Understanding the spatial distribution of agricultural land use in view of climate-driven hydrological changes

EXPERT POOL REPORT

Knowledge for Climate (KfC) research programme

Theme 6: High-quality Climate Projections

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Summary

In the context of Knowledge for Climate programme, an expert pool was requested from Theme 8 to provide data and information to study the future impacts of climate change on the agricultural land-use patterns in the Netherlands. More specifically, a number of questions were posed in regard to: 1) representing and explaining the spatial distribution of different types of farming; and 2) simulating with Land Use Scanner the future developments of agricultural land-use while taking into account effects of climate change and changes in (agricultural) policy. The main findings are summarized in the present report.

Question 1: Which aggregation of crop types can best be used to describe the spatial distribution of different types of agricultural activity?

Open-field agricultural activities in the Netherlands comprise the cultivation of a large number of different crops, including food consumption and industrial crops (e.g. cereals, potatoes, beets, vegetables, fruits), feed crops (mainly grass and silage maize) for dairy farming and cattle breeding, and ornamental plants (e.g. flowers, garden trees, etc.). These crops are usually grown in rotation schemes, in which different crops are sequentially grown in the same plot season after season. Farmers implement this practice in order to improve soil structure and its chemical and biological environment, as well as distributing financial risks over different crops.

Therefore, a certain degree of aggregation is required in order to correctly represent the spatial distribution of different types of farming over time. Previous studies on agricultural activities in the Netherlands have aggregated crops at the production system level (e.g. Van der Hilst et al., 2010; Kuhlman et al., 2013). This approach allows taking explicitly into account the crop rotation schemes and management practices conducted by farmers, such as field operations and required inputs. A typology of agricultural production systems and related aggregation of crops is presented in Table 1. This typology is based on LEI's statistical records on Dutch farm accounts. *Adopting LEI's typology as a benchmark for crop aggregation allows developing a modelling framework that is able to consistently link spatial patterns of agricultural activities with economic data on gross revenues and production costs of agricultural production* (see Question 2).

Table 1: Crop aggregation and related typology of production systems

Crop type	Production system
Grassland for agricultural production Maize	Dairy farming
Potatoes Beets Grains Onions Fallow	Arable farming
Legumes Vegetables Horticultural seeds	Open-field vegetable farming
Tree fruits Berries	Fruit growing
Flower bulbs Flowers	Flower growing
Tree nursery Perennials	Tree nursery

Question 2: Which approaches exist to explain current patterns in agricultural land use?

Farmers have to make decisions in terms of land allocation for different activities, taking into account the local biophysical suitability to pursue them. The combination of multiple individual decisions leads to the emergence of the observed spatial patterns of agricultural land use. Firstly, we discuss existing approaches to represent the biophysical suitability for agriculture in a spatially-explicit way. Then, a modelling framework aiming to explain the economic rationale of agricultural land-use decision-making is presented. Finally, the ability of this approach to reproduce current patterns is discussed.

Biophysical suitability

The spatial patterns of agricultural activities are largely influenced by biophysical suitability for crops, which in turn is a factor of local features such as soil type, topography, climate and hydrological conditions. The Her-Evaluatie van Landinrichtings Plannen (HELP) system (Brouwer and Huinink, 2002; Van Bakel, 2007) has been widely used to spatially represent crop biophysical suitability in Dutch case studies (e.g. van der Hilst et al., 2010; Diogo et al., 2012; Kuhlman et al., 2013). In this method, maps of groundwater level and soil type are combined to determine the degree of yield reduction, in relation to the maximum attainable crop yield, resulting from the damage caused by drought and water surplus (see Question 4 for a discussion on the effects of groundwater levels in crop suitability). The estimation of yield reduction takes into account not only direct damage but also indirect damage (e.g. loss of product quality due to harvest delay resulting from the impossibility of operating machines in heavy soils when they are wet). Total yield reduction is then calculated as follows:

$$D_{tot} = D_{wa} + \left(\frac{100 - D_{wa}}{100}\right) * D_{dr}$$

where:
D_{tot} is the total yield reduction
D_{wa} is the yield reduction caused by water surplus
D_{dr} is the yield reduction caused by drought

The HELP system was last updated in 2006 (van Bakkel, 2007) and currently includes the definition of biophysical suitability for the main types of crops in the Netherlands (potatoes, beets, cereals, grass, silage maize, vegetables, fruits, flower bulbs and tree nursery), based on the combinations between 14 soil types and 11 water level classes. This method has the advantage of being readily available and covering the full extent of the country.

However, some criticisms have been raised, questioning the accuracy and usefulness of the HELP system. Firstly, drought direct damage function is based on a quasi-stationary hydrological model (LAMOS) using outdated climate data. Secondly, water surplus damage was calibrated according to expert judgement, but the calibration process has not been fully documented. Thus, the method has a low degree of transparency. Finally, parameters related to indirect damage are based on outdated technology from previous decades, and therefore they do not reflect current management practices dealing with non-optimal conditions.

As a result, a major revision of the HELP system is currently ongoing (Bartholomeus et al., 2013). New meta-relationships between crop yields and hydrological conditions are being established based on SWAP model. SWAP is an agro-hydrological model that simulates transport of water, solutes and heat and actual evapotranspiration of crops as a function of meteorological data (precipitation, evaporation and temperature), combined with crop and soil data (Feddes and Raats, 2004). These new meta-relations will allow obtaining yield reduction maps based on up-to-date crop damage functions related to drought, water surplus and water salinity, for both current and future climate conditions. However, the revision of HELP system is still at its initial stage of development and thus a complete version should only be expected to become available in forthcoming years.

Other alternative approaches to represent crop biophysical suitability are also currently being developed, for example:

- MetaSWAP+WOFOST model coupling - WOFOST crop growth model determines crop productivity by simulating processes such as photosynthesis and respiration according to transport of materials and heat simulated by SWAP model. First model applications have been developed and tested for grass (Kros and Supit, 2011).
- Groundwater To Stress Transfer (GTST) model - originally developed to simulate nature vegetation growth, crop productivity is hereby determined as a function of oxygen stress, which in turn depends on factors such as groundwater level and soil moisture, texture and

temperature. Model applications to determine grass and potatoes have shown promising results.

However, similarly to the revised HELP system, it will take time until model applications for all crops become fully developed and available. Therefore, it can be concluded that, *for the time being, the current version of HELP system appears to be the best available option to represent crop biophysical suitability in a spatially-explicit way.*

<u>Economic performance</u>

Irrespective of the method used to represent it, crop biophysical suitability does not fully explain by itself the observed distribution of agricultural production systems. While the spatial configuration of the biophysical environment sets the opportunities and constraints for agricultural activities, farmers primarily account for expected profitability rather than crop productivity to choose among different crops. Differences in production costs, yields and market prices among crops (Fig. 1) imply that the relative economic attractiveness between crops is not proportional to their biophysical suitability (Fig. 2).
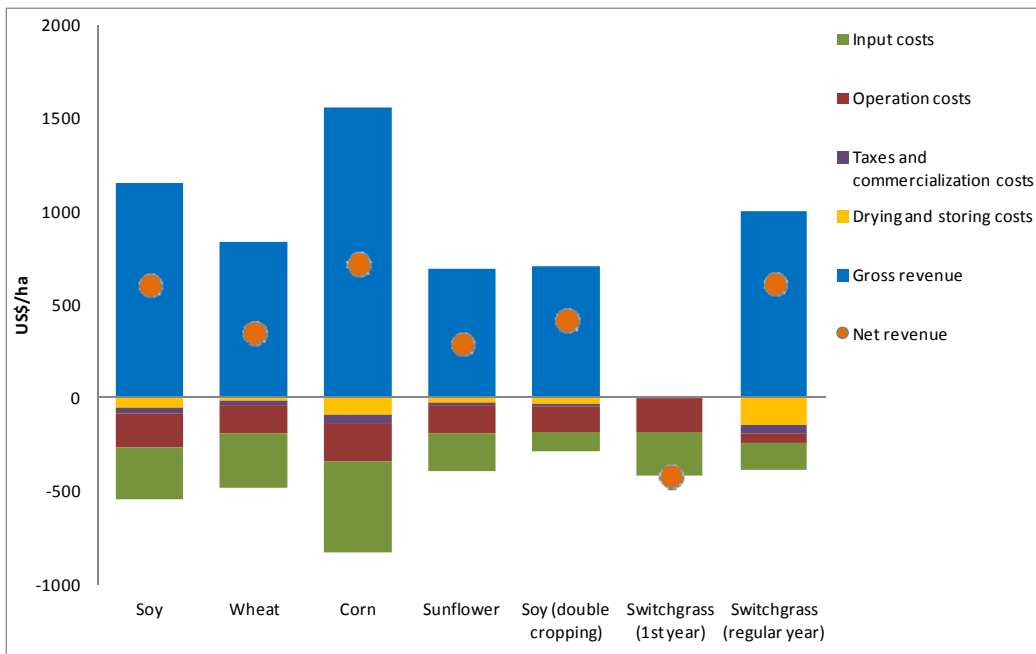

Figure 1: Example of breakdown of yearly production costs and revenues for different crops (Diogo et al., 2013)
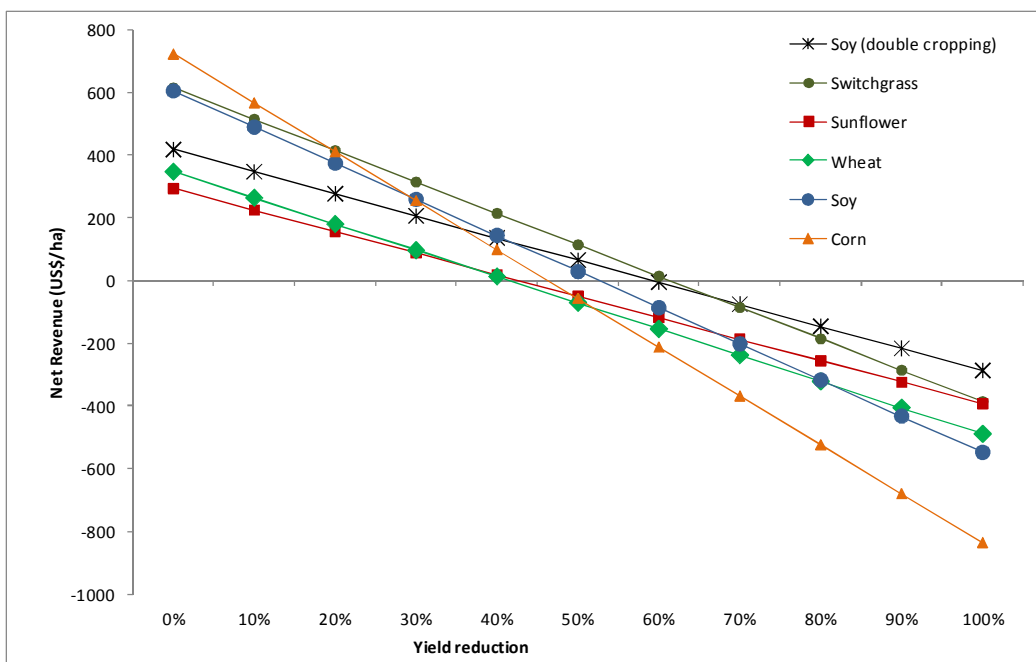

Figure 2: Example of yearly net revenues as function of yield reduction for different crops (Diogo et al., 2013)

Therefore, crop yields have to be translated in monetary terms as net revenues, by taking into account the costs involved in crop production and gross revenues obtained from selling the products. A modelling framework based in the economic performance of production systems is presented in Fig. 3 (a more detailed account will be available in Diogo et al., forthcoming).
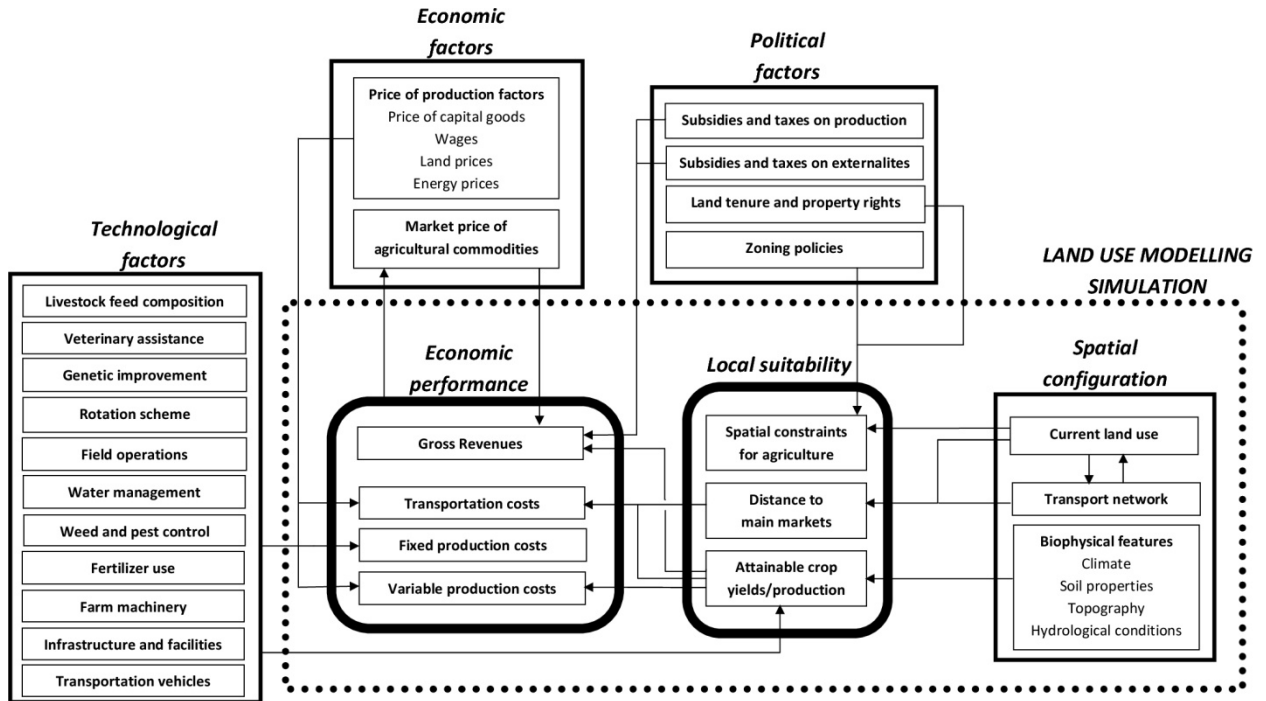

Figure 3: Modelling framework for simulation of agricultural land use patterns

Net present value (NPV) is a standard method used in capital budgeting to appraise long-term projects which measures discounted time series of expected cash inflows and outflows, while taking into account the time value of money. When applying this method to agricultural land-use decision-making, NPV is determined in the following way:

$$NPV_{c,i} = \int_{t=0}^{\infty} (R_{c,i,t} - C_{c,i,t}) \exp(-st)\, dt$$

where $NPV_{c,i}$ is the net present value of production system i in land parcel c, t is time, $R_{c,i,t}$ and $C_{c,i,t}$ are respectively the gross revenues and total costs of production system i in land parcel c and $s=ln(1+r)$, being r the discount rate. This equation can be discretised in yearly time steps as follows:

$$NPV_{c,i} = -\text{Inv}_{c,i} + \sum_{y=0}^{n} \frac{R_{c,i,y} - C_{c,i,y}}{(1+r)^y}$$

where $Inv_{c,i}$ are the initial investment costs (e.g. land, new machinery, buildings and facilities) of production system i, $R_{c,i,y}$ and $C_{c,i,y}$ are respectively the annual gross revenues and total costs of production system i in land parcel c in year y, r is the discount rate and n is the lifetime of the project. The yearly costs related to crop production include the following main categories of expenses: field operation costs (contractor, machinery, labour and fuel costs), input costs (seeds, fertilizers and pesticides), fixed costs (insurance, soil sample assessment, etc.), storing costs and transportation costs:

$$C_{c,i,y} = \sum_{p=1}^{n} \%p * \left[FOC_{p,y} + IC_{p,y} + FC_{p,y} + Y_{c,p,y} * (SC_{p,y} + TC_p * d_{c,p}) \right]$$

where:
$C_{c,i,y}$ are the total annual costs resulting from production system i in cell c in year y (€/ha)
p is a product generated by production system i
n are the number of products generated by production system i
$\%p$ is the share of product p in crop rotation system of production system i

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$FOC_{p,y}$ are the field operation costs (€/ha)
$IC_{p,y}$ are the input costs (€/ha)
$FC_{p,y}$ are the fixed costs (€/ha)
$Y_{c,p,y}$ is the yield of product p in cell c in year y (ton/ha)
$SC_{p,y}$ are the storing costs of product p in year y (€/ton)
TC_p are the specific transportation costs of product p (€/ton.km)
$d_{c,p}$ is the distance to nearest market of product p (km)

Gross revenues are derived from selling the main product products and from (CAP) subsidies. Services and amenities that are explicitly monetised can also be taken into account (e.g. subsidies to farmers for providing environmental services, maintaining landscape, etc). Gross revenues are strongly related to local biophysical characteristics and calculated as follows:

$$R_{c,i,y} = S_{i,y} + \sum_{p=1}^{n} \%p * [Y_{c,p} * P_{p,y}]$$

where:
$R_{c,i,y}$ are the annual gross revenues derived from production system i in cell c in year y
$S_{i,y}$ are subsidies per unit of land-parcel area using production system i in year y
$P_{p,y}$ is the price of product p in year y

The NPV method has proven to be a suitable approach to assess the economic performance of agricultural production systems in a spatially-explicit way (e.g. Van der Hilst et al., 2010; Diogo et al., 2012; Kuhlman et al., 2013; Diogo et al., 2013). NPV can be used as a measure of local suitability in Land Use Scanner (Hilferink and Rietveld, 1999), a land use model based on bid rent theory (Alonso, 1969) and discrete choice theory (McFadden, 1978), to investigate (future) land-use patterns.

A model application has been recently developed to simulate agricultural land-use patterns in the Netherlands, using the typology proposed in Question 1 and NPV method as a definition of local suitability. A model validation is currently ongoing, in order to assess the ability of this approach to reproduce currently observed patterns (Diogo et al., forthcoming). For arable farming and dairy farming, maximum yields and production costs were specified at the crop level and according to soil type, based in a previous study by van der Hilst (2010). For the remaining production systems, average production costs and gross revenues were derived at the production system level from BINternet (LEI's farming accounts database). HELP system's yield reduction maps were implemented in the model to differentiate crop yields and gross revenues according to location.

Four alternative definitions of suitability were considered:

I) Only production costs were taken into account;

II) Production costs and transportation costs were taken into account;

III) Besides production costs, land-use in previous years is taken into account by assuming that a change of production system involves investment costs (e.g. in new machinery, facilities, etc). Investmenst costs per production system were derived from Binternet;

IV) Besides production costs, land-use in previous years is taken into account by assuming that a change of production systems involves both investment costs and land acquisition costs. Land acquisition costs are used as a proxy for farmer specialization, implying that a change of production system involves a change of the type of farmer that manages the land. Land costs per province were derived from CBS.

Spatial patterns of agricultural land-use were simulated in Land Use Scanner according to these definitions of suitability and then compared to currently observed patterns (Fig. 3). The *Basisregistratie percelen 2012* (BRP, 2012), a census dataset based on farm surveys regarding crop grown at the plot level, was used as a reference to compare simulated and observed patterns. Crop rotation schemes for arable farming and dairy farming were defined per soil type according to the average rotations observed during the period 2007-2012. For suitability definition III) and IV), land-use in 2007 was taken as the initial time step.

Figure 3: Spatial patterns of agricultural land-use in 2012

The degree of correspondence (Loonen and Koomen, 2009), an indicator comparing the ratios of simulated and observed land use per cell, is used as measure of comparison:

$$C_i = 100\% - 100\% * \left(\frac{\sum_c |M_{c,i} - O_{c,i}|/2}{\sum_c O_{c,i}} \right)$$

where:

C_i is the degree of correspondence for production system type i

M_{ci} is the simulated amount of land in cell c for production system type i

O_{ci} is the observed amount of land in cell c for production system type i.

Preliminary results are shown in Table 2. According to suitability definition I), it can be concluded that annual cash flows of production costs and gross revenues only partly explain the observed spatial patterns. Transportation costs do not seem to play a role on the allocation of production systems, which can be explained by the fact the Netherlands is a relatively small country with high-quality transportation network. The higher degree of correspondence for suitability definitions III) and IV) indicates that the spatial distribution of production systems appears to show path-dependency and inertia of land-use, which might be explained by socio-economic and cultural factors such as high investment costs, farm specialization and aversion to change.

Table 2: Degree of correspondence for alternative definitions of suitability

Production system	I) Production costs	II) Production + Transportation costs	III) Production + Investment costs	IV) Production + Investment + Land costs
Arable Farming	31.9%	31.9%	50.2%	71.7%
Dairy Farming	72.0%	72.0%	80.5%	90.1%
Flower growing	5.7%	5.8%	10.8%	33.6%
Fruit growing	2.2%	2.2%	33.6%	74.6%
Open-field vegetable farm.	6.1%	6.1%	13.0%	29.8%
Tree nursery	6.0%	6.4%	20.1%	46.0%
Total agricultural land-use	57.6%	57.6%	68.7%	82.3%

The proposed method and model calibration do not perform equally well among production systems. Production systems that were calibrated with yield and economic data at the crop and soil type levels (i.e. arable farming and dairy farming) appear to perform best. In particular, dairy farming systems appear to be fairly well allocated for all definitions of suitability. This might indicate that dairy farming systems are mostly located in areas in which the suitability for other systems is low. Production systems that were calibrated at the aggregated production system level perform overall very poorly. Fruit growing is the exception, performing well for suitability definitions that account for inertia of land-use and path-dependency, thus reflecting their permanent crop attributes. For the remaining, important (regional) differences might exist within these production systems in terms of crop rotation, suitability and relative economic performance and therefore describing and calibrating them at the production system level is insufficient to fully capture their management practices, determine their economic performance, and reproduce their spatial distribution. Therefore, additional effort should be put on refining the calibration of these systems in future model applications in order to obtain improved results.

It should also be noted that the distinction between different production systems might not be always as strict as assumed. For instance, rotation between arable farming, vegetable farming and flower growing can be observed (see Table 3). Therefore, comparing the simulated patterns with only one specific year might also partly explain the observed error.

Table 3: Share of observed rotation among arable farming, vegetable farming and flower growing in relation to total area where arable farming was observed during 2007-2012

Rotation	Only Arable farming	Arable Farm. + Vegetable Farm.	Arable Farm. + Flower Growing	Arable Farm. + Vegetable Farm. + Flower Growing
Share	70.2%	24.0%	2.6%	3.2%

A more detailed account on modelling errors and analysis of spatial factors will be provided elsewhere (Diogo et al., forthcoming]. It can be concluded that *the proposed modelling framework is able to explain and reproduce most of the currently observed agricultural land-use patterns, when accounting for factors related to farm specialization and investment costs. It is also able to simulate future land-use changes, explicitly taking into account future developments of socio-economic factors (e.g. changes in crop market prices and input costs), climate change impacts (e.g. change in biophysical suitability and costs of adaptation measures) and political factors (e.g. changes in subsidy schemes).* However, while a good level of confidence can be put in the results obtained for production systems that are calibrated at the crop level, the results for production systems calibrated at the aggregated level should be interpreted with caution.

Question 3: What is the added value of detailed plot survey data (*Basispercelen registratie*) over land-use/cover data (*LGN*)?

LGN6 land-use/cover dataset has been used to represent agricultural land-use patterns in the most recent versions of Land Use Scanner. The majority of LGN6 agricultural land-use classes are clearly defined as specific crop types - agricultural grass, maize, potatoes, grains, sugarbeet, flower bulbs, tree fruits, fruit nursery, tree nursery - and thus could eventually be aggregated into a production system typology similar to the one proposed in Question 1. Table 4 shows the agreement between agricultural classes in LGN6 land-use map and a map combining *BPR* datasets for 2007 and 2008 according to the same geographical coverage of LGN6 satellite images. It can be seen that most classes have a high level of agreement. However, there is one class in LGN6 that appears to be more ambiguous, "Other Crops". This class is defined as "an agricultural parcel with crops that are not included in the previous classes" (Hazeu et al., 2010). Different types of crops seem to be included in the same class – vegetables and horticultural crops and arable crops such as onions, rapeseed and hemp. This implies that a class such as "Open-field vegetable farming" cannot be considered while using LGN6. Furthermore, the classification accuracy of this class is rather low, since it appears to have a relatively high level of agreement with many different crop types such as grass, corn, potatoes and grains.

Table 4: Agreement between LGN6 and BPR 2007/08 classes

		BPR 2007/08											
		Agric. grass	Corn	Potatoes	Beets	Grains	Onions	Other arable crops[1]	Fallow	Vegetables	Flowers	Fruits	Tree nursery
LGN6	Agric. Grass	91.8%	3.6%	0.7%	0.2%	1.2%	0.0%	0.2%	0.5%	0.4%	0.2%	0.1%	0.2%
	Corn	8.0%	78.5%	3.7%	3.3%	1.8%	0.2%	0.3%	0.4%	1.9%	1.1%	0.1%	0.5%
	Potatoes	6.8%	8.0%	72.2%	2.0%	3.7%	0.5%	0.9%	0.6%	4.3%	0.4%	0.0%	0.2%
	Sugarbeet	1.7%	8.2%	3.2%	75.7%	3.6%	0.7%	0.4%	0.7%	4.2%	1.2%	0.1%	0.1%
	Grains	6.4%	2.1%	4.5%	1.4%	80.2%	0.5%	1.1%	0.6%	1.9%	0.5%	0.1%	0.4%
	Other crops	11.9%	8.6%	9.2%	4.2%	12.3%	18.0%	5.7%	1.3%	22.8%	3.3%	0.4%	1.7%
	Flower bulbs	4.5%	2.0%	2.2%	0.7%	4.9%	1.1%	0.9%	0.9%	7.2%	74.0%	0.1%	1.3%
	Fruits	5.5%	1.4%	1.1%	0.5%	1.6%	0.3%	0.6%	0.4%	0.6%	0.3%	86.6%	0.7%
	Tree nursery	7.4%	9.3%	1.5%	1.8%	2.6%	0.2%	1.6%	2.2%	2.7%	5.1%	2.5%	60.5%

[1] "Other arable crops" include industrial crops such as rapeseed, flax and hemp

Furthermore, BPR classification has a more detailed classification, distinguishing between crops within the same general group, such as different types of potatoes (starch, consumption and seed potatoes) and different types of grains (e.g. winter and summer wheat, winter and summer barley). This more refined classification can be linked with specific economic data on production costs regarding these crops (e.g. using data from van der Hilst et al., 2010) and thus improve the characterization of the economic performance of arable farming systems. Furthermore, BPR is collected and updated every year, which allows performing a more detailed analysis of crop rotation schemes and land-use changes over time. Therefore, *BPR data series should be preferred over LGN to study spatial patterns of agricultural land-use.*

Question 4: What is the importance of groundwater levels in explaining agricultural land-use patterns?

Groundwater levels can vary in space, depending on soil structure and altitude, and in time, according to seasonal rainfall and evaporation patterns. Shallow groundwater levels of only a few feet below ground level occur in peat and clay polder areas, on sandy soil ridges and in shallow stream valleys. On the other hand, very deep groundwater levels of several meters are observed in the coastal dunal areas and in the Pleistocene moraines (Veluwe, Utrecht Ridge and Hondsrug). Typically, groundwater levels rise in the winter and decrease in the summer. Due to differences in soil permeability and capillary action, much stronger fluctuation between seasons are observed in sandy soil areas than in the polders (Klijn et al., 2012).

Groundwater levels play a role in explaining the spatial patterns of agricultural land-use by contributing to the biophysical suitability of different crops in terms of potential crop damage and water availability. Crops differ in their tolerance to water stress and water surplus, which can both inhibit crop growth. Too dry conditions during spring can reduce soil moisture and thus decrease availability of water for crops (if not irrigated), leading to delayed seed germination and poor crop emergence. On the other hand, too wet conditions can lead to saturation of the root zone, resulting in reduced root development and root rotting, deficient nutrient uptake and impediment of gas exchange of oxygen and carbon dioxide within the root zone. Water logging can also cause indirect damage by preventing machines to be taken to the field, thus delaying operations such as spraying and harvesting, and by promoting the occurrence of certain pests and diseases.

The extent of crop damage due to water stress/surplus depends in a combination of factors such as precipitation patterns, soil type (which determines soil drainage conditions), temperature (which affects the rate of oxygen depletion) and biological activity in the soil. Therefore, *although groundwater levels contribute to crop biophysical suitability, considering it as an independent factor is not enough to explain the observed patterns of agricultural land-use.*

It should be also noted that shallow groundwater levels can be actively managed by pumping. The economic feasibility of this option might depend on specific pumping costs and on the allocation of these costs (e.g. farmers vs. water boards). Historically, groundwater levels have been managed as a function of the use aspired by farmers, with water boards accommodating the large majority of pumping costs. However, there are a number of undesirable impacts resulting from pumping (e.g. soil subsidence, withering of natural vegetation, damage to buildings). Therefore, there is an ongoing political debate to change the current policy regime.

As discussed in Question 2, the currently available version of HELP system represents crop biophysical suitability according the local combination of soil type and groundwater levels. The impact on suitability resulting from eventual changes in groundwater levels could hypothetically be taken into account by the HELP system. However, since this method is based on historical data series of climate patterns, it is only able provide meaningful results as long as other factors remain unchanged. *Therefore, the current version of HELP system is only suitable to explore short-term impacts on suitability resulting e.g. from changes in the groundwater management regime.* See Question 5 for a discussion on methods dealing with long-term changes resulting e.g. from climate change.

Deep groundwater aquifers can be used for irrigation purposes and thus availability of groundwater for irrigation might also play a role on determining local suitability for agriculture. Factors such as water quality (salinity and pollution), water extraction rights for different uses and the efficiency of the irrigation technology in use determine the availability of water for different types of agriculture. *However, water availability and processes related to water quality (e.g. salinization) are not taken into account in the current version of HELP system. Hydrological modelling tools such as the National Hydrological Instrument (Delsman et al., 2008; Klijn et al. 2012) might be better equipped to provide input for studying the role of water availability for irrigation from deep groundwater as an explanatory factor of agricultural land-use patterns.*

Question 5: What is the expected impact of climate change on future groundwater levels?

Future sea level rise and changes in precipitation and evaporation patterns might potentially lead to changes in groundwater levels, as well as availability and quality of groundwater for irrigation. *According to climate scenario G (KNMI, 2006) in combination with Global Economy socio-economic scenario, winter and summer precipitation levels are expected to increase, but so does evaporation in the summer. As a result, the additional increase in annual precipitation only leads to a marginal increase in water surplus and therefore, future groundwater levels are expected to differ little from those currently observed (Klijn et al., 2012). On the other hand, summers are assumed to be warmer and drier in climate scenario W+ (KNMI, 2006) in combination with Regional Communities socio-economic scenario. These changes are expected to lead to different spatial patterns of groundwater level variation: the average highest annual groundwater levels are expected to increase in the low lying polder areas, while in the higher sandy soils they are expected to decrease; on the other hand, the average lowest annual groundwater levels are expected to decrease in the entire country, but to a lesser extent in the polders. Deep groundwater levels react much slower to seasonal fluctuations, variations in the weather and even to climate change than shallow groundwater levels. Therefore, availability of water for irrigation from groundwater aquifers appears to depend to a much a larger extent on changing water demand (e.g. for human consumption and/or industrial use) than on declining availability due to climate change (Klijn et al., 2012).*

While shallow groundwater levels can, to some extent, be kept within an optimal range through a number of water management practices, groundwater salinization might affect substantially the local suitability for agriculture. For example, *sea level rise might affect coastal groundwater systems and trigger saline water intrusion along the coastline (Oude Essink et al., 2010). In clay soil polder areas, upcoming of brackish water might occur during extreme wet periods and lead to deposition of salts in the root zone during the dry season (Velstra et al., 2011). In extreme dry periods, the salinity in polder waters generally increases, particularly because seepage of brackish water is less diluted by fresh water from precipitation (Klijn et al. 2012). The southwestern delta, Hollandse polders, Groningen-Frisian coastal area and the IJsselmeer polders are expected to be the most affected by internal salinization, particularly if future climate conditions develop according to W+ scenario (Klijn et al., 2012).*

The current version of HELP system is not able to take into account future changes in climate patterns and resulting salinization processes. Therefore, *the impact of changes in groundwater levels on agricultural land-use patterns resulting from climate change can only be better understood when new methods such as the forthcoming HELP system revision, WOFOST+metaSWAP or GTST become fully developed and available.*

Other (seasonal) effects of climate change rather than changes in groundwater levels might be expected to also affect suitability for agriculture. These effects include extreme rainfall events, heat waves, warm winters, combination of warm and wet conditions in the summer (which promote occurrence of bacterial diseases), among others. Schaap et al. (2013) has quantified the material, quality and economic loss resulting from these impacts for a number of agricultural commodities and according to different climate change scenarios. The costs and efficiency of a number of possible adaptation measures to cope with these impacts have been also determined. These findings can be incorporated in the modelling framework proposed in Question 2, in order to assess the resilience of existing production systems to climate change impacts and simulate future changes of agricultural land-use patterns.

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