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An environmental yardstick in farm economic modelling of future pesticide use: the case of arable farming

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Abstract

In this paper the integration of a new environmental yardstick for pesticide use in an economic farm model to monitor the environmental-economic interplay under changing price and policy conditions is discussed. The model is used to compare the effects of two control systems for pesticide use in Netherlands arable farming; the governmental system focusing on the amount of active ingredients used per hectare and an alternative based on the detailed environmental criteria of the yardstick. The application for arable farming on a sandy soil indicates that, in the context of the national pesticides use reduction objectives for 2000, the economic effects of the two systems are similar. The environmental implications are far better represented by the yardstick, however.

Keywords: pesticides, farm economics, environmental criteria

Introduction

Environmental quality problems generally have at least an economic and an ecological side. This implies the necessity of multidimensional (economic-ecological) projections. Coherence and integration between such projections require special measures, especially in regard to relevant time periods, choice and measurement levels of variables, spatial scale and structure. A minimum requirement for coherence and integration is a transformation (or linkage) of (attributes of) variables of the one dimension to the other (Braat & Van Lierop, 1987).

The aim of this article is: (1) to describe an example of an environmental-economic farm model with special attention for the environmental component and (2) to present an application of this model to monitor the implications of two environmental control systems for arable farming on sandy soils in the Netherlands

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Materials and methods

Environmental economic modelling

Aggregation level and method

Emphasis on the economic and the ecological components of agricultural production, and their interactions implies that attention has to be given to the identification of the hierarchical level where the relevant disciplines meet, i.e. the aggregation principle. This principle includes both spatial and temporal aspect. The single hierarchical level where the agro-economic and the agro-ecological discipline meet is the farm level. On this level the actual decisions are made concerning cropping pattern, production intensity etc. Environmental effects of production, such as nitrogen leaching, can only be assessed in the context of rotation scheme and fertilization practice and the environmental effects are related to specific natural conditions, such as type of soil and ground water level (Wossink, 1993).

In environmental economics two major approaches can be distinguished : (a) extended traditional cost-benefit analysis, and (b) extended physical-economics models with resource inputs and polluting output: material balance models and input-output models. Since choice processes are not included, cost benefit models and materials balance models are essentially descriptive models and can not be used for planning purposes, i.e. to assess the optimal farm organization under changing conditions.

Input-output models provide a detailed description of the production side of economy activities (linkages, input requirements and deliveries of outputs). The input-output framework is flexible in regard to environmental repercussions, as it is also able to incorporate emission of various pollutants and pollutant abatement activities. The total collection of input/ (good and bad) output relations relevant at the farm level, for instance, can be gathered into an input-output system. By adding input constraints and a linear objective function to an input-output system a linear programming (LP) model evolves, by which the optimal farm organization can be assessed. New technology, input substitution, price changes and emission figures retrieved from ecological models, can be easily incorporated in such models by modifying and expanding the input-output matrix and objective function. In this way a descriptive/explanatory model is modified to an prescriptive (planning) model.

An environmental-economic farm model based on the linear programming technique covers – besides the regular items of production such as cropping pattern, cultivation operations, labour supply and needs and investments – an additional component, which incorporates the parameters for the environmental effects the production activities considered. Ascertaining the environmental parameters, requires the use of ecological models, i.e. models that incorporate variables to indicate pollution impacts. A great number of pollution models have been developed. An inventory of these models, to evaluate their applicability for environmental economic analysis at the farm level, was made by Jarosch & Murschel (1989). They concluded that the ecological model with the lowest requirements with regard to input data (i.e.

CREAMS; see Knisel, 1980) even requires data on: the daily precipitation, temperature and radiation as well as soil porosity, extraction coefficients and many more. Since in the present study the primary interest was in the polluting effects of only pesticide use and not at the crop but at the farm and regional level, a model such as CREAMS is much too detailed. The polluting effects of pesticide use are assessed by means of a recently developed environmental yardstick, instead (Reus & Pak, 1993). The yardstick values are incorporated as quasi-external data into a linear programming model (Jarosch, 1990; Wossink *et al.*, 1992). Economic and environmental aspects can be simultaneously considered in the optimization procedure in this manner, and a separate module to link the economic model and the ecological model is not necessary.

Model structure
The general form of the model is the familiar linear programming problem (see Paris, 1991). The activities out of which the optimal combination is to be chosen by the solution procedure, are: production activities representing different crops and a range of cropping variants per crop, variable operations (choices among using own mechanization or contract work and among methods of control), seasonal labour, integer activities representing new machinery for chemical and mechanical crop care and the use of a whole range of pesticides. The constraints include: total land, rotation restrictions, supply of fixed and of seasonal labour, several coupling restrictions. Among the inputs the type and quantity of pesticides (in kg active ingredient (a.i.)) is specified. Further the environmental impact is included by means of adding the yardstick values (EIP figures, see next section) to each production activity. In this way the linear programming procedure takes account of listing the total use of pesticides in kg a.i. and their environmental impact.

The matrix described, contains about 200 activities and circa 210 constraints. The initial farm situation is specified by circa 70 non-zero right hand side values, depending on the number of crops in the rotation scheme. The LP procedure assesses the optimal farm organization, indicating: gross farm result, *i.e.* total returns minus variable costs (including annual cost of the optional new machinery), cropping pattern and cropping technique per crop, regular and casual labour hours used, input of pesticides and the impact figures according to the yardstick. See Wossink (1993) for a detailed description of the model structure.

An environmental yardstick to indicate the impact of pesticide use

In 1991 the Dutch government published the Multi-Year Crop Protection Plan (MYCPP) which sets reduction targets for the use of pesticides and for their emission to the environment. Moreover, stricter environmental criteria were proposed for the authorization of pesticides (Anonymous, 1991).

The MYCPP focuses primarily on the reduction of the amount of kilograms of active ingredients used per hectare by the year 2000 (Table 1). This objective is relatively easy to quantify and to measure. It is, however, not very appropriate from an environmental point of view, as pesticides differ considerably with regard to their en-

Table 1. Reduction goals for biocide use in arable farming in the Netherlands.

Category	Percentage reduction total kg active ingredients[a] by 1995	by 2000
Nematicides	46	70
Herbicides	30	45
Insecticides	15	25
Fungicides	15	25
Other	42	68
Total	39	60

[a] Compared to the average use over 1984–1988
Source: Anonymous (1991)

vironmental impact. In order to weigh the kilograms of active ingredient according to their environmental impact an environmental yardstick has been developed (Reus, 1991; Reus & Pak, 1993). The yardstick is primarily intended as an extension and management instrument for farmers to make the environmental effects of pesticides measurable and to enable farmers to make a more environmentally-sound selection of pesticides.

The environmental yardstick for pesticides includes three environmental effects: leaching into ground water, effects on water organisms and effects on soil organisms. The yardstick assigns so-called environmental impact points (EIP) to pesticides for each of the three environmental effects. The more EIP a pesticide gets, the higher its impact on the environment.

The methods used to calculate the EIP are derived from the ecological evaluation models utilized by the Dutch government for its pesticide registration procedure. The reference point of the environmental yardstick has been set at 100 EIP. This means that at a score of 100 EIP per application, the impact on the environment is still acceptable. If the score amounts to 500 EIP the environmental standard is exceeded five times.

The number of EIP depends on:
- properties of the chemical, like rate of biodegradation, mobility in the environment and toxicity to non-target organisms;
- application factors, like dosage per hectare and method of application;
- environmental conditions, like soil properties.

The EIP are assigned for a standard application of 1 kg/ha^{-1} (Table 2). If a different dose rate is used, the number of EIP should be multiplied by the actual dose rate. The EIP are added to the linear programming model as quasi-external data related with specific cropping activities.

Data

Cropping variants

Pesticide use depends not only on the crops grown, but also on the cultivation

Table 2. Environmental Impact Points for some pesticides*.

	Ground water		Soil organisms	Water organisms
	spring	autumn		
maneb	10.0	8000.0	1009.1	1666.7
parathion	0.0	0.0	315.7	5000.0
pyrizafos	0.1	0.1	2601.3	22222.2

* Application of 1 kg a.i. ha^{-1}, organic matter content of 3-6% and drift of 1%.

method. In the present study for every crop several so-called cropping variants are defined which differ in economic and environmental values. The cropping variants range from the intensive to the ecological production system. With this range of variants it is possible to investigate the effects of technical innovation and of several policy instruments on farm organization. The variety of the cropping variants with regard to environmental values is represented in the technical coefficients in the LP matrix. Financial differences are given by means of the gross margin figures in the objective function.

All cropping variants, except for the organic farming variants, where retrieved from information of the experimental station at Vredepeel, where conventional and environmentally-friendlier farming systems are being compared for the sandy soil conditions (Wijnands & Vereijken, 1992). This yielded variants for potato, winter wheat, triticale, sugarbeet, peas + beans, carrots, green maize and scorzonera. Next, organic farming variants for potato, wheat, sugarbeet, peas + beans and carrots were established by less region specific data (Anonymous, 1992). Information on labour supply, mechanization versus contract work etc. was retrieved from additional sources.

Price and yield changes

The environmental and economic implications of a reduction in pesticide use for future years cannot be assessed without including the effects of changes in prices and yield levels. Comparative static computations where made for the present situation (1993) and for the year 2000. The latter year was chosen since the governmental reduction targets for pesticide use are formulated for this year, see Table 1.

With respect to output prices, the Dutch farmer is directly and indirectly dependent on EC agricultural policy. The price scenario formulated reflects a trend policy extending the present McSharry regulations. Decreases of products prices are moderate (based on minus 2.5 percent anually for wheat) in combination with set-aside (15% of the acreage). Price developments for fixed and variable inputs are also a part of the price scenario. For a detailed description of price changes see Wossink (1993, p. 68–69).

Also yield changes were included. These percentages are based on the assumption that in the medium term (10 to 15 years) a continuous increase in yield potential can be expected by conventional plant breeding as well as by means of biotechnology. Genetic improvement is little influenced by economic and institutional conditions because of the long time scale of biotechnological progress in crop production (Gotsch & Bernegger, 1990). Another motive for using constant percentages is given by Weber & Ehlers (1988). They used a logistic function to simulate the development of yields over time in relation to the theoretical maximum and indicate that near the point of inflection of such a curve the annual yield increase can be assumed to be constant. This situation applies for crop production in the Netherlands. The yield increases vary between 0.4 per cent anually for potato to 2.5 for a new crop as oilflax. See Wossink (1993, p. 68).

Results

Application: comparison of control systems for arable farming

The representative farm

The region of the south east sand region in the Netherlands was selected as a case-study. Particularly, for crop farming on a sandy soil the implications of a reduction of environmental impact according to the yardstick was expected to be different from just a reduction of pesticide use expressed in a.i. The model farm for this region (Table 3, first column) was selected by consulting a farming system expert (C. Huys, personal communication). The gross farm result sums to NLG 109 100 for the current situation (1993). Total pesticide input sums to 7.3 kg a.i. ha^{-1}, of which 4.2 from fungicides. This is well below the average use of 24 kg ha^{-1} in arable farming in the Netherlands (Kavelaars & Poppe, 1993). According to the EIP the cropping practice of the model farm is most threatening for water organisms. This is caused by the use of specific pesticides namely the fungicides maneb in potato cropping (1700 EIP kg^{-1} ha^{-1}) and pyrazofos in scorzonera (22000 EIP kg^{-1} ha^{-1}) and the insecticide parathion in peas/beans (5000 EIP kg^{-1} ha^{-1}). Further the use of bentazon in peas/beans leads to groundwater pollution in spring and autumn: 14 000 EIP for application in spring and 100 000 EIP for application in autumn.

Effect of innovation

Next, calculations were made for the year 1993 by optimizing with all cropping variants for all the crops. The outcomes of these computations express the potential for environmental economic improvements if the most modern techniques were to be introduced in the given farm type. The optimal plan calculated by the extended model shows almost the same financial results (plus NLG 848 for the total farm). At the same time, total use of pesticides decreased significantly (32% in a.i and minus 50 to minus 64% according to EIP figures). The cropping pattern as such gives only minor changes. Compared with the basic situation, however, a different selection of cropping variants is made. There is a particularly important change-over regarding the potato variant. Instead of Bintje, the environmentally friendlier variant based on the variety Van Gogh is selected. Metribuzin and diquat are not longer applied for weed control and haulm killing. Instead the LP optimization procedure opts for mechanical methods, namely late ridging + hoeing and haulm shredding. Further smaller quantities of maneb/fentin and bentazon are used.

Effects of price and yield changes

Optimization of the extended model under the t = 2000 conditions for price and yield levels gave only one change-over; wheat is replaced by triticale which does not need any pesticides. However, the increase in yield levels cannot compensate for the lower

Table 3. Results of the computations.

	Current situation[1]	Optimization with all cropping variants included	Optimization with all cropping variants, yield increase and trend price policy	
			without pesticide volume constraint	with pesticide volume constraint[2]
	t = 1993	*t* = 1993	*t* = 2000	*t* = 2000
Cropping pattern (ha)				
Wheat standard	3.0	3.0		
Triticale			3.0	1.6
Green maize	6.0			
Green maize integrated		6.0	6.0	8.8
Potato standard Bintje	7.5			
Potato integrated van Gogh		7.5	7.5	7.5
Sugarbeet	7.5	7.5	7.5	7.5
Peas + beans	3.0			
Peas + beans integrated		3.0	3.0	3.0
Scorzonera	3.0	3.0	3.0	1.6
Total	30.0	30.0	30.0	30.0
Use of pesticides (kg a.i.)				
Herbicides	56.78	34.49	28.49	24.67
Insecticides	5.25	4.03	3.66	3.66
Fungicides	126.68	97.65	93.77	82.32
Other	29.38	13.58	13.58	13.58
Total	218.10	149.75	139.49	124.23
Env. Impact Points (EIP)				
Groundwater spring	147000	53000	53000	53000
Groundwater autumn	184000	86000	86000	86000
Soil organisms	88000	37000	37000	36000
Water organisms	289000	146000	141000	134000
Gross farm result (NLG year^{-1})	109 130	109 978	97 212	96 103

[1] Optimization with only the standard cropping variants.

[2] Herbicides minus 45%, insecticides minus 25%, fungicides minus 25%, others minus 68% and total minus 60%.

output prices. The farm result shows a loss of NLG 12 800 compared with the 1993 situation (all cropping variants included).

Effects of the governmental pesticide policy

In Table 1 the quantitative governmental reduction goals for the year 2000 in terms of the weight of active ingredients are presented compared to the average use over 1984–88. These reduction goals were translated to the situation of the model farm. Note, however, that in this way the reduction objectives formulated for the total arable farming sector are imposed to the single arable farm, which leads to an overestimation of the economic effects (income, cropping pattern). Assuming a first reduction in pesticide use in 1990 and a linear trend the decreases realized by 1993 were derived: herbicides minus 24%, fungicides minus 11%, other minus 32% and total minus 31%. These decreases are in line with those in the evaluation report of the MYCPP (Anonymous, 1993).

According to the results in Table 3, the 'farm specific' (see above) reduction targets of the MYCPP for the different categories of pesticides can be achieved by technical change, without changes in cropping pattern. However, the reduction target of 60% reduction in total use is not met. Imposing this reduction target to the model yields a cropping pattern with less scorzonera and triticale; silage maize is selected instead. The additional income loss is not more than NLG 1100.

Implications of a reduction of environmental impact

Next, the implications of an increasing reduction of EIP were assessed. It appeared

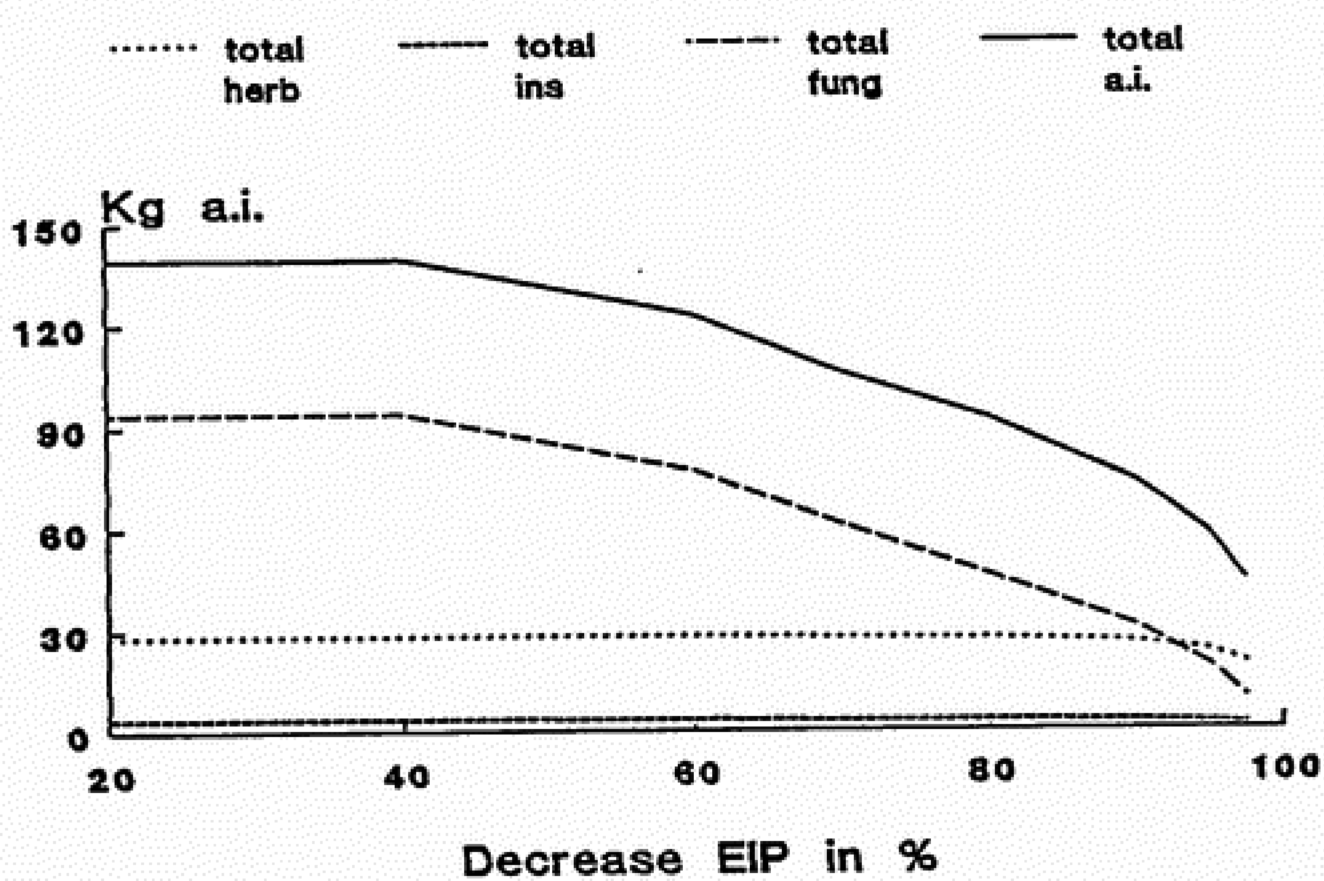

Figure 1. Relation reduction EIP and pesticide use in kg a.i., t = 2000 conditions.

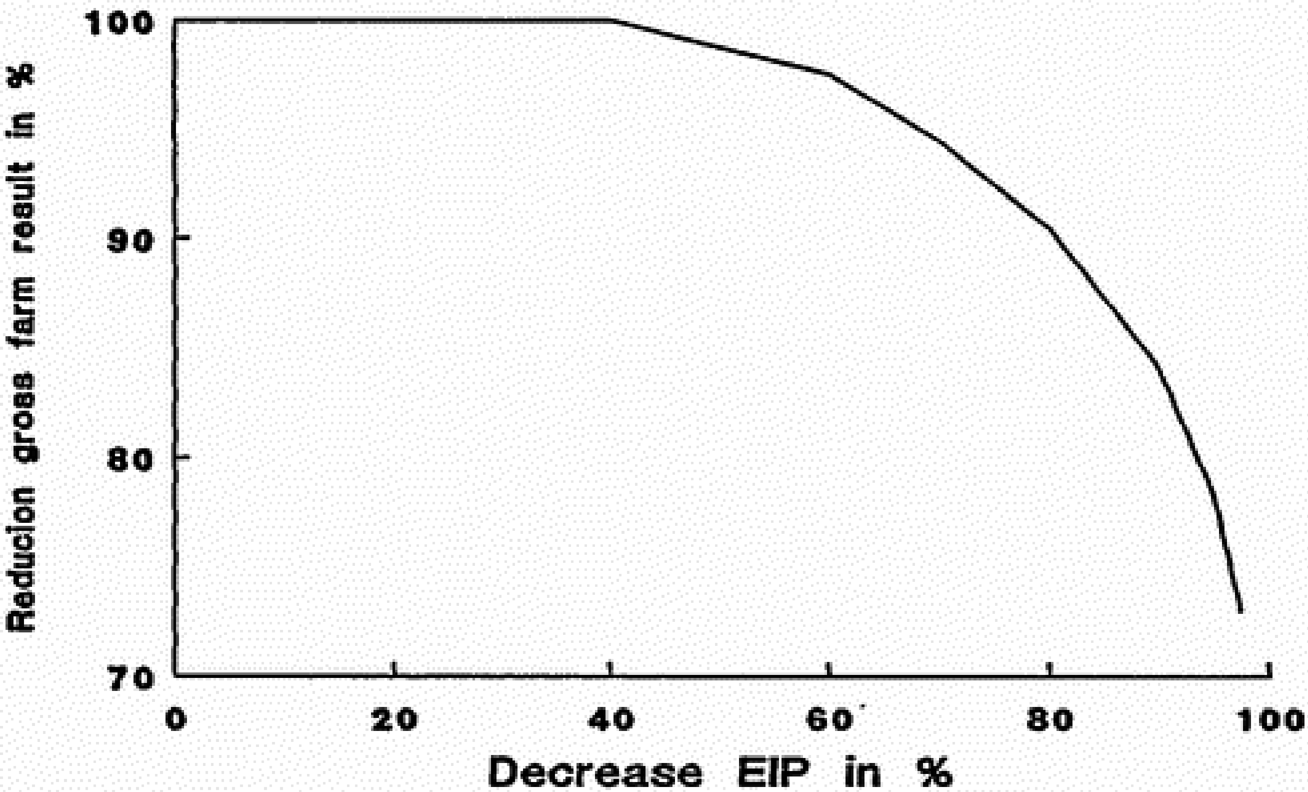

Figure 2. Relation decrease EIP and gross farm result, t = 2000 conditions

that under the t = 2000 conditions the EIP had to be limited to 60 percent of the figure for the current situation to yield a first change in cropping pattern and financial result. It also followed that a reduction of 60 percent of the EIP gave a reduction in kg a.i. sufficient to fulfil the MYCPP goals. Figure 1 presents the relation between the reductions in kg a.i. and in EIP. Obviously the use of fungicides reacts strongly when imposing limits to the EIP level. This is due to the use of the harmful fungicide maneb in potato growing. Figure 2 visualizes the financial impact of a decrease in EIP level.

Discussion

In theory, environmental economic modelling involves the same principles and technical rules as standard monodisciplinary modelling. Additional hypotheses need to be formulated, however, about the relationships between economic activities and environmental components and processes. Choosing the relevant spatial scale and temporal dimension is a special problem. This paper argues that modelling the year-to-year farm decisions offers a useful approach to explore the interactions of production intensity, environmental aspects and farm income and to compare the implications of different innovations, price change and environmental policies.

Linear programming (LP) is virtually the only approach available which can produce projections of changes in farm organization outside the range of past experiences (such as future technological change and policy measures). An important characteristic of the LP method is its ability to investigate technical and environmental questions. Because of the physical-economics basis of a LP model it can easily be connected to ecological 'flow' models designed to assess pollutant input impacts, as demonstrated in this paper.

The value of the environmental economics farm model is twofold. Since the model provides a means to assess the importance of technical parameters, it can indicate where research effort is best directed. In this descriptive role the value of the model is in the elaboration of (precise) technical specifications in the areas of environmental pollution and technical innovations. Further applications in this field will require a continuous dialogue with experts of several disciplines to update the model for technical change and to examine more restrictive or other environmental criteria.

In its other (prescriptive) role, the environmental economics model allows real life decision makers the opportunity to explore various strategies and thus enables them of gaining valuable insights. In this way, the model can help encourage and structure debate by enabling policy evaluation. The efficiency of alternative environmental policies can be compared by examining the costs involved and the reduction in pollution achieved. This can be realized by making calculations for a series of representative farms and aggregating the model outcomes.

The environmental-economic model can be used for many purposes. The application for technical innovation, pesticide use and two control systems, is one example with particular relevance for the environmental policy debate in the Netherlands. Note that this application covers only one specific group of farmers. Hence, the relationships and trends are more important than the absolute figures. A general conclusion that can be drawn is that, in further research, special attention should be given to the integration of new, less harmful pesticides into the model (e.g. the alternative fluazinam for maneb). In this way the potential for reduction of the environmental impact without reducing farm result could be assessed.

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