Model documentation

Spatially Explicit Rural Agent-Based Model
(SERA)

A spatially explicit multi-agent approach to model social-ecological system dynamics in European rural landscapes

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1. Introduction

Agent-based models have become a popular method of modelling complex real world systems in the land based sector. Agent-based models (ABMs) within the specific agricultural policy context were pioneered by Balzann (1997) with the Agricultural Policy Simulator (AgriPolIS); Jagers, Janssen, & Vlek (2002) who explored how overharvesting affects the relationships between human activities and natural resources and Berger (2001), Happe, Kellermann, & Balzann (2009), Lobianco & Esposti (2010) and Schreinemachers & Berger (2011) who evaluate the way agricultural policy intervention affects a heterogeneous population of farm households and their resources. Matthews (2007) summarizes the advantages of agent-based models as follows: ‘Specific advantages of agent-based models include their ability to model individual decision making entities and their interactions, to incorporate social processes and non-monetary influences on decision-making, and to dynamically link social and environmental processes.’ This document helps to gauge the potentials of agent-based models for rural complex systems. This occurs first and foremost using the example of the spatially explicit rural agent-based model, which is discussed in this documentation.

The model presented in this documentation contributes to literature by looking closely at how agents embedded in rural landscapes adapt to agricultural policy interventions and change the rural landscape in this process and how this can inform governance processes in rural development. The model is applied to the complex system dynamics of dairy farms in the area of Winterswijk, The Netherlands. This model will describe the strategic decisions and behaviour of individual farmers in response to changes in their economic, ecological, social or political environment, and link to the production, economic and environmental impacts of their management. Our model moves beyond previous work in several respects. First, farm agents and their respective parcels are modelled in detail, including heterogeneity in parcel size, quality, shape and distance to the homestead. Second, to explore the impact of policy interventions on land market outcomes, we explicitly model a land-auction mechanism that takes into account multiple parcels with multiple characteristics at once. Third, we are able to experiment with the division of gains from trade depending on whether there is a buyers’ or a sellers’ market, and give insight into the consequences of the revenue from trading on the allocation of land.

We proceed as follows. Chapter 2 describes the conceptual framework of the model. Chapter 3 gives an overview of how the model is implemented in Repast S 2.0. Chapter 4 describes the case study area and chapter 5 describes the behavioural rules of the agents in the model.

2. Conceptual framework

2.1 Background Agent Based Model SERA

Modelling human decisions in coupled human and natural systems by means of an ABM approach has become a popular bottom-up tool that has been extensively employed over the past decades to understand system complexity and non-linear behaviour (see, for instance An, 2012; Heckbert, Baynes, & Reeson, 2010; Rounsevell, Robinson, & Murray-Rust, 2012). Also many studies exist that focus on ABMs to investigate land use changes and
consequences of land-use policies at landscape level (see, for instance Bakker & van Doorn, 2009; Le, Park, & Vlek, 2010; Parker, Manson, Janssen, Hoffmann, & Deadman, 2003). With respect to spatial ABMs applied to agricultural policy analysis, Balmann (1997), Berger (2001), Happe, et al. (2009), Lobianco & Esposti (2010), Schreinemachers & Berger (2011) and Schouten, Polman, Westerhof, & Kuhlman (2012) focus on the impact assessment of agricultural policy support measures that are part of the EU Common Agricultural Policy, taking into account both microeconomic farm management theory and modules for simulating biophysical dynamics. Advantage of these policy assessment models is that the effects of policy changes on different farm types can be shown, taking into account both structural and spatial heterogeneity of the farms in a spatial explicit way. This type of models is gaining importance as tools for managing tomorrow’s agriculture, as they allow to study a wide range of price and trade policy options. Traditionally, predicting the behaviour of individual farmers is typically based on mathematical programming methods. These models usually aggregate individual decision-making at the regional or sector level to evaluate policy options. They do not capture the interactions between actors (i.e. individual farm households) assuming that there are no transactions and information costs. Furthermore, these models do not fully capture the spatial dimension of agricultural activities and their effects on surrounding (nature) areas (Berger, 2001). ABMs focused on agricultural policy assessment are able to capture these farmers’ interactions, as well as the spatial dimension of their activities while being subject to policy interventions. Farmers in ABMs are called agents or in our case farm agents.

2.2 Farm agents
For the purpose of the model discussed in this documentation, an agent is defined as ‘an entity that acts individually, senses parts of its environment and acts upon it’ (Tesfatsion, 2002). In the context of regional agricultural systems, the main group of agents we define in the model are the farm agents or in other words farmers. In the context of the model, one farm agent corresponds to one farm or agricultural holding. In accordance with the above definition, a farm agent is an ‘independently acting entity that decides autonomously on its organization and production to pursue a defined goal (e.g. to gain the highest profit)’. A farm agent reacts to changes in its environment and its own state by adjusting its farm organization through for instance selling or buying land. By “own state” we mean the available factor endowments like the total amount of land, land use or the number of cows. Farmers can adjust their farm organization for instance by extending their farm through buying land. We will discuss the farm agent en environment in the next sections in more detail.

2.3 Model modules per farm agent

Figure 2.1 summarizes the different modules and course of events per year of the model for this study which are run for every farm agent separately.
Figure 2.1: Course of events during one simulation period

Figure 2.1 provides an overview of the dynamics of the model, and the course of events during one simulation period. The model consists of an *initialisation module* in which data is conditioned to be used in the model, a *farm module* that allows the calculations of farm income contribution, a *land lease market module* distributing the land among the farmers, and an *output module*. The *initialisation module* contains exogenous agricultural census data (reference year 2010). The attributes on farm level are the farm structure, namely age, type of farm, size and the total number of owned and rented parcels. At parcel level, attributes are soil quality, crop suitability and land use. At landscape level, attributes are number of farms in the region, spatial land characteristics, size and distance from the parcels to the homestead. These attributes do not change during the simulation period. In the *farm module* each farm agent is equipped with a behavioural model that determines whether conventional farming or an AES is chosen. This module keeps track of the farm management decisions, thereby taking into account attributes such as age, location, farm size, whole-farm feed and nutrient balances and farm business succession. According to their behavioural models the individual farm agents evolve subject to their current state of attributes and to changes in their environment.

The results of the farm module serve as input for the *land lease market module*. Finally, the function of the *output module* is the conditioning of the model results for the next simulation period. Results at farm level and at regional level are used to update farm attributes and regional attributes in the next period.

### 2.4 The regional environment

The farmers’ external environment consists of a spatial environment and an economic-policy environment in the region. The first build block is space where land is an essential input for most kinds of agricultural production activities, be it for crop production, as fodder ground or as manure disposal area. Hence, space is a factor that cannot be neglected where agriculture is concerned. One way of considering the spatial environment of a farm in the context of an agent-based model is to use Geographic Information Systems (GIS) as a representation of landscape. GIS provide a way for organising spatial data and assigning certain properties to space. A common way to organise space in a GIS is to define a grid of
cells. A grid categorises land with respect to attributes of the cells (see i.e. Parker, et al., 2003; Berger, 2001). This model differs from currently existing models by mapping the exact location of farms and their farm parcels within a region. This means, the model represents a region in a two-dimensional spatially explicit map. For the case study area Winterswijk, which is characterized by small-scaled sand landscapes with landscape attributes characterized by small fields surrounded by hedges or wooded banks, we focus on dairy farming. Sixty percent of the main production area in the region is used for specialized dairy farming.

Furthermore, we introduce spatially explicit mapping between farm production and landscape through integrating ecological quality of the parcels using an index for biodiversity. In this manner, the model can be used for environmental impact assessments. The basic approach is to incorporate environmental impacts within the assigned parcels with agri-environment schemes within the production economic choices farm agents make in the model. We derive an indicator, namely the spatial cohesion Reilly index, to characterise biodiversity in terms of spatial cohesion of the parcel with agri-environment schemes within the regional ecological species habitat network. See section 2.5 for an extensive elaboration on this point.

The economic-policy environment represents the second block of a farm agent’s external environment. Agricultural (and environmental) policies affect the farm at different instances such as prices, EU Common Agricultural Policy payments, and payments for agri-environmental schemes.

2.5 Biodiversity and habitat network
To monitor the ecological impact of parcels with agri-environment schemes, we look at the contribution of the parcel to the spatial cohesion of habitat networks in the landscape. This assumption is based on the idea that natural ecosystems with viable populations of species need a low degree of fragmentation (Saunders, Hobbs, & Margules, 1991; Kinnaird, Sanderson, O’Brien, Wibisono, & Woolmer, 2002; Myers, 2003). Opdam, Verboom, & Pouwels (2003) applied metapopulation ecological theory to infer spatial characteristics for configurations of landscape elements that can be used in landscape management for sustainable biodiversity. They introduced the concept of spatial cohesion of habitat networks in the landscape. The degree of cohesion of the habitat network determines whether or not local extinction and recolonization rates are in equilibrium, and whether the network allows the population to persist under stochastic demographic processes and environmental perturbation (Hanski, 1999). The spatial cohesion concept implies that the number of species finding sustainable conditions in the regional landscape increases with the size and environmental quality of the network elements and the degree of connectivity in their pattern. These characteristics can be used as proxies for the number of species that potentially occurs in a landscape (Opdam, Pouwels, Rooij, Steingröver, & Vos, 2008). For our purpose, we use the change of connectivity brought about by adding a piece of land to the conservation network as a proxy for the change in the spatial conditions for biodiversity. The simplification of this approach is that we neglect the time required for redeveloping the piece of land from a conventional farmers grassland into a conservation grassland. This transition requires a period of at least 5-10 years. The advantages of our approach is that we obtain a measure of potential quality in the absence of long term monitoring data.
To be able to assess the potential of a specific landscape pattern to conserve biodiversity we introduce a landscape cohesion method based on spatial data. For this study, we assess the parcels contracted with agri-environment schemes on their potential to conserve biodiversity thereby taking into account their spatial configuration in the surrounding landscape. Whittingham (2011) demonstrates that at landscape scale, the effect of parcels with agri-environment schemes on farmland biodiversity has been shown to be positively related to the extent of nature conservation area and land under agri-environment schemes in the surrounding landscape. Spatial econometric literature provides an appropriate tool for this problem: The Reilly index. The Reilly index derives from Newton’s law of gravitation, where gravity is stronger for larger ‘bodies’ and gravitational strength is inversely related to the distance between ‘bodies’. It was originally applied to the study of retail markets (Reilly, 1931), to reflect the attractiveness of different retail areas (cities) in terms of the trade-off between consumers’ travel costs and the size of alternative retail areas. We modify the Reilly index to calculate the impact of surrounding nature conservation areas (within the area, and within a radius of 20 km around the case study area) on the potential for biodiversity conservation by parcels with agri-environment schemes. Rather than distance to urban centres, we employ distance to nature conservation areas. Instead of population, we use the size of the nature conservation areas (measured in square meters). Equation (1) gives the formula for the calculation of the spatial cohesion Reilly-index.

Equation (1) gives the formula for the calculation of the spatial cohesion Reilly-index. The calculation of the spatial cohesion Reilly-index starts at the point where the site is located. After that, the size of the nature conservation areas (abbreviation NCA) within a certain radius (i.e. 5 km) is determined, as well as the size of the AES site. Based on the sum of all the distances of the site to the nature conservation areas located within the chosen radius, and on the size of the nature conservation areas and AES sites, the spatial cohesion Reilly-index can be calculated:

$$R_i = \sum_{j=1}^{J} \frac{A_i + C_j}{d_{ij}}$$

Where $R_i$ represent the Reilly index of parcel $i$, $A_i$ the surface area of parcel $i$, $J$ the number of conservation areas within range, $C_j$ the surface area of the $j^{th}$ nature conservation area, and $d_{ij}$ the distances from the parcel to the centres of the conservation areas. The index captures, in one number, the size of the nature conservation areas in proximity to the AES site, and the distance from the site to the nature conservation areas (Cotteleeer, 2008). We calculate the spatial cohesion Reilly index for each individual parcel with AESs or the potential for an AES, $R_i$. Strong points of the spatial cohesion Reilly-index are the combination of distance with size, and the fact that nature conservation areas located further away or which are smaller in size are weighted less. As such, the spatial cohesion Reilly-index is a measure for the share of land used for a certain land-use function in the surroundings of a specific location.
Figure 2.1: Graphically presentation of the spatial cohesion Reilly-index

We illustrate the calculation of the spatial cohesion Reilly-index in Table 2.1 and Figure 2.1 for the location of two parcels with agri-environment scheme: A and B. The two parcels (A and B) are heterogeneous in size and are situated in the proximity of four different nature conservation areas. The size of the four nature conservation areas is also given. Figure 2.1 shows the two parcels, and their location in relation to the four NCAs. The arrows in Figure 2.1 give the distance to the four nature conservation areas. The size and distance correspond with Table 2.1.

Table 2.1: Spatial cohesion Reilly-index for two parcels with agri-environment schemes given the size of parcels and NCA and the distance to the NCA

<table>
<thead>
<tr>
<th>NCA</th>
<th>NCA size (m²)</th>
<th>Size parcel A (m²)</th>
<th>Distance to parcel A (m)</th>
<th>Size / (Distance)²</th>
<th>Size parcel B (m²)</th>
<th>Distance to parcel B (m)</th>
<th>Size / (Distance)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000,000</td>
<td>20,000</td>
<td>1,000</td>
<td>1.02</td>
<td>40,000</td>
<td>1,400</td>
<td>0.53061</td>
</tr>
<tr>
<td>2</td>
<td>500,000</td>
<td>2,100</td>
<td>2.100</td>
<td>0.11791</td>
<td>400</td>
<td>3.375</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>200,000</td>
<td>600</td>
<td>0.61111</td>
<td></td>
<td>700</td>
<td>0.4898</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>900,000</td>
<td>1,200</td>
<td>0.63888</td>
<td></td>
<td>900</td>
<td>1.16049</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spatial cohesion Reilly-index</td>
<td>2.38791</td>
<td></td>
<td></td>
<td>5.5559</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from Cotteeleer (2008, p.101) and adjusted.

From Table 2.1 and Figure 2.1, it is apparent that for parcel B, the spatial cohesion Reilly index is much larger than for parcel A, because parcel B is located closer to two of the nature conservation areas. Although NCA 2 is not the largest area, the shorter distance from parcel B to this area is largely responsible for the larger spatial cohesion Reilly score for this parcel. From this theoretical example, it can be seen that a parcel with agri-environment scheme located near or in a NCA, has a higher spatial cohesion Reilly-index than a parcel that is located further away. Also larger parcels result in a spatial cohesion Reilly-index when compared with smaller parcels.
3. Implementation of the conceptual model

A well-known way of transferring the conceptual framework into a computer program is to use an object-oriented programming language such as C++, Java or Smalltalk. Object-orientation describes a system of entities in terms of elements called objects. Objects consist of data (or attributes) and actions (or methods). The data represent the state of the object. The actions operate on an object's data and change it. The software code of this model is written in the object-orientated programming language Java using the open-source agent based modeling framework *Recursive Porous Agent Simulation Toolkit Symphony 2.0* (Repast S). Repast offers libraries designed for the needs of agent based modelers which include scheduling mechanisms, spatial classes, visualizations and basic statistic output features. The model is a middle ranged model and was built with the objective to contribute to the insights into rural system dynamics. In accordance to other ABMs in the field, the designed ABM inherits features from the fields of ACE and MAS/LUCC. Namely, the interaction of economic agents in a realistic GIS-based landscape.

**UML class diagram**

To visualize and document the design of an object-oriented computer programme, it is convenient to use a standardized language such as the “Unified Modelling Language” UML. Accordingly, figure 3.1 shows the object-oriented class design of the model.

**Figure 3.1** Class diagram of the spatially explicit rural agent-based model

The current version of the model contains two types (classes) of agents, the *TraderAgent* and the *Auctioneer*, both subclasses of the abstract type *Agent*. *TraderAgent* is an abstract class describing all agents that can be traders, i.e. an agent - person, organisation or institution - that wishes to buy and sell certain goods or commodities. The model contains one such *TraderAgent*, the Farm. Every *TraderAgent* has a *ValuationStrategy* that it uses to...
determine a (private) price for the goods it wishes to trade. *ValuationStrategy* is also an abstract class, and various concrete implementations can potentially be used in the model for distinct commodities. Currently, the only tradable goods in the model are farmlands. The strategy used to determine the value of farmlands is described in chapter 6. The resulting value of a farmland is expressed by the class *Valuation*. A Valuation is of a certain *ValuationType* conveying that the same farmland may have several valuations.

Every *Agent* also may have one or more decision making strategies. These are described by the class *DecisionMakingStrategy*. Again this is an abstract class, so distinct implementations can be used in the model for different aspects of the agent’s ‘daily operations’. The decision making strategy used by a Farm in the current model can be found in chapter 4. Farmlands are represented in the model by the class *FarmLand* that holds all information pertaining to parcels that belong to Farms. Farmlands hold crops, one per farmland and described by the abstract class *Crop*, and are of a certain quality (class *ParcelQuality*). The class Crop currently has two concrete implementations, *Maize* and *Grass*. FarmLand may also hold contracts, for instance a nature contract represented by the class *SANContract* (AES contract) (see chapter 4).

The other agent currently in the model is the *Auctioneer*. The *Auctioneer* is a mediator between traders and can be representing an actual person or organisation, or - in a more abstract manner - a market. The *Auctioneer* ‘requests’ traders to make offers (abstract class *Offer*) to either express their willingness to buy (class *Bid*) or sell (class *Ask*) a good. The *Auctioneer* ‘uses’ a mechanism to match bids and asks to clear the auction. This is represented by the abstract class *AuctionMechanism*. Again, several concrete implementations of this class are possible. Currently, the model contains a heuristic mechanism to clear the auction in a number of iterations. It presumes that multiple buyers and sellers are present and the goods traded are heterogeneous (characterised by multiple attributes). The mechanism is represented as a sequence diagram in Figure 3.2.

At the start of each auction, the auctioneer informs the traders the auction is open. Based on the outcome of a decision-making strategy (does the agent want to buy or sell?), traders can respond by expressing interest in the auction. Next, the auctioneer requests all interested agents to provide the commodities they would like to sell with a related reserve price for these goods. This reserve price is determined by the valuation strategy the agent is applying. Once all asks have been identified, the auctioneer requests the interested agents to provide bids for the commodities on offer. A prospective buyer evaluates all available goods and is allowed to create one bid, for the asks that he or she values the most. Again, this is decided by the agent’s valuation strategy.

After all bids have been collected, the auction mechanism matches bids and asks based on creation of the largest buyer/seller surplus (difference between bid price and reserve price). The auctioneer will inform the traders involved in an accepted bid, who then complete the transaction and are asked to provide new offers, or can update or retract their open bids and asks in the auction, based on their valuation and decision-making strategies. If there are still unaccepted asks left after the matching process, a new cycle or iteration of the auction is started, in which all participating agents are again asked to provide a bid for the one of the remaining asks. The process continues until there are no asks left, or no more bids are made. The auctioneer will then inform all interested traders that the auction is closed.
In order to calculate the transaction prices for all matched bids in the auction, the auctioneer uses a pricing policy. This policy is represented by the PricingPolicy interface in Figure 3.2. The model currently contains three implementations of this interface. The class K_PricingPolicy is used to divide total surplus between a buyer and seller using a parameter k (between 0 and 1). K_PricingPolicy has a subclass RelativePricingPolicy, which is a pricing policy that divides total surplus between a buyer and seller based on buyer or seller pressure in the auction. If there is a large number of sellers compared to buyers, most of the surplus will go the buyer and vice versa. There is also a ‘Vickrey’ pricing policy (class VickreyPricingPolicy), in which the highest bidder wins, but the price paid is the second-highest bid. Again, the model could be easily extended with other pricing policies by creating additional classes implementing the PricingPolicy interface.

4. The case study area: Dairy farming in Winterswijk, The Netherlands
We adapted the model to the agricultural region Winterswijk, which is located in the eastern part of the Netherlands. From a landscape perspective, the area represents a cultural-historic landscape where small-scale agriculture and nature conservation areas are closely related, thereby providing particular cultural, recreational, ecological and economic value to the region (Provincie Gelderland, 2005). The spatial structure of the landscape attributes are characterised as small fields surrounded by hedges or wooded banks (Mastboom, 1996). Large parts of the region contain important nature conservation areas which belong to the National Ecological Network (NEN) which is part of the European Natura 2000 network. In
the 1990s, the Dutch government launched the NEN as a structure of existing nature areas that was to be made more robust and cohesive by enlarging areas, improving environmental quality, and developing new areas and local ecological corridors (Opdam, Pouwels, van Rooij, Steinröver, & Vos, 2008). In this way, the NEN is contributing to development of biodiversity in the Netherlands (Lammers & Zadelhoff, 1996). Figure 4.1 gives an overview of the study region.

![Figure 4.1: The study region Winterswijk](image)

This study concentrates on dairy farms, both specialised dairy farms and mixed dairy/pig fattening farms. Data on 201 individual farms were taken from the Agricultural Census (reference year 2010). The model initialisation uses farm-level data on their current number of dairy cows, farmer’s age and land use, and also data at parcel level on ownership, size and distance to the farmstead. These parcel-level characteristics are derived from Cadastral GIS-maps. GIS-maps on land use, soil quality, crop suitability and water tables were used to integrate the production characteristics of individual parcels in the model. These dairy farmers are typical for the region; in aggregate, they represent 13,150 hectares (5,846 parcels), and cover 60% of the main production area in the region. The size of the nature conservation areas in the region is 3,565 ha (289 parcels).

5. The dairy farm agent in SERA
Dairy farm agents can produce milk, grass, maize or nature. They can also engage in land rental activities. They are assumed to act autonomously and to attain the highest possible operational farm profit. The decision making of the modeled farms is highly simplified compared to that of real farmers in Winterswijk, and only serves the purpose of this study. For example, strategic aspects such as speculation on land between farmers is not included in the model, as well as fluctuation of input- and output prices, future expectations about an uncertain political environment etc. With respect to expectations of farm agents, they
anticipate to price changes in the same period, taking into account the prices from the previous periods.

For the farm agents it holds that the farm is handed over to the next generation after a given number of periods (≥ 65 years), unless there is no successor. Dairy farms differ with respect to their farm size in terms of parcels, number of cows, hectares of maize grown, soil quality, spatial location as well as age (yes/no successor). In this way the identity of the dairy farm agent is constituted.

Dairy farm agents’ objective is to attain the highest possible operational farm profit, given the information the dairy farm agent has. Although no explicit linear optimization problem is used in SERA because of heterogeneous parcels used, the farm agents’ objective function can be expressed in the following way: Operational dairy farm profit is based on the sum of the contribution of each individual parcel \((i)\) and crops grown \((j)\) (either grass or maize) on land controlled by the farm agent, based on the following function \((2)\):

\[
Y_{farm}^{dairy} = \sum_{i=1}^{\text{n}} Y_{ij}
\]  

(2)

For each parcel the profit \((Y_{ij})\) is calculated based on the following function

\[
Y_{ij} (DI_{ij}, S_i, TRC_i, MAR_i, FC_i, FB_i, p_{\text{milk}}, p_{\text{manure appl dispose}}, p_{\text{fertilizer}})
\]  

(3)

With

\[
Y_{ij} = DI_{ij} + S_i + MAR_i - TRC_i - FC_i - FB_i
\]  

(4)

Revenue from dairy production \(DI_{ij}\) is calculated as the sum of the number of cows per hectares, set at the initial farm level, times the size of the parcel in hectares, times the average milk production per cow, which is set in accordance to the average milk production of dairy cows in The Netherlands in 2010 (CBS&LEI, 2011). The milk price is given in the model at the average rate in 2010 (CBS&LEI, 2011). Local variation in prices due to for instance quality differences among farmers is not permitted in the model, meaning that all producers receive the same exogenous product price.

Table 4.1 gives an overview of the main parameters in the dairy farm model

**Table 4.1: Main model parameters dairy farm agent**

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit of Analysis</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer costs on parcel (i)</td>
<td>Euro/kg N</td>
<td>(FC_i)</td>
</tr>
<tr>
<td>Manure application revenue (or costs) for parcel (i)</td>
<td>Euro/kg N</td>
<td>(MA_i)</td>
</tr>
<tr>
<td>Transport costs depending on parcel (i)</td>
<td>Euro/ha</td>
<td>(TRC_i)</td>
</tr>
<tr>
<td>Parameter</td>
<td>Units</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Transport costs for SNL parcel</td>
<td>Euro/ha</td>
<td>$TRC_{i}^{\text{nature}}$</td>
</tr>
<tr>
<td>Milk production per cow</td>
<td>Kg/cow</td>
<td>$q_{milk}^i$</td>
</tr>
<tr>
<td>Nitrogen production per cow</td>
<td>N kg/cow</td>
<td>$NP_{i}$</td>
</tr>
<tr>
<td>Fertilizer application for two crops (grass or maize) $j$</td>
<td>N kg/ha</td>
<td>$FU_{j}$</td>
</tr>
<tr>
<td>Mineralisation grassland</td>
<td>N kg/ha</td>
<td>$M_{i}$</td>
</tr>
<tr>
<td>Yield losses for the parcel $i$</td>
<td>% point</td>
<td>$y_{\text{loss}}_{i}$</td>
</tr>
<tr>
<td>Milkprice</td>
<td>Euro/kg</td>
<td>$p_{milk}^i$</td>
</tr>
<tr>
<td>Workability coefficient grassland</td>
<td>%</td>
<td>$work_{grass}^i$</td>
</tr>
<tr>
<td>Leaching coefficient grassland</td>
<td>%</td>
<td>$leach_{grass}^i$</td>
</tr>
<tr>
<td>NEL (feed) requirements per dairy cow</td>
<td>NEL/cow</td>
<td>$NEL_{i}$</td>
</tr>
<tr>
<td>SNL subsidy for parcel $i$</td>
<td>Euro/ha</td>
<td>$S_{i}$</td>
</tr>
<tr>
<td>SNL contract length</td>
<td>year</td>
<td>6</td>
</tr>
<tr>
<td>Nitrogen application crop $j$ (maize)</td>
<td>N kg/ha</td>
<td>$NA_{j}$</td>
</tr>
<tr>
<td>Feed production crop $j$ (maize)</td>
<td>NEL</td>
<td>$yield_{j}$</td>
</tr>
<tr>
<td>Fertilizer application crop $j$ (maize)</td>
<td>N kg/ha</td>
<td>$FA_{j}$</td>
</tr>
<tr>
<td>Maximum number of cows per hectare</td>
<td>Cows/ha</td>
<td>$r_{cow}^i$</td>
</tr>
<tr>
<td>Expectation price for greening permit</td>
<td>Euro/permit</td>
<td>$p_{\text{expectation}}^i$</td>
</tr>
<tr>
<td>Reserve price for greening permit</td>
<td>Euro/permit</td>
<td>$p_{\text{reserve}}^i$</td>
</tr>
</tbody>
</table>

This documentation describes the dairy farm agent’s behavior and the dairy farm agent’s actions.

### 5.1 Parcels revenue from dairy production activities

The parcels income from dairy production ($DI_{i}$) is calculated as the sum of number of cows per hectare, known as the cow-ratio ($r_{cow}$), which is set at the initial level, times the size of the parcel in hectares ($parcel_{i}$), times the average milk production per cow ($q_{milk}$) which is set at 7875 liter/cow/year (see CBS & LEI, 2011), times the milk price ($p_{milk}$). The milk price is given in the model at a rate of 0.35 euro/liter milk. In the model is a possibility to fluctuate this level.

\[
DI_{i} = \sum \left( r_{cow} \cdot parcel_{i} \cdot q_{milk} \cdot p_{milk} \right)
\]
5.2 Nitrogen production

The nitrogen produced by dairy cows on the parcel \( (N_{P_y}) \) is calculated as the sum of nitrogen production per cow \( (N_P) \) (115 kg N/cow/year, see (CBS & LEI, 2011)) times the cow-ratio \( (r_{cow}) \), times the size of the parcel in hectares \( (\text{parcel}_{ij}) \).

\[
N_{P_y} = \sum_N \cdot r_{cow} \cdot \text{parcel}_{ij}
\]

(6)

At the farm level, a nitrogen availability for grassland is calculated, where the nitrogen application of maize is subtracted. In this way a nitrogen balance is created at farm level. Fertilizer use is assumed to be only on grassland which is not subject to agri-environmental schemes. Several studies, such as Aarts (1995, 1996, 2000) on nitrogen application and feed requirements in "De Marke" show that the average use of fertilizer, \( F \), in the Winterswijk region can be set at 35 kg N/ha. A future model extension could be the estimation of a function for fertilizer use, related to the size of the farm, the number of dairy cows, using FADN data.

The relation between N-application and NEL production per ha per year is adapted from Middelkoop & Aarts (1991), Van de Ven (1992), Groeneveld, Bouwman, & Kruitwagen (1998) Groeneveld, Bouwman, Kruitwagen, & van Ierland (2001), and Peerlings & Polman (2008) and the following nitrogen supply, leach, nitrogen availability, uptake and dry matter yield per parcel were calculated. The legal limits of the Ministry of EL&I prescribe that nitrogen can be applied to the parcel up to a maximum of 250 kg N/ha \( (N_{\text{legal}}) \) for manure from livestock. Here derogation applies; farm agents are allowed to apply 250 kg N/ha on their parcels whenever >70% of their farm is grassland. Whenever this changes, the legal norm is decreased to 170 kg N/ha (see http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2005D0880:20100206:EN:PDF). In the model, we take derogation into account. The nitrogen supply \( (N_{S_{ij}}) \) which has to fulfill the legal norms is calculated as legal supply=manure. Only transportable manure is assumed to be produced by the livestock.

But, the amount of N available for the grass is higher, \( N_{S_{ij}}^{\text{real}} \) due to mineralization and deposition. The nitrogen supply \( (N_{S_{ij}}^{\text{real}}) \) is calculated as supply=manure+fertilizer+deposition+mineralisation. We assume mineralization \( (M_i) \); process in which N is released from organic matter and becomes available for uptake by plants is 250 kg N/ha, we assume deposition \( (D_i) \); N deposited by cattle during grazing) is 50 kg N/ha. A workability coefficient of 100% is assumed for the use of fertilizer \( FU_j \), which is now set at 35.

The nitrogen supply \( (N_{S_{ij}}) \) which is used for the legal limits norm, set by the Ministry is:

\[
N_{S_{ij}} = \text{parcel}_{ij} \cdot N_{P_y} \leq N_{\text{legal}}
\]

(7)
The nitrogen supply which is used to calculate the availability for grass later on (\(NS_{ij}^{real}\)), is calculated as

\[
NS_{ij}^{real} = parcel_{ij}(FU_{ij} + M_i + D_i) + NP_{ij}
\]  

(8)

Not all supplied N will be available for grass because of N leaching (\(L_{ij}\)). The fraction of nitrogen supply that is leached is calculated using the following function:

\[
L_{ij} = 15 + 0.32(NS_{ij}^{real} - 300)
\]  

(9)

Available N (\(NA_{ij}\)) at the parcel level can then be derived as follows:

\[
NA_{ij} = NS_{ij}^{real} - L_{ij}
\]  

(10)

Only part of the N from available N is taken up by the sward. Uptake N/ha (\(NU_{ij}\)) is calculated as

\[
NU_{ij} = \frac{(-\alpha_b + NA_{ij}) + ((\alpha_b + NA_{ij})^2 - 4\alpha_a \alpha_c NA_{ij})^{0.5}}{-2\alpha_a}
\]  

(11)

Where \(\alpha_a\) is a constant \((1.14)\), \(\alpha_b\)is the ratio \(\alpha_b / \alpha_c = 1.176 \cdot \alpha_c\), \(\alpha_c\)is the horizontal asymptote that is 11.85 per cent above the maximum N uptake per parcel.

### 5.3 Feed production

The dry matter yield of grass per parcel is expressed in tons of DM. The DM production depends on the N uptake of grass:

\[
DM_{ij} = \frac{(-(\beta_b + NU_{ij}) + ((\beta_b + NU_{ij})^2 - 4\beta_a \beta_c NU_{ij})^{0.5}}{-2\beta_a}
\]  

(12)

Where \(dm\) is DM yield per parcel, \(\beta_a\) is a constant \((19.88)\), \(\beta_b\) is \(21.6 \times \beta_c\), \(\beta_c\) is \(1.078 \times \) maximum DM production. Maximum DM production is derived from the questionnaire by Peerlings & Polman (2008) and is based on the subjective judgments of individual farmers.

The nett energy for lactation (\(NEL\)) is the energy value of forage expressed in NEL kJ/kg DM is based on grazing, according to

\[
NEL = (\gamma_0 + \gamma_1 NU_{ij} + \gamma_2 NU_{ij})^2
\]  

(13)
Where \( \gamma_0 \) is 5947.932, \( \gamma_1 \) is 15.0628 and \( \gamma_2 \) is -0.020439 (based on Peerlings & Polman, 2008).

\[
DMNEL_{ij} = \frac{NEL \cdot DM_{ij}}{\delta}
\]  

(14)

The DM (\( DMNEL_{ij} \)) produced per parcel, expressed in NEL kJ, per year is calculated by multiplying the NEL in kJ per kg DM by DM production per parcel divided by a production coefficient (\( \delta = 6.9 \)). This coefficient is set at DM production to be medium quality grassland, given the questionnaire of Peerlings and Polman (2008).

### 4.4 Feed requirements grazing dairy cows

To calculate the feed requirements of the grazing dairy cows on the parcel the total net energy requirements for lactation (\( TFR_{ij} \)) of the herd should be calculated.

\[
TFR_{ij} = TF_{cow} \cdot r_{cow}
\]  

(15)

It is written as the NEL requirements per dairy cow (\( TF_{cow} \)) times the cow-ratio (\( r_{cow} \)) (see statement below).

The NEL requirements per dairy cow are calculated following the guidelines by the Dutch Ministry of EL&I (see Tamminga, Aarts, Bannink, Oenema, & Monteny, 2004). The energy requirements of calves and heifers is not taken into account in this model. This can be a valuable model extension.

\[
TF_{cow} = 1.02 \cdot (NEL_{milkprod} + NEL_{maintenance} + NEL_{premium}) = 6374.8kJ/\text{NEL/cow/year}
\]  

(16)

\[
NEL_{milkprod} = 3747.56kJ/\text{cow/year}
\]

\[
NEL_{maintenance} = 1900.24kJ/\text{cow/year}
\]

\[
NEL_{premium} = 602kJ/\text{cow/year}
\]

Given the NEL requirements and the feed production for grassland, the amount of feed bought can be calculated as follows

### 5.5 Feed costs

It is assumed that the costs for buying feed are higher than for selling feed. We assume a 10% variation around the feed price of 0.19 euro/NEL. The feedshortage/surplus on parcel level (\( TFB_{ij} \)) is calculated using the following equation:

\[
TFB_{ij} = TFR_{ij} - DMNEL_{ij}
\]  

(17)
The total feed bought can be calculated as the total feed required by the dairy cattle \((TFR_{ij})\) minus the yield of energy production value from grass \((DMNEL_{ij})\).

5.6 Manure disposal costs
Whenever the nitrogen production (from dairy cows grazing on the parcel) exceeds the legal limits of 250 kg N/ha the farmer needs to dispose of the manure from the parcel. Costs are involved to do so. Average cost of manure disposal is taken as 2 euro/kg N based on (CBS/LEI, 2007) and is calculated from the manure disposal cost or manure application revenue per m3 manure (Middelkoop, 2007).

\[
\text{when } NP_{ij} > 250
\]

The nitrogen surplus \((MAR_{ij})\) is a cost when the total nitrogen production \((NP_{ij})\) exceeds the legal limits of 250 kg N/ha. Whenever there is a shortage, the farmer is assumed to apply nitrogen on the parcel until a maximum of 250 kg.

\[
\text{When } NP_{ij} < 260 \text{ then } MAR_{ij} < 0
\]

5.7 Fertilizer costs
On grassland a fixed amount of 35 kg N/ha is assumed to be used. Later on, the fertilizer use will be calculated as depending on size of the parcel and number of dairy cows within a regression analysis using FADN-data. For now, we stick to the 35 kg N/ha.

\[
FC_{ij} = p_{fert} \cdot 35 \cdot parcel_{grass}
\]

This results in fertilizer costs \((FC_{ij})\) which are calculated by the price of fertilizer, which is set at 0.70 euro/ kg N \((p_{fert})\) (CBS/LEI, 2007) times 35, times the hectares of grassland \((parcel_{ij})\).

5.8 Transport costs
Total transport costs \((TRC_i)\) depend on the distance from the parcel to the farmstead \((km_i)\). For each parcel this distance is known. A fixed average of \(TRC_{fixed} = 50\) euro costs per kilometer is used, to represent the costs of machinery, manure and cattle transport to the parcels. Furthermore, a constant \((const)\) is used to represent the costs of mowing and other machinery on the parcel, multiplied by the size of the parcel. This constant is now set at 50 euro.

\[
TRC_i = TRC_{fixed} \cdot km_i + const \cdot parcel_{ij}
\]

5.9 Maizeland parcels
Maize land is included in the model but is not taken into account for the agri-environmental schemes which a farmer could choose. It is assumed that grassland parcels cannot be switched into maize land parcels and vice versa for reasons of simplicity. Maize land is used
for the production of fodder for the dairy cattle in the model. In the model, two types of revenue can be distinguished for the maize land parcels: manure disposal revenue (150 kg N/ha) and feed revenue (14973 NEL kJ/ha).

Manure disposal revenue

On maize land parcels, no nitrogen is produced as grazing is not allowed. The fixed maximum manure application for maize land is set by the Ministry of Agriculture at 150 kg N/ha. Average revenue from manure application is set at 2 euro/kg N based on CBS/LEI (2007) and is calculated from the manure disposal costs per m³ (Middelkoop, 2007). Whenever the farmer has a negative nitrogen balance, the farmer is able to attract external manure on the farm and a revenue could be gained. Transport costs are calculated in the same way as done for grassland parcels.

5.10 Agri-environment schemes: transport costs

Farmers receive a subsidy of 1065 euro per hectare for plant species protection contracts under agri-environment schemes.

\[
(S_i) = S \cdot parcel_{ij} \\
S = 1065
\]

(22)

Transportation cost for parcels with AESs is assumed to be lower than for conventionally managed parcels. A fixed average of \( TRC_{\text{fixed}}^{\text{nature}} = 20 \) euro costs per kilometre is used. This is lower than the transport costs for conventional farming, because it is assumed that less transport for i.e. manure disposal is needed. The transport costs \( (TRC_{ij}^{\text{nature}}) \) depend on the distance from the parcel to the farmstead \( (km_i) \) and the constant parameter \( (\text{const}) \) which is equal to the constant used in the conventional grassland functions.

\[
TRC_{ij}^{\text{nature}} = TRC_{\text{fixed}}^{\text{nature}} \cdot km_i + \text{const} \cdot parcel_{ij}
\]

(23)

The model has also been applied to Ecological Focus Areas. A description of this application is found in Schouten et al. (2013).

References


