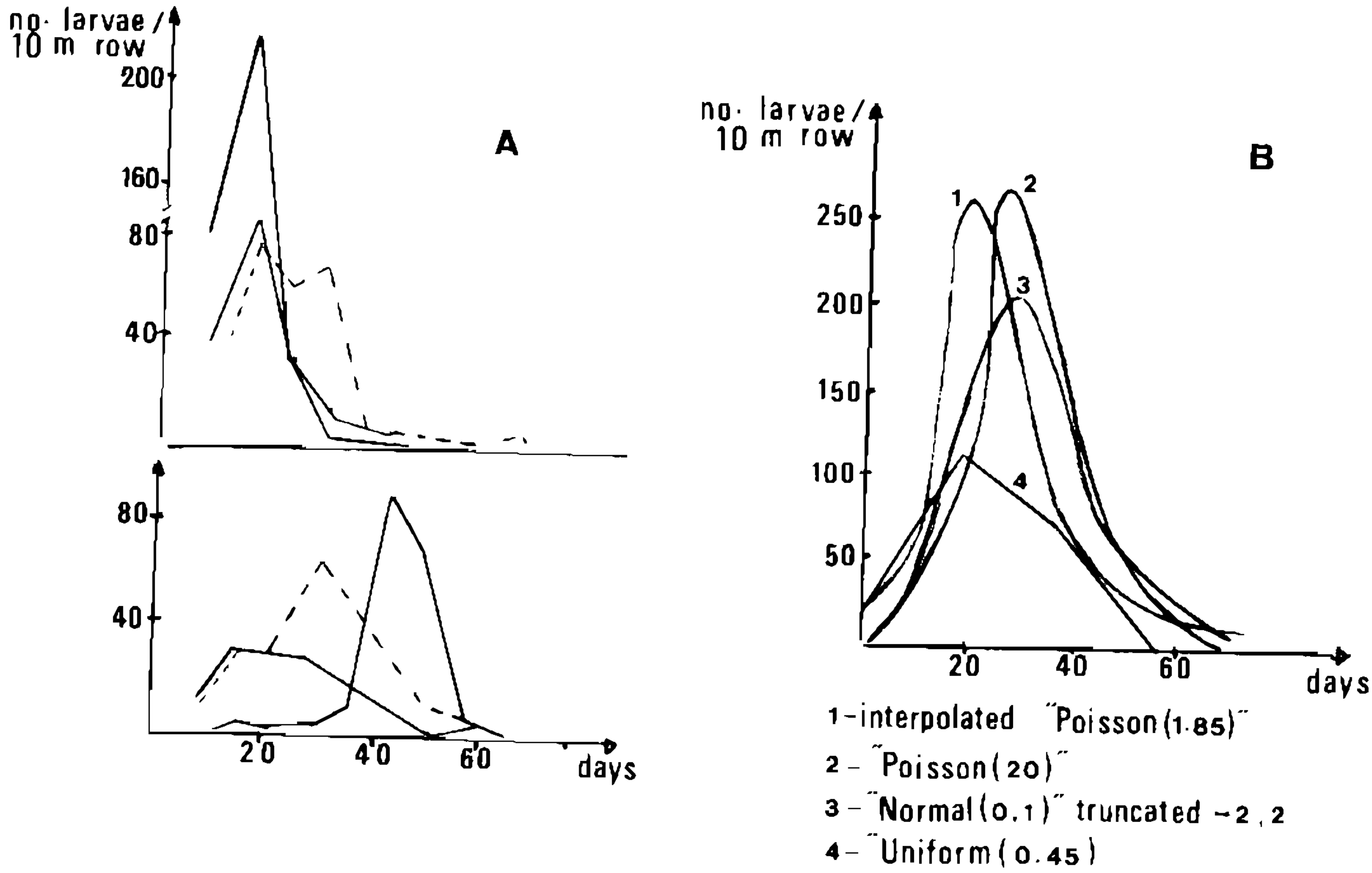

Fig. 2: A. Field data of pest dynamics in Brazil (after Gazzoni et al., 1978). B. The Model's simulated pest dynamics.

Oviposition – As metioned previously, the ovipositon rates vary according to moth's age. They additionally depend on climate and on pest density. Effects of pest density on the oviposition rates are not available and could not be incorporated into the model, whereas the other aspects could.

Mortality factors – Natural death rates, effects of predators and parasites are known for the egg stage and for all instars of the larval stage. These phenomena are also climate and density dependent. We used the values obtained in the American case when no data was available for the Brazilian conditions. The disease caused by the fungus *Nomuraea rileyi* must be set apart, as it can decimate the entire population of *A. gemmatalis*. Given the purpose here, we did not allow for its development, although the model is flexible enough to incorporate its possible occurrence.

Leaf consumption – Leaf consumption rates depend on the instar of larval development and on the same factors as the above two items; the same procedure was adopted when no specific data for the Brazilian case was available.

Arrival of pests and defoliation after spraying – As mentioned previously, pest may still enter the fields after the pesticide has been applied. The arrival distribution is assumed to be the same as before spraying, although an adjustment constant was used to simulate a possible decrease in these rates, as the pesticide may repel new arrivals of moths. This adjustment constant is independent of the residual toxicity of the insecticide, which affects both pests and its natural enemies, and which is also incorporated into the model. However, this residual toxicity was assumed to be independent of dosage due to lack of data.

After the interactions of pests and its natural enemies are computed, as well as the effects of the residual pesticide toxicity, the new number of larvae at each instar is calculated again. In order to determine the defoliation after spraying, however, the number of survivors must be calculated as well. This number of survivors is a function of the dosage to be sprayed. Because this dosage is only determined in the maximisation part of the model, the defoliation after spraying can only be determined after the maximisation.

Determination of the optimum dosage – The calculation of the optimum dosage could be made analytically – simple first and second order derivatives. However, as mentioned previously, this dosage depends on the day of application, which is also to be determined by the model. Because larvae are present in the system for only 45 days, the procedure was to determine the optimum dosages for each of these 45 days; the one which implied the minimum profit loss corresponds to the best strategy. We then refer back to the system to analyse its conditions on the day of the optimum application. The number of larvae on this day is precisely the Economic Threshold Level. The level of defoliation before the application can also be seen.

Two other relations used in the model have to be described. The first is between the level of defoliation and the level of yield loss. This relation involves the plant capacity to compensate for injury which, as mentioned before, depends on the plant growth stage. Four relations are used in the model, which works with data from the Brazilian Embrapa in the basic case. The second is the pesticide effectiveness. A traditional S-shape curve was used to fit data from the only two experiments where dose-response tests are carried out (Turnispeed, 1974; Moscardi et al., 1985).

Finally, the maximum possible yield and the economic parameters (the insecticide and the soybean prices and the set-up costs - which are the fixed costs of application of the pesticide plus all other costs to produce the maximum yield) were taken from major periodic official publications for Febuary/1987. The sensitivity analyses also consider variations in all these parameters.

Before the presentation of results, Figure 2 illustrates some field data of pest dynamics in different regions in Brazil – Fig. 2a – and some of the model's simulated cases – Fig. 2b. In the same way that only a single application is allowed, only one peak of pest density is assumed, although the model can be easily adjusted for multiple peaks. Allowing two sprayings, however, would require significant changes in the model's structure, because there would be two optimum days and two optimum dosages to be determined. The most typical situation seems to be the one of a single peak, when a single spraying should produce the optimum results.

RESULTS

Pest control does not represent a major cost in soybean production in Brazil, usually less 5% of the variable costs. The Embrapa action-strategy is based on both ETLs and on levels of defoliation. When the number of larvae longer than 15mm reaches 400 thousand per hectare or when the level of defoliation reaches 15% (30% for early attacks), a dosage of 125g of A. I./hectare of the same insecticide as used in the model should be applied. Table I summarises the major results of the model's basic case, comparing with those implied by the Embrapa's strategies.

The choice of the day of applicaton in the crucial aspect of the strategy, while the dosage does not significantly affect its results. Farmers would not be affected by stringent regulations (limitations) on dosages allowed to be sprayed. The Embrapa's dosages certainly take into consideration losses caused by factors such as wind, poor application practices, etc. . This could explain the higher dosages but not the delay of its strategies, which could only be attributed to differences in assumptions about the pest population curve shapes. But the model's results are equally better under other three distributions (not shown). The two strategies become similar under later attacks, so that it may be the case that the Embrapa's strategies are aimed at these more severe conditions.

The ETLs of the model's strategies and those of the Embrapa's recommendation are not too distinct, but the levels of defoliation before the application are. Again, this could only be explained by the assumptions over the shape of the arrival distributions, but they remain very distinct under the other distributions as well.

The different scenarios or assumptions related to the effects of pest density on the oviposition, leaf consumption and mortality rates did not significantly affect the final results. The effects of temperature are more pronounced, particularly those of lower temperatures, which cause the damage to be less severe. There are no studies attempting to quantify the plant capacity to compensate for injury, so we adopted the procedure of Gazzoni et al. (1984) that a 10% recuperation is initiated after defoliation is greater than 5%. Even using the alternative 30% value, the phenomenon is only noticeable under late attacks, as they are the ones causing the greatest losses.

The shape of the arrival distribution of moths is another critical factor, as well as the day of pest outbreak. Because leaf availability decreases in time, later attacks imply greater defoliation levels. But the distribution itself

TABLE I

Comparison of the Model's results with the Embrapa's strategies

	Model	Embrapa 1+	Embrapa 2+
% Profit Loss	9.13	12.2	14.47
% Yield Loss	3.65	4.82	5.96
ETL (1000 Larvae/ha)	481.6	400*	489.3
% Def. Before Spray	3.98	12.8	17.2
Final % Defoliation	14.58	17.7	20.5
Dosage (g A.I./ha)	99.1	125	125
Day of Application	41	45	47

+ – Embrapa 1 = based on no. of larvae; Embrapa 2 = based on defoliation.

* – Larvae longer than 15 mm.

Assumptions – arrival distribution poisson (1.85); pest outbreak on day 30; Peak population = 540.8 thousand/ha on day 44 (after planting); other parameters after Margulis (1988).

is even more important, particularly its variance. It is intuitive that an uniformly distributed attack will cause more severe damage; in the concentrated case a single spraying can kill most pests.

Changes in the relation between the levels of defoliation and yield losses cause no changes in the strategies, but produce the greatest variations in the final levels of profit losses. Using data from Turnispeed (1972), there are gains rather than losses in yield and profits. The regression obtained with this data certainly incorporates the plant capacity to compensate for injury. The relation is crucial in the 10%-30% range of defoliation level, which is the one where the strategies are usually initiated. This suggests that more specific studies at these levels should be carried out.

Assumptions of lower rates of arrival of moths after spray – i.e., the possible repellence caused by the insecticide (not its residual toxicity) – produce almost proportional effects on the levels of profit losses. If the new arrival rates are multiplied by 0.75, the profit losses decrease by 18%, and if they are multiplied by 0.5, the profit losses decrease by 36%. No alternative scenarios are made for the residual toxicity, as it does not seem to be relevant in the determination of the number of pests after spray.

With regard to the economic parameters, changes in both the set-up costs and in the price of the product cause slightly less than proportional variations in the levels of profit losses. A 20% decrease in the set-up costs or an equal increase in the soybean price will cause a 15% decrease in the level of profit loss (from 9.13% to 7.83% and 7.55%, respectively). A similar trend is observed with variations in the values of the maximum possible yields.

More surprising results relate to the pesticide effectiveness. The system is almost entirely insensitive to changes in either its effectiveness or its price. Halving the pesticide effectiveness coefficient causes the level of profit losses to increase by only 14%; doubling the insecticide price will only cause an increase of 16% in the level of profit losses and a decrease in the optimum dosage from 90 to 60 g of A.I. per hectare. This shows that environmental policies based on price increases should be considered: farmers will not be affected in terms of profit losses, but the dosages (and thus the environmental degradation) will decrease, even though in less than proportional magnitudes.

More efficient than the price policy would be the establishment of limits on the maximum dosages to be sprayed. If these limits are set to be 80 g of A.I./ha, the profit losses would increase by less than 0.2%; with a 60 g limit, the profit losses would increase by less than 3%, and even with a 40 g limit, the losses would only increase by less than 10%. These must be regarded as simple exercises to analyse possible strategies for improvement in environmental quality. The case of soybeans, in particular, does not seem to cause much concern, contrary to many non- export crops, although information is definitely missing. The procedure could be employed for other crops in different regions.

Finally, the benefits of the implementation of the biological control programme (with the baculovirus *anticarsia*) can be estimated. Assuming that this strategy involves no environmental costs and that the same insecticide effectiveness could be achieved with prices reduced to half of the insecticide price, a 12% decrease in profit losses would occur. If the price were one-tenth of the insecticide's, there would be a 25% decrease in profit losses. Assuming that only one spray is made for the control of the velvetbean caterpillar on soybeans in Brazil, the annual savings which could be achieved with the implementation of the biological control programme at a national level should reach US$ 135 millions (in the more favourable price case), excluding the improvement in environmental quality. It is difficult to accept that the implementation costs could be so high.

It was also mentioned previously that the model incorporated the possible development of pest resistance to the pesticide. This implies that the model also analyses the system in the long term. Despite the fact that even in the United, States, where the crop has long been sprayed, no cases of resistance development have been reported, it is still interesting to observe the possible effects of the incorporation of the phenomenon onto the different strategies. Following Regev et al. (1985), we assumed that resistance is regulated by a single dominant gene, with susceptibility to the pesticide depending on the frequency of the dominant gene. Under a social perspective, susceptibility must be treated as an exhaustible resource (Hueth & Regev, 1974); the determination of the optimum strategy is made for the entire planning horizon and takes the resistance effect into account. In the private case, farmers take the level of resistance exogenously, and maximise their profits repeatedly every year of the planning horizon, having no control over the level of resistance. Table II summarises the results of the model's basic case in the long term under the private and social perspectives, as well as the results of the Embrapa's best strategy.

The objective functions do not differ significantly between the private and the social perspectives, although the latter always produced better results. The most interesting feature is that in the private case farmers tend to spray heavily in the first years, decreasing the dosages in time. In the social case there is a reverse trend: dosages decrease in the first years and increase after the seventh year. The consequences is that the level of resistance in the private case reaches 10% in 5 years, whereas in the social case in only 9 years. The indirect costs associated with these higher levels of resistance are that higher dosages will be sprayed, more pollution should be caused and that the continuous development of new products will be necessary.

TABLE II

Long-term results under the private and the social perspectives and comparison with the Embrapa's best strategy

	Social Persp.(970)*				Private Persp.(962)*				Embrapa's(905)*			
Year	%Y.L.	%P.L.	Dose	Res.	%Y.L.	%P.L.	Dose	Res.	%Y.L.	%P.L.	Dose	Res.
1	4.3	9.6	50.8	.01	3.7	9.1	89.1	.01	4.8	12.2	125	.01
2	4.4	9.7	48.9	.03	3.7	9.2	89.7	.07	4.9	12.3	125	.14
3	4.4	9.8	47.2	.08	3.7	9.3	91.0	.45	5.1	12.7	125	1.84
4	4.5	9.9	45.8	23	3.9	9.7	93.5	2.7	5.8	14.1	125	14.8
5	4.6	10.0	44.9	.61	4.3	10.6	94.8	12.5	7.3	17.1	125	50.7
6	4.7	10.2	44.8	1.46	5.2	12.1	81.8	37.1	8.5	19.6	125	82.2
7	4.7	10.4	46.0	3.38	6.3	13.4	42.4	62.9	9.0	20.6	125	95.1
8	4.8	10.7	49.6	7.40	6.7	13.6	15.2	73.8	9.2	20.9	125	98.8
9	4.9	11.0	58.8	15.4	6.8	13.7	4.3	77.1	9.2	21.0	125	99.6
10	5.0	11.7	86.9	30.5	6.8	13.7	–	77.1	9.2	21.0	125	100.

* – Value of objective function = sum of present values of profits.

%Y.L. = percent yield loss; %P.L. = percent profit loss; Res. = percentage of resistants in the population. Rate of discount = 10%.

For assumptions about the resistance development function and the physical system see text and Margulis (1988).

The alternative, which is not costless, is the rational use of the resource (susceptibility to the existing pesticides). The Embrapa's fixed dosage strategy would cause the 10% resistance level to be reached even earlier, the economic losses would be 6.7% higher than the model's optimum and the amount of pesticide sprayed throughout the period – thus the environmental degradation – much higher as well.

CONCLUSIONS

Despite the controversies over the practical applicability of the concept of Economic Threshold Levels as defined in this paper, there are circumstances when the concept properly translates the decision-makers' goals. A model for the determination of ETLs for the velvetbean caterpillar on soybeans in Brazil was developed. The reliability and thus the relevance of this and other models attempting to determine ETLs can only be evaluated in light of the availability of data and information. The greatest difficulties relate to the description of the physical system – the biological, entomological and ecological phenomena occurring in the fields – and to the translation of these aspects into economic terms. This involves farmer's different perceptions of the problem and also their different goals, which are influenced by a number of subjective values. Reduction of the problem at the farm level to a maximisation of profits may be inadequate, but for systems with better levels of information and assistance or in centralised decision-making, the procedure becomes adequate. This seems a good approximation for the case of soybeans in Brazil.

The model can be an useful tool for analysing responses of the system to the incorporation and variations in assumptions about different phenomena of the physical system, as well as those differences caused by different levels of decision – private or social.

In comparison to the Embrapa's current control recommendations, the model suggests that the level of defoliation before the application may be too high, which means that the strategy is usually implemented too late.

Better knowledge about the relation between the level of defoliation and yield loss at the 10%-30% level is needed, as well as the effects of pest density onto oviposition, leaf consumption and mortality rates. The day of pest outbreak, the variance of the arrival distribution of moths, the effects of temperature, as well as obviously, the intensity of the attack, seem the factors that mostly affect the system. And the day of application is the crucial aspect of the (chemical) control strategy. Price and standards, particularly the latter, are effective environmental policies. The implementation of the biological control programme will imply great social benefits, with estimated savings of over US$ 135 millions every year, plus the improvement in the environmental quality, which includes pesticide residues on food and, more important, human intoxications.

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