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**The What, How And Where of Nature Conservation  
and Agriculture: *The Coordination of Ecological-  
Economic, Behaviourial and Spatial Aspects***

**Ada Wossink, Jaap van Wenum, Clifford Jurgens and  
Geert de Snoo**

Ada Wossink and Jaap van Wenum are associate professor and graduate student, respectively, in the Department of Farm Management, Wageningen Agricultural University, The Netherlands. Cliff Jurgens is associate professor in the Department of Physical Planning & Rural Development of the same university. Geert de Snoo is head of the section Ecosystems & Environmental Quality, Centre of Environmental Science, Leyden University, The Netherlands

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# **The What, How And Where of Nature Conservation and Agriculture: *The Coordination of Ecological- Economic, Behaviourial and Spatial Aspects***

**Ada Wossink<sup>1,\*</sup>, Jaap van Wenum<sup>1</sup>, Clifford Jurgens<sup>2</sup> and  
Geert de Snoo<sup>3</sup>**

1. Department of Farm Management, Wageningen Agricultural University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands
2. Department of Physical Planning & Rural Development, Wageningen Agricultural University, Gen. Foulkesweg 13, 6703 BJ Wageningen, The Netherlands
3. Centre of Environmental Science, Leiden University, PO Box 9518, 2300 RA Leiden, The Netherlands

\* Corresponding author, e-mail: [Ada.Wossink@alg.abe.wau.nl](mailto:Ada.Wossink@alg.abe.wau.nl).

## *Abstract*

An approach is presented to address three questions: (a) what is to be considered as valued nature at the farm level, (b) how can nature management be integrated in farming practice, *i.e.* operational and behavioural acceptability, and (c) where should nature management be implemented, *i.e.* the optimal spatial arrangement.

*Keywords:* biodiversity, farmer perceptions, spatial optimization, GIS, crop farming, ecological infrastructure

## 1. Introduction

The European's Commission's Fifth Environmental Action Programme ('Towards Sustainability') and the Reform of the Common Agricultural Policy in 1992 have both initiated new legal and strategic actions to integrate environmental objectives into sectorial policies. Agriculture in particular is considered a driving force for the state and trends of Europe's biological and landscape diversity. On the European continent where the former natural vegetation has been changed almost entirely under the influence of human land use activities, large proportions of existing and future ecological values are more or less directly dependent on the way the land is being utilised.

In the Netherlands the issue already became a topic of public and political interest back in the 1980's. It has led to new policies on land use, agricultural practices and nature and landscape (the National Environmental Policy Plan of 1989 and the Nature Policy Plan of 1991). The Nature Policy Plan describes a National Ecological Network (NEN) in which core areas, nature development areas and connecting migration zones are designated. The areas outside the NEN are referred to as "white areas" (see Joenje). In the NEN, land use has only one function: nature conservation. Around the NEN buffer zones need to be established for protection and interaction of endangered species. The connecting migration zones blend with the white areas. Desirable ecosystems and goal species have been formulated for the areas within the NEN. In the white areas, the main function is agriculture; nature and other uses are secondary. There is no specification of the desirable nature in these white areas. Instead it has been left that provinces and local authorities must come up with policy proposals for the implementation of nature conservation and restoration within these areas. Meanwhile there are also efforts by private organisations and groups of farmers explicitly aiming at developing nature; i.e. the idea of paying farmers for the "production" of certain species.

Previous ecological and economic studies of nature management at the farm level have generally focused on the impact of land use regimes on farm income and biodiversity. For example, the positive effects of refraining from pesticide use in northern European agriculture on the abundance of flora and fauna was reported by e.g. Rands; Tew, MacDonald and Rands; Boatman and by De Snoo (1994;1995). Economic studies at the whole farm level generally involve a comparison of specific land use regimes by analysis of accounting data and/or farm level modelling (e.g. Van Eck, De Jong and De Boer).

Previous studies on the spatial aspects of agricultural production and the environment, focus on the sediment and sediment-bound pesticide, nitrogen or phosphorus problem in relation with water quality of an agricultural watershed (e.g. Braden et al.; Braden, Larson and Herricks; Moxey and White; Lintner and Weersink). The regional spatial dimension, however, is also important in the case of the positive externalities of agricultural production on biodiversity. Ecologically, the spatial distribution of species is important for their

changes of propagation. Economically, the 'where' question is of importance because of the advantages of selective control, i.e. protecting where it is most effective and least costly. Selective control requires to identify the most effective nature conservation methods and also where to apply these. In this field geographical information systems (GISs) offer important opportunities. Despite their significant potential for environmental economic research, GIS techniques are seldom used for this purpose in practice (Fletcher and Phipps; Moxey).

Furthermore, farmers' perceptions and preferences need attention. In an approach that advocates close involvement of farmers with the management of nature, it is important that the acceptability of conservation practices to farmers is carefully considered. In agricultural economics research the role of perceptions has received little attention. In behavioural economics it is not the objective characteristics of actions/goods which matter, but the subjective perceptions of the decision maker (Gilad and Kaish). Interview techniques based on the theoretical insights of behavioural economics are common in fields as marketing research and analysis of consumer behaviour. In the agricultural economics literature few papers address the impact of farmers' (the consumers of agricultural technology) perceptions on their choices among management practices (Adesina and Baidu-Forson; Wossink et al.).

The paper presents a multidisciplinary approach for the optimal design for nature conservation within an agricultural area. The method takes account of the costs and ecological benefits at the farm level, farmers' perceptions, and the spatial arrangement of ecological infrastructures at the regional level. Integration of these aspects is crucial both from the scientific point of view (concerning sustainability) and with regard to policy implementation, i.e. to accomplish co-ordination of environmental, nature conservation and agricultural policy. The insights gained can be used to structure and stimulate the dialogue on nature conservation and restoration among farmers and policy makers.

Section 2 presents a generic model. In section 3 we consider the issues of measuring biodiversity<sup>1</sup>, ecological economic modelling, analysing farmers' perceptions and modelling spatial dispersion of species. Section 4 provides an illustration for the situation of the Haarlemmermeer, an area near Amsterdam, the Netherlands. Section 5 discusses the results and provides conclusions.

## **2. Generic model**

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<sup>1</sup> In this paper biodiversity and nature are used interchangeably. Biodiversity includes three aspects: (a) ecosystems and natural processes, (b) species, and (c) genetic variety. The focus here is on the second aspect, the other two are only partly considered namely as far as they relate to agro-ecosystems.

The model builds on the *casco* concept used in land use planning. This concept implies that within the countryside, areas with low and high anthropogenic claims can be identified, such that choices can be made in connection with agriculture. Corridors are to be made to interconnect the niches where valued species are found, for purposes of dispersion and recolonization (Opdam et al.; Jurgens, 1994). From an economic point of view the *casco* concept has much similarity to selective control or targeting; i.e. to protect most where it will be most effective and least costly. Furthermore, the *casco* concept enables the economic treatment of nature conservation in a way comparable to mobile non point source pollution.

The theoretical model meets three criteria (Braden et al.; Antle and McGuckin): (a) it accounts for the effects of management restrictions on nature, (b) it identifies the pattern of land use in the area studied which maximises overall profits within limits on nature conservation, and (c) it starts at a highly disaggregated level to account for the heterogeneity of the natural environment.

Farm fields are the sources of nature production. Index  $j = 1, \dots, J$  denotes the fields, and index  $i = 1, \dots, I$  denotes farming activities on the fields. In addition let  $f$  denote the production relationship between agricultural input and outputs including the effects of management patterns on nature, let  $C$  denote the costs function and let  $h$  denote the spatial correlation of the species studied, i.e. network forming. The objective is to maximise the agricultural profit for the total ecologically interesting area while meeting biodiversity restrictions. The core of the optimisation then is the following planning problem of co-ordinated action:

$$(1a) \quad Q^*(N): \text{Max } Q = \sum_{j=1}^J \sum_{i=1}^I p' y_{ij} - C(y_{ij}, z_{ij}, x_{ij}; l_j)$$

$$(1b) \quad \text{s.t.} \quad f_{ij}(y_{ij}, z_{ij}, x_{ij}; l_j) \leq 0 \quad \forall i, j$$

$$(1c) \quad h(z_{ij}, x_{ij}; l_j) \geq N$$

$$(1d) \quad x_{ij} \leq X_{ij} \quad \forall i, j$$

where

$p$	=	vector of prices of agricultural outputs (crops);
$y_{ij}$	=	vector of marketed output quantities;
$x_{ij}$	=	vector of management variables;
$z_{ij}$	=	vector of nature output (occurrence * ecological rating of species studied);
$l_j$	=	vector of site characteristics;
$N$	=	vector of minimum spatially correlated biodiversity.

The fields  $j$  in the model given in eqn. (1a-1d), are not owned and operated by  $J$  individual farmers, rather a farmer manages a set of adjacent fields. The planning model presented can be extended to account for this situation by setting up  $n$  objective functions ( $n$  is number of farm operators,  $n \leq j$ ). Each of these operators chooses farming practices for his fields independent of the activities of others. Notice that this will also affect the spatial pattern. In this way the existence of actual farm units and decision makers can be incorporated, instead of treating the total area as a single farm unit (see Lintner and Weersink).

Solving the equation set will yield  $x^*$ , the vector of agricultural practices including management restrictions that satisfies the requirement for nature conservation as expressed by  $N$ . Varying  $N$  gives a nature conservation costs frontier for the total region studied. By means of  $x^*$ , location c.q. farmer specific proposals for the increase of natural values can be given, rather than a general advice or directive<sup>2</sup>. The latter would likely lead to an overestimation of the costs of nature conservation and restoration and to inappropriate policy proposals.

To implement this theoretical model, it is necessary to address the full range of issues that arise in applied production economics including measuring nature, assessing costs and the spatial aspects of the physical models. In addition we included the issue of farmer' perceptions of the nature management options  $X_{ij}$ . Implementation implied close co-operation between agricultural production scientists, economists and experts in the fields of biodiversity. The next section discusses how the various aspects were merged.

### 3. Implementation

#### *Measuring biodiversity*

Recently an instrument for measuring biodiversity, the so-called yardstick for biodiversity on farms, has been introduced (Buys). This yardstick aims at giving farmers, and other interested groups, an impression of the "ecological production" at individual farms. Biodiversity measured by the yardstick refers to organisms which (may) establish and sustain spontaneously, and is assessed at the level of individual species based on a selection of (groups) of species. Selected were 199 species of vascular plants, 17 of mammals, 77 of nesting and 14 of wintering birds, 7 species of amphibians, 2 of reptiles and 26 species of butterflies. The score on the yardstick is the product of the number of units resulting from the census and a rating score which is based on the ecological importance of the species (rarity, trends in size of the population and the international importance). A subdivision

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<sup>2</sup> This would restrict  $d h/dz_{ij}$  to be a positive constant and the partial derivative of  $h$  for an individual input to zero (see Braden et al.).

according to the biotopes found at the farm level makes it possible to apply the yardstick to all types of farms. An example is given in table 1.

Table 1 Example form for biodiversity yardstick at the farm level

<b>Farm scores</b>	plants	Nesting birds		Winter-	Mammals	Amphibians	
	Butterflies	terr.	nests	ing birds	and reptiles		
Grassland	318	112	58	10	10	0	15
Ditches		309	95	0	0	0	6
81							
Farmyard	228	93	66	0	9	0	22
Total (abs.)	855	300	124	10	25	81	37

Source: Buys, see also references there.

#### *Ecological economic trade-offs at the farm level*

Costs of changes in farming practice to improve biodiversity are not addressed by the yardstick approach. However, ecological-economic modelling enables the trade-offs between farm income and biodiversity to be assessed for a range of farming situations. Several economic methods are available that incorporate the relationships between agricultural output  $y_{ij}$ , environmental impacts and production techniques  $x_{ij}$  at the crop or whole farm level. Partial budgeting and programming techniques are the predominant methods (for an overview see Roberts and Swinton). Typically, the normative models are used to gain insight into the trade-offs between income and environmental stress (see e.g. Wossink, De Koeijer and Renkema; Verhoeven, Wossink and Reus; Foltz et al.; Teague, Bernardo and Mapp). These approaches also can be used to study the implications of nature conservation at the farm level.

Three nature management categories can be considered: (1) along the field (i.e. crop edges), (2) within the field, and (3) in between two crops in the rotation (fallow land, stubble field). In this study we only focus on the first category;  $X_{ij}$  is restricted to unsprayed crop edges. In arable fields the largest number of plant species is found in the outer few meters of the crop. Crop edges are also more attractive for fauna than the field centre (De Snoo, 1995). At the same time, unsprayed field margins are of special interest to reduce pesticide concentration in surface water (De Snoo and Wegener Sleswijk). In economic terms, crop edges are less valuable than the field interior. Management of the edges often requires additional effort, for instance in the case of wedge-shaped fields, and the resulting yields from the edges are often lower. So, field margin management offers special opportunities to integrate economic, ecological and environmental aspects.

Implementing unsprayed field margins can be done in several ways. Fallow field margins or grass strips are examples of changes concerning the extensive margin whereas unsprayed crop strips imply changes regarding the intensive margin. In the Netherlands many experiments by biologists are done in which yield reductions and savings on pesticides and ecological benefits in terms of the occurrence of species are assessed. By means of partial budgeting the information can be used for a first assessment of  $X_{ij}$  and  $f_{ij}(y_{ij}, z_{ij}, x_{ij}, l_j)$  of the generic model presented in section 2. For clay soils it was found that establishing unsprayed edges in potato and wheat is feasible. In other crops a better options is to substitute the regular crop on the perimeter for cereal, grass or a fallow strip (De Snoo 1994; 1995).

#### *Analysis of farmers' perceptions and preferences*

The next step is to consider the acceptability of the nature management regimes  $X_{ij}$  to farmers. Survey analysis can provide insight into the influences of additional behavioural attributes. Perception analysis and conjoint analysis are well known procedures for determining the perceptions and preferences of individual decision makers (Katona; Churchill; Hair, Anderson and Tatham).

In a survey study behavioural attributes for five types of unsprayed crop edges on clay soil were evaluated (Van der Meulen, De Snoo and Wossink). All respondents preferred to have the unsprayed edges in cereal crops (table 2). Obviously, farmer's perceptions of an unsprayed edge in potato in particular differs from the normative cost-ecological benefits assessment. The results of the perception analysis showed that this was mainly due to agronomic concerns.

**Table 2 Preferences for different types of unsprayed crop edges (overall and with or without experience with field margins) (1 = greatest 5 = lowest preference)**

type	overall (n = 31)		with experience			without experience		
	av.	s.d.	n	av.	s.d.	nw	av.	s.d.
unsprayed edges in cereals	2.06	±1.03	23	1.83	±1.03	8	2.75	±0.71
unsprayed edges in potatoes	3.77	±1.38	10	2.60	±1.58	21	4.33	±0.86
unsprayed cereal edges along other crops	3.06	±1.03	9	2.33	±1.32	22	3.36	±0.73
grass strips	2.13	±1.26	15	1.80	±1.01	16	2.44	±1.41
set-aside strips	3.71	±1.47	6	2.43	±1.51	25	4.08	±1.25

Legend: n = number of respondents; av. = average score; s.d. = standard deviation; ne = number of respondents with experience; nw = number of respondents without experience.



**Table 3 Results of the conjoint analysis**

Attribute and attribute levels	overall (n=31)		Gelderland province (n=9)		Zeeland and Groningen (n=12)		Haarlemmer meer (n=10)	
	import. (in %)	utility	import. (in %)	utility	import. (in %)	utility	import. (in %)	utility
Width:	46.15		45.90		40.00		66.20	
* 3 metres		-0.84		-1.70		-0.83		0.00
* 6 metres		-0.21		0.89		0.11		-1.74
* defined by the farmer		1.05		0.81		0.72		1.74
Payment system:	23.48		20.66		35.36		4.23	
* conditional		0.48		0.58		0.69		0.11
* result		-0.48		-0.58		-0.69		-0.11
Guidance:	17.00		31.48		16.07		5.28	
* frequent		-0.35		-0.89		-0.31		0.14
* infrequent		0.35		0.89		0.31		-0.14
Location in the field:	13.36		1.97		8.57		24.30	
* fixed		-0.28		-0.06		-0.17		-0.64
* rotation		0.28		0.06		0.17		0.64

Legend: import. = importance of attribute; the three columns relate to the three experiments in which the respondents participated.

By means of a conjoint analysis significant insights were gained for a description of the "ideal" unsprayed field margin (table 3). Important factors for farmers turned out to be the width of the crop edge and whether the edge could be included in the rotation. Among groups of respondents significant differences were found in the preconditions, relating to differences in the intensity of farming and existing parcel structures. The outcomes of table 3 were used in the assessment of  $X_{ij}$  for the ecologically interesting areas. For the

Haarlemmermeer region only narrow (3 m wide) rotational strips were considered, for instance. The outcomes of the perception analysis were used to make additional calculations of the nature costs frontier for subsets of  $X_{ij}$ .

### *The spatial element*

By means of unsprayed crop edges a system of “green veins” can be created through agricultural regions, which enhances the changes of propagation of the species studied.. The design quest here is to identify the most effective "network", thus identifying parcels to be assigned a low anthropogenic land use claim.

Geographical information systems (GIS) provide the foundations necessary for the spatial correlation function  $h$ . The models ECONET 1-4 provide a GIS package to optimise corridor designation (Jurgens, 1992). The probability of a habitat successfully being colonised is mainly dependent on four factors: (1) the local suitability  $l_j$  and the size of the habitat patch  $j$ , (2) the number of individuals departing from habitats, (3) the travel capacity of the species considered, and (4) the distances between the habitat niches. In ECONET the emphasis is on the spatial position; i.e. mainly on aspects (1) and (4) above in relation to the biological parameters (3).

In ECONET identified landscape patches are put in their topographical position, with their geographic distance determining the nearest neighbour situation. A vector-data approach is applied rather than a grid-base data method. ECONET 1 is a model applicable for situations where dispersion is homogenous through the landscape. ECONET2 restricts the dispersion to pre-determined or pre-allocated pathways, e.g. along linear elements like waterways and ditches. ECONET3 allows for size of habitat and of areas obstructing the colonisation and dispersion. ECONET4 combines the dispersion restrictions of ECONET2 with the spatial approaches of ECONET3 and is especially suitable to analyse the spatial issues of crop edges; given the position of (a small number of) existing unsprayed field margins it will assess where additional ones have to be located to ensure dispersion. ECONET optimises by means of the minimum spanning tree method<sup>3</sup>. ECONET 2 and 4 have the option of using weights for the network links which enables the most cost-effective location of the connecting elements to be identified (Jurgens, 1993; 1994).

Notice that an important difference between the theoretical model and the combination of ECONET4 with the ecological-economic assessment is that only specific management alternatives are considered. As a result the nature conservation frontier is determined by numerical solution.

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<sup>3</sup> The minimum spanning tree method links all eco-objects together in such a way that the sum of the length of the links is minimal and all eco-objects are connected.

#### 4. An empirical application

As an example, the modelling framework outlined in the previous sections was applied to the geographically simple research area of the Haarlemmermeer<sup>4</sup>. To this end three steps were taken: (1) digitisation, i.e. co-ordinate information of the fields in the area was captured for GIS processing, (2) determination of the distribution (frequency/spatial) of crops and of field margin management for the baseline situation and (3) assessment of the optimal ecological network.

Data on costs and benefits of unsprayed crop edges were available from an experiment by the Centre of Environmental Science, Leiden University in the area during 1990-1994 (see De Snoo, 1995). Only 3 metre wide edges in potato, wheat and sugarbeet were considered and the analysis was applied to combinations of field margins. All field margins are located alongside a ditch, so a combination was made up of the non-sprayed margins in the crops on two adjacent fields. Non-spraying propagates the biodiversity of dicotyledonous species and flower visiting insect, particularly. In this example, the yardstick value for butterfly species was taken as indicative for total biodiversity. However, this approach can be easily extended to all species included in the nature yardstick.

**Table 4 Costs and biodiversity of field margins combinations, Haarlemmermeer.**

Field margin in	Costs NLG km <sup>-1</sup>	Nature value Butterflies Score km <sup>-1</sup>	Ratio of costs and nature value	Weight <sup>a</sup>
WW/WW	111.54	1868	0.06	1
WW/POT	0.77	1652	0	1
WW/SB	565.38	1293	0.44	3
POT/POT	-110.00	1436	-0.08	1
POT/SB	454.61	1077	0.42	3
SB/SB	1019.22	718	1.42	9

The GIS model uses impedance values 1-9.

Source: Timmerman and Vijn

The area covers 36 farms each of 20 ha with identical cropping patterns (wheat WW, potato POT, wheat, sugarbeet SB). The 36 farms have identical physical characteristics in all aspects of *l*. Each farms covers four adjacent fields of 5 ha. Field size is 500 by 100 m. To

<sup>4</sup> An area of reclaimed land, known as a polder.

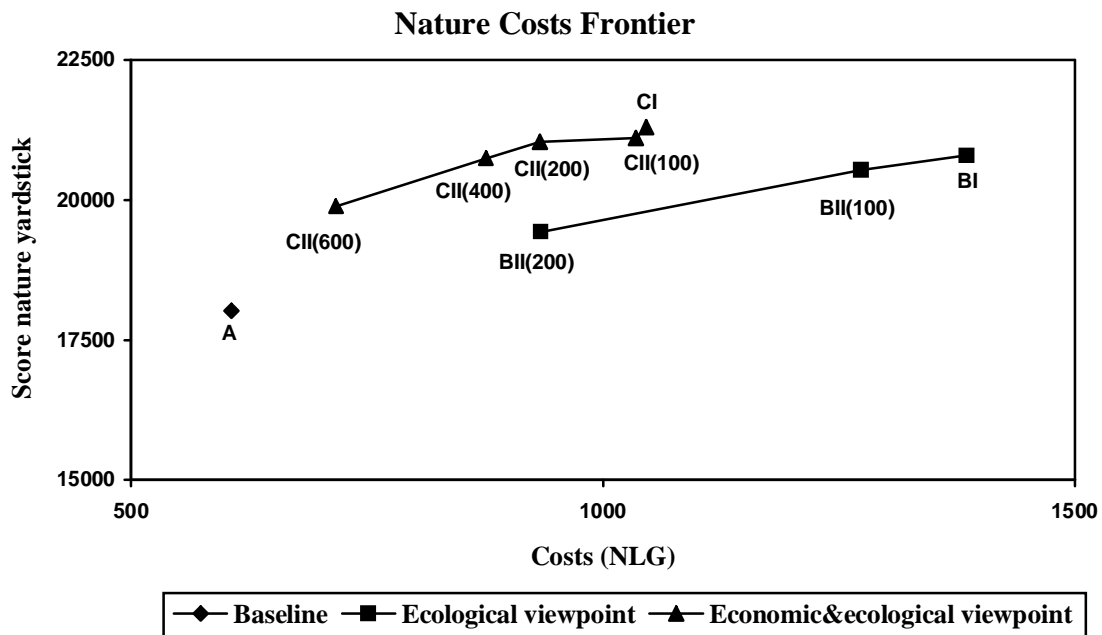
simulate a basic situation, each farm was ascribed a type of field margin management out of four options (all margins sprayed, POT unsprayed, WW unsprayed, POT and WW unsprayed) by means of random selection. For this base line situation (A), costs and nature value at the regional level were calculated. Next, four strategies for network designation were distinguished: (BI) Optimisation according to a strict ecological point of view: non spraying on the total ecological infrastructure as calculated by ECONET4; (BII) Optimisation according to a less strong ecological point of view: non spraying on part of the network, leaving out distances that can be bridged by the species (100-600 meters), (CI) Optimisation according to the principle of selective control, and (CII) as BII but according to the principle of selective control.

Strategy BI enables propagation of all organisms found in the margins to all other margins. Under the assumption that the species studied can "travel" a certain distance, the unsprayed margins need not to be connected in a closed network, which is expressed by strategies BII and CII (100-600 m). Less effort is required to establish a network but at the same time less extra nature value is added.

The results of the calculations are summarised by means of a nature costs frontier relating the minimum losses in farm profits with attaining particular biodiversity levels (Fig. 1).

Comparison of the results of strategies B and C indicates the advantages of selective control. In strategy C not the minimum distance but the costs per unit of for each of the optional connecting strips are decisive in the assessment of the ecological network. The frontiers clearly diverse as nature production increases. Field margins in sugarbeet are avoided in particular in strategy C. This is in line with the high impedance value for field margin combinations with sugarbeet (table 4).

The series of computations was repeated for other baseline situations, for individual crop edges instead of combinations of edges, and for other  $X_{ij}$ . In the latter calculations the preference scores (Table 2) for the region were used to assess subsets of  $X_{ij}$ . In that way costs and benefits of less efficient, but more acceptable, strategies can be assessed. For instance, if in the basic situation only non-sprayed margins in winter wheat are considered, total costs for each of the three strategies range between 2400 - 2600 NLG for the region and the nature score between 40300 - 40700.



**Fig 1 Nature costs frontier for the area (720 ha, random field margin management at the farm level) for two strategies (B, C) of establishing ecological networks**

### 5. Concluding remarks

The nature cost frontier shows the advantages of selective control in nature conservation: more biodiversity at lower costs. The approach further enables the spatial identification of can be very valuable for (a) the discussion on imposing a "nature quality minimum" for ecologically desirable field margin management and which farmers should participate. The information on management options available, and the associated cost and ecological benefits agricultural areas in the Netherlands and (b) private initiatives by groups of farmers, the "nature co-operatives".

The study shows that when research and extension programmes in nature management are being developed, it is important that an early attempt is made to obtain information on farmers' perceptions and on spatial constraints affecting management options. This analysis should be conducted at the regional or sub-regional level to account for differences in farm situation and farmers' objectives.

In this study only field margins were considered. For a complete picture to be given two other options for nature conservation and restoration need to be included: within the field, and fields left fallow in the rotation.

Partial budgeting was used to capture cost at the farm level. This technique has the advantage of simplicity but may leave out the influence of fixed, allocatable inputs. Our analysis can be performed using a more sophisticated method such as linear programming for a more detailed assessment of the costs.

In conclusion: this paper presents an approach for the co-ordination of ecological, economic, behavioural and spatial aspects in order to explore the supply side of nature conservation and restoration in agriculture. The use of ecological field survey data and a yardstick for biodiversity offers a tool for designing management actions. These actions are then analysed through an economic model which describes the trade-offs between conservation and financial costs.

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